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Agricultural Aviation Research

A workshop held at
Texas A & M University
October 19-21, 1976

NASA Conference Publication 2025

Agricultural Aviation Research

Coordinated by

Howard L. Chevalier
Texas A & M University

Louis F. Bouse
U. S. Department of Agriculture

A workshop sponsored by
NASA Langley Research Center
Hampton, Virginia and held at
Texas A & M University
October 19-21, 1976

National Aeronautics
and Space Administration

**Scientific and Technical
Information Office**

1977

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FOREWORD

This document is a compilation of papers, comments, and results presented during a workshop on Agricultural Aviation Research that was held at Texas A&M University, College Station, Texas, October 19-21, 1976. The workshop was sponsored by NASA Langley Research Center.

The purpose of the workshop was to review and evaluate the current state of the art of agricultural aviation, to identify and rank potentially productive short and long range research and development areas, and to strengthen communications between research scientists and engineers involved in agricultural research. Approximately 71 individuals actively engaged in agricultural aviation research were invited to participate in the workshop. These were persons familiar with problems related to agricultural aviation and processing expertise which are of value for identifying and proposing beneficial research.

The workshop program was divided into four major areas of work, 1) presentation of invited papers, 2) equipment demonstration and displays, 3) presentation and discussion of proposed NASA research, 4) study groups. The papers presented an overview of agricultural aviation development and scope and the state of the art and problem areas in agricultural aviation. Demonstrations were conducted to show various measuring techniques and static displays were available to show various aircraft, liquid and dry material distributors, and ground support equipment. NASA personnel presented a summary of proposed research work in various areas of agricultural aviation along with descriptions of test facilities suitable for future agricultural aviation research work. Five study groups were organized to define areas of needed research. These study groups included aircraft design, dispersion of dry materials, dispersion of liquids, ground support, and monitoring and measuring equipment.

Certain commercial equipment and materials are identified in this paper in order to specify the procedures adequately. In no case does such identification imply recommendation or endorsement of the product by NASA, nor does it imply that the equipment or materials are necessarily the only ones or the best ones available for the purpose. In many cases equivalent equipment and materials are available and would probably produce equivalent results.

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Environmental Protection Agency
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National Agriculture Aviation Association
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Agriculture Research Service
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ACRONYMS

AI	Active Ingredient
CAA	Civil Aeronautics Agency
CAM	Civil Aeronautics Memoranda
CAR	Civil Aeronautics Regulation
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulation
NASA	National Aeronautics and Space Administration
NTSB	National Transportation Safety Board
OSHA	Occupational Safety and Health Agency
USDA	United States Department of Agriculture
vmd	volume mean diameter

CONVERSION FACTORS

are = 40.468564224 · acre*

$^{o}C = (^{o}F - 32) \cdot 5/9$*

hectare = 10^2 · acre*

cm = 2.54 · inch*

km = 1.6099344 · mph*

kN = 8.889644 ton

l = 0.946 · qt

l/are = 0.005844 gal/acre

m = 3.048 · ft*

m^3 = 0.0035239 bushel

m^3/are = 8.7077 · 10^{-5} · bushel/acre

N = 4.4482216152605 · lbf*

N/are = 0.10992 · lbf/acre

N/m^3 = 157.09 · lbf/ft^3

Watt = 745.7 · horsepower

xact definition

SESSION I

AN OVERVIEW OF AGRICULTURAL AVIATION DEVELOPMENT AND SCOPE

CHAIRMAN

William R. Ciesla
Leader, Methods Application Group
Forest Insect and Disease Management
U.S. Department of Agriculture,
Forest Service
Davis, California

OBJECTIVES AND CHARGE FOR WORKSHOP

W. G. LOVELY
UNITED STATES DEPARTMENT OF AGRICULTURE

This workshop is being held to accomplish the following:

(1) Review and evaluate the present status of agricultural aviation

(2) Develop a list of research, development, and extension needs for agricultural aviation and establish priorities

(3) Strengthen communications among federal agencies, state universities, aircraft manufacturers, application equipment manufacturers, and users who are concerned with agricultural aircraft.

We expect this to be a true workshop where all in attendance participate and contribute to the stated goals. By working together we should be able to describe the agricultural aircraft system that will be needed 10 to 25 years from now. We should also develop a research program that will result in technology developments and breakthroughs so that the envisioned agricultural aircraft system will become a reality.

Today, we will discuss the historical development of aircraft and dispersal systems, use patterns for agricultural aircraft, constraints (such as regulations, certification, economic) on the utilization of aircraft, and agricultural aircraft research in progress. These discussions should provide the needed background information for the study group activity tomorrow and the next day.

Each of you will be assigned to a study group and I hope you will take your assignment seriously. The titles of the study groups reflect our present thinking on the important aspects of a forward looking research and development program for agricultural aviation. Hopefully, each study group will develop a list of and establish the priorities for research needs, justification statements for each need, an estimated cost and manpower requirement for each need, and last, but not least, projected benefits for each need.

Tomorrow afternoon we will have the opportunity to see some of the research and commercial aircraft equipment that is being used. Weather permitting we will also see some of the aircraft actually applying liquid and granular materials. The researchers here at Texas A&M will also make some collections of the liquids and granules so that we can see the distribution patterns.

On Thursday, we will discuss NASA's agricultural aviation proposal and some of the related research and development programs that are being carried on by that agency. We will spend Thursday afternoon discussing the reports from the study groups.

It is a pleasure for me to participate in this workshop. I am sure that the workshop will be a success and that by working together we can develop a forward looking research and development plan that will result in improved agricultural aircraft systems, improved control of agricultural pests, and, of course, a substantial increase in the use of agricultural aircraft.

HISTORY AND DEVELOPMENT OF THE AGRICULTURAL AIRCRAFT

FRED E. WEICK
CONSULTANT
VERO BEACH, FLORIDA

There are stories of cotton fields having been dusted by airplane as early as 1917 and 1918. The first well recorded use of an airplane in agriculture, however, appears to have been on August 3, 1921, when a grove of catalpa trees near Troy, Ohio, was treated with arsenate of lead powder to combat an infestation of Catalpa Sphinx caterpillars. The report, which appeared in National Geographic (Mar. 1922) magazine, said in parts:

> "The plane used was a Curtis JN6 (Hisso-Jenny) equipped with a hopper for carrying and liberating the poison powder.
>
> "Not a tree could be found, and many were climbed and examined, whose leaves did not bear particles of the deadly poison which were easily detected by the unaided eye.
>
> "A careful investigation revealed the fact that not over 1 percent of the caterpillars remained alive on the trees.
>
> "When one considers the success which attended the test, conducted as it was with crude apparatus and without the aid of a guiding experience in the manipulation of the machine, it seems certain that the airplane will be used successfully in the future to control forest insects.
>
> "Whether it will be possible to employ this method for the treatment of cotton or other low growing crops or even large fruit orchards which permit the economical use of terrestrial machines remains to be seen. In the treatment of tall trees in park and forest areas, the tremendous saving in time and labor in which its use would result seem to indicate that the method is wholly practicable."

The predictions of these men made 55 years ago have been borne out to an extent that is probably well beyond their anticipations, for the activity is now well enough established in this country so that it touches all of us in our daily lives.

Commercial aerial dusting activity commenced shortly thereafter. One company which was started in 1923 later sprouted Delta Air Lines, and it remained in operation as a small duster division until the recent death of Dr. Coad, its manager. For many years they used the Huff-Daland duster, a plane that was reworked from an unsuccessful Navy trainer design and which served the purpose very well as a duster. The dusting activity grew slowly at first, but by 1930 there were 20 to 30 companies operating with about 100 airplanes.

By the start of World War II, there were still only a few hundred airplanes in agricultural work. Immediately after the war, however, a remarkably rapid expansion took place which was made possible by three factors: first, the development during the war years of more potent agricultural chemicals, such as DDT; second, the large number of training airplanes adaptable for agricultural use that became available as surplus equipment at very low prices; third, the large number of trained pilots released from service who had sufficient funds to purchase an airplane or two and to get started in application work.

The growth was rapid and steady up to the early 1950s, when more than 5000 airplanes were listed by the CAA as being used in agricultural work. The number of operating companies reached nearly 2000. These numbers dropped off somewhat during the following years as some of the surplus airplanes were used up and the weaker businesses fell by the wayside, but they picked up again as new specially designed airplanes became available.

In 1950, the airplanes used for agricultural purposes in this country varied over a wide range from heavy WWII bombers to the lightest of light airplanes. When classed as heavy, medium and light, only 3 percent were in the heavy category. These were mainly Douglas DC-3, Boeing 247, and Ford Trimotor airplanes. Nearly half of the planes were in the medium class. Most of these were Boeing-Stearmans, which originally had 220-hp radial engines some of which had been replaced by 450-hp radials. In the medium category there were also a number of Navy N3N training planes with engines ranging from 220 to 450 hp. Both the Stearman and the N3N designs were very rugged since they were built for military student training, and they were well adapted to agricultural use. Other airplanes in the medium category included a few Travel Airs, Wacos, Pitcairns, Curtis Robins, BT 13s, etc.

The light category also included nearly half of the airplanes. Most of these were Piper Cubs, from 65 hp up to 150 hp. The 135 and 150-hp Supercub models were fitted with hoppers for agriculture use by the factory. The rest of the light planes were mostly Aeroncas, with a few Luscombs, Cessna 120s and 140s, and a sprinkling of others.

Up to 1950, substantially all these planes had to be converted for agricultural use, usually by the operator himself, who also usually designed and built the dusting and spraying equipment.

AIRCRAFT DESIGNED ESPECIALLY FOR AERIAL APPLICATION - (Excerpts from previously published material)

The first airplane designed from the ground up for the purpose of distributing agricultural materials was the experimental Ag-1, which was developed in 1949-1950 at the Texas A&M Aircraft Research Center. The project was initiated by the National Flying Farmers Association, and was carried out under the sponsorship of the Civil Aeronautics Administration, the U. S. Department of Agriculture, and the Texas A&M University System.

The first step in the design of the Ag-1 was to determine the characteristics and specifications desired in an airplane to be used for aerial application. Information was obtained from a country wide survey of dusting and spraying operators and from personal interviews with many operators throughout a fairly wide area. As a result of this study, plus the written comments of over 500 pilots throughout the country who were given the opportunity to fly and comment on the Ag-1, the following general specifications were evolved for an airplane applying agricultural materials to the general run of crops.

Desirable Characteristics of Applicator Airplanes (1953)

Desirable characteristics for the applicator airplanes are as follows:

(1) Airplane should carry large spray or dust load, at least 35 to 40 percent of gross weight.

(2) Airplane should be capable of taking off with full load from relatively soft unpaved ground and climbing to height of 50 feet within a total distance of ¼ mile (1320 feet). In standard air at sea level this performance is desirable.

(3) The range of safe operating speeds while applying materials should be from about 60 mph to 100 mph or more.

Flying and Handling Characteristics

The control forces, particularly the aileron control forces, should be light because applicator operations require almost continuous control movements for several hours per day with relatively large control deflections in the turnarounds between swath runs.

The aileron control should be rapid in order to save time in banking and in changing from one bank to the other in the turnaround. Fighter plane effectiveness is desirable ($\frac{pb}{2V} = 0.12$ or higher, where p is rate of roll in radians per second, b is the wing span in feet, and V is the airplane velocity in feet per second).

The lateral stability and control at the stall should be such that if the airplane is in a flat skidding turn and the control stick is eased full back, the airplane will continue to turn under control and will not suddenly increase its bank and start into a spin, as in the case with the former training airplanes now in use in applicator work.

Pilot's Field of View

(1) Forward and down - an excellent view forward and down is very important for low altitude dusting and spraying, and for clearance of fences, trees, wires, etc.

(2) In turns - making turns at low altitude at the end of each swath requires a clear field of view in the direction of turning. A low-wing monoplane is the best configuration for this purpose.

(3) To the rear - some pilots desire a clear view to the rear in order to see the swath they have been laying.

(4) Taxiing - a good view ahead over the nose is desirable for taxiing in small unprepared fields.

It appears that the arrangement that best fulfills most of these requirements would be a low-wing monoplane with the pilot located high, and with flat engine (as a tractor arrangement is assumed). View over the nose can be improved in flight by operating with flap deflected to a suitable angle.

Protection of Pilots in a Crash

Fortunately, nearly all crop-dusting crashes occur at relatively low speeds following collision with objects or loss of control due to stalling, and it is now known that such low-speed crashes need not be fatal. The following ten recommendations for crash-survival design were made by the Crash Injury Research unit of Cornell Medical College:

(1) Design forward fuselage and cabin structures to resist nominal crash loads as well as flight and landing loads

(2) Design aircraft structures to absorb energy by progressive collapse

(3) Design tubular structure to bend and fall outwardly away from the occupants

(4) Locate the passengers' and pilots' seats as far aft in the fuselage as possible behind the wing

(5) Locate fuel tanks in, or on, the wings—not between the firewall and instrument panel

(6) Provide space between the instrument panel and firewall (or nose section) to permit forward displacement of the panel and instrument cases

(7) Design the instrument panel to be free of sharp, rigid edges in range of pilot's head

(8) Fabricate the instrument panel of ductile material and/or use an energy-absorbing shield on the panel face

(9) Mount instrument cases on shear-pins and/or as low as possible on the panel

(10) Provide shoulder harness, safety belts, seats and seat anchorages of sufficient strength to resist failure up to the point of cabin collapse

Loading Facility

(1) The hopper should have a large door conveniently located for unobstructed, easy and quick loading, either by hand or by machine

(2) The door should be tightly sealed when closed

(3) For certain working conditions provision should be available to change from dusting to spraying without any delay

Maintenance and Repair

It is extremely important that the airplane be inspected and maintained easily and repaired quickly in order to keep it in operation without loss of time during the busy season.

(1) Simple, rugged construction should be used throughout

(2) All control linkage and critical parts should be visible and easily inspected

(3) All parts likely to need servicing should be accessible and easy to remove and replace

(4) Propellers should be easily repairable after deformation in minor accidents, solid aluminum blades are excellent in this respect

(5) The structure and dispersing equipment should be unaffected by or very well protected from corrosion, particularly the corrosion from agricultural chemicals

(6) The entire airplane should be constructed in such a manner that it is easy to clean thoroughly, the structure should be accessible from both sides and suitable for flushing with a hose

(7) The engine cooling system should be ample to avoid high operating temperatures

(8) The engine should be unusually well protected from dust by judicious location of the carburetor air inlet, the use of ample air filters, and, under adverse conditions, by the use of full-flow oil filters.

The Ag-1 Experimental Agricultural Airplane

The Ag-1 airplane was designed to fulfill substantially all these specifications. It was a low-wing monoplane of simple all-metal construction,

carrying a spray or dust load of 1200 pounds, and powered with a 225 horsepower flat six-cylinder Continental engine. The airplane was fitted with powerful full-span high-lift flaps and special slot-lip ailerons, which together made possible flight at exceptionally low speed with rapid response to aileron control. It was fitted with both a hopper in the fuselage for dust (27 cubic feet) and tanks in the thick wing for spray fluid (150-gallon total) for change from dust to spray without any loss of time. The pilot's field of view was exceptional and was considered adequate in every respect by the 500 pilots who reported on it. At the same time the pilot was located to the rear of all loads and heavy masses, in a cockpit designed to protect him, and with a long and substantial structure ahead of him designed to fail progressively and reduce the shock in a nose-down crash.

As stated previously, investigations over the past ten years show that human beings can ordinarily withstand low-speed airplane crashes without injury if adequate support and protection are provided (references 1 and 2). It is essential that the head not come in contact with any heavy structure or mass, such as projecting instruments, and in most airplane cockpits a shoulder harness is necessary in addition to a seat belt for suitable support in this regard.

Nearly all the fatal accidents that have occurred in crop-control flying in this country have been associated with either stalls or collisions with obstructions (usually electric wires or trees) (reference 3). In these accidents the nose of the airplane usually strikes the ground at approximately the minimum flying speed of the airplane. Because of the low speed at contact, this type of accident is definitely survivable. It follows, and it is now generally accepted, that a large proportion of the serious and fatal injuries associated with these crashes could be prevented by suitable airplane design coupled with the use of a suitable shoulder harness in addition to the seat belt.

A novel arrangement combining the shoulder harness with the seat belt was used in the Ag-1 airplane. This arrangement has been found to be easily and quickly fastened, and it allows the pilot freedom of movement. It thus appears to overcome the main objections of duster pilots to the use of shoulder harness. It has been tried and apparently favorably accepted by the many pilots who have flown the Ag-1 airplane for the purpose of evaluating it.

The basis of the Ag-1 installation was a standard Navy seat belt and shoulder harness (reference 4) which is strong enough to support a 200-pound man experiencing an acceleration of 40 g (or momentary load 40 times the man's weight, or 8000 pounds). It has been demonstrated that a man can withstand momentary acceleration of this order when properly supported (references 5 and 6). Since the indications from safety belt failures are that accelerations of 15 to 25 g are likely to be obtained in crashes of the kind under consideration, a harness capable of withstanding a 40 g acceleration appears to be well warranted. Adequate support for this harness is, of course, necessary.

The harness as originally installed had the usual loop at the lower end of each shoulder strap which the pilot had to slip over a portion of the belt clasp before fastening the belt. Thus there were four loose ends, two for the shoulder straps and two for the belt, that had to be located and assembled before the harness could be fastened. This is a time-consuming operation and probably explains why many pilots, particularly duster pilots who may get in and out of their airplanes every few minutes, often do not bother to use a shoulder harness even when it is available.

The only final change made in the Ag-1 installation, after considerable experimentation, was the permanent attachment of each shoulder strap to its respective side of the seat belt. Each attachment was made by means of a piece of 1/8-inch flexible steel cable, using a standard thimble in the eye at each end and lapspliced by means of oval sleeves compressed with a hand squeezing tool. The overall length was made as short as feasible.

After the harness has been disengaged, it has been found convenient for a pilot to rest each side on a hook on the fuselage wall. There are no loose ends to hunt for. On entering he merely sits down and slips each side on. This is usually quicker and easier than locating and straightening out the ends of the ordinary seat belt alone. The single fastening of the belt is the only one that is made.

It was thought at first that this arrangement of harness and belt might require slightly more time to get out of following a crash, but experience with it to date under ordinary circumstances indicates that the difference in time probably would be negligible.

At the rear, the shoulder straps slide over a tubular support and down to an inertia-locking reel mounted on the rear wall of the cockpit. The two shoulder straps are linked together by a whippletree and a single cable extends down to the inertia reel. The reel itself is provided with a light spring which tends to keep the cable wound up on it.

Under ordinary conditions the pilot could lean forward easily. His freedom of movement is adequate for comfort and attendance to ordinary cockpit duties.

If the airplane is given a deceleration of 3 g or more, such as would occur in even a mild crash, the inertia reel locks the harness in the position it has at the start. It does this because the inertia of the reel itself, which is going forward with the airplane, causes it to continue forward against a light spring pressure and to engage with a ratchet which locks it in place. Thus, the pilot's shoulders are restrained from going forward while the airplane is coming to a stop. As soon as it has come to a stop, the freedom of movement is available again if he should desire it.

If the pilot knows in advance that he may crash he can, if he desires, lock the shoulder harness in the rear position by moving a handle located on the left side of his seat.

The inertia reel has been found to be a great convenience, particularly for the duster pilot. However, the modification in which each shoulder strap is fastened permanently to its respective side of the seat belt can be used whether or not an inertia reel is incorporated.

Demonstration Tour of Ag-1 Airplane

During 1951 the CAA took the Ag-1 airplane on a demonstration tour throughout most of the country. At each stop the airplane was demonstrated by a CAA pilot and then was flown and evaluated by other pilots, largely duster and sprayer operators. In all, over 650 pilots flew the airplane and approximately 500 filled out forms indicating their evaluation of its various characteristics. Since it was a single-place airplane, the pilot had no opportunity to receive dual control instruction or to be checked out by a pilot familiar with it. The mere fact that the Ag-1 survived this treatment and returned to College Station appears to be some vindication of both its handling characteristics and its ruggedness.

It is desirable to obtain a pilot's considered judgement of an airplane after he has become used to it and has had considerable experience with it. His first impression, such as was obtained in the one or two flights possible for each pilot during this tour, is often different from his opinion after he is familiar with the airplane. The first impressions of several hundred pilots however are of substantial value. In an average of all the ratings, 90 percent were "satisfactory" or better, with 67 percent "excellent." Overall, 2 percent of the ratings were "unsatisfactory." Of the 37 characteristics evaluated, the two rated lowest were considered unsatisfactory by about one-seventh of the pilots who checked them.

After two and one-half years of testing, spray pattern checking, and demonstration flying, it was agreed generally that the airplane could well have greater power when operating under full load, and the Continental Motors Corporation has agreed to donate a motor which would have approximately 300 horsepower available for take-off.

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HISTORY AND DEVELOPMENT OF AIRCRAFT DISPERSAL SYSTEMS

GEORGE S. SANDERS

PRESENTED BY TOM O. COBB
AGRINAUTICS

George Sanders sends his sincerest regrets that he was unable to attend this very important conference. He has asked me to transmit the information he has gathered, and I will do my best to describe the history and the development of agricultural aircraft dispersal systems. Starting back in the very early 1920s, the United States government developed one of the first dispersal systems that was hand powered from an open cockpit aircraft. Since that time, the operators of agricultural aircraft have conceived, designed, and put to use many of their own inventions to accomplish the job.

It is the belief of George Sanders and Agrinautics that major accomplishments in dispersal systems will only come as a result of a concentrated research effort by one national organization such as NASA. The primary goal of a central research agency for the systems research could be directed entirely to the development of fundamental data that can be utilized by equipment manufacturers to design various configurations of components in coordination with all agricultural aircraft airframe manufacturers.

We are thoroughly convinced that gadget making by research agencies has no place in the effort, and the goal should be the generation of empirical relationships that would lead to the optimum deposits of material on desired surfaces at the current application rate and dosages.

Referring back to the pure jet agricultural aircraft developed jointly by Poland and the Soviet Union, you have noted that the characteristic wing-tip vortices still remains the unsolved problem in the control of distribution patterns.

Agrinautics wishes to offer its complete cooperation with NASA and the NAAA to meet the ever-increasing need for the development of better and more efficient dispersal systems.

THE USE OF AIRCRAFT FOR CONTROL OF INSECTS

ARTHUR GIESER
U.S. DEPARTMENT OF AGRICULTURE

Aircraft are used to control insects on many kinds of truck crops, field crops, and orchards. They are also used to control insects in forests and range lands and insects affecting man and animals. Statistical information on acreage treated annually varies considerably. The total acreage treated by aircraft, including multiple treatments on much of the acreage, is estimated to exceed 200 million. Estimates on acres treated for insect control vary from 40 to 65 percent of the total. Aerial application programs conducted by various federal and state agencies normally average from 30 to 40 million acres annually. Although these figures represent acreage treated by aerial applications, credit should also be given for the use of aircraft to release sterile insects. The areas over which sterile insects are released almost daily involve thousands of square miles.

Sterile Insect Releases

The sterile insect release technique was first used successfully to eradicate the screwworm from the United States during the 1950s. Sterile insects have since been used to eradicate several species of flies from several islands in the Pacific. The technique was used to eradicate the Mediterranean fruit fly from the Los Angeles area last winter. Aircraft have released sterile pink bollworm moths in the lower San Joaquin Valley of California, six days per week, from May into November, annually since 1968. Although a few wild pink bollworm moths have been caught in that area, there is no known pink bollworm infestation in the San Joaquin Valley. Tests have also been conducted with aerial releases of sterile boll weevil, Caribbean fruit fly, and codling moth.

To use this technique requires a facility to rear millions of insects every week. In most cases, the insects are made sterile by exposure to radiation. In others, chemo-sterilants are used. When the insects are irradiated in the pupal stage, it is necessary to have holding rooms in which temperature and humidity can be controlled. This provides a control over the number of insects that must be released each day. When the free release technique is used, it is necessary to have a walk-in refrigerator for loading the insects into the free release machines.

Before beginning the screwworm eradication program in the southeastern states, the technique was proven by eradicating the screwworm from the island of Curacao in the Caribbean Sea. For that test, the sterile flies were packaged in small paper bags. A man, riding with the pilot, tore the top off each bag as he tossed it out of the window. For the program in Florida, and the first few years out of Mission, Texas, the paper bag was replaced by boxes about 2 1/2 x 4 x 6 inches. A machine was designed for installation in

the aircraft that dispersed the boxes at controlled intervals, opening each box to release the flies as it left the aircraft. The boxes were later increased in size to about 4 x 5 x 10 inches. In each case, the aircraft is crammed full of boxes, leaving room only for the pilot and a man to place the boxes into the dispersing machine.

When we first began releasing sterile pink bollworm moths, they were packaged in paper cylinders about 2 1/2 inches in diameter and 4 inches long. A measured number of moths was placed into each cylinder. To do this, it was necessary to chill the insects down to a temperature of 34° F without injury. A hopper, installed in the aircraft, released the cylinders. The number released per mile was controlled by an electrically driven gear box. The outlet had rollers that popped the lids off the cylinders as they left the aircraft.

At first it was believed that some type of container was necessary to protect the insects from the sudden airblast as they were released into the slipstream. However, numerous tests showed that they could withstand releases at speeds up to 180 mph without apparent injury. Since the insects could be chilled and held at cold temperatures for some time, it was decided to use small deep freezers to carry them in the aircraft, devise a method to disperse them, and thus eliminate all the small containers.

A 6-cubic-foot deep freeze will hold up to 1 1/2 million insects. The machine can be loaded through the doors of a Cessna 172, 180, or 182. Cargo doors are more suitable because it is necessary to place the machine into the aircraft prior to each flight. The inside mechanism is removable. It consists of a framework that holds multiple flat trays. Insects are placed on the trays to a depth of 1/2 to 3/4 inch in a cold room. At the bottom is a funnel into which the trays drop the insects. It has a controllable speed belt and an adjustable orifice to control the release rate. An electric eye in the funnel automatically triggers the release of the trays, beginning with the bottom trays and continuing upward, in sequence, to maintain a supply of insects in the funnel. From the funnel, the insects fall into a long tube that extends to the tail so they will fall clear of the aircraft.

The entire operation is automatic. The pilot has a small box that he can hold on his lap or lay on the seat beside him. It has an on/off switch to start and stop the belt, a counter to indicate the number of insects he is releasing, and red lights to indicate system failures. Should this system fail, he has means to operate the machine manually to continue the flight until all insects are released.

Problem areas include:

(a) Finding a replacement for the 110-volt refrigeration unit that will operate efficiently on available power from 12 or 24 volt aircraft electrical system.

(b) In high humidity areas, condensation inside of the release machines has caused the insects to cling together.

(c) Boxes are still used to release screwworm flies because the doors of the Twin Beech airplanes that are used on the program are too small to install the machines. The Beech airplanes are now being replaced with Beaver and Douglas C-47 airplanes and consideration is being given to building large dispersal machines to free release the flies.

Applications of Materials Other Than Insecticides

Considerable work is now being done to find effective and economical methods and materials, other than insecticides, to control insects. This includes the applications of pheromones, sex attractants, parasites, growth regulators, viruses, and bacteria. It may be somewhat premature to discuss equipment needs, since much of this work is still in the testing stage. However, ultimately, special equipment for applying materials that cannot be applied with conventional dispersal apparatus will need to be developed. These materials are now being applied in liquids, granules, flaky bran, micro-sized capsules in liquid and dry form, capsules about the size of a cigarette filter, hollow fibers about the size of a small stick pin, ground cork, paper confetti, traps, wafers, and loosely woven soft cotton string.

(Microsporidium-Nosema in flaky bran—grasshoppers and Mormon cricket, Bacteria-Brucillus Thuringiensis. Virus—Tussock moth, gypsy moth, and range caterpillar. Growth regulator-Dimilin—gypsy moth, Tussock moth, forest tent caterpillar, elm spanworm, elm leaf beetle, pin tip moth, hemlock looper, cotton boll weevil, and range caterpillar. Parasites-free release—gypsy moth. Pheromone—boll weevil. Sex attractant—gypsy moth).

We have applied all these materials except wafers and string. ARS applied wafers and string that were impregnated with a fruit fly baitlure and insecticide on islands in the Pacific. We have no information on the apparatus that was used to apply these materials. We heard that a machine was devised that was supposed to cut the string into 6-inch lengths as it left the aircraft so that the string would hang in the trees. Apparently the cutters failed, for as the aircraft landed on a coastal runway, the string trailed behind the aircraft the full length of the runway. No attempt was made to determine how far the string extended into the ocean.

The problems associated with the application of these materials are similar to those for applying insecticides. They include uniformity of deposits, regardless of the materials and rates applied, and wider working swaths, particularly with granulated materials.

Application of Insecticides

In the application of insecticides, more standardization of dispersal apparatus is needed. Are all of the different and special spraying devices now in use really necessary? Apparently, each operator believes the devices he uses are the best. Is this because he has tried the different types, or did he succumb to a sales pitch? Standards should be developed that include the

acceptable range of droplet sizes for specific purposes, nozzle sizes and direction, their arrangement for uniform deposits, and spray pressures. Swath spacing and height of flight should be included. Standards are needed to control those insects that move about and feed on the crops and for those that move very little and are killed by contact with the insecticide. A standard is also needed for applications to control weeds and one to control plant diseases.

Another need is an accurate and rapid method to qualify and quantify spray deposits in the field. Most laboratories and research units have elaborate equipment to evaluate spray tests. However, the fieldmen and operators have relatively few methods to evaluate spray deposits or coverage; yet they are the ones who have the responsibility to assure themselves that the aircraft are set up and flown in accordance with the standards.

The boom and nozzle spraying system is the most popular because of its adaptability for a variety of applications. Nozzles can be shifted on the boom to change deposit patterns. Droplet sizes can be changed through use of different orifice sizes and types or by changing nozzle direction.

Pressure is usually provided by wind-driven centrifugal pumps. Pumps are also driven by hydraulic motors, belt drives, and in some large aircraft and helicopters, by small gasoline engines.

Prior to the development of spray concentrates, wind-driven wire brushes and spinning discs were developed to apply wettable powders at relatively high rates per acre. Then came the Micronairs which are still used today. Current models are available in two sizes, with several screen sizes, and adjustable pitch propellers. When the ultra low volume technique was developed, small spinners came into use. These included the Minispin and the U-car spinner. The major factor that determines the droplet sizes produced by spinners is their rotational speed. Increasing the flow rate through a spinner reduces its speed. Their rotational speed is quite sensitive to changes in airspeeds. This led to the development of rheostat-controlled electrically driven spinners, such as the Fisher spinning screen, the Bals spinning discs, and the Becomist. The mistake commonly made with small spinners is the forcing of too much material through them, which destroys their performance and the main purpose of their use.

Spinners, used properly, will produce more uniform droplets than fixed nozzles. But is this necessary? Several years ago, we equipped an aircraft with flat fan nozzles, hollow cone nozzles, and several types of spinners. An application rate was selected that would provide only a partial kill of the insects on which the test was conducted. The same rate per acre was applied through each device. The intent was to determine which of these devices might give the best kill. The tests were replicated a number of times, changing only the order in which each type of device was used during each morning. When the results were analyzed, there was no detectable difference in insect kill with any of the devices.

One of the serious problems at the moment is achieving good underleaf coverage of citrus leaves with insecticides. We have a citrus blackfly infestation

in Florida and another in the Lower Rio Grande Valley in Texas. This insect moves very little and remains under the leaves. Tests have been conducted with fine sprays applied by airplanes and by helicopters flying at 20 to 25 mph. None of the tests has provided adequate underleaf coverage to control this insect.

Considerable improvement can be made in spreading devices for dry materials such as baits and granules. The first bait applied was a mixture of sawdust and bran and swaths were very narrow. An operator, who had a contract to apply steam rolled wheat bait, first used an augur about 12 feet long under the belly of a B-18. The overall swath was about 25 to 30 feet wide. Adding a 9-inch tube to each side so that the bait was released at the trailing edge, increased the swath 10 to 15 feet. Replacing that mechanism with a Swathmaster increased the overall swath to 125 feet. Another system an operator tried to increase swath width was a small hopper suspended under each wing of a Piper Cub. The vertical wind-driven impeller did a fair job. However, one day the gate on one hopper failed. By the time the pilot became aware of it, he had an extremely wing-heavy airplane, but he made it back to the airport.

All the current production agricultural aircraft have vane-type spreaders. George Roth, of Murray Air, has probably spent more years developing spreaders than anyone else. When he worked for an operator in Hawaii, most of their workload was applying dry fertilizer at very high rates. The spreader on the MA-1 is the final result of all his work.

The spreader on new aircraft is an all-purpose type, designed primarily to satisfactorily apply the material at the heaviest rates. To my knowledge, none of the aircraft or equipment manufacturers build a spreader for light application rates. The amount of work that can and will be done at less than 10 pounds per acre is continually increasing. For example, we have treated up to 20 million acres annually at 1¼ pounds of granulated bait per acre. Tests in progress with clay granules, if successful, will probably be applied at 10 pounds per acre or less.

About a year ago, we purchased a new aircraft for test applications. Since all the dry materials that we use are applied at 5 pounds per acre or less, we built a new spreader. We reduced all dimensions of the standard spreader, except the span, by 50 to 75 percent. We gained 10 mph in speed and 10 feet in effective swath. By reducing drag, we also increased safety, particularly in turnarounds and pull-ups over obstructions. It should save fuel and extend engine life because it will reduce the extent of high power use when heavy loads are carried.

Since the acreage that will be treated with dry materials at light application rates will undoubtedly increase in the future, a test we conducted a number of years ago may be of interest. When we began working with corn cob grit bait, we had a 150-hp Pawnee for test applications. To increase the width of the swath, we devised a temporary method to release bait at the wing tips to take advantage of the vortices. Bait was released at a number of locations, fore and aft, adjacent to the top and bottom wing surfaces and at 6-inch increments, fore and aft, below the wing tips. Bait was also released 3 feet beyond the wing tips at a number of locations. With the bait outlets located

even with the wing tips and 12 inches below the rear spars, we were able to double the overall swath. Had it been possible to devise an internal wing system to deliver the bait to the tips, we probably would have continued. But an external spreader of that size on a 150-hp aircraft was out of the question.

Aircraft manufacturers may want to consider this possibility in future designs. About 80 to 90 percent of all large multiengine aircraft used on our baiting programs have internal wing distributing devices. A few use an airblast, but most use augurs. If tests could be conducted to release granules into the right spot in the vortices, the swath width could be increased substantially. Aircraft that have been used to apply bait include the Boeing B-17, Martin 404, and Lockheed PV-2.

There is a need for a dependable and economical guidance system. Although flagmen may be satisfactory on row crops and other easily accessible fields, there are millions of acres treated annually to control insects in forests, on rangelands, and other large scale programs.

Finally, another problem that needs attention is noise. Agricultural aircraft are attracting too much attention, not because of the work they are doing but because they are noisy. In many cases, there are as many complaints about noise as there are about the pesticides applied. The number of airports that now limit direction of take-off and traffic patterns due to noise is increasing. Anything that can be done to reduce the noise problem will surely be appreciated by the public as well as by the agricultural aircraft operators.

USE OF AIRCRAFT IN VEGETATION MANAGEMENT

R. W. BOVEY
U.S. DEPARTMENT OF AGRICULTURE

The use of aircraft in weed and vegetation management makes possible: (1) proper timing of agricultural chemicals, (2) treatment of large areas rapidly, (3) operation in wet soil and sensitive crops without damage, (4) application on rough terrain or in tall vegetation, and (5) excellent coverage of target plants or soils with minimal cost.

For efficiency, aircraft should be able to adequately apply a range of chemical rates and carriers, apply liquid and solid materials, and provide adequate coverage of the chemical with reasonable drift control. The dispersal equipment should be simple to operate and maintain, durable, and provide accurate metering and distribution of the chemical.

Drift control is one of the major safety requirements for application of herbicides. Spray drift can be adequately controlled in many situations by making applications at low wind velocities and by reducing fine spray droplets with the proper nozzles and placement. However, improvements in dispersal equipment and possibly aircraft will be required to apply chemicals to agricultural lands near sensitive crops and urban areas. Millions of acres are difficult to treat or go untreated because of the drift of materials with aircraft and ground equipment.

The potential uses of aircraft for weed control in crops, such as corn, cotton, wheat, grain sorghum, small grains, soybeans, alfalfa, and other forages and fallow land are very great. About 150 million acres of these crops are treated annually with herbicides or defoliants. Most of the present acreage is treated with ground application equipment. More of this acreage could be treated by aircraft when the dispersal equipment is improved.

Other potential areas needing weed control include 300 million acres of timberland, 320 million acres of rangeland, and several million miles of rights of way, including highways, railroads, overhead electric lines, and other industrial sites. Only a small percentage of these lands are presently treated annually, because of high cost, drift control problems, and the inefficiency of present herbicides.

Major chemicals used includes the following:

Corn - 2,4-D; atrazine; and alachlor
Grain sorghum - 2,4-D; atrazine; dicamba; MCPA; and propazine
Soybeans - trifluralin, alachlor, and chloramben
Wheat - 2,4-D; MCPA; and dicamba
Alfalfa - EPTC; propham; and 2,4-DB
Cotton - triflualin, cotoran, diuron, DSMA, and MSMA

Pastures, rangeland and timberland - 2,4-D; 2,4,5-T; silvex; picloram; and dicamba

Industrial lands - phenoxys (2,4-D, etc.), paraquat, picloram, dicamba, bromacil, and tebuthiuron

Legal requirements for use of agricultural chemicals include materials registered by the Environmental Protection Agency (EPA). Each aerial applicator must be familiar with the requirements as indicated in the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) as amended by the Federal Environmental Pesticide Control Act of 1972 (FEPCA).

The use of aircraft in agriculture will greatly increase in the future. Aircraft, dispersal systems, and adequate techniques need to be developed for improved drift control and efficient application of agricultural chemicals. New and improved agricultural chemicals will also be developed to reduce drift, environmental residues, toxicity to nontarget organisms, and increase effectiveness on target species. The potential for aircraft use to improve agricultural efficiency and practices is very great, providing unreasonable legal restrictions and associated costs will not be a major burden to agriculture and ultimately to the consumer.

CONTROL OF PLANT DISEASE WITH AIRCRAFT

H. L. BISSONNETTE
UNIVERSITY OF MINNESOTA

Actually in themselves, agricultural aircraft have never controlled plant diseases. But the agricultural aircraft is a good machine for supporting equipment to dispense chemicals that can control plant diseases. The agricultural aircraft is used to carry and dispense many different materials from seeding wild rice to fertilizing crops to applying 1 quart of liquid per acre to applying 30 pounds of dust per acre. Each use is for a different purpose and often requires different techniques.

A parasitic plant disease is the result of an interaction between a causal agent and a host plant in a favorable environment. Microorganisms such as fungi, bacteria, and virus are causal agents. A plant disease is usually recognized by the occurrence of some type of symptom, e.g., chlorotic or necrotic leaf spots, wilting, dying, etc. This disease interaction often results in reduced yields and quality of a crop. Because of the interaction between the host and the causal agent, this injury or loss sustained by the plant is often much greater than if a similar mechanical injury occurred.

In disease control work, agricultural aircraft are involved for the most part with leaf spot diseases. Fungi account for most of the causal agents in such diseases. The microorganisms, usually in the form of spores, come to rest on the plant surface and directly penetrate the plant. Once the microorganism has entered the plant, it proceeds to grow or multiply inside the plant.

The chemicals used to control plant diseases are known as fungicides. Fungicides may be further identified by their action or type of activity; e.g., surface protectants, systemic protectants, and erradicants.

Protectant fungicides, as the term suggests, protect the plant from infection and, therefore, must be on the plant surface prior to infection. There may be several infection cycles in the course of a disease on a single leaf surface. Therefore, the distribution of the fungicide on the plant surface is very important to the success or failure of the disease control program. Once the microorganism has effected penetration of the plant and thus established an interaction with the host, the surface protectant fungicide has little or no influence on the disease development at that site.

Placement of protectant fungicides on plant surfaces involves several physical functions: droplet size, velocity of droplet, penetration, type of plant canopy, wind, temperature, relative humidity, particle size, surface tension, retention, etc.

The systemic fungicide when placed on the plant surface, is absorbed by the plant and translocated throughout the plant. Unfortunately, these chemicals

only move upward in the plant. Such chemicals protect the plant from infection internally. The systemic nature of fungicides is not the panacea that it first appeared to be.

Such materials usually protect against relatively few fungi, and already there are several examples where the pathogenic fungi are resistant to these fungicides.

Fungicides are being applied by aircraft to several field crops: wheat, barley, potatoes, sugar beets, dry beans, soybeans, and corn, in addition to orchards and vegetable crops. Each crop, because of its growth characteristics, may require different techniques for good fungicide applications.

In the case of spring wheat where Septoria Leaf Blotch is a problem, two applications of fungicide can increase the yield by 28 percent or more. With the techniques available, this program does not give complete control. In the 1975 growing season, 500 000 acres of spring wheat were treated in Minnesota with an average yield increase of 11.2 bu. per acre. Such disease control programs require the use of agricultural aircraft.

In contrast to disease control programs in cereal crops, the potato crop often requires four or more fungicide applications during a season to control the early blight and the late blight diseases. The potato, as well as the sugar beet, continues to grow new foliage throughout the season; thus, a penetration problem for aerial applications is created.

The agricultural aircraft, as usually set up, does not develop a uniform spray pattern or swath width. To make field crop disease control programs work, I started testing spray planes in the field. Since 1962, each year 50 or more planes have been checked. Each plane may require as many as 4 or 5 test patterns to make necessary adjustments. The idea of testing spray patterns is not new. Our system, Dr. H. Johnson and myself, is certainly crude, but it is done under all flyable conditions in the field. Over the years, we have observed improvement by our aerial sprayers in the use of their aircraft as spray equipment.

For disease control programs, the agricultural aircraft must develop a uniform spray pattern. The spray must penetrate the crop canopy; to do so will require droplet size control. To help all aerial sprayers do a good job will require a more extensive educational program, and better pattern testing procedures in the field will have to be developed.

SEEDING AND FERTILIZING WITH AIRCRAFT

G. F. MITCHELL, JR.
M&M AIR SERVICE

Since seeding and fertilizing are the major use areas for our company aircraft and our company being one of the largest in the U. S., it is appropriate that I talk to you about some of the things that we are doing.

Before I get into the details, one of the things we must remember is our purpose here today. The reason we are meeting today to discuss research is food. Food! We have got to feed our populations. Aircraft are used extensively for seeding and fertilizing rice. Rice represents one of the United State's largest export commodities and is the main food in the diets of people living in most of the hungry parts of the world. In 1976, there were approximately 2.5 million acres of rice grown in the United States.

Large, modern, efficient tractors can prepare land at the rate of 100 acres per day per piece of equipment, given favorable weather conditions. The airplane plays a vital role as another tool of production. Weather and time are important during the seeding periods from March through July of each year. Many air tractors are needed to accomplish numerous seeding and fertilizing schedules in a short period of time. Each piece of equipment has to have the capability of covering 100 acres per hour while applying dry material. Special loading equipment is required for the application process. Another fellow aerial applicator will talk to you later in the day about loading and handling equipment.

My presentation will be oriented toward dry material applications. The rice seed is usually presoaked for 24 hours and allowed to sprout in bags on the truck prior to planting by air. Not all seed is sprouted, but in California, Texas, and Louisiana most of the seed is sprouted prior to planting. When the sprout and root reach a length of 1/16 to 1/8 inch, the seed is ready for air-sowing. Bulk density of the wet rice seed is about 40 pounds per cubic foot. Dry rice seed has a bulk density of 38.7 pounds per cubic foot. By mentioning bulk density—and I will refer to it as we go through my presentation—I am trying to emphasize that similar materials flow at different rates. This presents metering problems.

The seed is loaded into the airplane. When sprouted, it has to be planted within a few hours, or it will spoil. It makes no difference if there is a thunderstorm in progress or if there is 6 inches of water on the runway and the wind's blowing 50 knots, it has to be planted. The airplane takes off from the on-farm airstrip and flys to the flooded rice field, usually less than 2 miles away. We feel that if we have to ferry over 2 miles with current agricultural aircraft that it is not profitable for us to apply dry materials without a surcharge.

Two flagmen are required for guidance. Here we see a problem that has been discussed several times this morning. Pacing each swath leaves something to be desired for accuracy. Two men have a hard time staying

in line on uneven terrain or in the mud. And in the rice country, they are in the mud almost all of the time. New guidance systems, reasonably priced, need to be developed.

Flight altitude is 25 to 30 feet with a seed rate of 80 to 180 pounds per acre being applied on a 25-foot swath. That is not a very wide swath, and that is another problem. Flight altitude is high to give a better spread or distribution. If we fly low, we will not get any spread at all. The water is drained allowing the rice field to dry and crack.

Now the ground is ready for fertilizing. It is time for a base fertilizer application at rates of 200 to 300 pounds per acre. The high volume usually requires many loads with swath widths of 20 to 30 feet. For this reason, we work our aircraft in pairs, one loading and one flying, but never in tandem over the field. Bulk density of this analysis is approximately 60 pounds per cubic foot. Special aircraft loading equipment and special fertilizer bulk delivery equipment is used. We apply 300 pounds per acre of 12-24-12 fertilizer. It contains nitrogen, phosphate, and potash. Distribution uniformity will vary with the application rate, swath width, bulk density of the material, expertise of the pilot, and the accuracy of the flagmen. Many variables are always present.

The rice field is reflooded (flushed) and then drained. Rice and grass emerge. The broad-leaf plants are the grass and weeds. A selective herbicide application is made to control the grass and weeds. Normally, we spray when the wind is less than 10 miles an hour and at an altitude of less than 10 feet. Straight nitrogen fertilizers are used at rates of 80 to 300 pounds per acre depending on the soil requirements. This is called top-dressing. Flight altitudes are 25 to 30 feet with a swath width of 20 to 40 feet. Bulk density of 45-0-0 nitrogen, and that is the highest analysis that you can buy, is 45 pounds per cubic foot. Bulk density of 21-0-0 is 64 pounds per cubic foot, and there are 4 grades of it ranging from 50 to 80 pounds per cubic foot. When using an airplane, I think you can see that it is advantageous to use higher analysis fertilizers and less poundage per acre.

Rice seedlings then spend the balance of their growing season in a flooded field. This is one reason why the airplane is so important to a rice farmer. Rice is grown in water, and the only way to chemically care for the crop is by air. The water is drained 2 weeks prior to harvest, and the rice then ripens. The combines reap the crop. That's what it is all about! We are after that grain. Right there! The rice is then hauled to the local rice drying and storage facility.

Fertilizer is loaded again for an application to the stubble in preparation for a second crop. We fertilize the stubble, flood the field, and the succulent shoots come out to make a second crop. This is the last dry aerial application which is usually straight nitrogen.

Streaked fields are due to improper and sloppy application. These occur due to human error and faulty equipment. The expertise of the pilot, the quality of the equipment, and proper flagging are important.

I want to mention a few facts about our company. As far as I know, M&M Air Service planted the first rice in Texas by airplane on April 9, 1946. Our company is one of the oldest and largest in Texas. We operate Ag-Cat and Stearman aircraft. We are very receptive to change to meet future demands. I am a pilot with over 7000 hours of application flight time.

I would like to recommend some research activities on aerial application and for agricultural aviation. First, we need new, low drag, more efficient dispersal equipment to cover wider swaths; an accurate system that will put near 100 percent of the material in the target area. Present systems are not going to be good enough for the EPA or the public in 10 years. Liquid systems need much research. Dry systems can put a higher percentage in the target area. There may be a trend to the use of pelletized or granular materials.

We need improved training procedures for personnel. There are several schools, but which one do you go to? There is not enough standardization among the schools that train aerial applicators and their personnel. Our company employs many people involved in this team effort during the peak season. It is difficult to coordinate machines and people to do a highly skilled, professional task without a standard. Schools should emphasize standard techniques. The amount of trial and error in operational practices and in calibration procedures needs to be reduced.

Develop new concepts to disperse liquids and dry materials by air. Redesign the spreader and the spray equipment to permit on-target application. Reduce drag of the dispersal equipment, but do not put it inside the cockpit area. Toxic chemicals and their plumbing should not be near the pilot. That is why you now see all of it hanging on the outside of the airplane. We have to figure out something better.

Design a guidance system that will work on irregular fields in rough terrain. One that we can afford. Several omni procedures, similar to the one used in Russia, operate on the Decca or VOR principle. Private industry cannot afford to pass the cost of such a system on to the farmer who is trying to produce food as cheap as possible.

How urgent are these research needs? We are 30 years late now. We have been using diaphragm-pressure nozzles, fan-driven pumps, and trays for spreaders from the beginning. The people who manufacture dispersal equipment have done a terrific job of picking up the individual ideas in practical use and developing systems that are standard on new aircraft.

What impact would solving the industry's problems have on agricultural production? We could produce more, high quality food and use less energy. Remember, the airplane can cover 100 acres per hour and use one-third the amount of fuel a tractor uses. We need to increase the efficiency and accuracy of production with more certainty. The element of time is always present.

What impact would solving the problem have on the agricultural aviation industry? It would promote more uses for air application because of increased productivity from time and energy savings.

What agricultural commodities would benefit the most? All of them. I see a trend toward granulating or pelletizing all pesticides in the future to promote on-target applications. Presently, cereal grains, cattle production with pasture improvement, rice, corn, cotton, cane, and other crops are benefiting.

How many scientist years and what level of funding will likely be required to find a solution? My estimate is 10 years and $50 million.

What will be the consequences if the solution is not found? A limit on our ability to produce high-quality foods in volume at a reasonable cost and higher energy use and cost due to the lack of productivity and efficiency.

Urgency? Now!

Who can help? The men right here in this room can help. Government, extension, engineers, colleges, practicing aerial applicators, associations, and trade groups. I do not think you need to spend time developing a new agricultural aircraft. Our agricultural aviation manufacturers: Cessna, Piper, Grumman, Rockwell, etc. all have given us a good selection of airplanes.

I think you need to spend your time in finding out how to put 100 percent of what comes out of an airplane where you want it, like you want it. Thank you.

SESSION II

STATE OF THE ART AND PROBLEM AREAS IN AGRICULTURAL AVIATION

CHAIRMAN

F. W. Wittemore
Office of Pesticide Programs
Environmental Protection Agency
Arlington, Virginia

OPENING REMARKS

F. W. WITTEMORE
OFFICE OF PESTICIDE PROGRAMS, EDP

I should like in opening this particular session, to offer a few thoughts along the lines that were presented by the last speaker, with respect to the coming world food crisis. I wonder how many of you realize that one-half of the people who have been born since the start of recorded history are alive today. Think about that for a moment. One-half of the people who have been born since the beginning of recorded history are alive today. The second point: at the World Food Congress which was held in Rome in 1974, it was estimated that the current world food aid assistance program is of the order of 9 million tons per annum. And by 1985, the demand for food aid will be 100 million tons per annum. There is not enough money in the developed or the developing countries even to be able to pay for the costs of the shipment of food aid in such astronomical quantities. And the developing countries do not have the infrastructure necessary to receive and distribute food aid of that magnitude. Now this is the type of crisis we are facing, and we in the United States, the affluent United States, frequently do not realize that even today more than 50 percent of the world's population goes to bed hungry every night. We have very real problems today, and I think they will become more acute in the future. Therefore, any actions we can take, such as these proposals to upgrade the efficiency of the use of agricultural aircraft, will contribute to the solutions of the world food problem.

PRESENT AND FUTURE CONSTRAINTS ON THE UTILIZATION OF AGRICULTURAL AIRCRAFT

A. F. JOHNSON
AIR ENTERPRISES, INC.

My primary emphasis today will be on the new breed of aircraft, those which are on the market today. These will be compared with those of the past and with those of the future. We have no idea what the future aircraft will look like or how it will handle. Its development is the purpose of this meeting.

There are 10 or 12 aircraft types on the market today which we call the new breed—all are similar to the Ag Cat, Ag Wagon, Thrush, and Weatherly. In speaking today I will refer to the average operator. This average operator using the new breed of planes covers somewhere between 75 to 150 acres per hour depending on the type of work he is doing. This operator grosses between $80 000 and $125 000 per aircraft per season. Generally, each aircraft flies from 400 to 700 hours depending on the geographical area.

Twenty years ago the average operator covered from 40 to 60 acres per hour using converted military planes, old Stearmans, Cubs, etc. The annual gross per aircraft was $25 000 to $50 000 with 400 to 500 hours of flight time. The pilots were much more fatigued than those of today, although we now fly as many or more hours.

What we would like to see in the future aircraft, although we may not get it, is one which would be capable of producing 150 to 200 acres per hour. We would like to turn over a gross of between $200 000 and $325 000 per aircraft per season or higher. Now that is not to say that we will be able to meet this figure, but it certainly would be nice particularly in light of the increased cost of the planes.

I bought my first Stearman for $5000, and that was high at the time. In later years we purchased Ag Cats for $30 000, and today we pay $70 000 for an Ag Cat. The price per acre has gone up only 25 to 30 percent in the last 20 years. Why is that? It's only because of the higher production capabilities of the newer planes. We are able to produce more acres per hour or, if you want to convert that, more dollars per hour.

The performance parameters mentioned above (150 and 200 acres per hour with a gross of $200 000 to $325 000 per aircraft per season) could be met by using planes similar to those of today but with improved flying techniques and different equipment designs. This would be based on a use rate of between 500 and 700 hours per season, keeping in mind that this would be an average for both short and 12-month seasons. Assuming that this plane could be built (meeting these requirements as well as other demands) for between $150 000 and $350 000, I am certain the industry would find it acceptable.

A little history of my operations, I mentioned that the first aircraft I bought was a Stearman. I figured to pay it off in one year—which we did. At that time we flew only about 400 hours per aircraft and sprayed some 20 000 acres. This is again my operation; now we are up at 5 and 6 gallon/acre work. This was 18 years ago. In 1967 I bought a 450 Ag Cat, sprayed approximately 30 000 acres, and flew 450 hours, a very low hourly increase but again a large increase in acreage. And I expected to pay that aircraft off in three years, which I did. Later I bought a 600 Ag Cat, flying an average of 600 hours and spraying somewhere near 40 000 acres per season. Also I paid it off in three years. The future breed I would expect could be paid off somewhere in five to six years. You are getting into more sophisticated equipment, and you are going to have different pilots flying them than you do today. They are about the same pilots—just a little sharper.

A very serious constraint would be the length of season that an operator would have. If he is up in North Dakota and operating for only two weeks or three weeks out of the year, there is no way in the world he is going to make this airplane pay for itself. But the average operator around the country today works anywhere from six to nine months, and he should have a long enough season to pay it off. This is similar to my operation now; we are operating roughly seven months out of the year, and I feel as though these more expensive planes would be advantageous to us.

Over the years our industry has made improvements on its own. As you heard earlier when Mr. Cobb was speaking, operators have developed newer systems or they have improved the old ones over the years, but basically we are still operating on the same equipment that we operated 20 years ago. I am talking about spray dispersal equipment now. We have improved the airplane. The boom that I had on my Stearman is about the same boom that is hanging on the Ag Cat today. I am not saying that that is not doing a good job, but I am sure there could be quite a few improvements made, not only on the boom but also nozzling, and whatever goes with the boom. In the last 10 or 12 years there has been very little improvement made by the industry. They have improved what they have, but basically there has been no new development.

We, as operators, are entirely too busy today to be developing newer equipment. We are trying to stay in business and also meet with the present requirements of the EPA and a few other regulatory agencies. They are doing the job they are supposed to, but some regulatory people have a picture of our industry that has been distorted some. These pictures that they have were drawn 10, 15, or 20 years ago when we did have a lot of problems. I think operators around the country have improved their own operations enough to where a lot of regulations we are being forced to live with today have already been controlled. I am sure the regulations are aimed at the operators who are not operating up to Hoyle and are operating in high winds, etc., and these are the problem operators. Of course, a lot of this has come from bad publicity over the years. The papers do not print anything good. The people do not like to read it, I suppose. The future aircraft

being designed around our problem areas can stop further harrassing regulations and possibly cancel out some present ones. If I had an ideal situation, I would like to perform my spraying operation between the hours of midnight and 4:00 a.m. in the morning, from an altitude of 500 feet. I see a lot of puzzled looks. I am sure you wonder why I feel that way. Well, as far as elimination of any further regulations, I feel that first, no one would notice any spray drift. Second, at 500 feet I would not hit anything. And third, no one would see me. And I think this is a lot of our problem. We are too obvious out there. You could put 20 ground sprayers on the same farm, and nobody would complain at all about anything they are doing, but you put one airplane, and everybody sees you. (And we get the blame.) That is a little far fetched, but I mean this is one way of trying to avoid having any more regulations thrown on us.

Aircraft meeting the future requirements should eliminate many regulations now existing for both the pilot and also ground crew personnel. The ground personnel's exposure would be shortened tremendously, because of shortened periods of exposure of chemicals. More than likely, the newer type loading systems meeting the future agricultural aircraft requirements could be developed, such as closed systems, and pre-mixed load systems.

Pilots of the future would have to spend more time keeping their skills sharpened, becoming more like an airline pilot. Go through training sessions, doing less routine chores than he is today such as his maintenance and his field crop service. Many operators and pilots today are doing more chores than flying. I think the pilot of the future is strictly going to be a pilot. In my operation he has been that way for years. And I know of several operations around the country in which the pilot does nothing but fly. But some operators haven't been able to get this far advanced, but they are going to have to have pilots that are extremely sharp.

Another very serious constraint would be the lack of highly skilled pilots. We would have to look at improving our training facilities. The old type "Johnny crop duster" of 20 years ago certainly would not fill the bill today. He is the one that a lot of you people in Washington have had the image of, the old guy sitting in the corner with a cloth helmet, goggles, and boots. That was in the corner of a bar, too, by the way. And if you wanted him to go to work you knew where to find him—that was his office. But today that's different, and we are trying to change this image. That man certainly would not fill the bill for current or future aircraft.

Along with any new equipment that is developed, we've got to constantly keep in mind the pilot. He must have comfort to reduce fatigue. This has been one of the biggest assets to the new breed of aircraft over the older breed. I find that I can fly twice as many hours as I did 20 years ago and not be near as tired. Mainly that has been because of reduced fatigue due to enclosing cockpits, getting rid of spray odors, and reducing the noise factor. Another item I think we should be concerned with is the over regulation of what we face today. As I mentioned about flying at night at 500 feet, noise would possibly be eliminated also. Noise is one thing that we

should be looking at in the future. Building aircraft around this problem, whether it be turbine power, different propeller design, whatever—we should keep this in mind. I think in a sense we are making a big change in noise levels with the new turbine type aircraft that have been developed in the last few years.

Another factor to keep in mind is drift. This is a problem area and always has been. But I'm sure many aspects can be looked at which would reduce drift. Insect and disease control can be changed, like utilizing vapor as a means of insect control instead of contact spray. We are doing some of this at the present time; we do use vaporization in some insect control. But maybe this will be the complete answer of the future. This way you could apply a coarse spray which vaporizes and does its job instead of a direct contact spray trying to apply on the target. Now of course, this isn't going to cover every aspect of the industry, but it could be a help. I don't know how you could vaporize and use herbicides safely. I think that is our problem now.

We need to develop an accurate swath marking system, as George showed you this morning. Swath marking is important. You have a flagman that sits down on the job, and you will leave a streak. I did talk with the NASA people at the Washington meeting, and they already have some ideas on what they can do, and I am sure it would be something that will be looked at for the future. This would also ease the pilot again and take his mind off watching his last mark, which is a constant source of strain, and fatigue. It would also assure and show our regulatory people accurate chemical placement.

The future aircraft should still be able to maneuver around trees and other objects and not be cumbersome and bulky. I would say that its size would be restricted, but it still would have to be able to land in unproved landing areas and also be able to take off out of the same area. You want to look at length of wing compared with boom length for drift elimination. This is something some operators are already doing. But I am sure this is something we would want to keep in mind for the future aircraft. These aircraft need to be placed in a special maintenance category. I was talking to a fellow this morning about a complete new category just for agricultural aircraft. We are under the restricted category at the present time, but I think that agricultural aircraft should be almost in a category of its own.

We should be looking at ferry speed compared with application speed. Satellite runways could be reduced by an aircraft's ferry speed being increased. The idea would be ferry 200 and spray at 100. Again, I am asking for a lot, but I am giving you the far exception to the rule. Mostly what I discussed here today has been developed from problems of the past and areas that I feel we could improve on in the future.

OPERATIONAL MISSION ANALYSIS AND ECONOMIC EVALUATION

J. C. BRUSSE
TEXAS A&M UNIVERSITY

The title of my presentation this afternoon contains words like "analysis," "economic," and "evaluation" could lead you to think that I am an economist of some type. Be assured that I am not an economist—I was quite interested in George Mitchell's remarks about the roles of people involved in the aerial application of agricultural materials and their importance in providing food and fiber. All of us who go to Safeway or A&P to buy groceries shudder at the checkout counter because of the cost. Food is expensive and is likely to become even more expensive as the cost of production services escalate. Agricultural aviation is one of those production services that is involved in almost every aspect of food and fiber production so we have got to be concerned with its cost.

I think cost is one of the most important things that this group here must keep in mind when we talk about sophisticated new airplanes, or guidance devices, or regulations or all of the things we can do. We can do an awful lot of things, but let us keep in mind that we must do these things efficiently and economically because the last pocket the money comes out of is mine and yours—at the store.

If we are going to try to do more at less cost, some sort of optimization of efficiency is necessary even if new machines and methods are used. We will not only have to increase the land productivity but also increase the productivity of the aircraft we used in treating the crops grown on the land.

In order for a custom aerial applicator to know what a given operation costs and therefore, how much to charge his customer, he must make some sort of cost analysis. The cost analysis which should provide a measure of productivity is often known as a mission analysis. An operator that has been in the business for a long time and active in aerial application to only one or two crops, usually will know the productivity of his equipment. But if he is to attempt an operation somewhat different than the usual for him, a more complete mission analysis would be required.

The aerial application of agricultural materials requires that an aircraft hopper be filled with the desired material which is to be released later at a prescribed rate while flying over the intended application area. When the hopper or tank is emptied, the aircraft is flown back to the loading area, and the process is repeated. This process continues until the entire application area is treated. One can say then, from filling hopper one time to filling it again is one cycle in the process of treating an area with agricultural material. It can also be said that

this cycle consumes a span of time. Within this time cycle, several different operations have been performed. The airplane has been loaded, it has taken off and flown to the treatment area, it has performed several swath runs, sprayed or dispensed dry material, and has turned around following each swath run after which it returned to the loading area and landed. Each portion of the total process is different and each requires certain actions by certain people as well as a certain amount of time. The basic time cycle from load to load can be broken into as many parts and made as complex as desired to serve any specific purpose. Written as an equation, an aerial application operation can be expressed as follows:

$$T_c = T_g + T_f + T_s + T_t + T_{trim} \qquad (1)$$

where

T_c Time for one cycle
T_g Time on ground
T_f Time to ferry
T_s Time in swath
T_t Time in turns

It can be seen from the equation that most of the time cycle is consumed while the airplane is flying, and therefore, the productivity of the entire operation is primarily dependent on the performance characteristics of the aircraft and the piloting techniques employed.

Another equation using the time cycle as one term can be written to describe the work rate or productivity of the aircraft:

$$\text{Productivity} = \frac{A}{Hr} = \frac{W_L}{QT_c} \qquad (2)$$

where

A Acres
Hr Hours
W_L Weight of one load, pounds
Q Flow rate of materials, pounds/acre
T_c Time cycle from Eq. (1)

In a combined form, the productivity formula appears as follows:

$$\text{Productivity} = \frac{A}{Hr} = \frac{W_L}{Q\,(T_g + 2T_f + T_s + T_t + T_{trim})}$$

Appropriate conversion factors must be used where required to change the various values from convenient or normally used units to like units. For example, T_g is usually expressed in minutes while T_t normally in seconds, and since the formula yields acres per hour, different conversion factors are required to calculate the various time elements in portions of hours.

The productivity formula is valid for only one set of conditions, and in order to establish or predict expected productivity for each application job, the specific operating conditions for that job must be used. Most of these values are readily available, and little difficulty is encountered in converting them to the desired units. There are many factors that cannot be conveniently expressed mathematically, and adjustments or correction factors must be applied.

One possible correction of this type is to the time required to avoid obstructions. If the obstructions are in the field, the correction should be applied to T_s, and if they are at the ends of the field where they affect pull-up and trim time, it should be applied to T_t.

The following example was selected to demonstrate a use that can be made of the productivity formula or operation analysis on a comparison basis with an actual timed application. In the example, the productivity equation was solved using time element estimates made by the pilot, manager, and ground crew chief. These time estimates were entered in the productivity formula, and a productivity value was calculated.

Another productivity value was calculated on the basis of the field dimensions, intended application rate, and the indicated air speed, but with trim times and turn times calculated on the basis of safe, near maximum performance procedure turns. See appendix. A procedure turn involves a moderately steep-banked downwind turn providing about 45^0 heading change followed by a rolling maneuver into an upwind turn of approximately 225^0 at an airspeed near the best angle of climb speed. A 1.35V stall is reasonable for the best angle of climb speed for most airplanes and can be used if the actual best angle of climb speed is not known.

The equation used to determine turn times for the calculated productivity value is

$$T_t = N_s \frac{2v_s}{g \tan \phi} = N_s \frac{0.264_s}{\tan \phi} \qquad (3)$$

where

N_s number of swaths used since one turn per swath is required

V_s speed in swath, mph

ϕ angle of bank, degrees

g gravitational acceleration

It can be seen in the turn time equation that the constants have been consolidated into one value which includes a factor of V_s to provide an approximation of the best angle of climb speed. In the form shown, the value of T_t is found in seconds.

An actual observation of the time elements involved in the operation was made while the field was being treated to determine the actual productivity achieved for the particular conditions of wind and temperature that existed at the time of the treatment.

Three productivity values for the one application are, therefore, available for comparison.

Table 1 shows the differences between the estimated, calculated, and actual times involved for the elements of the time cycle expression as well as the productivity values calculated from equation (2).

It is immediately apparent from the tabulated data that the productivity value derived from the estimates of time is very close to the value resulting from the time study. This indicates that this pilot is familiar with the field and the obstructions involved and is capable of accurately estimating the time to make the application. The major differences occur in the turn time and the trim times. The disparity between the three values of T_t can be explained by the presence of moderate low-level turbulence and high ambient temperature which required maintaining a higher than usual airspeed in the turns.

The large value of T_{trim} in the timed data indicates poor calibration of the equipment in that the pilot spent roughly twice the time trimming than was estimated or calculated. The additional T_{trim} was used in expending the excessive material remaining in the hopper after completing the normal trimming runs.

An analysis based on only one small acreage treatment will not permit making significant conclusions about overall operation. Productivity values from a series of timed evaluations concerning a variety of field shapes and sizes compared with calculated productivity values may indicate areas of the operations that need improvement. The use of the productivity formula as an operations analysis tool should be undertaken cautiously and with an awareness of the complex interactions of the many variables involved.

Variations of this approach, as well as more sophisticated methods, can be devised to estimate to any practical limit any variable involved in a mission and thus, will provide a manager with more information on which to base cost cutting or efficiency-related decisions.

APPENDIX

VALUES USED IN EXAMPLE

Element	Value	Origin
W_L	552 pounds	Metered
Q	17 pounds/ acre	Required
T_g	5 minutes	Estimated
D_f	4 miles	Map measurement
V_f	100 mph	Indicated airspeed
T_t	25 to 30 seconds	Estimated
S_w	35 feet	Measured by flagman
S_{L_1}	2750 feet, 0.52 miles	Map measured
S_{L_2}	825 feet, 0.156 miles	Map measured
V_s	100 mph	Indicated airspeed
T_{trim}	4 minutes 45° to 50°	Estimated Angle of bank estimated

TABLE I

ESTIMATED, CALCULATED, AND ACTUAL AGRICULTURAL AIRCRAFT PRODUCTIVITY

ELEMENT	ESTIMATED	CALCULATED	ACTUAL
T_g	5.00	5.00	4.35
T_f	4.80	4.80	4.06
T_t	10.50	7.98	9.09
T_s	4.57	4.57	2.61
T_{trim}	4.00	3.12	7.96
T_c	28.87	25.47	28.07
Productivity	67.4 A/Hr.	76.5 A/Hr.	69.4 A/Hr.

DISPERSION OF MATERIALS IN AN AIRCRAFT WAKE

H. L. CHEVALIER
TEXAS A&M UNIVERSITY

One of the major factors affecting both aerial distribution and drift is the aerodynamic wake of the aircraft. The aerodynamic wake affects the trajectory very near the aircraft and continues to affect the trajectory for a considerable length of time after the aircraft passed over a given point. This lingering effect is the result of the aerodynamic wake produced by the aircraft trailing vortices.

Although there are many aerodynamic effects to be considered, the three major effects are: (1) aircraft propeller wake, (2) the wake of the two-dimensional airfoil, and (3) the wing-tip vortices.

The propeller effect produces a twisting motion of airflow. Below the aircraft a velocity component is produced that results in flow from right to left. Although the description of the propeller wake is simple, current theoretical techniques cannot adequately predict this effect. Many influencing factors must be considered in the prediction of the resulting propeller wake. One factor is the engine horsepower and propeller design. The second, and probably most important, is the influence of the fuselage on the propeller wake. Another problem is the effects of wing interaction. With the trend toward larger horsepower engines in agricultural aircraft, the resulting propeller wake could produce undesirable distribution problems. Additional experimental information and theoretical techniques are needed for predicting propeller wakes.

The location of spray booms along the trailing edge of the wing is determined by practical considerations. Some of these considerations are maintenance, location such that the pilot can see the boom, and location sufficiently high to avoid damage during take-off and landing. In general, little consideration is given to the aerodynamics of the flow field around the airfoil section when locating the boom. The velocity of the air at the spray nozzle will obviously affect the trajectory of spray droplets and more attention should be given to optimizing spray nozzle locations with respect to the airflow over the wing surface. In addition, efforts should be made to develop theoretical techniques for analyzing the aerodynamics of the airfoil and spray equipment as an integral system.

Both propeller effects and airfoil wake effects occur very near the aircraft, and the influence of these effects diminish very rapidly after the aircraft has passed a particular point on the ground. In the case of wing-tip vortices, the influence of the resulting aerodynamics occurs at the aircraft and lingers for several minutes after the aircraft has passed a particular point on the ground. The Flight Mechanics Laboratory at Texas A&M University has conducted numerous experimental tests to study the

characteristics of trailing vortices. Although this previous work was for wake turbulence associated with transport type aircraft, the results are applicable to the agricultural type aircraft.

Flow Induced Near the Wing

Particular attention must be given to the induced velocities at the trailing edge of the wing. Textbooks show the formation of aircraft vortices as a result of a simple sheet of vorticity which rolls up behind the aircraft. Studies have shown that this simple model is, in general, sufficient for predicting airloads on the aircraft, but is grossly oversimplified for predicting the velocities in the region behind the aircraft. The formation of vortices at the wing tips of the aircraft is very rapid and occurs at a very short distance behind the wing.

Recent theoretical and experimental work enables us to predict more accurately the vortex roll-up pattern and resulting flow fields immediately behind the aircraft. Theoretical analysis, along with flight validation, has shown that by changing the load distribution across the aircraft's wing, more than two vortices can be obtained, and various arrangements of these vortex patterns can be obtained. The vortices can be arranged to attract each other so that the flow field behind the aircraft wing is concentrated in a small area or they can be arranged to repel each other so that the flow field is dispersed over a much larger area. This work could be highly significant in agricultural aviation studies and current technology is available for programming this type of information within a computer modeling scheme.

Flow Induced in the Far Field

Although it would be difficult to accurately estimate the length of time that must be considered to account for the total distribution, test results show that the aircraft's trailing vortices can float above the ground surface and thus, linger for as much as fifteen minutes after the aircraft has passed a particular point. In addition to the effects of weather, terrain, and other factors, the dissipation time for these velocities can be greatly altered by the airload distribution on the airplane wing, height of the aircraft above the ground, and the aerodynamic interactions for the multiple passes.

Some techniques for predicting the flow field after the aircraft has passed over a particular point are too greatly simplified and inadequate. Most work assumed the vortices to be formed around a horizontal sheet of vorticity which would descend after the aircraft had passed until it reached the ground. Flight tests have shown that these vortices are not straight and, because of an instability, tend to form a wavelike pattern. The vortices will initially descend at a rapid rate but the descent will become slow near the ground surface. The buoyant vortex pattern near the ground will tend to linger for long period of time before dissipating.

The effects of vortex lingering, buoyancy, and drift are obviously major factors and must be considered in predicting the distribution pattern during aerial operations. By using recently developed theoretical and analytical tools, an accurate description of the velocity induced both in the horizontal and vertical planes in the area of spray operation can be predicted.

Flight Pattern

The induced flow field behind the aircraft produces downward velocity in the region between the vortices and upward velocity in the region beyond the vortices on either side. With this type of flow pattern lingering for several minutes near the ground, it is easy to see that during subsequent passes the aircraft could be dispersing material in the upward velocity region and thus could cause a potential drift problem. The mutual interaction of the flow fields generated by the aircraft on several passes must be considered. A complete modeling of the spray pattern would include a timed history for all passes over a given area by the aircraft. The aircraft speed, height above the ground, and path would be important factors considered in these calculations.

Meteorological Parameters

Recent flight test studies have shown that the induced flow field behind the aircraft and weather conditions such as wind direction, temperature, humidity, and gust conditions must be considered simultaneously to accurately predict drift. To predict vortex drift patterns for wind speeds and directions is similar to that of predicting the drift patterns for several vortex configurations where one vortex is inducing winds upon the other. However, the total picture of drift is more complicated than simply including wind speed and direction. The effects of humidity, temperature, and turbulence drastically affect the stability of the aircraft's wake.

In the past, the effects of winds have been considered to be a disadvantage due to the potential for drifts. Recent studies of aircraft trailing vortices have shown that moderate winds and low level turbulence can easily trigger vortex wake instabilities and cause rapid dispersion of the high intensity velocity behind the aircraft. This rapid dispersion, approximately twenty seconds instead of several minutes, could significantly reduce drift. With rapid dissipation of the velocities, the drift of spray particles could be significantly less than that for an extremely calm day where particles could be suspended in mid air because of high velocities for several minutes. Computer modeling that could accurately predict the optimum spray pattern for varying meteorological conditions could be used to reduce the hazards of drift.

Terrain

The physical characteristics of a target area and the area surrounding it is a major factor in considering total drift. The location and height of hills, trees, buildings, and other obstructions can greatly affect wind

speeds and directions. In addition to affecting meteorological conditions, ground obstructions can highly affect the stability and duration of the wake behind the aircraft. Numerous flight experiments have shown that obstructions, such as fences and trees, can penetrate the vortex core and cause a bursting of the vortex.

AIRCRAFT CERTIFICATION PROCEDURES

HERBERT SLAUGHTER
SIKORSKY AIRCRAFT

Introduction

It is a pleasure for me to be here today to discuss a most important subject, Aircraft Certification Procedures. NASA has embarked on an agricultural aviation program which has gained wide support in its initial stages. The program plan, as I understand the scope, includes many areas of research and development which will affect the aircraft design, its modification, the equipment it carries, and its handling characteristics in operation.

Acknowledging that changes to civil aircraft require FAA approval, I believe it is very appropriate to discuss the subject of aircraft certification at this workshop. When the results of the NASA research and development program are appropriate for application, it is essential that the regulations and procedures pertinent to aircraft certification be current and, most important, be realistically appropriate to agricultural aviation. At this time, it is not clear that all the requirements that are being applied to agricultural aviation aircraft are appropriate. If this is a correct assumption, and if the fruits of NASA agricultural aviation programs are to be realized, then we must construct a system in which it is conducive for the results of research to be readily applied to the aircraft in operation today or for those that will be designed and produced in the future. In order to put this in better perspective, I would like to set forth the regulatory basis for aircraft certification, develop typical aircraft certification procedures, discuss significant agricultural aircraft safety factors, identify some problem areas, and make some observations and recommendations for research and development.

Regulatory Basis

A regulatory basis for aircraft certification has been developed over the past 50 years by a series of acts by the U. S. Congress, namely:

(1) Air Commerce Act of 1926
(2) Civil Aeronautics Act of 1938
(3) Federal Aviation Act of 1958.

In each of these acts, the administrator has had a clear mandate with regard to aircraft certification. May I quote this mandate?

> If the administrator finds that such aircraft, aircraft engine, propeller, or appliance is of proper design, material, specification, construction, and performance for safe operation and meets the minimum requirements, standards, rules, and regulations prescribed by the administrator, he shall issue a type certificate thereof.

That is the basis for the aircraft certification system, and the Federal Aviation Administrator has established standards, rules, and regulations pertinent to agricultural aircraft certification. The regulations from which the certification basis is established for the agricultural aircraft in production and operation today are as follows:

(1) Civil Air Regulations (CAR) Part 3 - Airplane Airworthiness
(2) Civil Air Regulations (CAR) Part 6 - Rotorcraft Airworthiness
(3) Civil Air Regulations (CAR) Part 8 - Restricted Category
(4) Civil Aeronautics Manual (CAM) 8 - Restricted Category
(5) Federal Aviation Regulations (FAR) Part 23 - Airplane Airworthiness
(6) Federal Aviation Regulations (FAR) Part 21 - Procedural Rules
(7) Federal Aviation Regulations (FAR) Part 27 - Rotorcraft Airworthiness

Many of you may know that the Civil Air Regulations (CARs) were recodified in the early 1960s as Federal Aviation Regulations (FARs). CAR 3 and CAR 6 were recodified to FAR 23 and FAR 27 for airplanes and rotorcraft, respectively, and CAR 8 was recodified to FAR 21.25, for restricted category aircraft. Although the CARs have been recodified, they are still applicable to those aircraft types for which the CARs are referenced on the type design data sheet as the certification basis. When these older aircraft are modified, it is done on the basis of the minimum standards specified in the applicable CARs. However, an applicant with the new type design must show compliance with the Federal Air Regulations (FARs). In the past, CAR 8 and CAM 8 provided a needed liberal basis upon which to certificate an agricultural aircraft. In view of recodification, there seems to be some question as to whether CAM 8 is still pertinent and can be used as policy. It can! FAA Advisory Circular 20-33B references the older CAMs and states that the policy material contained therein may be used in conjunction with specific sections of the Federal Aviation Regulations. Let's review certification basis for the current production agricultural airplane types. A predominant number have been certificated in accordance with the standards of CAR 8 and CAM 8, Appendix B. (See Table 1.) Appendix B presents the airworthiness criteria for agricultural and similar special purpose aircraft. The purpose of Appendix B states

> These airworthiness criteria have been derived from CAR 3. Certain requirements of CAR 3 have been waived, modified, or presented in a different form to provide criteria appropriate to the types of airplanes in operation, and to simplify methods for insuring compliance in accordance with CAR 8.

Let's keep this philosophy just quoted in mind and note that the criteria was developed in the 1950s and represents a technology dating previous to 1950. With new technology developing from the proposed NASA agricultural aviation program, it would appear appropriate to reassess the airworthiness criteria applicable to agricultural aircraft.

Aircraft Certification Procedures

Aircraft certification procedures are established by the FAA to provide a system whereby the administrator can make his finding of compliance, as we have mentioned previously. (See Table II.) The FAA engages in the certification process only after the application is made by the applicant for a type certificate or supplemental type certificate. One of the key elements in the process is the determination of the certification basis, the regulations with which compliance must be shown. With the certification basis established, the applicant and his designers can proceed in an orderly manner with the design and with program development. In these certification programs, the FAA has design evaluation responsibility, and conducts flight tests when such are required. In complete and more complex projects, the FAA will convene a Type Certification Board of experts to insure that full compliance has been shown in the various technical disciplines involved. In simple and less complex projects, the TC Board is not involved, and an FAA Engineering Service Representative can be assigned to handle the complete program. Designated Engineering Representatives, which are not FAA employees, can be hired by the applicant in certain technical areas to prepare data for FAA approval. When the FAA Engineering and Manufacturing Branch in the FAA region is satisfied that compliance has been shown with all the pertinent regulations specified in the certification basis, the Type Certificate (TC) or Supplemental Type Certificate (STC) can be issued to the applicant. The applicant then can be authorized to produce a modified product in accordance with the terms of the STC or the TC. It is appropriate to keep these procedures in mind as new technology is developed and applied to civil aircraft. In the past, the general aviation industry has not readily applied the results of NASA's new technology developments. Part of that problem has been generated because the FAA has not been aggressive in recognizing these new technological developments and in setting forth the applicable civil safety criteria for the guidance of industry. With such timely guidance, industry can make plans to use the new technology and can determine what the certification risks are. This is an area that needs to be explored more progressively.

Agricultural Aircraft Safety Factors

The development of appropriate regulations for new technology and the certification procedures, and the need for research and development is frequently motivated by the accident statistics and factors. It would appear appropriate then to review the current information on accident records for agricultural aircraft for 1974, those currently available

from NTSB. Figure 1 shows total accident rates for 100 000 aircraft hours flown with the various kinds of general aviation flying in 1971 through 1974. The accident rate for aerial application in 1974 is considerably above, almost double in fact, the general aviation average rate and almost equal to that of pleasure flying. This reflects, in my opinion, the nature of the business and the continuous exposure and risk involved. A more discouraging sign, however, is the increasing rate in 1974 after several years of an improving trend. Figure 2 shows the fatal accident rate per 100 000 aircraft hours flown for the various kinds of general aviation flying for 1971-1974. The fatal accident rate for aerial application in 1974 is below that of the general aviation average rate and is less than half that of pleasure flying. You can observe the contrast between total accidents and fatal accidents and the favorable position of the fatal accident rate in comparison. This would indicate that even though the exposure is high and continuous, the contact speeds with the ground and objects are lower, crashworthiness designed provisions are contributing favorably, and professional pilots can control the aircraft much better in adverse situations. A survey was made of the accident factors involved in 467 accidents. (See Table III.) Stall/mush and the engine failure/malfunction are the most frequent type accident. The swath run, procedure turn-around, and the initial climb are the operational phases in which agricultural aircraft accidents occurred most frequently. It is significant to note that only 31 fatal accidents occurred during 1974 in aerial application operations. Engine failure or malfunction accounted for 30 percent (139) of the total number of accidents. The increasing trend in aerial application accident rate in 1974, together with the high percentage of total accidents caused by engine failure/malfunction, indicate that a more in-depth study of accident data could identify areas where needed research could contribute to safety improvement—particularly in the operational phases.

Some Problem Areas

The proper utilization of the agricultural aircraft is the worry of every successful agricultural operator, and I am sure if he is unsuccessful, he is worried about that too, but he opts for higher payload and maximum acreage coverage per day. He keeps safety in mind! However, higher payloads than normal reduce performance and quite often adversely affect the aircraft handling characteristics. High utilization per day has its effect on pilot fatigue. These areas quite often lead to problems. Let us take a look at just a few examples.... Stall warning is a required safety feature which advises the pilot of impending stall sufficiently above the stall so the pilot can take corrective action. Yet some agricultural airplane pilots are disconnecting the stall warning system to avoid the incessant noise during the continuous spraying and maneuvering operations where they may be operating close to stall. With the new technology that has been developed in recent years in sensors and rate mechanisms, and new emphasis on the stall

spin research by NASA, hopefully a new method can be found to provide stall warning which can eliminate the nerve-wracking conditions of nuisance noise that the agricultural pilot must now endure.

Meeting the aircraft's stability requirements in a given phase of flight or configuration can introduce poor handling qualities in another phase of flight. This can occur in the phase of flight in which most of the flying is done. Such is the case with current agricultural airplanes. The manufacturer has taken steps to improve this condition, but it is reported that the operators have gone a step further. They have altered the aircraft and improved the handling qualities in the most used phase of flight and the threshold of pilot fatigue has improved. It is questionable now, however, whether the airplane meets specific FAA flight requirements. But is the operation now safer for the agricultural pilot when the pilot fatigue is considered as part of the equation? Another question is asked: should handling quality requirements be developed specifically for and tailored to agricultural operations?

Higher operating weight approval has been continuously sought by the agricultural operator since the agricultural operations first began. The maximum gross weight for the aircraft type specified under type design data sheet has been determined on the basis of FAA requirements for performance, structure, and flight characteristics. Higher operating weights were granted on the basis of flight demonstration to the FAA field inspectors.

These higher operating weights over the type design data sheet maximums have not been recognized by some of the airworthiness authorities in foreign countries; this condition presents difficulty in the export of these aircraft. Recently, the FAA has issued a policy whereby the manufacturer can demonstrate this higher operating weight in the restricted category and incorporate the specifics as a note on the aircraft type design data sheet. The note would appear on the aircraft type design data sheet when the demonstration has been made by the aircraft manufacturer. "These aircraft have demonstrated satisfactory operations in the restricted category under the following conditions..." and the applicant would list the weight, standard altitude at which it was demonstrated on a standard day, the center-of-gravity range, the maximum speed in that configuration, and some have identified the increase in stall speed.

Recommendations for Research and Development

In summary, let us consider the following observations and recommendations for research and development:

(1) Develop Agricultural Operation—Compatible Stall Warning Techniques

If aircraft designs and systems meeting FAA safety requirements are not used and are bypassed by agricultural operators and pilots, an alternative method should be developed to provide stall warning and still meet the FAA safety objective.

(2) Develop Handling Qualities and Requirements Tailored to Agricultural Operations and Tuned by Agricultural Pilots

Agricultural pilots have gained much experience since the 1950s in agricultural operations. With all this experience background, agricultural pilots could contribute along with the engineering pilots in the development of new handling quality techniques specifically tailored for agricultural airplanes. Such new techniques could provide safety improvements in agricultural operations.

(3) Determine Research and Development (R&D) Emphasis Areas Based on Assessment of Agricultural Accident Data

The total accident rates for agricultural operations are high even though operations are conducted by professional pilots. Most accidents occur in the operational phase close to the ground while maneuvering. Concentration of R&D efforts in these areas could contribute to safety improvements for agricultural operations.

(4) Establish a More Aggressive VHG Recording Program

A more substantial and realistic data base should be developed from agricultural operations to provide design criteria specifically for agricultural aircraft.

(5) Assess Present Design Criteria and Using New Agricultural Technology Make Criteria More Agriculturally Compatible

The present design criteria for agricultural airplanes is based upon 1950 and earlier technology. This criteria, based upon new technology, could be adjusted more favorably to the agricultural aircraft mission without degrading safety. Perhaps a more realistic criteria could be removed from the stigma of Restricted Category and incorporated as an Appendix to FAR 23. This could create more favorable international acceptance of U.S. agricultural aircraft and ease export problems.

In order to be responsive to the needs of aviation in the times of changing technology, Aircraft Certification Procedures must be current, realistic, and compatible with regard to the particular operating mission. Hopefully-this presentation has provided a better understanding of the Aircraft Certification Procedures relating to agricultural aircraft and the areas for needed improvements.

TABLE I

CERTIFICATION BASIS

MANUFACTURER	MODEL	TYPE CERTIFICATE NUMBER	CERTIFICATION BASIS
Grumman	G-164	1A-16	CAR 8.10 (a) (1), October 11, 1950, CAM 8, Appendix B - 1957
Piper	PA-25	2A8	CAR 3, May 15, 1956, Amendment 3-1
Piper	PA-25	2A10	CAR 8.10 (b), October 11, 1950
Rockwell Commander	S2A	2A9	CAR 8.10 (a) (a), October 11, 1950, CAM 8, Appendix B - 1957
Rockwell Commander	S2B, S2C, 600-S2C	2A7	CAR 8.10 (a) (1), October 11, 1950, CAM 8, Appendix B - 1957
Rockwell Commander	600-S2D, S-2R	A3SW	CAR 3, May 15, 1956, Amendment 3-1, 3-8
Cessna	188 Series	A9CE	FAR 21, February, 1965, Restricted Category FAR 23, February, 1965, Normal Category

TABLE II

AIRCRAFT CERTIFICATION PROCEDURES

APPLICANT	FAA
Submits application for type certificate or supplemental type certificate	
	Establishes certification basis
Designs product	
Provides to FAA descriptive data	Evaluates design data, analyses
Conducts analyses and tests	Witnesses tests and evaluates test results
Provides product for inspection and tests	Conducts flight tests and conformity inspections
	Conducts Type Certification Boards (TCB)
Owns type certificate or supplemental type certificate	Issues type certificate supplemental type certificate

TABLE III

SIGNIFICANT ACCIDENT FACTORS

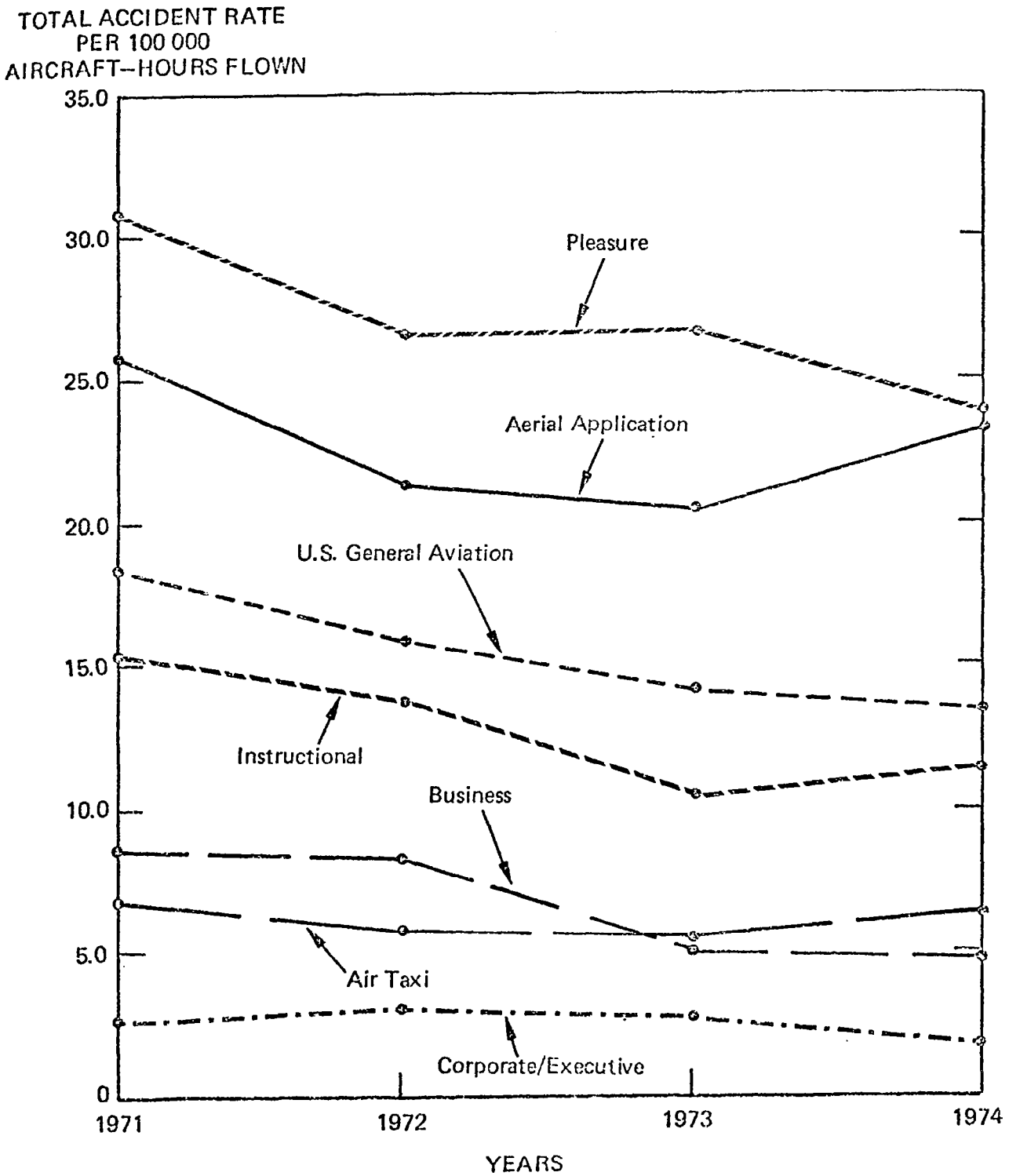
1974 - Total Accidents - 467
Fatal Accident - 31

ACCIDENTS	NUMBER OF ACCIDENTS	PERCENT
Type of accident:		
Ground Loop, Etc.	46	10
Wires, Poles	60	13
Stall, Mush	77	16
Engine Failure or Malfunction	139	30
Operational phase:		
Take-Off Run	37	8
Initial Climb	69	14
Swath Run	79	17
Procedure Turn-Around	78	17
Landing Roll	37	8

SOURCE: NTSB

FIGURE 1

KIND OF FLYING—TOTAL ACCIDENT RATES PER 100 000 AIRCRAFT—HOURS FLOWN
1971 - 1974

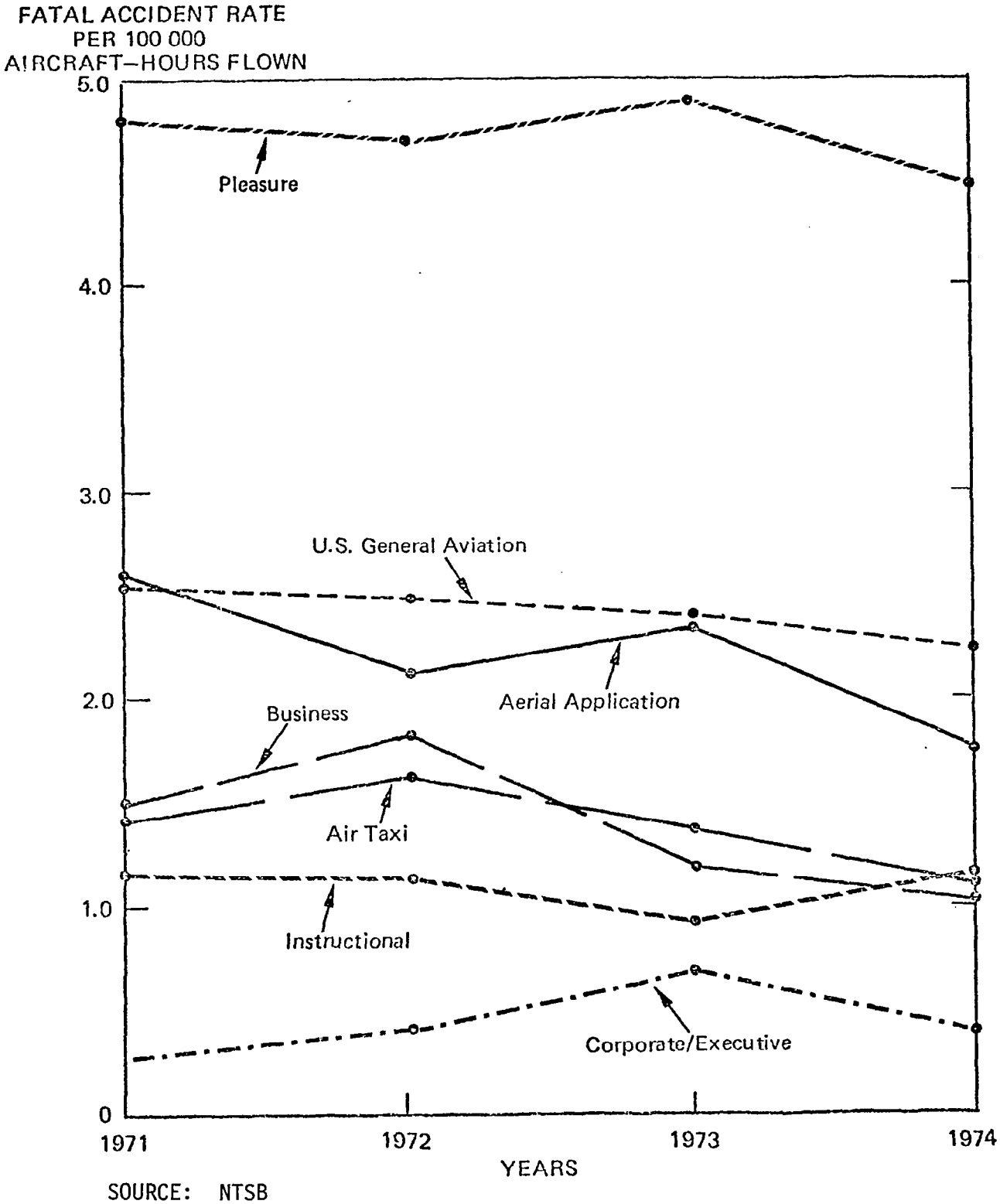


SOURCE: NTSB

FIGURE 2

KIND OF FLYING—FATAL ACCIDENT RATE PER 100 000 AIRCRAFT—HOURS FLOWN

1971 - 1974



SOURCE: NTSB

PHYSICAL AND METEOROLOGICAL FACTORS RELATING TO PESTICIDE APPLICATION, APPLICATION DECISIONS, AND SPRAY DRIFT

W. E. YATES
UNIVERSITY OF CALIFORNIA

I. Spray Drift - What is the Problem?

Spray drift is an important problem confronting the application of pesticides by aircraft. Spray drift refers to the movement of the pesticide out of the treatment area. The magnitude of the problem depends upon the quantity of drift, the type of chemical, and the surrounding environment. Translocated herbicides such as 2,4-D or related compounds may cause damage or symptoms to nearby sensitive crops. For example, minute quantities as low as 0.001 microgram of 2,4-D can cause symptoms on grape leaves (Kasimatis). Drift of certain toxic compounds onto surrounding plants or water may contaminate the food supply of humans, domestic animals, or wildlife. Tolerances of many compounds are less than 0.1 ppm. Also the drift of toxic compounds is a potential threat to the general pollution of the biosphere. There is evidence that there can be a problem of pesticides passing through the food chain from one species to another and causing injury to a distant species.

II. Precise Control Required

Precise control is necessary to keep environmental pollution of pesticides below acceptable tolerance levels. For example, if only 0.1% of a chemical application of 2 lb/acre to a given treated area would drift and fall on an adjacent alfalfa field of equal size, the residue on the alfalfa crop would be about 0.5 ppm. Another similar calculation shows that only one tablespoon of active ingredient is enough to produce a contamination of 0.5 ppm on 20 acres of alfalfa.

III. What is the solution?

There is no single solution. The problem will require a multidisciplinary effort of research, development, and education. A systems approach is necessary to minimize the multitude of factors affecting drift.

IV. Basic causes of drift. State of the art and research needs.

There are several important forces affecting the trajectories of spray particles. Some of the major factors affecting these forces are aircraft design and flight techniques, atomization system and rate of evaporation, and microweather.

Aircraft design and flight techniques

The aircraft design, relative location of atomizers, flight operating variables, and guidance all affect the destiny of the particles. There have been numerous theoretical and experimental studies conducted on the flow field characteristics of various types of aircraft. Also, there

have been some theoretical and experimental studies on movement of spray particles released from agricultural aircraft. (See studies by Wilmer Reed, M. Smith, P. Taylor, V. Young, and W. Yates). However, there has been very little coordination in designing agricultural aircraft flow field characteristics to match different application requirements. Thus, research should be coordinated to provide aircraft wake parameters to match dispersal requirements. For example, by use of various flap configurations and operating parameters, it may be possible to confine the sprays to a very limited area.

Atomization system and rate of evaporation

The particle size affects the terminal velocity and rate of evaporation which consequently has a predominant effect on the particle trajectory. A major contributing factor to the spray drift problem is the inevitable production of a small percentage of fine particles (<100 um) by conventional atomizers. Most present conventional atomization systems can be grouped into two types: (1) hydraulic nozzels with flat fan, hollow cone, solid cone or jet patterns, and (2) rotary atomizers with disks, cylinders, or brush elements. Most all nozzles produce breakup by means of mechanical or air shear or an unstable liquid film or ligament. The atomization and evaporation is also affected by the fluid properties. Presently there are some adjuvants and solvents that can be selected to alter the drop size and evaporation by changing the surface tension, vapor pressure, apparent viscosity, and viscoelastic properties. However, most all drop size spectrums are skewed normal distributions with a high peak of the finer particles. Thus, there is a real need to develop systems that can eliminate the production of fine particles.

One of the most promising developments is the use of low speed microjets. The AMCHEM "Microfoil" system utilizes a series of micro-tubes and is one of the lowest drift systems available today. However, this unit is limited to use with helicopters at speeds less than 60 mph. Also, clogging of the 0.013 inch tubes is a real operational problem, and since the drop size is very large (900 um), the applications are effective for only a few types of treatments. Several research groups are currently conducting research on the development of pulsed-microjet nozzles for the production of uniform size drops. These units look very promising but will probably require the development of special filtering systems to prevent clogging of the microjets.

Research is needed in several areas:

(1) Research needs to be accelerated in the development of new aerodynamic designed nozzles and the use of different fluid adjuvants in an effort to produce controlled uniform drops of selected size from 20 um to 400 um.

(2) It is important to coordinate research and development to design and develop complete systems to produce and introduce selected uniform size drops into optimum locations on the aircraft.

(3) Research will be required to accurately measure target recovery and drift from improved atomization systems.

Microweather

The microweather conditions during application are the basic transport and diffusion forces that may move some spray particles out of the target area. A knowledge of the wind direction is very important since it determines the area where the spray drift may occur. At the present time aircraft operators frequently utilize a smoke column at the application site to indicate the direction of spray drift movement. With increased concern over smoke pollution, it is necessary to have other low cost techniques to provide direct information to the pilot on wind direction at the target area. Atmospheric turbulence is also an important parameter that affects spray drift characteristics. A smoke column does provide qualitative information on possible temperature inversion layers and atmospheric turbulence.

A number of research instruments are available that can quantitatively measure atmospheric turbulence. Some of the different types include a sigma meter for use with a bivane, calculation of stability from the temperature profile, wind-velocity measurements, and use of three components and heated film sensors for turbulence calculations. However, most units are expensive and require considerable installation time. Thus, it would be desirable to develop a low-cost portable unit that could provide immediate quantitative data on the turbulence during the application. The complete system should record measurements of wind direction, turbulence, temperature, wind velocity, and relative humidity. Thus, records of weather could be filed with other data from each spray application.

A limited amount of research information is available that shows the effect of atmospheric turbulence on spray drift characteristics. Additional theoretical and field research is required to develop accurate models to predict drift from a multitude of input variables. The ultimate goal would be the development of a computer program for use with a small microcomputer that could be used by laymen in the field to predict drift levels from real-time inputs. In this manner, "go" or "no go" decisions could be made during a given operation.

AIRCRAFT SYSTEMS FOR DISPERSING PESTICIDES, PLANT NUTRIENTS, SEEDS, AND BAITS

NORMAN B. AKESSON
UNIVERSITY OF CALIFORNIA

The research on and development of dispersal equipment to be used on fixed and rotary wing aircraft has largely paralleled that of the development of aircraft airframes and power plants which have made possible the load carrying capacity and rugged durability required for this type of work. The burden of dispersal equipment development has fallen to (1) the aircraft operators, (2) a small group of specific manufacturers and suppliers, and (3) Federal and State agricultural research groups. The latter have provided the basic funding and continuing manpower and the interface with biological aspects of these systems which has been a fundamental aspect of aircraft use in the bio-aeronautics area.

Thus, aircraft used in conjunction with biological systems has of necessity maintained a largely biologically oriented research position since the basic objectives of aircraft use here are to aid in the production of food and fiber as well as protection against attacks on man and animals by various vectors carrying diseases. The aircraft used for these programs were those made available from military or civilian designs, and until the early 1960s, no widespread impact on the bio-aeronautics market was to be found from any specific aircraft designed for this purpose. The World War II Stearman biplane and Boeing Kaydet (and a few Navy built N3Ns) with Pratt and Whitney R-985, 450-hp radial engines are still the most numerous among agricultural aircraft in the United States. However, as the industry has stabilized and established its position as a responsible and enduring partner in food and fiber production, a number of new and specially designed aircraft have appeared. Commencing with Fred Weick's design series (later to become part of the Piper line), Cessna, North American Rockwell, and Grumman have all added new agricultural types to their line, and these airplanes have found wide acceptance in the industry.

During this transition period, the support for dispersal system design and correlation to these new aircraft rested with the agricultural research personnel with increasing support coming from the suppliers of chemical plant nutrients and other pesticide formulations. But very little interface or support was to be found with aircraft manufacturers, whose position still remained as a supplier of hardware rather than an active participant in bio-aeronautic research and development.

Communication between the largely physical aircraft, dispersal equipment and application, and the biological requirements relating to formulation, crop plants, and pests has been uneasy at best. Up until about 1970, the basic communication was at the local or state level, between agricultural interests—farmers, agribusiness, and university agricultural experiment stations—and the aircraft operators. In recent years, a new and highly

visible element in the form of a national agricultural aircraft organization has appeared which has attempted to bring national level communication between aircraft and dispersal equipment manufacturers and chemical manufacturers. A notable reduction, however, has occurred in local communication with State and Federal agricultural, forestry, and vector control biologists. Although this has, I am sure, been the normal reaction away from the earlier domination of aircraft application by the biological oriented groups, it represents a limiting course for the future, one which neither the physical nor the biologically oriented groups can afford to pursue if the bio-aeronautics marriage is to develop and mature into a lasting partnership for the good of food and fiber production and, hence, mankind the world over.

The introduction of the National Aeronautics and Space Administration (NASA) as a factor in further bio-aeronautic research will undoubtedly have far reaching effects on as well as responses from the agricultural, forestry, and vector control research and commercial interests. The injection of knowledge and organizational know-how that NASA personnel have accumulated and so ably demonstrated in general aviation as well as space research can only be beneficial to agricultural aviation. The organizational recognition of an essential partnership between NASA and the United States Department of Agriculture (USDA) and Agricultural Experiment Station people and their facilities appears to be understood but cannot be taken for granted. Traditional sources for biological research support must not be dried up in the enthusiasm generated for association and support from NASA funding. It would be extremely desirable that an organizational guidance committee representing both the physical and biological aspects of research and development be formed at an early date to not only guide the future development and support of the proposed work but also to insure all the presently concerned actively participating groups that their voices and needs will be heard.

As agricultural engineers working in federal and state supported biological research organizations, we have long had to carry the weight of machines and application technology to the biologists and try to make compatible the limitations as well as the opportunities that exist between these two basic disciplinary and professional areas. We have frequently had to act in a coordinating role to try and make compatible the differing requirements and needs, services, and capabilities of the aircraft people in relation to the biological demands. That these are frequently incompatible should be obvious to anyone remotely associated or knowledgeable of the many regulations, federal, state, and county, that have appeared in recent years as a result of the essentially limiting requirements and capabilities of pesticide use.

Aircraft use in food and fiber production has been challenged on many fronts by ecology-minded interests, but more importantly by the farmer users as well. Although the days of cheap and consequently widespread overuse of pesticide chemicals is hopefully past, there is no evidence to suggest that pesticides and nutrients as an essential adjunct to crop production will be any less used in the future. On the contrary, the

statistical evidence for the past several years shows a good healthy 9 percent per year growth in pesticide chemical use, which interestingly enough is paralleled by a similar growth in use of aircraft for their application. However, a notable difference is occurring which has both good and bad implications for aircraft operations. The materials being used are becoming more expensive and regulations governing their use more specific so that the net result is a loud and clear demand that more careful, precise, and safe application equipment be developed, especially for aircraft application. There certainly can be no more opportune time for research and development support of agricultural aviation. The need is clearly evident, and the basic objectives are spelled out. But there remains, of course, the identification of the areas of research in which NASA can most effectively function, and precise manner of support and direction to be apportioned to their various groups as well as what sort of role NASA can play in respect to the biological side of the research need.

The USDA and State Agricultural Experiment Station have a highly significant position in relation to the development and ultimate acceptance of aircraft and type of dispersal equipment in food and fiber production. Similarly, the chemical manufacturers and formulators, having to not only prove the production value of their product through field evaluations, must also show that the product carries no fundamentally damaging elements to man and the environment. A very important limitation on any product relates to the manner in which it is used. Thus, application and evaluation of losses and an overall accountability function have become increasingly important. The impact of pesticide use has been more careful scrutiny and demand for more specific information on where these products eventually are found to come to rest in the environment, or if, in fact, they do degrade and convert to harmless products.

Thus, the biological research capability already exists primarily in USDA, the State Experiment Stations, and in chemical company facilities for doing the basic and the field research necessary to establish the use, value, and proper methods of handling various pesticides and nutrient materials. Similarly, the evaluation of damage potential, the monitoring and determination of environmental impact, and the accountancy factors which establish and insure the degradation route of these materials will also be best handled by the established research groups including the various health departments, federal, state, and local.

What remains then is the broad field of equipment development, starting with basic and more specific aircraft types and study of means for better utilization of inherent vorticity from fixed and rotary-wing aircraft, boundary-layer control, and induced airflow over wings. Further, the investigation and adaption of gas turbine (turbo-propeller) type power units to agricultural aircraft needs considerable study. A wholly new approach should be developed to integration and use of the fundamental aircraft vorticity in relation to the introduction and reaction of and ultimate control of dispersions of various liquid and dry pesticide and nutrient formulations. All these studies are fundamentally related to the aircraft and

perhaps, therefore, should be the primary objectives of NASA research and development.

Support of engineering inputs to coordination of the aircraft developments and agriculture, forestry, and vector control research must also be considered. It would be largely useless if NASA were to confine support to aircraft and dispersal systems research without providing for the logical carrying forward of these developments to the practical field application level where all new equipment must eventually pass examination before widespread acceptance will be forthcoming.

Dry materials, primarily as finely ground dusts of toxic chemicals, were the first formulation applied by aircraft to both agricultural areas and forests for insect control. Essentially, the system for dispersing the dry materials through a form of ram-air powered spreader remains much the same today as it was when developed 30 years ago. Various means have been attempted to obtain wider, more uniform applications of dry materials. With fixed-wing aircraft, the ram-air device still dominates the scene, with wider (and higher drag) units coming and going in popularity. Powered units utilizing a blower to provide additional air and power to the ram-air device have been tried in Mississippi and at Davis, California, in conjunction with the Razak boundary air control system. In both cases, advantages gained were not sufficient to justify the extra expense. If swaths greater than 100-foot width, for example, are to be applied with material rates of 200 to 300 pounds/acre, the flow rates (66 pounds/second at 200 pounds/A, 100 mph and 100 foot swath) and total loads of the aircraft become unrealistic. Thus for heavy rates of application aircraft capable of large loads of 2 to 5 tons, for example, may be found more useful, and the more important direction in which to develop capabilities would be in short landing and take-off equipment, such as the gas turbine-powered helicopters.

The potential for bleeding air from a gas turbine engine might also be considered for agricultural aircraft dispersal equipment use.

The use of dusts (ground to a 90 to 99 percent by weight under 25 um particle size) has largely been supplanted by either granular materials or liquid sprays. Dusts are not only susceptible to airborne transport losses, but are significantly less deposit effective. It was customary to prescribe 20 to 30 percent greater toxicant in the dust application than if applied in liquid form. Granular materials of from 30 to 60 USA mesh size (520-246 micrometers, um) to larger 8 to 16 mesh (2360-1000 um) are used wherever this type formulation is compatible with the biological requirements. Obviously, large particle size granules will not adhere to plants and, thus, tend to pass through foliage, for example, into water, for such things as mosquito and water insect control, or to the ground for weed and insect type control. Several newer type rotary spreaders have been designed for applying granular materials (particularly helicopters) and have been shown to be superior to the ram-air types insofar as swath uniformity is concerned. The swath width is still basically a function of the width of the distribution system and the

inertial functions of the material being spread. Thus, a centrally located spreader must displace material outward 15 to 25 feet on each side of the aircraft. Particles below 500 um size, and of low density materials, will not be capable of lateral displacement against the forces of air resistance. The aircraft shed vortex strength is insufficient to transport these beyond the wing or rotor tip of the aircraft. Hence, although dusts are thus spread to 60 or 100 foot swaths, the granular materials are largely limited to approximately the wing or rotor span.

In terms of airborne losses, the granular materials have probably the best record for reduction of loss of any formulations. However, granulars are very limited in biological effectiveness; hence, their use is limited.

Liquid formulations offer a great variety of physical properties as well as a range of atomization size from small airborne aerosols of 25 to 50 um average diameter to liquid drops equivalent to the larger granulars of 1000 to 2000 um diameter. As would be expected, the larger drops have the advantages of

(1) Rapid settling, hence low displacement and drift losses, or more precise placement of the spray

(2) Lower evaporation rates, which affect settling rates

(3) Greater deposit efficiency or collection on plant surfaces.

The principal disadvantages relate again to biological efficiency. Large drops provide a limited number per unit of applied volume; hence, for effective coverage, larger volumes of liquids must be used. But this only compensates in part since numbers of drops increase directly with volume, but decrease inversely as the cube of the diameter and the size is increased.

As with dusts, the smaller liquid particles will be displaced by the shed vortex of the aircraft as well as by winds occurring in the treatment area. Evidence of airborne transport indicates particles under 50 um diameter may be carried for several miles distance, whereas particles above 500 um diameter fall largely in a swath not exceeding 200 to 500 feet, depending on the cross wind velocity at the application site and the altitude of release. It is important to recognize that a cross wind will alter the ballistic settling of the spray released and will cause swath displacement of this by 200 to 500 feet. But this does not constitute the basic "drift" problem. This latter problem is related to the airborne portion of the released spray, or for practical purposes, the amounts in the released spray in particles under 50 to 75 um diameter. Drops this size will remain airborne for a significant time or can be displaced in a cross wind for several miles. Although crosswind velocity is the basic parameter affecting the ballistic or swath displacement,

the airborne drift is more affected by the temperature gradients or specifically temperature inversion situations which confine any vertical displacement and diffusion of the airborne drops and tend thus to concentrate them in the downwind area. The lower the wind velocity, the greater the concentration and potential damage from an airborne cloud of toxic chemicals.

With increasing use of translocated or systemic pesticides (more in the plants), the trend toward more precise placement sprays should be possible and also a reduction of the losses at the time of application. However, it should be noted that losses from a treated field after application can be severe and give rise to damages, particularly in the case of volatile herbicides. Some materials form small crystals after the carrier liquids are evaporated which then can be lifted from the treated plants and reentrained in the air.

There are basically two forms of atomizers used to derive the small drops from the usual spray liquids; these are hydraulic pressure nozzles and rotary devices. The first and most widely used are the hydraulic pressure nozzles which come in a wide range of sizes and types of cones and fans and will produce sprays having average drop size of 75 um to 1000 um vmd (volume median diameter). The vmd is a commonly used statistical dimension weighted to the volume (the diameter is cubed) and is defined as the drop size that separates all the drops produced in the spray into two equal parts. These parts would be numbers of drops or a number median size or the volume of the two parts for a volume median diameter.

The second type of atomizer, used on aircraft only to a limited extent, is the rotary type with screens, sintered metals, and perforated metal rotating sleeves. The drop size range is comparable with that of the hydraulic nozzles and drops of 75 to 1000 um can be produced.

For very small drops, or under 75 um vmd, greater energy input is required, and it is customary to use two-fluid (liquid-air) nozzles to obtain the aerosol size range.

Additives to liquid formulations such as thickeners and polymer viscoelastic agents will cause larger drops to form from a given atomizer because of a greater energy requirement to overcome the liquid viscosity. However, only limited benefits can be obtained from these, and it is better to use large drop size producing nozzles first and then the additives, if this is found necessary for drift control.

Since all the atomizers commercially available for aircraft use produce a wide range of sizes with a portion below the 50 um diameter or airborne size, it follows that airborne drift cannot be eliminated unless the small drops are eliminated. To accomplish this, there have been two basic atomizers introduced: (1) the controlled flow spinning disc and (2) the transducer powered pulsed jet. The first usually requires a form of small drop (satellite) collector, either by air aspiration or gravitation separation.

The second requires a 10 to 20 kHz (kilohertz) frequency amplifier to drive a transducer and pulse the liquid discharged from circular or jet orfices. These must be of the order of 0.005 inches in diameter in order to obtain a 250 um size drop. Hence, liquids must be clean and contain no particles such as in wettable powder formulations. The potential for increased precision and virtual elimination of airborne drift from the controlled atomizers appears to be very promising. However, cost of such atomizers as well as the greater care and limits of use will not permit their widespread use for some time to come.

The ability to control losses from aircraft applications during application has become a dominant requirement especially in the case of potentially damaging chemicals, where susceptible crops are grown downwind from an herbicide treatment or food and feed crops downwind may accumulate illegal residues of insecticides used to control pests on adjoining crops. However, knowledge of machines and their use has greatly reduced the potential hazard and has in many instances enabled the continued use of highly desirable chemical pesticides.

This is but a sketch of the many problems associated with aircraft use in pesticide, nutrient, and seeding operations. Each function has a biological requirement which controls the chemical, amount, time of application, and the point of contact between material and pest. Alteration in the dispersal equipment which changes the particle size and range, the number of released particles, and the swath width and uniformity of distribution of the materials will affect the biological effectiveness of the application. Thus, it is essential that new equipment designs in both aircraft and dispersal equipment be subjected to rigorous field testing with a sufficient range of physical properties of formulations to be used to identify the basic characteristics of the system and hence define its potential use.

Aircraft have become an indispensable part of food and fiber production the world over. New designs and refinement of existing machines have enabled continuation of aircraft use in the face of increasing questions regarding environmental contamination and wasteful application. However, research on basic aerodynamic characteristics both in regard to greater aircraft maneuverability and more precise application has not been pursued, probably because of the greater and more obvious need for biologically acceptable applications. The biological research needs to be continued, and the transfer of equipment development to field applications must be maintained. However, there also appears to be an area associated with the basic aircraft design which could benefit significantly from the type of research input that the NASA organization could provide. It is hoped that this type of research effort will be approved and that NASA will be permitted to enter the field of agricultural aviation or more inclusive bio-aeronautic research.

GROUND SUPPORT EQUIPMENT, MIXING AND LOADING TECHNIQUES, AND SAFETY PRECAUTIONS

E. H. PINGREY
PINGREY BROS., INC.

Since the first airplane was used in the application of materials to crop-land, one of the great problems associated with that application was the safe transfer of the material to the hopper of the airplane. The very first attempts were, to say the least, very rudimentary in nature. Picture, if you will, the handing of one open bag of a dust compound into the rear cockpit of an open biplane, and the swamper metering the bag into a hopper located in the rear cockpit and operating the gate mechanism with his foot or feet, as the plane flys over the crop. Needless to say, a better way was quickly found to apply the material; yet, almost 30 years went by before a better way to load the dry materials was found.

Liquid application by aircraft followed some 15 years after the first dry application attempts. Here again one of the big problems involved the safe transfer of the liquid to the hopper of the aircraft. As agricultural aircraft replaced surplus military trainer types and manufacturers of dispersal equipment developed their products, the mixing and loading equipment was left to the innovative ability of the individual applicator to design and manufacture or more appropriately, fabricate his own equipment.

Now, in many states and to some degree on the Federal level (primarily OSHA requirements), we are told either by legislative action or Department of Agriculture regulation or a combination of both to what extent we must safeguard our mixing and loading crews, and to some extent, these regulations go even beyond the "state of the art."

In any agricultural aircraft operation, one of the criteria for a successful operation is the speed with which that operation can be performed without compromising safety. So, when we begin to think of a particular piece of equipment for a specific function in a mixing or loading operation, the one common denominator that we must always apply is, will it slow down the mixing or loading operation in any way? If the answer is yes, then no matter how good the equipment may appear to be it is useless in that function as it will do nothing but increase the cost of the operation at a time when we are trying to decrease the costs of the operation.

There seems to be much more uniformity of design in the equipment in handling dry nontoxic materials such as seed and fertilizers. This may be because the application requirements and weather factors do not affect these applications to the same extent that they do pesticide applications. Generally, two pieces of equipment are needed; some sort of a

conveyor belt or its equivalent and the dump bucket on the loader truck which puts the load over the hopper of the airplane.

The liquid mixing and loading equipment present another story. You can visit 20 different agricultural operations, and you will see 20 different designs and techniques. They all accomplish the same thing—getting the mixed material into the hopper of the aircraft quickly and safely. One of the major reasons for this nonstandardization of equipment is the fact that the crops and crop pests vary from area to area, and the methods of combating these pests vary. An example of this would be spraying cotton boll worms in South Texas with a recommended chemical at an application rate of 2 to 3 gallons total solution per acre, and in the Sacramento Valley of California the same worm in a tomato field, then called a tomato fruitworm, using the same chemical at the same rate only in a total solution of from 10 to 20 gallons per acre.

Another factor of increasing concern is the tendency of the new chemicals being developed to be packaged in greater strength or concentration. Some organophosphate materials are now being used at the rate of 1/10 pint per acre. One 5 gallon container holds enough material to treat 400 acres. But a hypothetical job of 22 acres takes only 2.2 pints of this material. Now who has the equipment to safely and accurately measure those 2.2 pints and then seal and store the remaining chemical until needed again. This problem is becoming a real problem in those states that have enacted closed mixing and loading systems regulations. It is becoming very apparent that our industry needs new ideas in handling these toxic chemicals in such a way that we can get our mixers and loaders out of the "monkey suits" we are now required to put them into every time they handle a class I or II chemical. Just how safe is that man on a 100^{0} day wearing full sleeve coveralls, respirator, gauntlet rubber gloves, and rubber boots? There are many claims that the discomfort of the safety equipment is more of an inducement to accidents than a more climatically comfortable uniform.

SESSION III

EQUIPMENT DEMONSTRATION AND DISPLAYS

CHAIRMEN

L. F. Bouse
J. B. Carlton
Agricultural Research Service
U.S. Department of Agriculture
College Station, Texas

AIRCRAFT DESCRIPTION: DeHaviland Beaver

DISPERSAL EQUIPMENT: None - aircraft is equipped with photographic equipment

OPERATOR: James Wasson
Texas Forest Service
System Administration Building
Texas A&M University
College Station, Texas 77843

MAJOR USE: Aerial photography and fire control in Texas forest lands

COMMENTS BY MR. WASSON (FROM TRANSCRIPTION):

The aircraft has been extensively modified for aerial photography and fire control work. It is used for monitoring and inventory of timber resources, for insect and disease detection, and as a backup for contract aircraft on fire detection work in East Texas. During the last year, one of its major uses was monitoring of pine beetle infestations in East Texas.

Two different camera systems are installed in the aircraft. One is a regular 9" x 9" format mapping camera, and the other includes four 70 mm cameras that can be used as a multispectral system. Most of the detection work includes both color infrared and normal photography. The color infrared works very well for insect and disease detection. The mapping is done in black and white.

The aircraft is equipped with a Pratt and Whitney R985, 450-horsepower engine, and has 7 1/2-hour fuel range. A two-man crew is used to operate the aircraft and photographic equipment.

AIRCRAFT DESCRIPTION: Snow Air Tractor

DISPERSAL EQUIPMENT: Liquid system with whirljet nozzles

OPERATOR: Jon Whitten
Whitten Flying Service
900 Winding Road
College Station, Texas 77840

MAJOR USE: Field crop insect control

COMMENTS BY MR. WHITTEN (FROM TRANSCRIPTION):

We use two Piper Pawnees and the Air Tractor in our operation. The Air Tractor is normally used for the larger jobs. This aircraft is the 42nd Air Tractor manufactured by Leland Snow at his Olney, Texas, plant. The aircraft is equipped with a 600-hp engine. (See fig. 1.)

Basically, we do insecticide work in cotton, grain sorghum, and corn. Our dry materials work is limited, but we do some seeding and fertilizing.

QUESTION FROM AUDIENCE: What is the purpose of individual cutoff valves on some of the nozzles?

ANSWER: At times, we use all the nozzles; however, for most of our herbicide work and for some insecticide work, we turn off 3 or 4 nozzles near the end of the boom to reduce the amount of spray that is picked up in the wing-tip vortices.

COMMENT BY MR. GEORGE LANE (AIR TRACTOR DISTRIBUTOR):

I know several of you have been wondering about Leland Snow and his production of the Air Tractor. I took delivery of number 52 last week, and he is now working on number 54. His production at the present time is one every seven working days, and by the end of 1976, he hopes to have it up to six per month. The aircraft has been well received, and the people flying it like it real well.

One unique feature of the aircraft is called the flapperon system which gives it some improvement in stall characteristics. As the flaps go down, the ailerons droop with them. The maximum droop on the ailerons is 16°, and 40° is the maximum droop on the flaps.

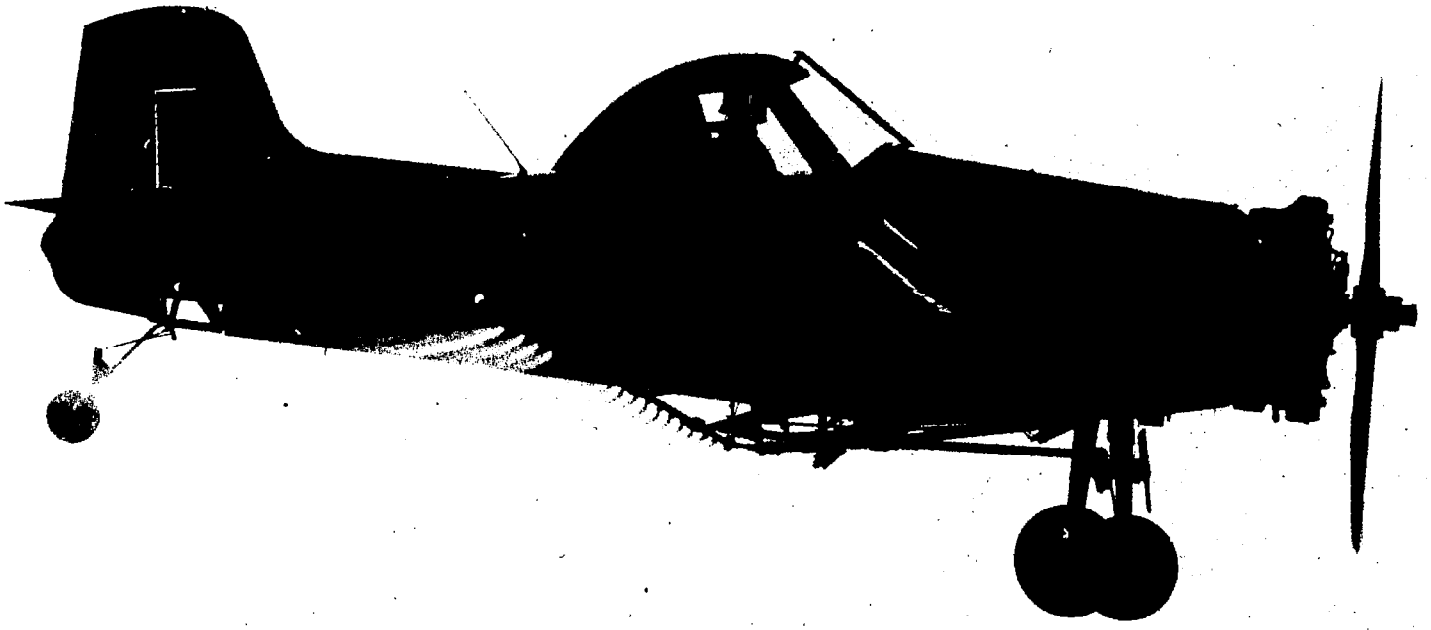


FIGURE 1

SNOW AIR TRACTOR

AIRCRAFT DESCRIPTION: Cessna Ag Truck

DISPERSAL EQUIPMENT: Liquid system with solid jet nozzles for low volume herbicide application

OPERATOR: Harold Hardcastle
Ag-Air, Inc.
P. O. Box 1614
Vernon, Texas 76384

MAJOR USE: Rangeland weed and brush control

COMMENTS BY MR. HARDCASTLE (FROM TRANSCRIPTION):

We operate in Northwest Texas and Southwest Oklahoma with a total of four agricultural aircraft. Most of our work is liquid and about 50 to 70 percent of it is dispersed at 1 gallon per acre. The remainder ranges from 1/2 to 3 gallons per acre. We do a lot of ferrying in our operation. This aircraft is economical to operate and is one that I can make money on. (See fig. 1.)

The aircraft is equipped with a spray system for low-pressure, low-volume herbicide application for brush control. This method of application was developed by the Texas Agricultural Experiment Station Brush Control Team in conjunction with Dow Chemical Company. We run 1 gallon total mix per acre of oil-water emulsion. There are no swirl plates in the nozzles, and the nozzles are pointed straight back to obtain large droplets. The working pressure is from 20 to 22 psi. This method of application was developed to reduce spray drift, and it has done a good job. One of the problems we have encountered is that if the plants are in less than ideal condition for herbicide treatment, the drop size must be reduced to get more spray coverage. We use this system for weeds and for mesquite control on rangeland.

Mesquite is a tree-type plant that grows in West Texas. Its height ranges from 6 feet to 20 feet. We have some severe problems with flagging and flying because a lot of our swath passes are from 1 mile to 4 miles in length in rolling country covered with 20-foot trees. We use from 3 to 6 flaggers in the field, and the pilot tries to keep them in sight and lined up. Flying at tree-top height requires precision flying. Normally, we operate between 800 and 1100 hours with two airplanes and spray from 75 000 to 175 000 acres in a season. We have studied the economic conditions in our area and believe that we need an airplane averaging about 150 to 200 acres per hour to make a profit.

Our ground equipment consists of gooseneck trailers and 2-ton trucks to transport our mixing and loading equipment. In the last 3 years, I have gone to stainless steel in my mixing equipment because of problems in decontamination when going from phenoxy herbicides back to insecticides or fungicides.

COMMENTS FROM MR. HAROLD WIEDEMANN (TEXAS AGRICULTURAL EXPERIMENT STATION):

One of the comments was on the boom length used on this aircraft. We had to shorten the boom length to keep the spray out of the wing-tip vortices. Development of this method for applying herbicides in low volumes was a cooperative effort between applicators, equipment manufacturers, chemical manufacturers, and the brush control research team. Thorough testing of the method required several years of evaluation on mesquite and about 4000 acres worth of 20-acre plots for screening various compounds. The method has been approved by the Texas Department of Agriculture and by EPA for a state label. The label does have the regulation on the length of the boom and the placement of the nozzles. Swirl plates are not used. The nozzles are directed straight back or back and down at up to a 45° angle when the smaller drop size is needed. This method resulted in a change in the recommendation for total volume applied from 4 gallons per acre to 1 gallon per acre. This is the first major change in the recommended gallonage in the past 25 years. We have increased the efficiency as far as the acreage is concerned by about 40 percent. One plane can now do the work previously done by two. We reduced the amount of diesel fuel required in the spray mixture by 86 percent and the amount of water by 78 percent. Aviation fuel savings are about 20 percent. Ranchers can now consider treating the entire ranch because the cost has been reduced by 50 cents to 1 dollar per acre.

COMMENTS FROM MR. HARVEY NAY (CESSNA MANUFACTURING COMPANY):

In response to a question, the wing tips provide an extension to the wing, and in the event of accidental damage, you don't have damage to the basic structure. The reason for having a wing tip of that type is primarily to provide a semi-structural fairing which is replaceable. As far as the drooped shape of the wing tip, it is primarily related to span extension. It gives you a little larger effective wingspan.

FIGURE 1

CESSNA AG TRUCK

AIRCRAFT DESCRIPTION: Grumman Ag Cat

DISPERSAL EQUIPMENT: A Liquid System

OPERATOR: Eugene Shanks
Farm and Ranch Aerial Service
Route 3, Box 71A
Wharton, Texas 77488

MAJOR USE: Rice and row-crop fertilizing and pest control

COMMENTS FROM MR. SHANKS (FROM TRANSCRIPTION):

This is a Grumman Ag Cat B-model. We have only flown it about 25 hours, so we really have not had a chance to evaluate it, but we are pleased with it so far. We have two of these and three A-models in our operation. Primarily, we run a 985 engine because we do about 60 percent rice and 40 percent row-crop work. I feel that the 985 is more economical when you get into the row-crop business. We use the Ag Cat primarily because it operates well off short, rough landing strips, and I believe that in our operation, it is a lower maintenance, better airplane. We normally operate about 3500 hours per year and use four airplanes with one back-up airplane. I also have a Cessna Ag Truck which we use for low-volume work. The spray booms on this airplane extend out past the wing tip. Probably the last 4 feet on each side are unnecessary. (See fig. 1.)

I was asked if you can buy a 600 in the B-model. I do not believe the 600 is available in the B-model. This airplane has 80 inches more wingspan than the A-model. In the A-model, with a 450 engine, a heavy load, and short swath runs which require a lot of turning, you sometimes are not flying much above the stall speed. This airplane seems to hold up much better in the turns with a load in it. Normally, most fertilizer loads are about 1800 pounds. I have worked this airplane with 280 gallons of spray material on soybeans. Most of our work is done from satellite strips, and we use ground equipment for hauling and loading materials. I think most rice operators use this type of operation. If you have to ferry over 2 miles, you just cannot turn out the volume of work required to make a profit.

FIGURE 1

GRUMMAN AG CAT

AIRCRAFT DESCRIPTION: Rockwell Thrush Commander

DISPERSAL EQUIPMENT: Dry materials spreader and liquid system

OPERATOR: George Lane
Lane Aviation, Inc.
P. O. Box 432
Rosenberg, Texas 77471

MAJOR USE: Fertilizing, seeding, and weed control in rice

COMMENTS BY MR. LANE (FROM TRANSCRIPTION):

This airplane is a 1975 Thrush Commander S2R powered with a 600-hp engine. Normally, in our operation, which is predominately a rice operation, we cut our booms off just inboard from the tip or about 52 inches off each side to get away from the wing-tip vortices. By doing this, we find that we do not shorten our swath width by an appreciable amount. We do just as good a job, and we get away from the wing-tip swirl. Large tires are used on the airplane because we often work under very wet conditions. When the rice is ready, we have to operate. We can operate this airplane with large tires on it when we can not operate with anything any narrower. The airplane is fitted with both a dry spreader and spray booms for display. We normally remove the system we are not using. It takes two men about 5 minutes to change from a spray unit to a dry spreader or vice versa. The airplane weighs about 4000 pounds empty. Our normal load in the rice country is about 2700 pounds. In my particular operation, we operate three to six of these as we need them. I also operate the Air Tractor. (See fig. 1.)

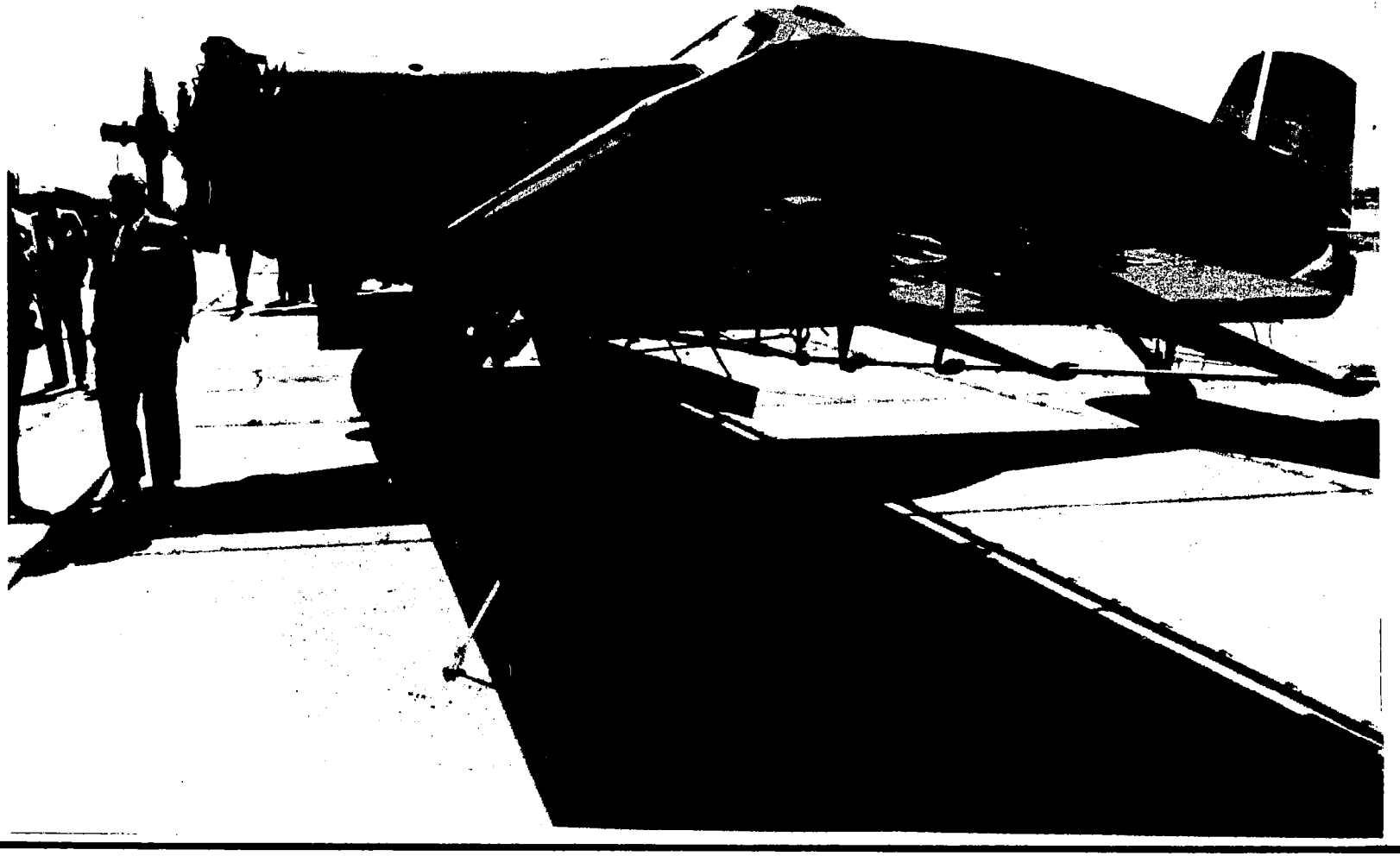


FIGURE 1

ROCKWELL THRUSH COMMANDER

AIRCRAFT DESCRIPTION: Cessna Ag Wagon

DISPERSAL EQUIPMENT: Liquid system with turret nozzles

OPERATOR: Don Graves
1710 B Lawyer
College Station, Texas 77840

MAJOR USE: Field crop pest control

COMMENTS BY MR. GRAVES (FROM TRANSCRIPTION):

This is a 74-model Ag Wagon. (See fig. 1.) It has the same engine that the Ag Truck has but a smaller hopper. It has a 200-gallon hopper. The airplane is equipped for liquid spray with a fan-driven pump and 24 turret-type nozzles. Each nozzle has five holes and a cut-off position. Most of my work is low volume and ranges from 1/2 gallon to 3 gallons per acre. Occasionally, we apply 5 gallons per acre. When we apply 5 gallons per acre, we have to double the number of nozzles. These nozzles are turned 90° to the slip stream so you can see that I am not worried about drift. I am trying to get coverage for cotton defoliation and it is difficult. This setup works well, and it is the best I have been able to devise. The boom is smaller than those on the other airplanes here. I use a 3/4-inch stainless steel boom. At the higher gallonage, I know we are getting some pressure loss so we use larger orifices on the last four nozzles out near the wing tip than we do on the nozzles near the center of the plane. When "round robin" or "race tracking" a field, this airplane does real well. Our pattern is light on one side, and I have yet to find it. I do not know which side it is, but the spray coverage does not look nearly as good if you go back and forth across the field. This is something I hope research will help us with.

The biggest problem is corrosion or electrolysis. The lights on the end of the wings are corroded. This is the way it starts. It starts under the paint and works out. On the lap of the leading edge of the wing on the bottom, it is starting to show pretty bad. We have a lot of work to do this winter. I have not handled dry fertilizer with this airplane but have put out a lot of sodium chlorate. Every time the plane has put out chlorate or any corrosive material, it has been washed before it was put up. We have about washed the plane to death, but it has not helped our situation. We fly 300 to 500 hours a year with just a single airplane operation. Therefore, the plane must operate nearly every day, and we try to take care of it.

A question was asked about why there is no air bleed line on the end of the boom on this Cessna, but there is one on the other Cessna. If the outside nozzles are located near the end of the boom, an air bleed is not needed. However, if the two outside nozzles are cut off, an air bleed is needed. On this plane, we located a nozzle out close to each end of the boom, and we never cut them off.

COMMENTS BY FRED BOUSE:

In visiting with Jon Whitten recently, he also voiced this concern over the corrosion problem, and pointed out several places on one of his Pawnees where the paint was peeling around some of the rivets and screws. I am sure that this is one of the real difficult problems that confronts these fellows day to day. The best care they can give their aircraft doesn't seem to eliminate the corrosion problem. This is an area that should receive research effort.

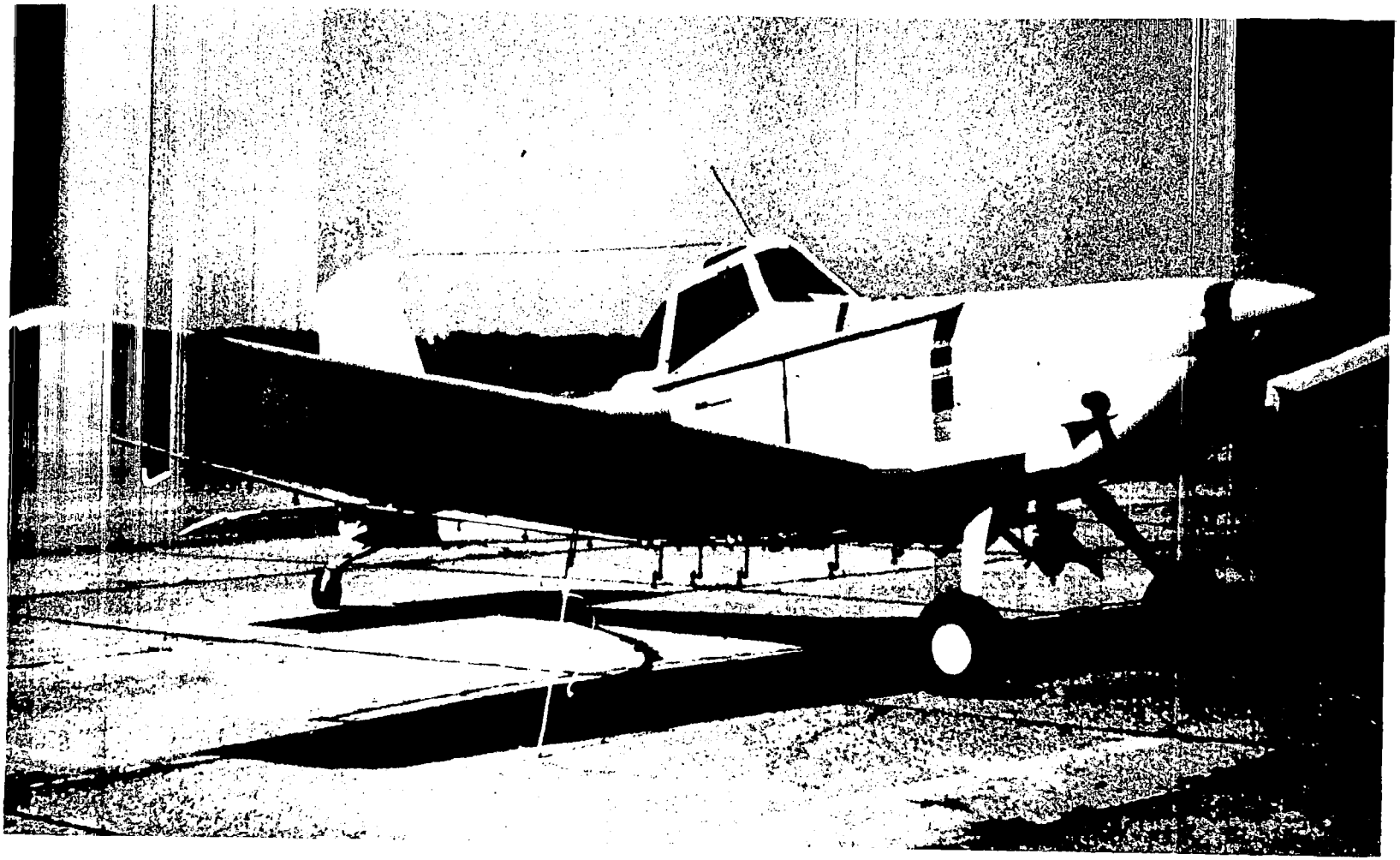


FIGURE 1

CESSNA AG WAGON

AIRCRAFT DESCRIPTION: Emair

DISPERSAL EQUIPMENT: Liquid and dry materials

OPERATOR: George Roth
EMAIR
Harlingen Industrial Air Park
Harlingen, Texas 78550

MAJOR USE: Manufacturers demonstrator

COMMENTS BY MR ROTH (FROM TRANSCRIPTION):

This is our MA-1B or what we call Emair 1200. We designated it 1200 because it has a 1200-hp engine on it. At the present time, we are only taking 900 hp out of it, but with the large engine, the large wing area and the large hopper capacity, I think it probably is the largest agricultural airplane in the United States. (See fig. 1.)

The hopper capacity is about 62½ cubic feet or about 470 gallons. We tried to build a simple airplane and a working airplane. We have it equipped for display with both the liquid and the dry dispersal equipment. The spreader is one of our own design. The fuselage is built in five separate sections for ease of repair. The panels covering the fuselage from the hopper back are all fiberglass. We try to utilize stainless steel and fiberglass wherever we can, primarily for corrosion prevention.

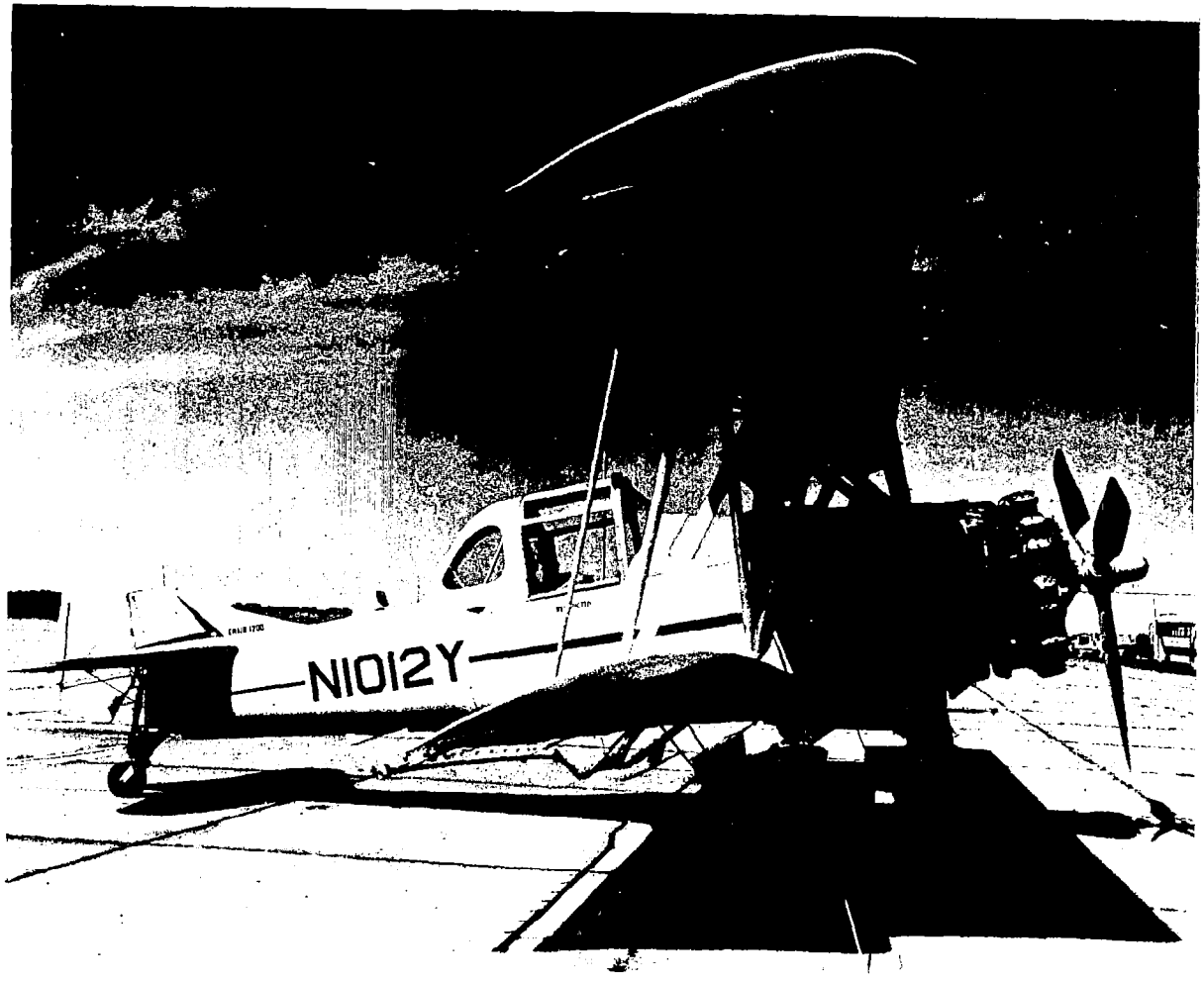


FIGURE 1

EMAIR

AIRCRAFT DESCRIPTION: Stearman

DISPERSAL EQUIPMENT: Dry materials spreader and liquid system equipped with low pressure flapper nozzles

OPERATOR: George F. Mitchell, Jr.
M&M Air Service
Route 5, Box 890
Beaumont, Texas 77706

MAJOR USE: Rice seeding, fertilizing, and weed control

COMMENTS BY MR. MITCHELL (FROM TRANSCRIPTION):

This Stearman has 12 000 hours on it. In midsummer of 1949, this airplane was sitting on this ramp somewhere, and it was one of 41 that were purchased by our company. This airplane has had a lot of modification. It has Smith wings on it with their upper aileron conversion. We use our own vibra-damp mount system. It has automotive 4-ply tires. We eliminated our gear cracking and forward fuselage cracking problems by going to a lighter tire that takes more of the shock. Most of the modifications, such as the servos, the aileron servos, the balanced elevators, and the rudders, were developed by trial and error. (See fig. 1.)

We operate 16 of these airplanes, and they are all identical to this one. The parts are interchangable on all 16. We also operate 8 A-model Grumman Ag Cats. The Ag Cat will carry more bulk. It won't do any better job of dispersing, landing, turning, or taking off than the Stearman, but it's got a bigger hopper on it. If you can carry more pounds, you can make more money.

The liquid system on this aircraft was developed in the late 1930s and 1940s by Ziegler and is know as the "flapper-nozzle" system. The volume mean drop diameter from that system is about 400 micrometers with a very narrow spectrum. We have better consistency of droplet size with that system than we do with the Teejets.

The airplane is rigged for high volume spray, 10 gallons and above per acre. At those rates, nozzle spacing is not critical so our nozzles are evenly spaced. As we go to lower rates, such as 1, 2, and 3 gallons per acre, spacing is critical. Therefore, we have cutoff valves to turn nozzles on and off at the various spaces to compensate for propwash and wingtip vortices.

COMMENTS BY MR. EVERETT PINGREY (PINGREY BROTHERS, INC.):

If I could make one comment, I'd like to point a statement at the representatives of the companies that are building the new generation airplanes. Our company just disposed of its last Stearman 2 years ago. When we sold it, the logbooks indicated 25 300 hours on the airframe of which about 24 000 hours were in agricultural service. The airplane is still flying at another company. I am just hoping that the airplanes we are buying now will equal or better that record.

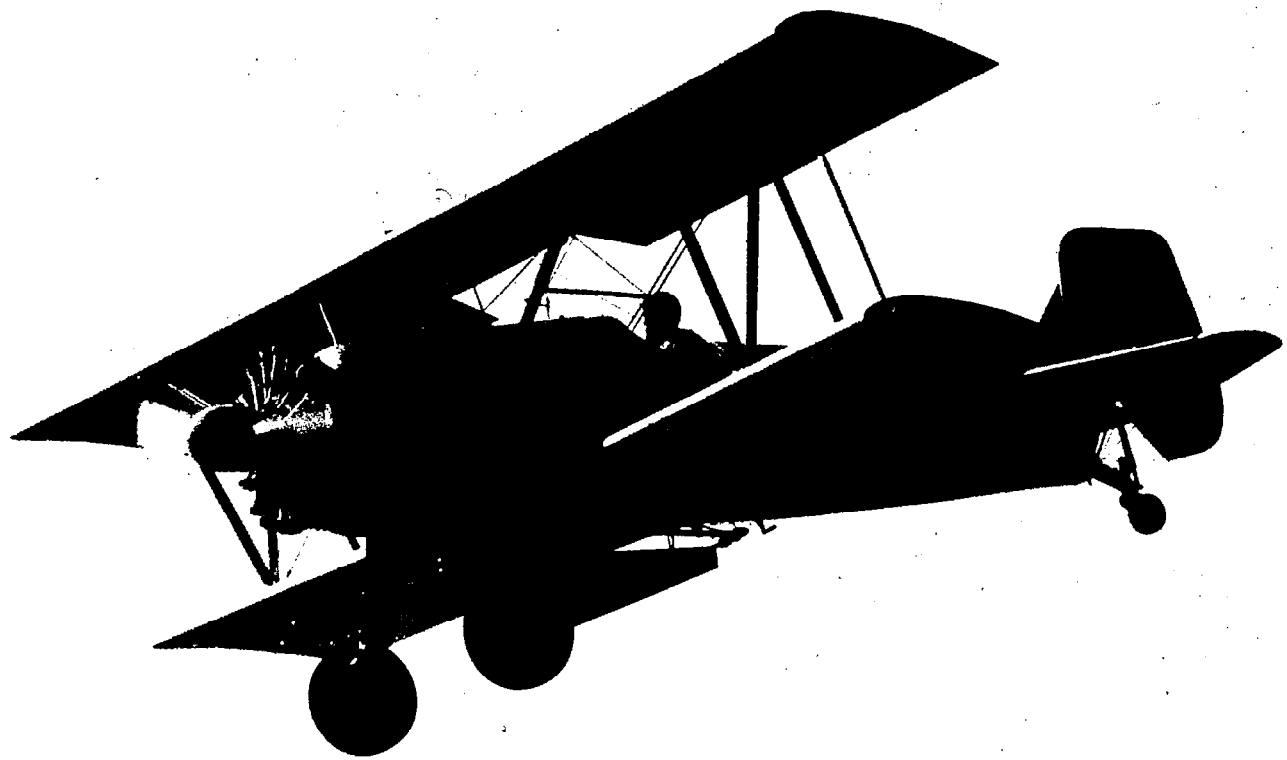


FIGURE 1

STEARMAN

AIRCRAFT DESCRIPTION: Stearman

DISPERSAL EQUIPMENT: Liquid system with hollow cone nozzles. (See fig. 1.)

OPERATOR: Merl Gough
Merl Gough Spraying Company
P.O. Box 428
Hearne, Texas 77859

MAJOR USE: Field crop insect control

COMMENTS BY MR. GOUGH (FROM TRANSCRIPTION):

One of the most important problems I have is keeping a ground crew. You can look at the airplane and tell. Fred asked me to bring one up after it had been working. This airplane operated about 3 days at no wind condition flying back and forth through insecticide. The airplane has standard Stearman wings, World War II surplus, and the coating is activated Kopon on top of fabric. This is done for a purpose. Kopon is not supposed to be applied to fabric because fabric is pliable, and the paint will eventually get hard and crack, but with the chemicals we're applying, we can get 5 to 8 years on the fabric by using Kopon and spot painting it each year. We use a high-pressure air hose to blow the paint off of it every 3 years and repaint it with 3 gallons of activated Kopon.

To clean it, we use a long-handled brush to apply concrete soap mixed with water and then rinse it off with a water hose. Even after the airplane has been setting like it is for two weeks, almost all the spray material can be removed by this method. The airplane doesn't look real good, but when we operate it 12 hours a day, we don't have time to wash it every day.

We've done several things to decrease the maintenance. The propeller is a Beech hydromatic hub with long blades machined to fit it, and the spray pump is a trial-and-error idea we're working on now. It had a Super-Boom-Master pump, but the pump on the airplane is much less expensive. We want to see whether we can do less maintenance and have less trouble by buying two pumps instead of one and throwing them away sooner.

The boom system is the Transland Y-boom system with Spraying Systems Company hollow cone nozzles. We use the nylon-type nozzle bodies. I find that my booms last a lot longer because vibration is reduced with the nylon nozzles because of their lighter weight. Some of these nozzles have been used for five seasons, so they last well with insecticides. They last longer than brass. We use the brass end cap assemblies on the diaphragm cutoff for insecticide work because some of the chemicals soften the nylon assemblies, and they do not shut off in the turn. By using brass assemblies, stainless steel orifices, and nylon screens inside the nozzle, we have a piece of equipment that is durable and lightweight enough to keep from cracking the booms. We use cutoff valves on the

booms so we can turn on all the nozzles for 5 gallons per acre applications, half of the nozzles for 2 gallons, and cut down to 6 nozzles on each side for a gallon and a quart.

We find on actual checking of our fields that the gallon and a quart per acre application on phosphate insecticides does a better job of keeping cotton insects under control. When we use this system with materials that need to penetrate the foliage canopy, we apply 2 gallons per acre and sometimes 5. For many applications, we have to put the insecticide on the insects, not just on the cotton. Highly concentrated insecticide seems to provide better control.

We have a bit of a problem with hoppers. This hopper is a 185-gallon fiberglass unit that has been on the plane 3 years. During the first month of use, insecticide removed the inside coating and some of the glass. We repaired it and finished the season. Then we ground it off and put a new cover inside, and that lasted about a month and a half the next season. We've tried all different types. We have two of these airplanes with fiberglass hoppers. We have one with stainless steel. The stainless steel is resistant to about everything we use, but we have a lot of trouble with cracks from vibration. I believe some form of nylon might work better than fiberglass.

I used to use automobile tires on my aircraft. However, I hit a rock and knocked a hole in a tire and very near lost a propeller. I am now using implement tires with 8-ply sidewalls instead of automotive tires. They last better and are much less expensive.

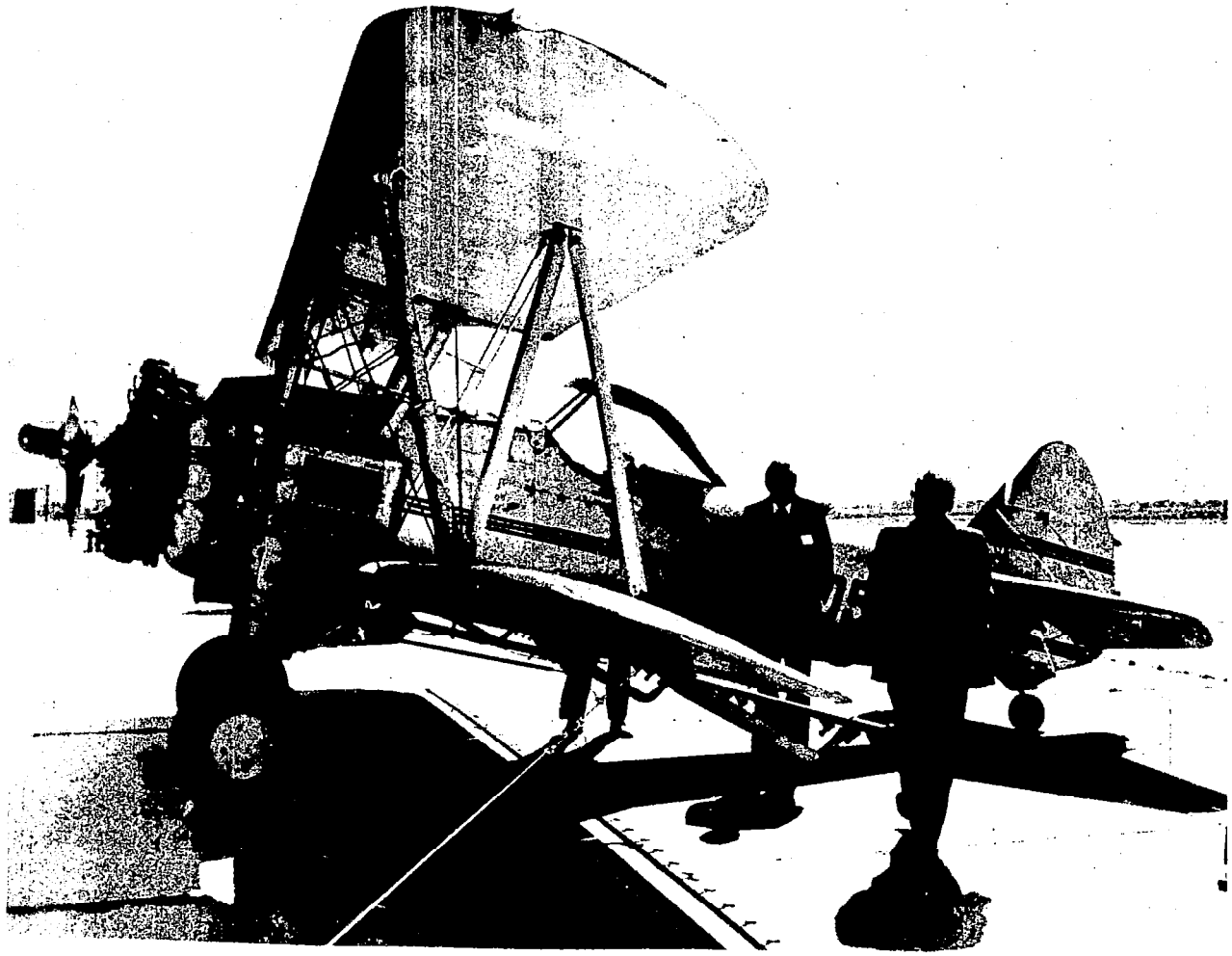


FIGURE 1

STEARMAN LIQUID SYSTEM

GROUND EQUIPMENT FOR LOADING AND MIXING

OWNER: George F. Mitchell, Jr.
M&M Air Service
Route 5, Box 890
Beaumont, Texas 77706

COMMENTS BY MR. MITCHELL (FROM TRANSCRIPTION):

This truck was developed by trial and error. (See fig. 1.) It is a standard Chevrolet 2-ton truck and has a 500-gallon aviation gasoline tank right aft of the cab. It has two 550-gallon water tanks and one 500-gallon mixing tank on the aft end of the truck. This truck might meet California's closed mixing standards with slight modification. It is a partially closed mixing system. It has some soft plumbing that may have to be changed. It has a safety equipment box and is marked with signs to meet most of the regulations for carrying hazardous material. There are lifting eyes on top of the tanks because the tanks have to be removed about every two years due to corrosion of the tank bottom. This is a combination unit for loading both liquids and dry materials. Fertilizer sometimes gets on the wet system and causes corrosion problems. The dry system is a cable arrangement, which is one of the older arrangements used in the industry. We use the plastic bag. We can unhook that bag and the bridle, and then we can hook on to the new Japanese 1-ton bag. Large bags are a new trend in the delivery of bulk dry products. Our trucks are radio-equipped. Our Stearman aircraft do not have radios because they do not have electrical systems. Our Ag Cats do have radios. The drinking water coolers are on the front of the truck to get away from the mixing area in the back. The manifold arrangement and mixing valves are color-coded. All of our trucks are equipped identically. There is a visual gauge on the mix vat, and the valve system is simple. The pilot can monitor the loading operation without leaving the airplane. The aviation gasoline supply is equipped with a hose reel and filter. There are screens for the bag on the back of the truck if the fertilizer is lumpy. There is also a new system for wettable powders, called the "honeybee." The "honeybee" hooks into the suction side of the manifold and has a built-in knife. It sucks the powder into the manifold. On the other side of the manifold, a valve and a plastic tube is used for adding a polymer drift control agent. It is metered into the spray solution which runs directly through the pump and into the airplane, thoroughly mixed, or it can be mixed in the mixing vat. One of the problems we have had is mixing 2, 4, 5, and 6 pound and all different size bags of wettable powders. That is something the chemical industry needs to take a look at—standardized packaging. You have to remember just exactly what size bag what company's putting what in!

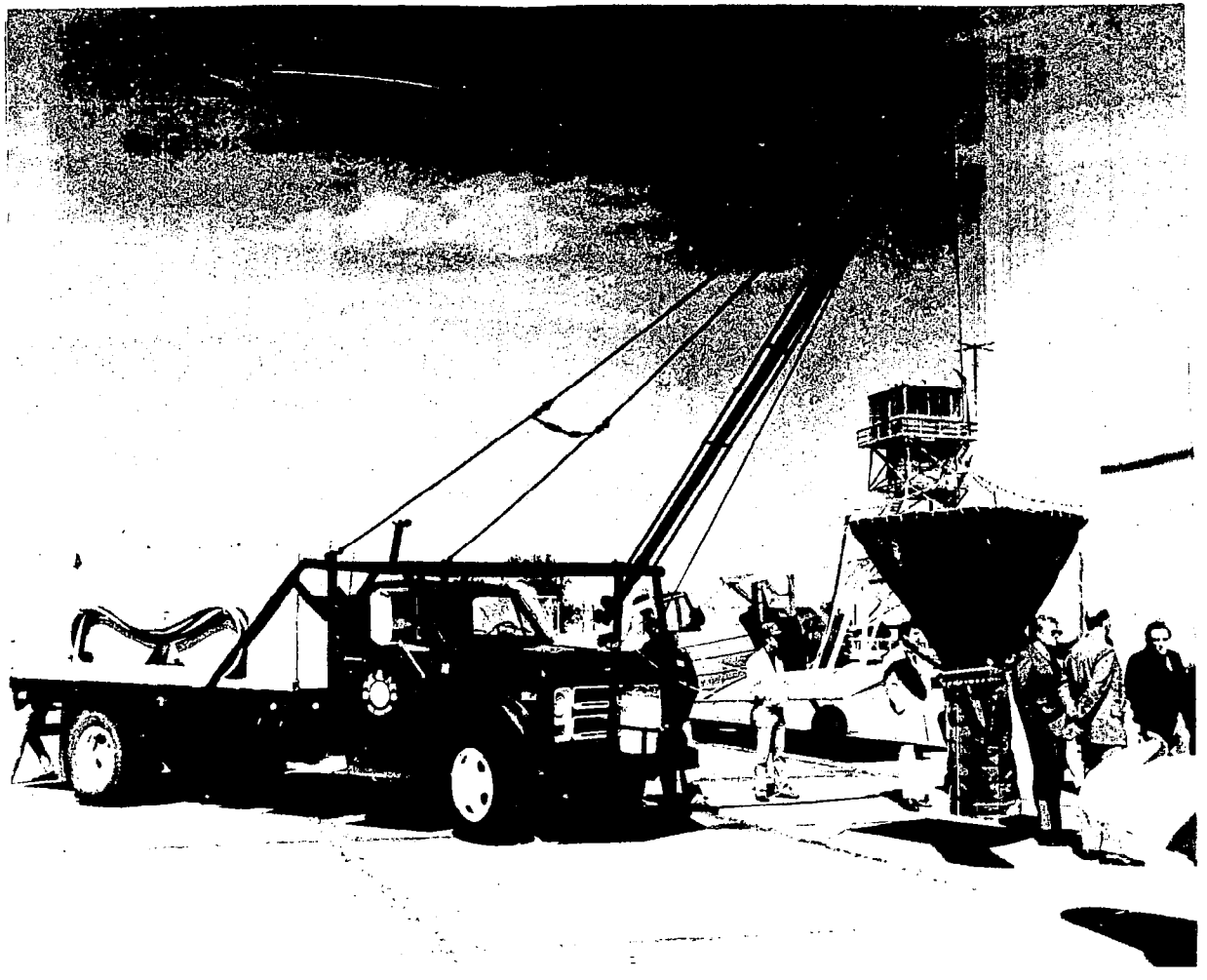


FIGURE 1

GROUND EQUIPMENT FOR LOADING AND MIXING

SESSION IV

PRESENTATION AND DISCUSSION OF THE NASA RESEARCH PROPOSAL

CHAIRMAN

F. F. Higbee
National Agricultural Aviation Association
Washington, D.C.

PRESENTATION AND DISCUSSION OF THE NASA RESEARCH PROPOSAL

SUMMARY REMARKS

The presentations given during this session provided the workshop participants with background information on the National Aeronautics and Space Administration and on the development of its involvement in aerial applications research. Six presentations by the participants listed in parentheses and below covered the rationale for NASA involvement in agricultural aviation research (Winblade), NASA facilities and experience at Langley, Lewis, and Wallops Centers (Stickle, Strack, Carr), NASA capabilities with computation aerodynamics (Bilanin), and preliminary program plans for Fiscal Year 1977 (October 1, 1977, to September 30, 1978) (Holmes). The speakers were:

Mr. Roger Winblade, Manager
General Aviation Technology Office
Code RAG
NASA Headquarters
Washington, DC 20546

Mr. Joseph W. Stickle
Assistant Chief
Flight Research Division
Mail Stop 246A
NASA Langley Research Center
Hampton, Virginia 23665

Dr. Alan J. Bilanin
Aeronautical Research Associates of Princeton
P.O. Box 2229
50 Washington Road
Princeton, New Jersey 08540

Mr. William Strack
NASA Lewis Research Center
Mail Stop 106-1
Cleveland, Ohio 44135

Mr. Robert Carr
NASA Wallops Flight Center
Wallops Island, Virginia 23337

Dr. Bruce J. Holmes
Aerial Applications Research Program Manager
Mail Stop 247
NASA Langley Research Center
Hampton, Virginia 23665

FIGURE 1

WHERE AG-AV PROBLEMS MATCH NASA CAPABILITIES

*WAKE INTERACTION	VORTEX FACILITY (LASER VELOCIMETER) COMPUTATIONAL AERODYNAMICS	LRC: DSB, SOPB
*AIRPLANE POWER (INCLUDING PROPELLER DESIGN)	PROPULSION SYSTEMS EXPERIENCE	LeRC
*MANEUVERING AND HANDLING QUALITIES (INCLUDING STALL/SPIN)	FLIGHT RESEARCH FULL-SCALE TUNNEL FLIGHT SIMULATORS	LRC: DSB, FVRB, SOPB
*FLIGHTPATH GUIDANCE	AVIONICS RESEARCH DISPLAYS FLIGHT RESEARCH, FLIGHT SIMULATORS	LRC: NGRB, FVRB, SOPB
*PERSONNEL ENVIRONMENT	SPACE EXPERIENCE	LRC: OTU
*CORROSION/EROSION	COMPOSITE STRUCTURES RESEARCH	LRC, LeRC
*DISPERSAL SYSTEM DESIGN TECHNOLOGY (INCLUDING POWER REQUIREMENTS)	WIND TUNNELS VORTEX FACILITY	LeRC, LRC
*LIQUID DROPLET CONTROL	COMBUSTOR AND AFTERBURNER DESIGN EXPERIENCE	LeRC
*MEASUREMENT OF DISPERSAL PATTERN (DROP SIZE AND DISTRIBUTION	LIQUID/DRY COLLECTION RIG LASER - FLUOROSENSOR CLOUD TRACKING RADAR LASER - DOPPLER	WFC

*LRC: Langley Research Center, Hampton, Virginia
*LeRC: Lewis Research Center, Cleveland, Ohio
*WFC: Wallops Flight Center, Wallops Island, Virginia
*DSB: Dynamic Stability Branch
*FVRB: Flight Vehicles Research Branch
*SOPB: Safety and Operating Problems Branch
*OTU: Office of Technology Utilization
*NGRB: Navigation and Guidance Research Branch

The purpose in describing research activities at the various NASA Centers was to determine where agricultural aviation problems match NASA capabilities. After the workshop, Figure 1 was prepared, summarizing the overlaps between NASA experience and the agricultural aviation industry needs.

The preliminary plans for Fiscal Year 1977 activities are presented as follows:

PRELIMINARY PLANS FOR NASA AERIAL APPLICATIONS
RESEARCH ACTIVITIES IN FISCAL YEAR 1977

1. Vortex Facility Experiments (Langley Research Center)

This is the key facility for wake interaction studies. The research done in this facility will be coordinated with the development of computational aerodynamic capabilities for modeling the aircraft wake with particle trajectories. Powered models will be built with interchangeable wings and with liquid and dry material dispersal capability. Qualitative (smoke visualization) and quantitative (laser velocimeter) measurements will be made to thoroughly define the aircraft wake as affected by dispersal equipment and various techniques for wake modifications. Examples of the wake modification devices and methods to be evaluated include

-Winglets
-Tip Spoilers
-Splines
-Span Loading Alteration
-Static-Tip Turbines
-Spanwise Blowing
-Tip Blowing
-Aerodynamic Fences

Full-scale wind-tunnel and flight-test experiments are planned to correlate and confirm results of the tests described.

2. Wallops Calibration System Development

(a) A conventional liquid and dry calibration rig will be constructed at Wallops for baseline testing.

(b) Experiments are planned to evaluate laser-doppler, photo-digital, laser-fluorosensor, and radar/laser cloud tracking systems for the documentation of airplane wake velocity profiles and dispersal pattern characteristics.

3. Lewis Exploratory Subsystem Studies

Lewis Research Center plans to fund a contract to define problems and the state of technological art in the areas of

-Liquid and dry material dispersal system design technology.
-Aircraft flight and subsystem power requirements.
-Control of corrosion and erosion.
-Automated control systems for dispersal equipment.

A workshop on dispersal systems technology is planned during the fiscal year.

4. Aerial Applications Systems Design Studies

Three separate design studies will be funded by Langley, one rotary wing one small-fixed wing, and one large fixed-wing aerial applications system design study. The purpose of the studies is to document the trade-offs in designing an aircraft in each of these three categories. Each study will lead to a conceptual design of an integrated aerial applications system.

5. Augumented VGH Program

Additional VGH (velocity, load factor, and altitude) recorders will be installed in about ten agricultural aircraft. Several installations are planned for turbinized agricultural planes. These recorders will supply additional data to airframe manufacturers on flight load histories for agricultural planes in the field.

6. User Requirements Study

A user opinion poll will be conducted by the National Agricultural Aviation Association to establish the research requirements of all groups within the agricultural aviation industry. The results of the poll will be useful in guiding future NASA research.

7. Cost/Benefit Study

A study is planned by NASA Headquarters (Washington, DC) to determine, on a macro-economic scale, the costs and projected benefits of an aerial application research program.

8. NASA/ASEE* Engineering Systems Design Study

An interdisciplinary team of university faculty professors will gather at Langley Research Center in the summer of 1977 to study the topic of "The Role of Space and Aeronautics in Agriculture." A report on the findings of this group will be published in the Fall of 1977.

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*American Society for Engineering Education

Topics on which research is planned to start in Fiscal Year 1978 (October 1, 1978) include an annotated research bibliography of technical references, present and future foreign agricultural plane market potential, and avionics and displays for flight-path (swath) guidance.

SESSION V

SUMMARY OF STUDY GROUP RECOMMENDATIONS

CHAIRMAN

W. G. Lovely
Agricultural Research Service
U.S. Department of Agriculture
Beltsville, Maryland

AIRCRAFT DESIGN, DEVELOPMENT, AND MODIFICATION

BRUCE J. HOLMES

Three low cost, early payoff items are recommended for immediate implementation. The results of these activities will play an important role in the early and long term phases of the entire proposed program.

Annotated Bibliography

A literature search should be made to bring together under one cover abstracts of all material pertinent to aerial application research. Foreign as well as U.S. sources should be included. Consideration should be given to organizing the results in the same major groupings as the study groups of this workshop.

VGH Program

The existing NASA VGH Program should be augmented to provide more and earlier data on agricultural aircraft. The program should consider weight-time histories if possible.

Mission and Operation Analysis

Analyses of typical aerial applicator missions should be conducted to determine the sensitivity of the economics of the mission to changes in mission parameters and aircraft design parameters.

Following is a list of research recommendations in approximate order of priority. These activities are considered to be of major importance in increasing the productivity of agricultural aircraft.

Wake Characteristics

Methods should be sought for the prediction and control of wake characteristics. These methods should consider crosswind, turbulence, and other atmospheric effects.

Maneuverability and Handling Qualities

A study should be made with the objective of improved maneuverability and handling quality of agricultural aircraft. This study must include operation in the flight range near the stall. The results of this work should provide criteria for design to reduce turning time as well as pilot fatigue.

Flight-path Guidance Systems

Anticipated improvement in the precision of dispersant patterns predicates the development of more precise flight-path control. Consequently, the technology should be developed for an inexpensive flight-path guidance system to replace present swath marking procedures.

Pilot Environment

Existing technology should be applied to the development of special clothing and other means to protect the pilot from chemical and fire hazard.

Dispersal Systems Power Requirements

The energy required to disperse both liquid and dry materials represents a substantial power loss. Methods to minimize this loss should be developed.

Materials

Reaction of agricultural chemicals with the aircraft structure, as well as with the hopper liner, constitutes a significant problem for the operator. Work should be done to identify candidate materials to alleviate this situation.

Regulatory Considerations

It can be anticipated that the results of the foregoing studies may indicate identification of agricultural aircraft as a separate category for airworthiness certification.

DRY MATERIAL DISPERSAL SYSTEMS

JOSEPH W. STICKLE

1. What are the problems that need to be solved? (Be specific)

   (a) Improved method of volumetric flow rates with increased swath width
   (b) Uniformity
   (c) Metering accuracy

2. What are some possible research approaches (both short and long range)?

   (a) Evaluate and document existing aircraft and distribution equipment for possible methods of improving this equipment in the short range
   (b) Explore new application concepts in the long range
   (c) Need new devices of instrumentation to measure flow rates and weights and given instantaneous readout information

3. How urgent is the need for a solution?

   The opportunity exists for increased productivity with dry materials (seed, fertilizer, and pelletized pesticides) while increasing crew and environment safety.

4. What impact would solving the problem have on agricultural production?

   The impact would produce more high quality feed and fiber with less energy.

5. What impact would solving the problem have on the agricultural industry?

   There would be increased uses for aircraft applications due to increased productivity from time and energy savings.

6. What agricultural commodities would benefit most from a solution to the problem?

   All commodities would benefit. The trends seem to be toward pelletization and granulation of pesticides in the future to promote on-target applications.

7. How many scientist years and what level of funding will likely be required?

   This answer was undetermined by the group.

8. What will be the consequences if a solution is not found?

   If the solution is not found there will be limits on the ability to produce high quality food and fiber in volume.

9. Assuming a scale of 1 to 5, with 5 being the highest and 1 the lowest, how would this problem be ranked in terms of:

   (a) Urgency, 5
   (b) Probability of success, 5
   (c) Cost/benefit ratio, 5

10. What individuals or groups could provide additional information pertaining to this problem?

    The individuals or groups that could provide additional information are government aeronautical and agricultural engineers, practicing applicators, land grant colleges, extension and experimental stations, chemical aircraft and equipment manufacturers, and farmers.

DISPERSION OF LIQUIDS

ROBERT P. INGEBO

1. The problems of dispersing liquids are mainly the problems of controlling the many variables that affect the dispersion process and the problems associated with improving our methods of measuring the uniformity of volume-concentration of the dispersed chemicals over a given area. Thus,

   (a) We need to control the formation of drops of a given uniform size.
   (b) We need to determine the optimum drop size for a specific application, depending on the type of treatment and the chemicals dispersed.
   (c) We need to control the droplet evaporation rate and trajectory.
   (d) We need to improve on aircraft guidance by use of electronic equipment in controlling the swath coverage to produce uniform pattern drops.
   (e) We need to simplify closed-mixing ground-handling equipment.

2. Possible research approaches would be to

   (a) Make a literature survey of atomization, vaporation, and penetration of drops
   (b) Investigate atomizers and develop new equipment to produce uniform volume-concentration profiles of liquid across swath patterns
   (c) Improve communication between the equipment manufacturer, the applicator, and the researcher
   (d) Investigate interaction of airframe and dispersion equipment.

3. How urgently is a solution needed?

   (a) The use of some chemicals may be restricted if problems are not solved.
   (b) There is a rapidly increasing need for safer and more economical applications, and better controlled drift of dispersed chemicals.
   (c) Low-volume-application problems are in urgent need of solution.
   (d) Problems of applications in forestry need attention now.

4. Impact on production would be

   (a) Wheat production could be increased by 28 to 30 percent through more effective application of herbicides
   (b) Environmental pollution would be reduced
   (c) Economic gains could be realized by grower
   (d) Timber could be preserved.

5. Impact on agricultural aviation industry would be

   (a) The acreage treated could be increased significantly
   (b) The economic outlooks would be improved considerably
   (c) Energy could be conserved by solving these problems.

6. The greatest immediate benefit would be realized by crops now receiving agricultural aviation attention such as cotton, range land, citrus, rice, and wheat.

7. Level of funding and man years are estimated as follows:

   (a) 3 to 5 year effort
   (b) $100 000/man year.

8. Consequences of unsolved problems are as follows:

   (a) Rising food costs and less growth in production
   (b) Increased restrictions in use of aircraft in agriculture.

9. Problem ranked in terms of

   (a) Urgency, 5
   (b) Probability of success, 5
   (c) Cost/benefit ratio, (No response).

10. Good source groups are

   (a) ASTM atomization specifications
   (b) State and federal government agriculture agencies, (USDA, NAAA, etc.)
   (c) Aircraft and dispersion equipment manufacturers
   (d) University experiment stations and research groups.

GROUND SUPPORT TECHNIQUES, PROCEDURES, AND EQUIPMENT

EVERETT PINGREY

1. What are the problems that need to be solved?

   (a) Develop portable pneumatic transfer and loading techniques of all dry materials, including weighing device, and anti-corrosion proof, and refueling capabilities
   (b) An integrated systems approach to rapid transfer, mixing and loading of liquids in a closed system including decontamination of equipment and container disposal. Economy and probability of prime importance.

2. What are some possible research approaches (both short and long range)?

   Short-range: Integrated and interdisciplinary meeting
   Long-range: Develop standards and prototype hardware for the interface points in the system, including formulation technology to produce the range of inputs.

3. How urgent is the need for a solution?

   This answer was undetermined by the group.

4. What impact would solving the problem have on agricultural production?

   Increasing efficiency and accuracy of loading systems will increase as production increases.

5. What impact would solving the problem have on the agricultural aviation industry?

   The impact of solving the problem will insure continued and orderly growth of agricultural aviation through economic productivity and enhanced safety.

6. What agricultural commodities would benefit most from a solution to the problem?

   All commodities and range lands and forest lands, particularly, will benefit.

7. How many scientist years and what level of funding will likely be required to find a solution?

   It will take 10 scientist years—$2 000 000 for 2 years—to find a solution.

9. Assuming a scale of 1 to 5, with 5 being the highest and 1 the lowest, how should this problem be ranked in terms of:

   (a) Urgency, 5
   (b) Probability of success, 5
   (c) Cost/benefit ratio, 5

10. What individuals or groups could provide additional information pertaining to this problem?

    The groups that could provide additional information are NAAA, NASA, ASTM, ASAE, WSSA, ESA, Container and Closure Manufacturers.

MONITORING AND MEASUREMENT

ROBERT E. CARR

1. What are the problems that need to be solved? (Emphasis should be placed on making these equipment and methods economical for the aerial operator to use.)

   *(a) Develop a guidance system for swath marking. Of equal importance is to develop methods of detecting the coverage one obtains.
   *(b) Develop a rapid and accurate method of determining droplet sizes and detecting drift, both quantitative and qualitative.
   (c) Establish standard techniques
      (1) Operator techniques
      (2) Equipment setup
   (d) Establish calibration procedures for aircraft and equipment performance.
   (e) Obtain baseline information on present performance of representative systems.
   (f) Catalogue present technique and disseminate the information.

2. What are some possible research approaches?

   (a) Short range: catalogue and categorize present techniques.
   (b) Long range: the group did not feel that we have information to address this problem until the present techniques were categorized.

3. How urgent is the need for a solution?

   The first two items listed under question (1) should be given top priority.

4. What impact would solving the problem have on agriculture production?

   (a) It would increase the quality and productivity of the agriculture aviation industry and provide the farmers with a more specific tool to use in his crop cycle.
   (b) In countries with a surplus of cheap labor, it would probably have less effect on agriculture productivity.

* Considered to be of prime importance and will require a concerted research and development effort.

5. What impact would solving the problem have on the agricultural aviation industry?

   (a) It would establish a basis for evaluating improved performance of new and existing systems.
   (b) It would allow the industry to grow at a much greater rate.
   (c) It would make the use of the aircraft in agriculture more acceptable.
   (d) It would make for a more stable industry.

   It was noted that many of the problems faced by the agricultural aviation industry in measurement are also common to the ground-based system, for example, drift control, droplet size determination, and standardization.

6. What agriculture commodities would benefit most from a solution to the problem?

   (a) No one commodity would benefit more than any other. They all would benefit.
   (b) No attempt was made to differentiate any commodity from any other.

7. How many man years and what level of funding will likely be required to find a solution?

   (a) This question cannot be answered until more is known about the present state of the art.
   (b) It is an intuitive feeling of everyone that continual investigations and improvements will be required at a fairly substantial funding and manpower level. This is a long-term effort.

8. What are the consequences if a solution is not found?

   (a) Continuation of the present uncoordinated R&D effort.
   (b) Growth of the industry will be slowed.
   (c) Some additional uses of agricultural aviation will be prohibited in addition to those that are already prohibited.

9. Assuming a scale of one to five, with five being the highest and one being the lower, how should this problem be ranked in terms of

   (a) Urgency, 5
   (b) Probability of success, 2 or 3
   (c) Cost/Benefit, ratio (Benefits will far outweigh the costs.)

10. What individuals or groups could provide information pertaining to this problem?

   (a) Members of the study group
   (b) USDA
   (c) EPA
   (d) University of California
   (e) Aircraft manufacturers
   (f) Equipment manufacturers
   (g) Texas A&M University

ADDITIONAL RECOMMENDATIONS

ADDITIONAL RECOMMENDATIONS

Verne E. Dietrich
Spraying Systems Co.

I've been thinking again on measuring particle size in flight. A phenomenon that is present for sound shows pronounced resonance of spheres for sound waves of particular size. The frequency of resonance is a function of the size. I think it might be worth investigating the possibility of using electromagnetic waves in like manner. This was an approach I considered at Spraying Systems Co. about 15 years ago and discarded for lack of oscillator in that range having sufficient energy output. There has been a great improvement in electronics since then, and I believe such an approach would be a feasible research project.

Such a device would allow simply directing a transmitter towards the spray and watching the response as one passes the frequency through a range. Micron magnitude wavelengths at the time I considered such equipment was attainable at fractional watt power. Detectors were not developed for these. I believe solid state science has the detectors for the weak returns and power to reach considerably above one watt now. At any rate I believe NASA has the personnel and research capacity to investigate this possibility.

THE USE OF AIRCRAFT TO CONTROL INSECTS

Arthur Gieser
U.S. Department of Agriculture

Aircraft treat over 200 million acres annually; 40 to 65 percent of the treatments are to control insects. Areas over which sterile insects are released almost daily involve thousands of square miles.

Considerable work is now being done to find effective and economical methods and materials, other than insecticides, to control insects. This includes applications of pheromones, sex attractants, parasites, growth regulators, viruses, and bacteria. They are applied in liquids, granules, flaky bran, micro-sized capsules in liquid and dry forms, capsules about the size of cigarette filters, hollow fibers about the size of small stick pins, wafers, ground cork, paper confetti, and loosely woven soft cotton string.

A variety of dispersal apparatus is used to apply insecticides. This includes conventional nozzles installed on booms and several types of wind driven and electrically driven spinners. Most dry materials are applied through vane-type spreaders.

Problem areas:

(1) A need for improved refrigeration units for installation on sterile insect release machines that will operate efficiently on available power from 12- and 24-volt aircraft electrical systems.

(2) A means to eliminate condensation inside of sterile insect release machines when operated in high humidity.

(3) Develop large portable sterile insect release machines for use in large aircraft.

(4) It is somewhat premature to determine equipment needs for biological control since so many tests with a variety of carriers are now being conducted. Ultimately it will be necessary to develop special devices to apply these materials uniformly.

(5) Develop standards for aerial application equipment. It is questionable whether all the different spraying devices now in use are necessary. Equipment should be evaluated by insect mortality rates rather than deposits on recovery receptacles. Standards should be developed for nozzle sizes and direction for specific purposes, their location for uniform deposits, swath spacing, and height of flight. Standards are needed for those insects that move very little and those that are killed by contact with the insecticide.

(6) Develop an accurate and rapid method for fieldmen and operators to evaluate equipment performance. These are the men who must insure that equipment is performing in accordance with recommendation.

Summary:

(1) Develop a method to achieve good underleaf coverage with an insecticide. May apply equally to disease control.

(2) Develop methods to increase effective swath width and deposit uniformity with dry materials.

(3) Develop a spreader for light applications of dry materials.

(4) Develop a dependable and economical guidance system.

(5) Develop methods to reduce aircraft noise.

RECOMMENDATIONS FOR RESEARCH ON AGRICULTURAL AVIATION

GEORGE S. SANDERS
AGRINAUTICS

1. What are the problems that need to be solved? (Be specific)

(a) Mathematical derivation of the material flow through a venturi distributor to optimize its design
(b) Optimum location and number of outlets for the uniform deposit of both solids and liquids in consideration of air flow field about an agricultural aircraft in flight
(c) The degree of variation in deposit distribution of solids and liquids due to changes in gross weight of the aircraft as the hopper load varies from full to empty and the fuel load decreases
(d) Determine the feasibility of minimizing the generation of wing-tip vortices to prevent entrained particles from being held in suspension in that airflow field for the long period now experienced in relation to the mid-span airflow field entrainment
(e) The variation of commercial flight operating envelopes, including heights and speed of aircraft
(f) The variation in chemical concentration in chemical loaded in aircraft under different mixing and loading methods.

2. What are some possible research approaches (both short and long range)?

Both short- and long-range research should be directed along lines of determining how and why a particular phenomenon operates. Equipment design should be left to the manufacturer. It is more useful to the operator if the principles are established (mathematically) by research and different designs based on those principles developed by various manufacturers. We manufacturers disapprove of so-called "basic research" that produces only gadgets.

3. How urgent is the need for a solution?

Airflow field research about an agricultural aircraft, leading to the significant improvement of deposit distribution through new wing airfoil, new solids and liquid distribution design, is the most urgent problem needing solution.

4. What impact would solving the problem have on agricultural production?

It would provide for less material to be applied because it would eliminate the excessive coverage necessary in some swath sections in order to meet minimum coverage in other areas of the swath.

5. What impact would solving the problem have on the agricultural aviation industry?

The agricultural aviation industry would benefit because it would mean less load to carry for the same acreage or conversely more acreage could be covered by the same load. The work rate would also be higher because less landings and take-offs and loading cycles would be necessary.

6. What agricultural commodities would benefit most from a solution to the problem?

All agricultural commodities would be affected by this solution.

7. How many scientist years and what level of funding will likely be required to find a solution?

It is estimated that at least 10 man years of scientific effort would be required; two scientists plus support manpower over a 5-year period.

8. What will be the consequences if a solution is not found?

Continued overapplication to obtain a minimum deposit would be perpetrated.

9. Assuming a scale of 1 to 5, with 5 being the highest and 1 being the lowest, how should this problem be ranked in terms of:

(a) Urgency, 3
(b) Probability of success, 4
(c) Cost/benefit ratio, 5

10. What individuals or groups could provide additional information pertaining to this problem?

NASA and airframe and equipment manufacturers.

SUGGESTED RESEARCH IN AGRICULTURAL AVIATION

R. W. TATE
DELAVAN MANUFACTURING COMPANY

Workshop study groups will be using special forms that will show detailed information on "Recommendations for Research." The first item is problems that need to be solved. Based on our company's activities and my personal background, I have prepared the following preliminary list. It includes research activities that pertain to dispersal of liquids from agricultural aircraft.

(1) Conduct comprehensive literature survey on aerial application techniques, including U. S. and foreign publications and printed proceedings from previous workshops and symposia. Prepare comprehensive list of references. (This is a logical first step in any bona fide research program. It is helpful in defining specific objectives and avoiding duplicative effort.)

(2) Evaluate the working relationships between manufacturers of agricultural aircraft and dispersal components (such as spray nozzles). Hopefully, this will eventually minimize the gap that presently exists between the design activities of these two groups of manufacturers and may lead to a "total systems" approach.

(3) Consider government-sponsored education programs for aerial applicators which would include not only information on proper operation and maintenance of aircraft, but would also emphasize the fundamental principles, performance characteristics, proper selection, and use of sprayer components. As the United States gradually metricates, appropriate information should also be supplied on SI units pertaining to application rates and sprayer operating variables, such as pressure and flow.

(4) It is my understanding that certain applicators use printed forms on which they enter information on the area to be treated. Such forms could be evaluated and standardized to make sure that they also provide for adequate information on the spray components and specific operating conditions required during a given application.

(5) Develop a plan to make sure that various government agencies and trade organizations concerned with aerial application enjoy adequate liaison with societies such as ASAE and ASTM. (ASTM recently developed a standard for "Aircraft Distribution Pattern Testing.")

(6) Conduct a broad systematic study for comparing alternative liquid spray devices and systems used on aircraft. For example, this would include various standard hydraulic nozzles (such as disc-core and flooding types), drift-reduction nozzles, rotary atomizers, and systems that utilize chemical additives such as emulsions and surfactants.

Although limited comparisons have been conducted by various investigators, the scope of such programs has generally been restricted by budgetary or proprietary considerations. In a broader program conducted by an impartial agency, spray devices could be evaluated in context with some of the performance parameters mentioned in the following paragraphs.

(7) Define research effort that might improve the uniformity of spray deposition over a target area. This could involve such factors as flow (capacity) consistency among nozzles mounted on a spray boom, minimization of pressure losses that could affect nozzle discharge rates, and optimization of nozzle locations to compensate for irregular air currents caused by the aircraft and boom.

(8) Schedule related research to optimize coverage and droplet size for specific applications. For example, a particular droplet size and application rate might provide suitable coverage (or "drops per square inch") for one type of application, but not another. This would require evaluation of efficacy for various systems and operating conditions. Although this might be determined qualitatively by human visual examination, there may be more sophisticated techniques that might involve high-altitude photography, infra-red photography, etc. Specific aspects of the same general research area could include (a) ability to adjust droplet size, (b) further information on relationship between droplet size and nozzle orientation, relative air velocity, etc., (c) further information on the "history" of droplets from the time of discharge until they are deposited, and (d) achieve better definition and understanding of the entire droplet-size spectrum, and not refer merely to "mean" or median" droplet diameters.

(9) Initiate research to evaluate existing methods and develop improved techniques for determining the size distribution of both airborne and deposited droplets. Regarding the latter, I suspect that many investigators are using incorrect "spread factor" data. Also, certain collection techniques may involve droplet shattering, or "streaking" that leads to erroneous results. Evaluate some of the recent optical techniques (e.g. laser instruments) to make sure that they are accurately sensing and are not interfering with the size distribution of airborne droplets. Try to understand more thoroughly why there are such wide variations among existing "laboratory" methods of determining droplet size. ASTM and other groups are concerned with this problem, and additional emphasis would be warranted.

(10) From a chemical standpoint, conduct additional research to make sure that a specified application rate is required for satisfactory efficacy. In other words, how large are the "safety factors" in existing label recommendations? Have the specified application rates been optimized on the basis of economics pollution control, or both? For example, if a prescribed application rate was cut in half, and the penalty was a 10% "efficacy loss," might not this be a step toward optimization? Perhaps the "economics of optimization" have been carefully considered in each instance, but I doubt that this is the case. Although the required input data and mathematical techniques could become quite complicated, this might be a very rewarding area for future research.

WORKSHOP PARTICIPANTS

Akesson, Norman B.	Agricultural Engr. Dept., University of California
Baen, Spencer	Texas Engr. Experiment Station, Texas A&M University
Barlow, Conrad R.	Transland, Inc., Harbor City, California
Benson, Fred J.	Dean, College of Engineering, Texas A&M University
Bergey, Karl H.	Dean of Engineering, University of Oklahoma
Bilanin, Alan J.	Aeronautical Research Associates of Princeton, N.J.
Bissonnette, Howard	Plant Pathology Dept., University of Minnesota
Bouse, Fred	USDA-ARS, Texas A&M University
Bovey, R.W.	USDA-ARS, Texas A&M University
Boving, P.A.	USDA-ARS, Yakima, Washington
Brazzel, J.R.	USDA-APHIS, Brownsville, Texas
Brothers, George B.	NASA, Wallops Island, Virginia
Brown, Philip W.	NASA-Langley Research Center
Brusse, J.C.	Texas Engineering Experiment Station, Texas A&M Univ.
Carlton, J.B.	USDA-ARS, Texas A&M University
Carr, Robert E.	NASA-Wallops Flight Center
Caviness, Bob A.	Delavan, Fort Smith, Ark.
Chambers, Joseph R.	NASA-Langley Research Center
Cherry, Heston	Texas Engineering Experiment Station, Texas A&M Univ.
Chevalier, Howard L.	Aerospace Engineering Dept., Texas A&M University
Ciesla, William M.	USDA-FS, Davis, California
Cobb, Tom	Agrinautics, Las Vegas, Nevada
Collins, Harold M.	Amchem Products, Inc., Ambler, Pennsylvania
Cross, Ernest J., Jr.	Mississippi State University
Deming, John	Monsanto Company, St. Louis, Missouri
Diefendorf, Charles	Piper Aircraft Corporation, Vero Beach, Florida
Dietrich, Verne	Spraying Systems Company, Wheaton, Illinois
Ekblad, Robert	USDA-FS, Missoula, Montana
Fletcher, Wendell S.	Sedalia, Missouri
Gieser, Arthur	USDA-Plant Protection, Hyattsville, Maryland
Gough, Merl	M.G.S.C., Hearne, Texas
Green, Stanley J.	General Aviation Manufacturers Association, Wash., D.C.
Grumbles, Jim B.	Dow Quimica Mexicana, Mexico
Haas, Robert H.	Range Science Dept., Texas A&M University
Hardcastle, Harold J.	Hardcastle Ag-Air, Inc., Vernon, Texas
Higbee, F. Farrell	National Agricultural Aviation Assoc., Washington D.C.
Hiler, Edward A.	Agricultural Engineering Dept., Texas A&M University
Holmes, Bruce J.	NASA-Langley Research Center
Huggins, George	Cessna Aircraft Company, Wichita, Kansas
Ingebo, Robert D.	NASA-Lewis Research Center
Jeffries, Jerry	Cessna Aircraft Company, Wichita, Kansas
Jenks, Gerald E.	Flight Research Laboratory, University of Kansas
Johnson, Al	NAAA-Air Enterprises, Inc., Magnolia, Delaware
Johnson, Joseph L.	NASA-Langley Research Center
Johnston, J.R.	USDA-ARS, Texas A&M University
Lane, George	Lane Aviation, Inc., Rosenberg, Texas
Lane, George C., Jr.	Lane Aviation, Inc., Rosenberg, Texas
Liljedahl, L.A.	USDA-ARS, Beltsville, Maryland
Lovely, Walter G.	USDA-ARS, Beltsville, Maryland

McMahon, Gordon E.	Rockwell International Corporation, Bethany, Oklahoma
Martin, J. Rod	USDA-ERS, Texas A&M University
Medders, Ken	Ken Medders Aircraft Sales, San Benito, Texas
Menard, Glenn	M&M Air Service, Beaumont, Texas
Mitchell, George F.	M&M Air Service, Beaumont, Texas
Muench, Steven B.	Monsanto Company, McAllen, Texas
Nay, Harvey	Cessna Aircraft Company, Wichita, Kansas
Noble, Dean	Cessna Aircraft Company, Wichita, Kansas
Ormsbee, Allen I.	Aero-Astro Engr. Dept., University of Illinois
Pingrey, Everett H.	Pingrey Brothers, Inc., Arbuckle, California
Razak, Kenneth	Wichita, Kansas
Reade, Richard	Mid-Continent Aircraft Corporation, Hayti, Missouri
Reimer, Charles	Dow Chemical Company, Midland, Michigan
Rippey, Michael	Grumman American Aviation, Elmira, N.Y.
Roth, George A.	EMROTH-EMAIR, Harlingen, Texas
Roth, George A., Jr.	EMROTH-EMAIR, Harlingen, Texas
Roth, Lawrence O.	Agricultural Engr. Dept., Oklahoma State University
Shanks, Eugene	Farm and Ranch Aerial Service, Wharton, Texas
Slaughter, Herbert H.	Reston, Virginia
Steen, Patrick J.	Operations Research, Inc., Silver Spring, Maryland
Stickle, Joseph W.	NASA-Langley Research Center
Strack, Bill	NASA-Lewis Research Center
Tate, Roger W.	Delavan Manufacturing Company, West Des Moines, Iowa
Taylor, J.L.	Union Carbide, McAllen, Texas
Tharrington, Bill	Delavan Manufacturing, West Des Moines, Iowa
Thomas, Richard E.	College of Engineering, Texas A&M University
Tuck, Dennis A.	FAA, Fort Worth, Texas
Voss, Carrol M.	Ag Rotors, Inc., Gettysburg, Pennsylvania
Webb, George I.	NASA-Wallops Flight Center
Weick, Fred E.	Vero Beach, Florida
Whitmore, Harry	Texas Engr. Experiment Station, Texas A&M University
Whittemore, F.W.	U.S. Environmental Protection Agency, Arlington, Virginia
Whitten, Jon R.	Whitten Flying Service, College Station, Texas
Wiedemann, Harold T.	Texas Agricultural Experiment Station, Vernon, Texas
Winblade, Roger	NASA-Headquarters, Washington, D.C.
Yates, Wesley E.	Agricultural Engr. Dept., University of California

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA CP-2025		

4. Title and Subtitle	5. Report Date
AGRICULTURAL AVIATION RESEARCH	November 1977
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
Howard Chevalier and Louis F. Bouse Coordinators	
	10. Work Unit No.
9. Performing Organization Name and Address	
Texas A&M University Flight Mechanics Laboratory College Station, Texas 77843	11. Contract or Grant No. P.O. L-49862 A
	13. Type of Report and Period Covered
12. Sponsoring Agency Name and Address	
National Aeronautics and Space Administration Langley Research Center Hampton, Virginia 23665	14. Sponsoring Agency Code

15. Supplementary Notes

Administrative support given by Industrial Economics Research Division, Texas A&M University

16. Abstract

This document is a compilation of papers, comments, and results presented during a workshop on Agricultural Aviation Research that was held at Texas A&M University, College Station, Texas, October 19-21, 1976. The workshop was sponsored by NASA Langley Research Center.

The purpose of the workshop was to review and evaluate the current state of the art of agricultural aviation, to identify and rank potentially productive short and long range research and development areas, and to strengthen communications between research scientists and engineers involved in agricultural research. Approximately 71 individuals actively engaged in agricultural aviation research were invited to participate in the workshop. These were persons familiar with problems related to agricultural aviation and processing expertise which are of value for identifying and proposing beneficial research.

The workshop program was divided into four major areas of work: 1) presentation of invited papers, 2) equipment demonstration and displays, 3) presentation and discussion of proposed NASA research, 4) study groups. The papers presented an overview of agricultural aviation development and scope and the state of the art and problem areas in agricultural aviation.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Agricultural Aviation Agricultural Aircraft Aerial Application Crop Spraying Crop Dusting	Unclassified - Unlimited

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	144	$6.00

* For sale by the National Technical Information Service, Springfield, Virginia 22161

NASA-Langley, 1977