Utah State University

DigitalCommons@USU

12-1964

Equipment and Techniques for Aerial Application of Evaporation-Reducing Monlayer-Forming Materials to Lakes and Reservoirs

Vaughn E. Hansen

Gaylord V. Skogerboe

Follow this and additional works at: https://digitalcommons.usu.edu/water_rep

Part of the Civil and Environmental Engineering Commons, and the Water Resource Management Commons

Recommended Citation

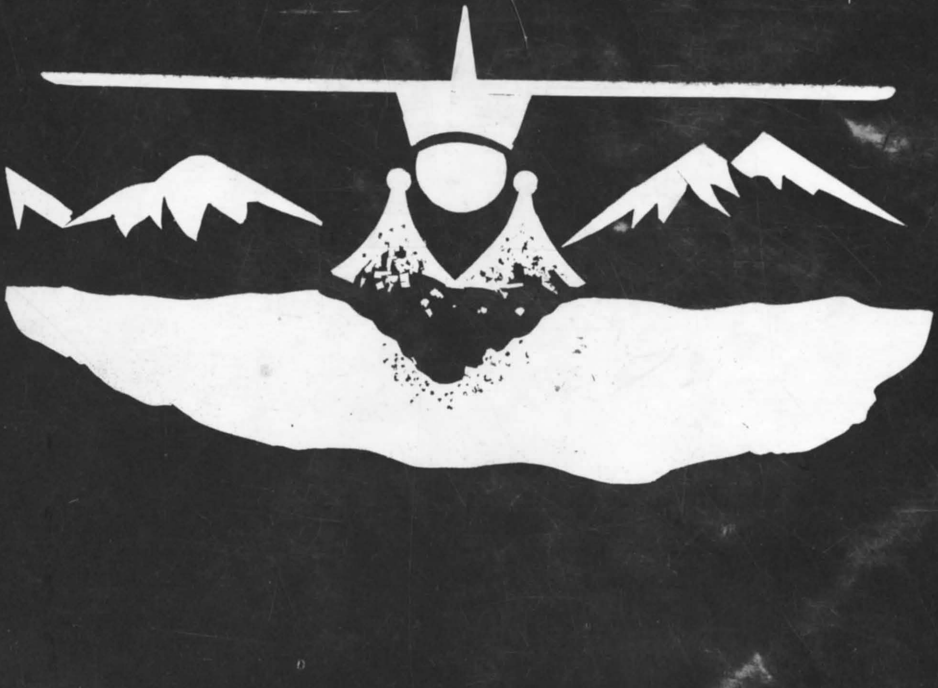
Hansen, Vaughn E. and Skogerboe, Gaylord V., "Equipment and Techniques for Aerial Application of Evaporation-Reducing Monlayer-Forming Materials to Lakes and Reservoirs" (1964). *Reports.* Paper 452.
https://digitalcommons.usu.edu/water_rep/452

This Report is brought to you for free and open access by the Utah Water Research Laboratory at DigitalCommons@USU. It has been accepted for inclusion in Reports by an authorized administrator of DigitalCommons@USU. For more information, please contact digitalcommons@usu.edu.

WG22-4

EQUIPMENT AND TECHNIQUES FOR AERIAL APPLICATION OF EVAPORATION-REDUCING MONOLAYER-FORMING MATERIALS TO LAKES AND RESERVOIRS

AH WATER RESEARCH LABORATORY • COLLEGE OF ENGINEERING



SCI/TECH
ASRS

TD
397
.H36
c. 1

72

Utah State University
Logan, Utah

UTAH STATE UNIVERSITY
3 9060 01300 5276

EQUIPMENT AND TECHNIQUES FOR AERIAL APPLICATION OF EVAPORATION-REDUCING MONOLAYER-FORMING MATERIALS TO LAKES AND RESERVOIRS

Final Report of USBR Contract No. 14-06-D-4911

Submitted to

United States Bureau of Reclamation
Department of the Interior

Prepared by

Vaughn E. Hansen
Gaylord V. Skogerboe

Utah Water Research Laboratory
College of Engineering
Utah State University
Logan, Utah

December, 1964

PR-WG22-4
(Formerly Project EC 47)

ACKNOWLEDGEMENTS

The authors wish to express their gratitude and sincere appreciation to the many organizations and individuals who assisted in this research effort.

The U. S. Bureau of Reclamation has sponsored the investigation of aerial application equipment and techniques. U. S. Bureau of Reclamation personnel concerned with the evaporation reduction research program have been most cooperative in supporting the efforts at Utah State University.

The Reeder Flying Service has worked with Utah State University in the development of aerial application equipment since the inception of the project in 1961. Mr. Charles Reeder has been very cooperative throughout the research program. Mr. Kenneth Jewkes, pilot and mechanic, has aided materially in the success of the equipment development. The efforts and interest displayed by Mr. Don Larson during flight and application tests have been very much appreciated.

The Commissioner of Utah Lake, Mr. David I. Gardner, has assisted in the research efforts at Utah Lake. The efforts of Mr. Dave Rowley, Price River Commissioner, and Mr. Francis Strang, caretaker at Scofield Reservoir, were very much appreciated. The continued cooperation of the Salmon River Canal Company has aided in the success of the research program.

Many of the staff at Utah State University have participated in the aerial application research efforts. The initial developments by Mr. Glen Stringham of the spray equipment, and subsequent contributions of Mr. Earl Israelsen in developing the powder dispensing unit are acknowledged. Professor Duane Chadwick and Mr. Don Griffin have undertaken the development of the radio altimeter. Messrs. Edwin Olsen, Derle Thorpe, and Eugene Israelsen have assisted during application tests. The illustrations contained in this report, together with the cover design, were prepared by Mr. Joe England. The efforts of Mrs. C. W. Lauritzen, editor, and Miss Barbara South, secretary, have materially aided in the preparation of the report.

Vaughn E. Hansen
Gaylord V. Skogerboe

551.572
U+1

TABLE OF CONTENTS

Table of Contents

LIST OF FIGURES

List of Figures

LIST OF TABLES

SUMMARY AND CONCLUSIONS

The aerial dispensing equipment performed very well in the Scofield Reservoir tests made in August, 1963; and the powdered alcohol was dispensed from the airplane at a uniform rate throughout the entire testing period. Although performances of the dispensing equipment were quite satisfactory at that time, additional modifications for improving performance, durability and safety, and for reducing weight and cost were proposed. These modifications have been incorporated into the development of a new dispensing unit. The powder dispensing unit uses steel-wire brushes to break up lumps of powdered alcohol rather than the wire-spoked flails used on previous powder dispensing units. The steel-wire brushes have proved to be more effective than the wire-spoked flails for breaking lumps.

Recommendations regarding application rates for aerial application under various conditions have been made. An application rate of 0.15 lb/acre should be used when very calm wind conditions exist and for the patching of uncovered areas on a water surface after an initial heavy dosing, during a sustained application. The optimum range of application rates for placing a monomolecular film on an uncovered body of water is between 0.20 lb/acre and 0.25 lb/acre. If the wind speed is greater than 8 mph, an application rate of 0.30 lb/acre is advisable.

Recommendations regarding the altitude of flight are listed below. These recommendations were derived from tests wherein materials having an average particle size of 100 microns were used.

a. Calm wind conditions. An altitude of flight of 150 feet should be used for wind speeds less than 3 mph.

b. Moderate wind conditions. If the wind speed is between 3 mph and 7 mph, an altitude of flight of 100 feet should be used.

c. High wind conditions. For wind speeds above 7 mph, the plane should be flown at an altitude less than 100 feet. The degree of air turbulence will govern the choice of altitude for safe flying.

At Utah Lake, tests conducted with a variety of chemical compositions, wherein speading rates and swath width were measured, showed clearly that the longer chain lengths, C_{20} and C_{22}, could be incorporated to advantage into the evaporation retardant to be used for aerial application. Based on the results of the Utah Lake tests, and taking into account manufacturing techniques and costs, it is felt that an evaporation retardant containing between 20 and 30 percent of C_{20} and/or C_{22} would be desirable for aerial application. The addition of the longer chain lengths should be effective in increasing the retarding ability of the material. Since development of an evaporation retardant suitable for aerial application is important to the efficient use of this method of application, research work is presently being pursued along these lines under sponsorship of The Proctor and Gamble Company.

Long-term, large-scale, sustained-application tests are essential for gaining the additional knowledge required regarding aerial application. The ability of the Australians to achieve application rates as low as 0.075 lb/acre/day (2) during long-term tests, and after an initial heavy dosing of the water surface, is evidence of the need for such tests. The Australians have been able to obtain evaporation savings of 15 to 20 percent over extended periods of time using evaporation retardants consisting of cetyl and stearyl alcohols (C_{16} and C_{18}). Higher evaporation savings should be achieved by employing longer-chain alcohols along with the cetyl and stearyl alcohols. Also, the employment of an airplane rather than a boat, as used in Australia, allows more rapid replenishment of uncovered areas during sustained tests and thus would aid in achieving higher evaporation savings. The size of the reservoir would effect the decision as to which method of application should be used.

Repeated field tests involving the aerial application of monolayer-forming materials to large bodies of water have indicated a necessity for developing an accurate radio altimeter which will warn the pilot when the aircraft is flying dangerously close to the water surface. The development of a radio altimeter for aerial application techniques is essential to the success of this method of application. The safety problem encountered to date in flying small aircraft at low altitudes over large bodies of water is acute and will be critical when aerial application becomes more extensive. The development of a new radio altimeter based on methods of modern circuitry is presently underway.

Improved methods for determing evaporation savings are a primary requisite to the widespread application of monolayer-forming materials to bodies of water. The accuracy of methods now used in determining evaporation rates is often no better than the percentage of evaporation savings. Equipment and procedures based on infrared technology, being developed at Utah State University show promise of overcoming, to a large extent, the disadvantages of present methods of measuring evaporation.

The research program at Utah State University has clearly shown the many inherent advantages of aerial application of evaporation retardants to large water surfaces. Aerial application can be conducted by a single person, the pilot, who can load the material in the hopper, observe uncovered areas on a water surface, and apply the material. A high utilization of the evaporation-reducing material is obtained on the larger reservoirs by aerial techniques. In addition, this method of application allows the use of the longer chain alcohols (because of greater swath widths) with a consequent increase in evaporation savings. The relationships between the parameters involved in aerial application have been developed to a great extent. The larger reservoirs, which are most suitable for aerial application, will also minimize the detrimental effects of wind in an evaporation reduction program. The development of improved methods of measuring evaporation, along with the ability to anticipate winds at a given water surface, will allow a prediction of the feasibility of aerial application (or for that matter, the feasibility of any method of application) at a particular site.

AERIAL APPLICATION RESEARCH PROGRAM

Previous Research Efforts

Utah State University first undertook research studies on the aerial application of evaporation-reducing, monolayer-forming materials to large lakes and reservoirs in 1961 under sponsorship of the U. S. Bureau of Reclamation. The first report resulting from this research program, which was written by Glen E. Stringham and Vaughn E. Hansen, was entitled "Aerial Spraying Equipment: Feasibility Study Applying Hexadecanol Monolayer Films on Storage Reservoirs." This report, dated September 1961, described the initial equipment development for spraying evaporation retardants. The next report, dated July 1963, was entitled "Aerial Application of Evaporation-Reducing Chemicals: Development and Evaluation of Equipment and Techniques" and was written by C. Earl Israelsen and Vaughn E. Hansen. The second report outlined the improvements made in the liquid dispenser and also described the initial efforts in the development of a powder dispenser. In addition, observations regarding the application of both powdered and molten materials on a number of lakes and reservoirs were cited.

The advantages of using a powder dispenser rather than a spray, or liquid dispenser, have been listed by Israelsen and Hansen (5).

1. The powder applicator is quickly and easily attached and removed. This feature permits use of the plane for purposes other than evaporation control. Several hours are required for installation of the liquid dispensing unit and assembly of necessary ground-support equipment.
2. A lower capital investment is required, since no heating, pumping, or installation are necessary for the powder dispenser.
3. Extra equipment and labor are required for melting the chemical before it can be used in the spray dispenser.
4. When powder is used the plane can be readied for flight in a few minutes time. Such is not the case when liquid is used. The tank, booms, and nozzles must be preheated to prevent clogging when the chemical is loaded.
5. Experience has shown that a fire hazard exists while the chemical is being melted prior to loading for spray application. On one occasion a sudden flashback of flames from the melting tank very nearly engulfed one of the workmen. On another occasion the high pressure required for liquid applications caused a gauge to fail and filled the cockpit with vaporized chemical. A serious fire could have resulted and destroyed both the plane and the pilot.
6. When spraying, hot water must be kept available to rinse out the equipment after each application. Any molten chemical remaining in the tank will normally be wasted when the equipment is flushed out. The powder dispenser requires no such special care. The use of powder reduces operational costs and the amount of material wasted after an application.
7. The use of a powder dispenser allows the pilot to load his own plane, thus eliminating the need for extra labor and equipment required for the preparation of molten chemicals for a spray dispenser.

Present Investigations

The primary research problems related to the use of aerial techniques in applying evaporation-reducing, monolayer-forming materials to large bodies of water to retard evaporation are:

1. Development of an economical and efficient unit for dispensing the evaporation retardant from an airplane,
2. Optimization of flight conditions related to the application of the monolayer-forming material,
3. Development of an efficient and economical evaporation retardant for use by aerial application,
4. Development of an economical and accurate means of determing evaporation savings, which is necessary regardless of the method of application.

Most of the effort at Utah State University to date has been on the development of the aerial dispensing unit and the techniques for optimum aerial application. The research carried out under the present U. S. Bureau of Reclamation contract has been concerned with the further development of equipment for dispensing powdered evaporation retardants from an airplane and, also, continued research into the interrelationships between parameters involved in aerial application techniques.

The development of an efficient and economical evaporation retardant is presently being pursued under sponsorship of The Proctor and Gamble Company. This endeavor entails two major facets of research. First, the desirable chemical composition of the material will be determined. This will be a matter of determining the combination of chain lengths that gives the best overall efficiency for aerial application. Evaporation reduction, spreading rate, the width to which the material will spread, and the resistance of the film to wind damage will be considered. Second, the most efficient particle size or gradation of particle sizes to minimize drift loss due to wind will be determined. The effect that particle size may have on efficiency of use of material, spreading rate, and total width of spread will be taken into account.

A number of sustained application tests on large bodies of water have been conducted in the United States by various organizations and institutions. During each of these tests, evaporation with and without the monolayer-forming material was evaluated. At the present time, three or four methods are being used in an attempt to determine the quantity of water evaporating from the water surface. The importance of developing more accurate and economical equipment and improved procedures for determining evaporation has been realized for some time. Consequently, work was initiated at Utah State University during 1963 based on an idea involving infrared technology. Preliminary work to date shows this method of evaporation measurement to be very promising.

Field Tests

A number of reservoirs have been used throughout this research effort for evaluating equipment development, optimization of flight conditions, and evaluation of spreading rates and swath widths for various chemical compositions of evaporation-reducing, monolayer-forming materials. The locations of the lakes and reservoirs that have been used by Utah

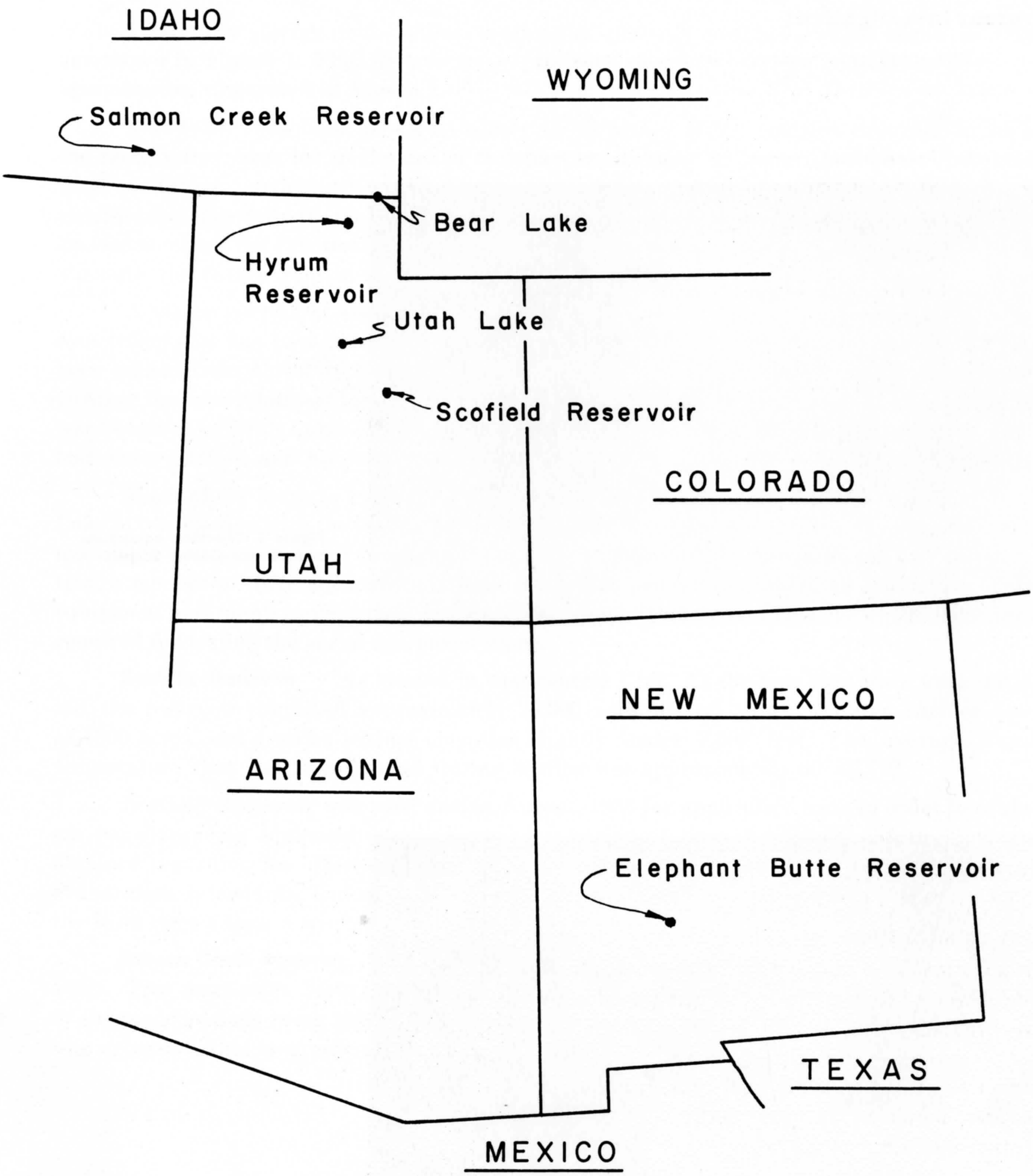


Figure 1. Location of lakes and reservoirs utilized throughout aerial application research program.

Figure 2. Checking equipment over Logan-Cache Airport.

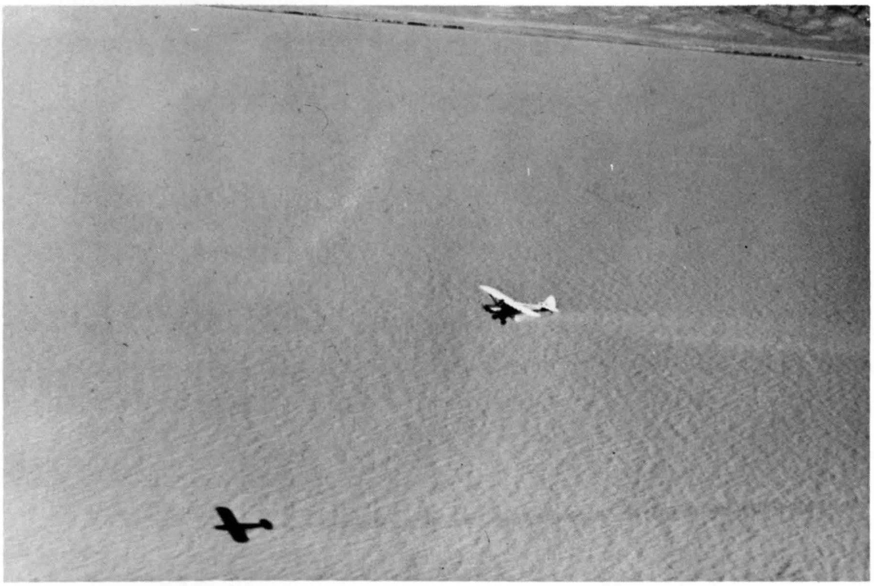


Figure 3. Applying powdered alcohol on Utah Lake.

State University during their aerial application research program, which began in 1961, are shown in Figure 1. Flights have frequently been made over airport runways to check the equipment as illustrated in Figure 2.

Utah Lake has been used extensively in all phases of the research program. Some of the factors that have led to the use of this particular body of water have been favorable wind conditions, particularly in the morning, and the vastness of the lake which has allowed considerable freedom in the extent of testing. Utah Lake has been used on numerous occasions to check the functioning of the equipment over extensive periods of time in order to simulate the future role to be performed by this equipment.

A major portion of the effort in optimizing the parameters involved in aerial application techniques has been accomplished at Utah Lake, although considerable information has been gained from aerial applications at the other reservoirs. The necessary information regarding the interrelationships between aircraft speed, dispensing rates, and application rates was obtained at Utah Lake, along with data regarding altitude of flight, particle size, wind, and water surface and air temperatures.

Much of the work in evaluating chemical compositions has been accomplished at Utah Lake in conjunction with the evaluation of the dispensing equipment. Rather than use the same monolayer-forming material throughout the period of time that the equipment was in operation, a number of different materials were used. This procedure allowed an evaluation of the equipment and many evaporation retardants at virtually the same cost as would have been required for testing the aerial equipment alone.

Scofield Reservoir is located in east-central Utah. At the time that tests were initiated, the reservoir contained approximately 20,000 acre-feet of water, a water surface area of 1900 acres, and a water surface elevation slightly under 7,600 feet. The average water temperature that was encountered during testing was approximately 66°-67° F.

Scofield Reservoir was used during August, 1963 for application tests in order to evaluate the dispensing equipment over an extended period of time. Additional information was obtained regarding the effects of wind and water surface temperatures on the application of evaporation retardants. Unfortunately, adverse wind conditions made it unfeasible to continue the tests longer than a week.

Salmon Creek Reservoir is located in Idaho, approximately 30 miles south of Twin Falls. This particular reservoir was employed primarily for rapid, single-day evaluations of the modifications being made to the dispensing equipment. Since the modification work was extensive, this reservoir was used frequently.

Figure 4. Partial monomolecular film on Scofield Reservoir.

Figure 5. Monomolecular film on Salmon Creek Reservoir.

DEVELOPMENT OF POWDER DISPENSING UNIT

Previous Development

The development of a powder dispenser was first pursued during 1962 under U.S.B.R. Contract No. 14-06-D-4387(5). At that time, considerable time was spent in evaluating the agricultural dust-spreaders that are used commercially on small aircraft. This review of available equipment showed the necessity for developing a powder dispenser that could be used specifically for application of evaporation-reducing, monolayer-forming materials. The primary difficulty with present agricultural dust-spreaders is that application rates of 20-30 lb/acre are employed, whereas, in aerial application of monolayer-forming materials on bodies of water, application rates of 0.05-0.30 lb/acre are required.

The first attempts at developing a powder dispenser employed auger tubes in conjunction with venturi tubes with screens located in the venturi tubes to break up any lumps in the evaporation retardant. (See Figures 6 and 7.) Later, the venturi tubes were replaced with wire-spoked flails for breaking up any lumps in the powdered alcohol. (See Figure 8.)

Initial Development

The initial equipment development under this contract (U.S.B.R. Contract No. 14-06-D-4911) is shown in Figure 9. Six-inch diameter auger tubes were employed. The small agitator located above the auger inlets was installed to facilitate the movement of the powdered alcohol to the augers. The wire-spoked flails are attached at the end of each auger tube. The variable-speed, ¼ h.p., 12-vdc motor is shown connected to the variable-speed transmission. Both the motor and transmission are bolted to an aluminum plate. The aluminum plate is attached to the underside of the fuselage of the aircraft just ahead of the auger tubes. The dispenser flange is bolted to the hopper flange, which is also located under the fuselage of the airplane. Figure 2 shows the aircraft checking-out this particular powder dispensing unit over the Logan-Cache Airport.

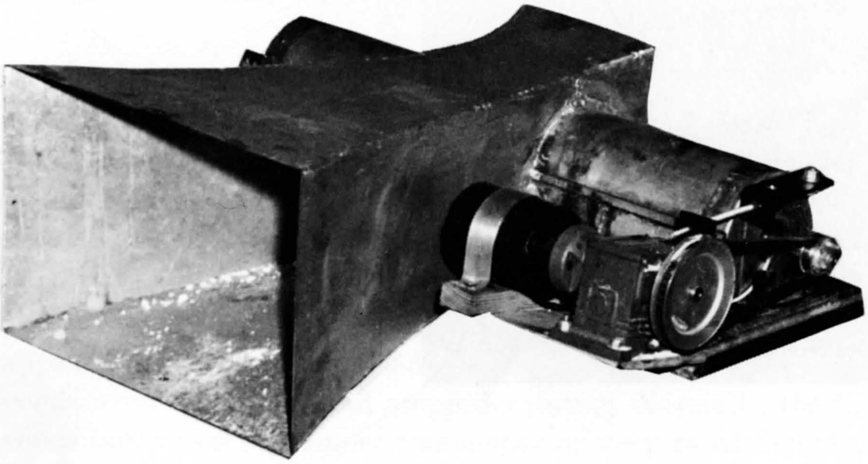


Figure 6. Motor-driven auger dispenser with single venturi outlet.

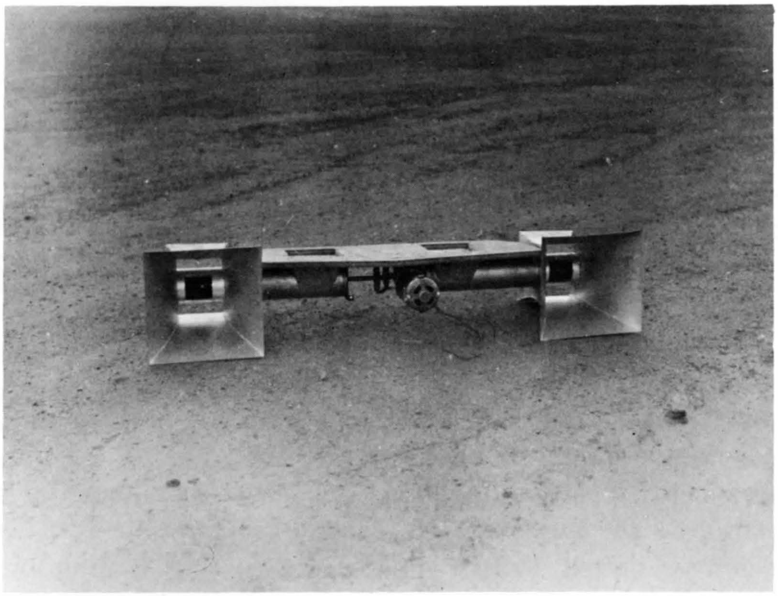


Figure 7. Auger powder dispenser with variable-speed motor and double venturi outlets.

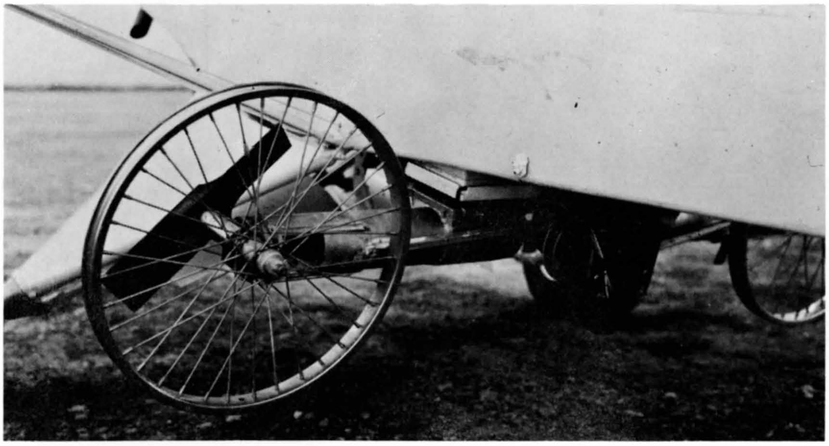


Figure 8. Wire-spoked flails are added to auger powder dispenser with variable-speed motor.

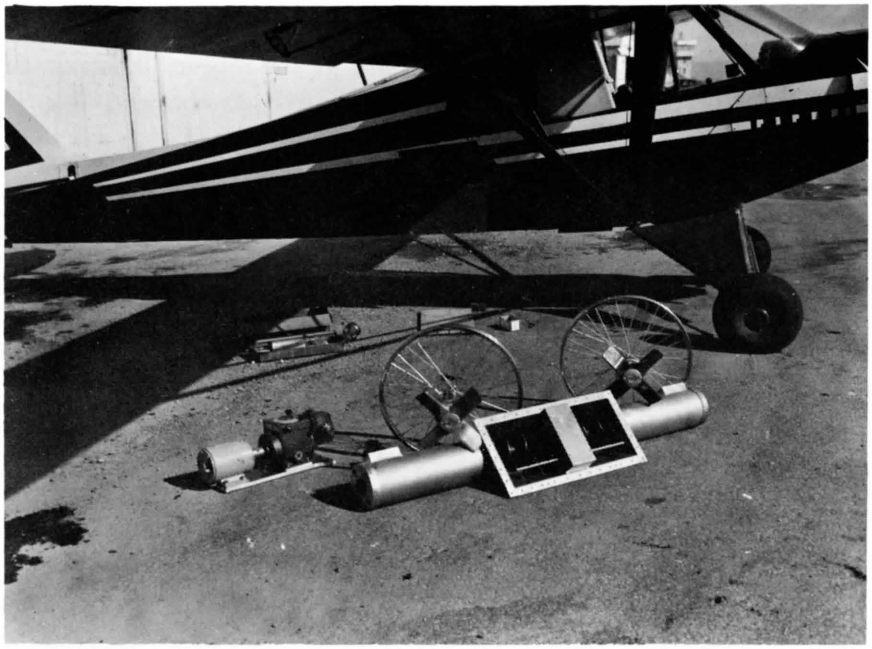


Figure 9. Initial equipment development under present U.S.B.R. contract.

Utah Lake Tests

The dispensing unit illustrated in Figure 9 was used at Utah Lake for a number of days in order to evaluate its performance. The primary difficulty encountered was that the evaporation retardant was dispensed somewhat erratically with occasional bursts of material from the auger tube outlets at some times, and no material at all at other times.

Other problems encountered during testing at this time were bridging in the hopper, which was due to the stickiness of the material as a result of the high temperatures, and some lumps of material were found on the water surface, which pointed out that the wire-spoked flails were not breaking up all of the lumps.

In order to correct the erratic discharge of powdered alcohol from the dispensing unit, air scoops were placed on the forward side of the auger tubes and immediately in front of the auger tube outlets. The air scoops would allow an airstream to pass through the end of each auger tube. It is hoped that the airstream would aid in discharging the material from the dispensing unit as rapidly as the augers carried the material to the auger tube outlets.

Scofield Reservoir Tests

Performance. Tests were conducted at Scofield Reservoir in August, 1963. The most heartening result of the testing program was the performance of the aerial dispensing equipment. The equipment was capable of dispensing the powdered alcohol from the airplane at a uniform rate throughout the entire testing period. This test was the most satisfactory performance of the equipment to date.

One item of unsatisfactory performance was the loss of material after the auger had stopped. The material continued to flow out of the dispenser for approximately two to ten seconds after the auger had stopped rotating. Normally, the flow continued for two to three seconds but, when the hopper was empty or very nearly empty, the flow continued until all of the material in the auger tube was removed. The material was lost because the air passing through the end of the auger tubing caused a vacuum near the end of the auger flighting, and material along the auger flighting was pulled into the airstream and discharged into the atmosphere.

Again, as previously disclosed at Utah Lake, lumps of powdered alcohol were found on the reservoir water surface. This evidence pointed out the necessity for improvment in material handling or in methods of breaking up any lumps that occurred in the material.

Proposed modifications. Although performances of the dispensing equipment were adequate, additional modifications were proposed which would improve performance, durability, and safety, and reduce weight and cost. The modifications which were proposed as a result of the testing program at Scofield Reservoir have been listed below:

1. Change the present sprocket drive to gear drive. A gear drive will out-perform a sprocket drive under extended field operations.
2. Raise the auger tube by placing the top of the tube against the dispenser flange. In this way the wire-spoked wheels will also be raised, increasing the safety of landings on rough surfaces.
3. Decrease the diameter of the auger tube. The tube diameter of 6 inches was considered larger than necessary. Weight and cost of the dispensing unit would be reduced and drag on the plane would be lessened.
4. Increase the length of the auger tube. The wire-spoked wheels would be moved farther away from the fuselage of the plane.
5. Raise the wire-spoked wheels 2 to 3 inches. The chance of damage to the wheels during landings on rough surfaces will be lessened.
6. Place brakes that can be operated from the cockpit on the wire-spoked wheels. If, during flight, a malfunction of the propeller and wire-spoked wheel unit should occur, vibration of the plane would result. The brakes would halt the operation of this unit.
7. Raise the outlet openings which are located at each end of the auger tube. If the wire-spoked wheels are raised the outlet openings should also be raised.
8. Place rearview mirrors in the cockpit in order that the pilot may observe the monolayer-forming material as it is being dispensed from the plane.
9. Place an agitator inside the hopper to prevent bridging of the material. An agitator is necessary to handle monolayer-forming materials which are sticky and lumpy because of improper handling.

New Powder Dispensing Unit

The lumps of powdered alcohol on the water surface encountered at Utah Lake and Scofield Reservoir emphasized the necessity for additional modifications to eliminate this problem. A decision was made to attempt the use of steel-wire brushes to replace the wire-spoked flails. This modification was incorporated into the proposed modifications resulting from the Scofield Reservoir tests. Extensive development work was accomplished during the fall of 1963 and early part of 1964.

The modifications proposed as a result of the Scofield Reservoir tests, along with using steel-wire brushes instead of wire-spoked flails, would materially decrease the time

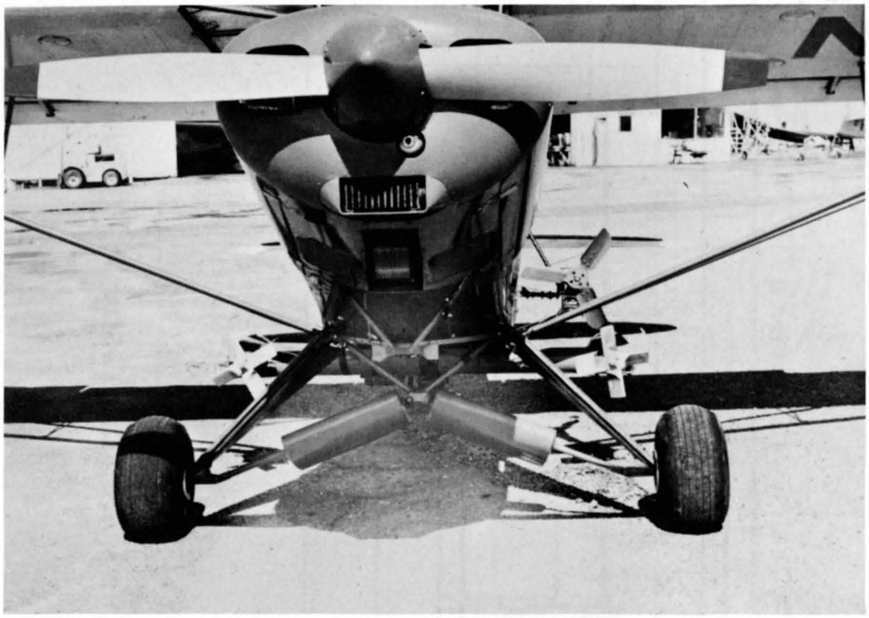


Figure 10. Forward view of new powder dispensing unit.

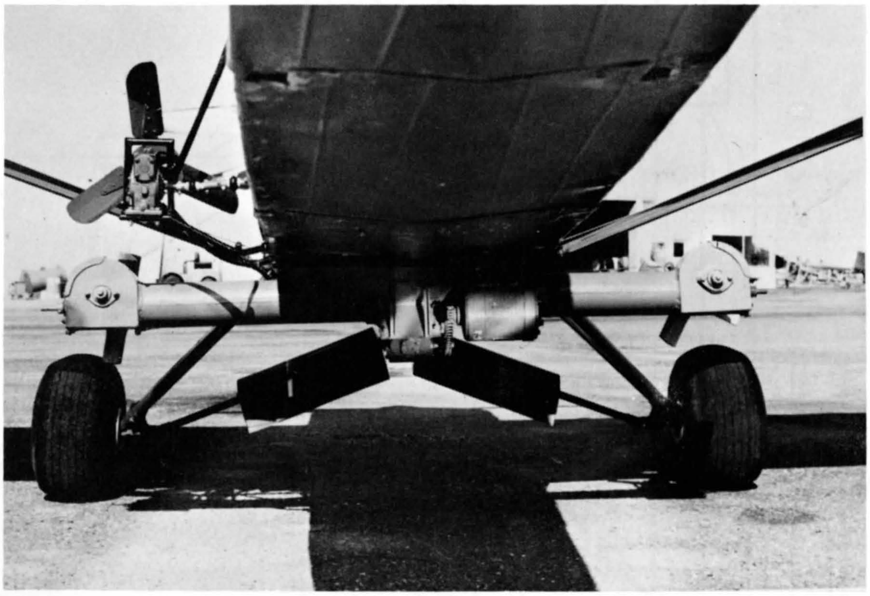


Figure 11. Rear view of new powder dispensing unit.

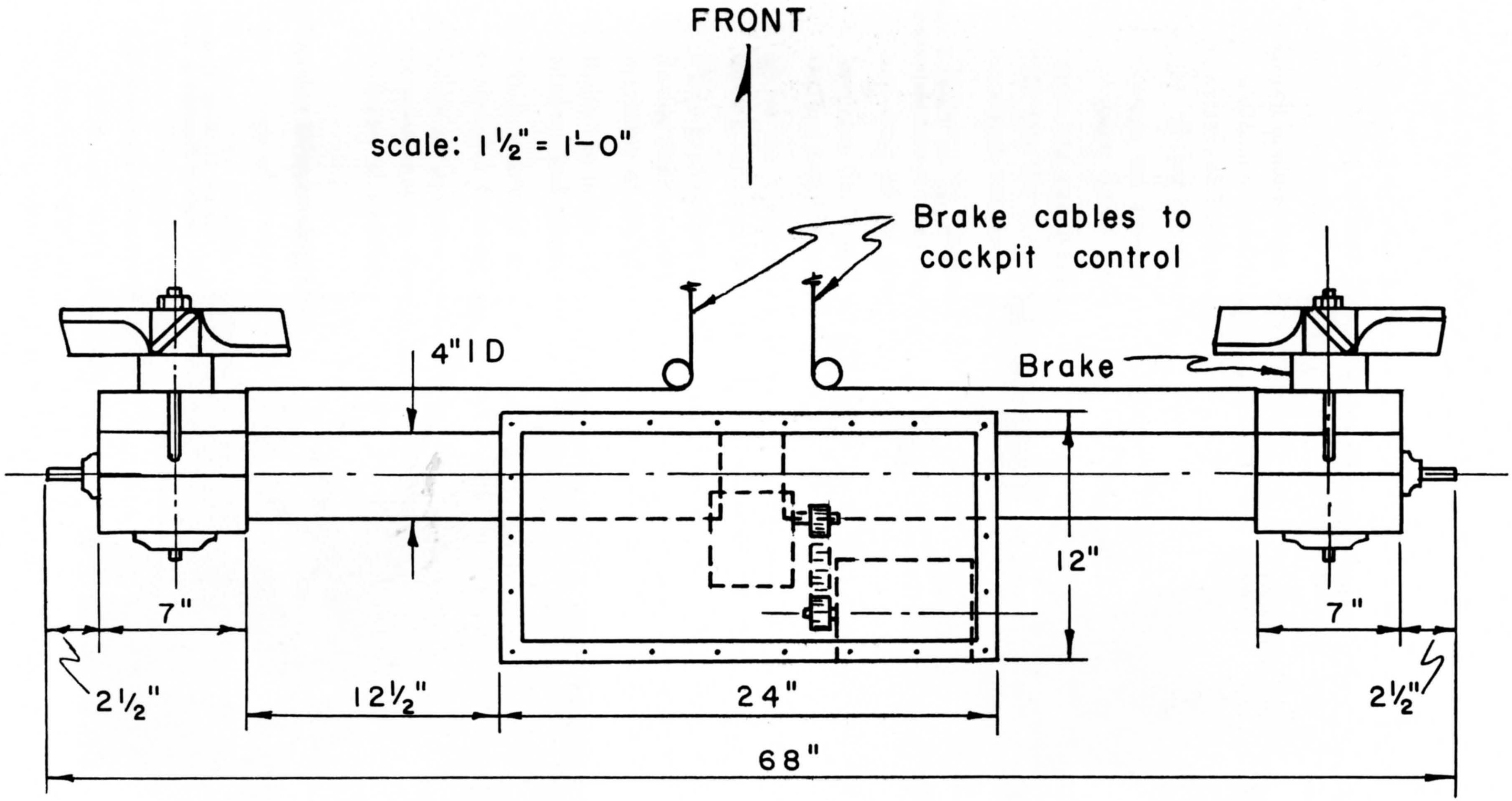


Figure 12. Top view of aerial dispensing unit.

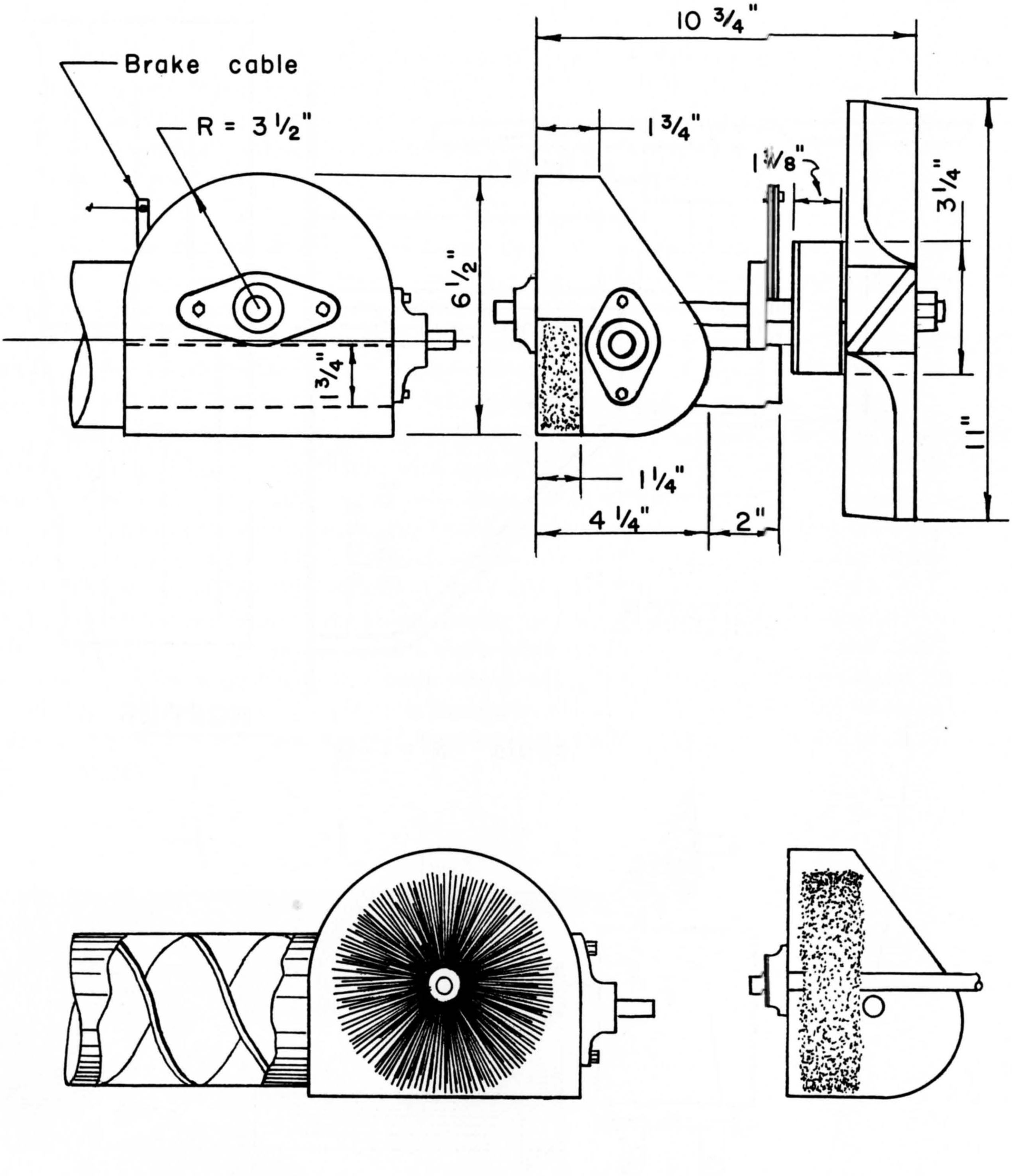


Figure 13. Details of steel-wire brush assembly.

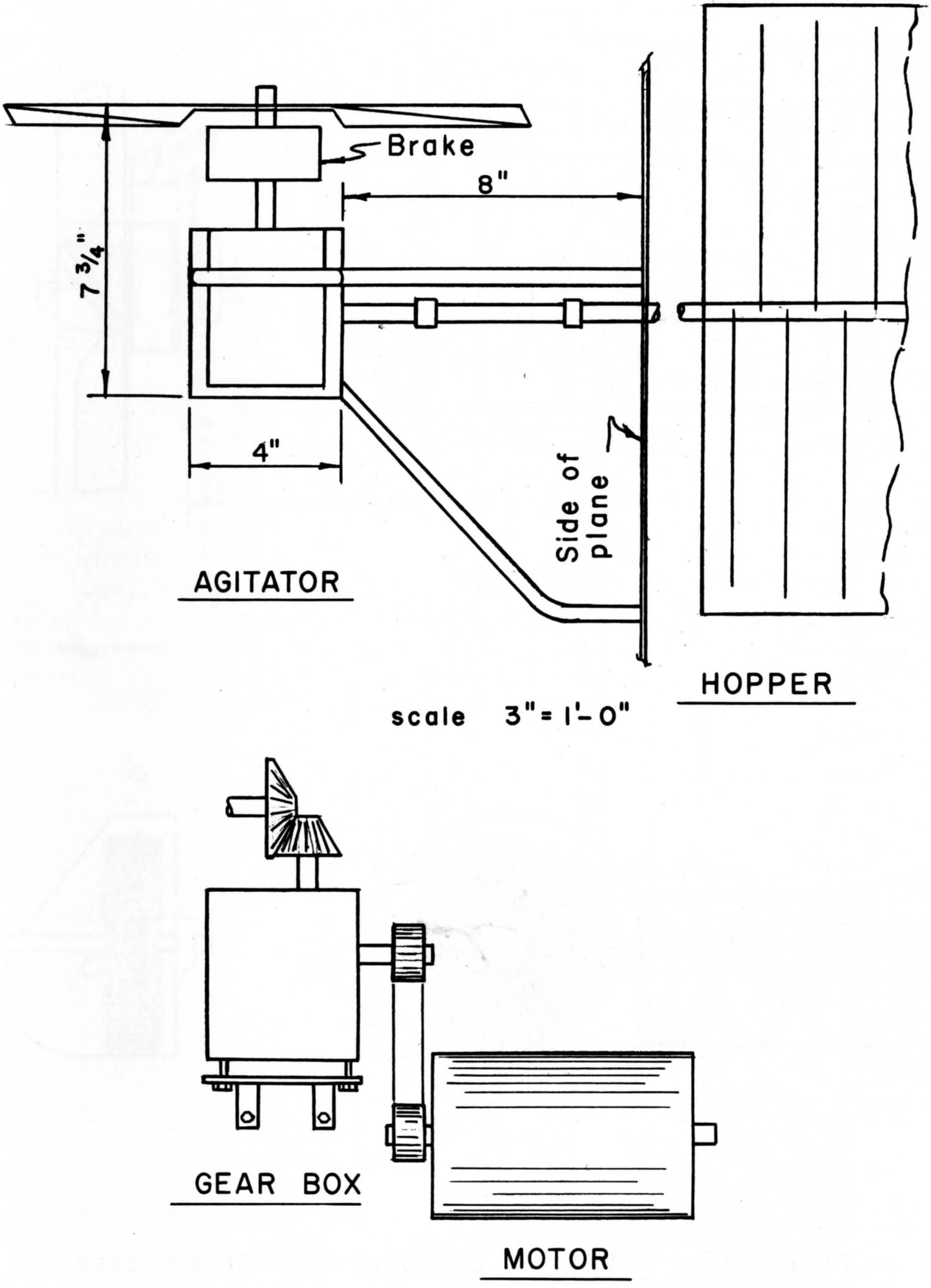


Figure 14. Details of agitator and gear reduction.

required to convert the aircraft from crop-dusting to aerial application of evaporation retardants.

Auger tubes. The diameter of the auger tubes was reduced from six to four inches. In addition, each tube was lengthened by six inches. Lengthening of the auger tubes has made it possible for the pilot to observe the monolayer-forming material as it is being dispensed from the aircraft without having to resort to rearview mirrors. Also, the tubes were raised to the point where the top of the auger tubes nearly butts up against the dispensing flange.

Gear and sprocket drive. The drive from the ¼-h.p., 12-vdc motor to the gear reductor is a sprocket drive. (See Figure 15.) The sprocket drive was retained between the motor and gear reductor in order to facilitate changing speed of rotation of the augers and thus control the dispensing rate. The dispensing rate can be changed quite readily by changing the sprockets on the motor or the gear reductor, or both. A gear drive (See Figure 16) has been employed between the gear reductor and the auger shaft.

Steel-wire brushes. Steel-wire brushes have been incorporated into the present dispensing unit and have replaced the wire-spoked flails which were previously used. (See Figure 17.) The steel-wire brushes rotate on a shaft which is operated by the propeller located in front of, and at the end of each auger tube. The brushes are so located that the evaporation retardant is dispensed at the end of each auger tube and perpendicular to the direction of flight. The action of the brushes causes any lumps to be slowly broken down by the action of the air stream entering the air scoop causing any lumps to be bounced against the steel-wire brushes. If a large amount of the material in the hopper is lumpy, the end of the auger tubes will become choked with the lumps which will prevent further dispensing of the material. In some respects this clogging is desirable since it will prevent the dispensing of material which has not been handled properly and would be quite ineffective as an evaporation retardant.

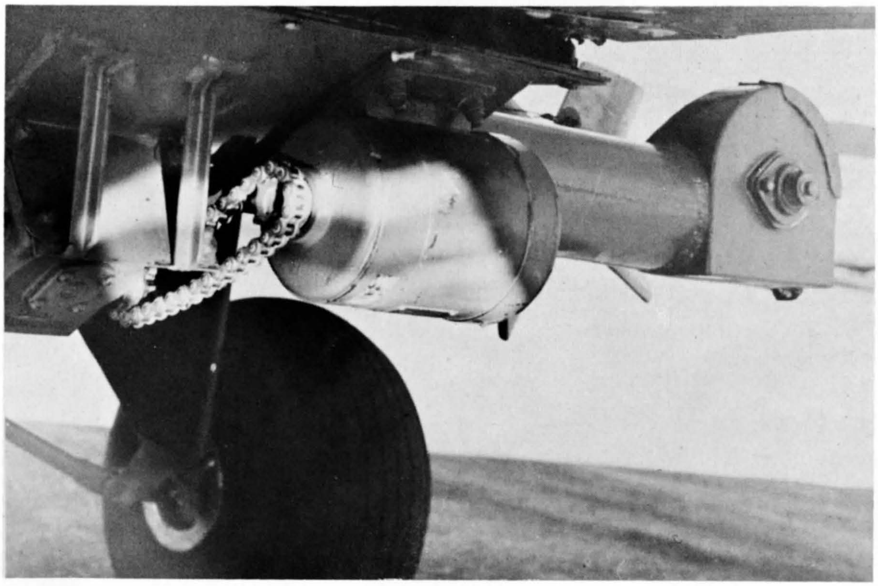


Figure 15. Sprocket drive between motor and gear reductor.

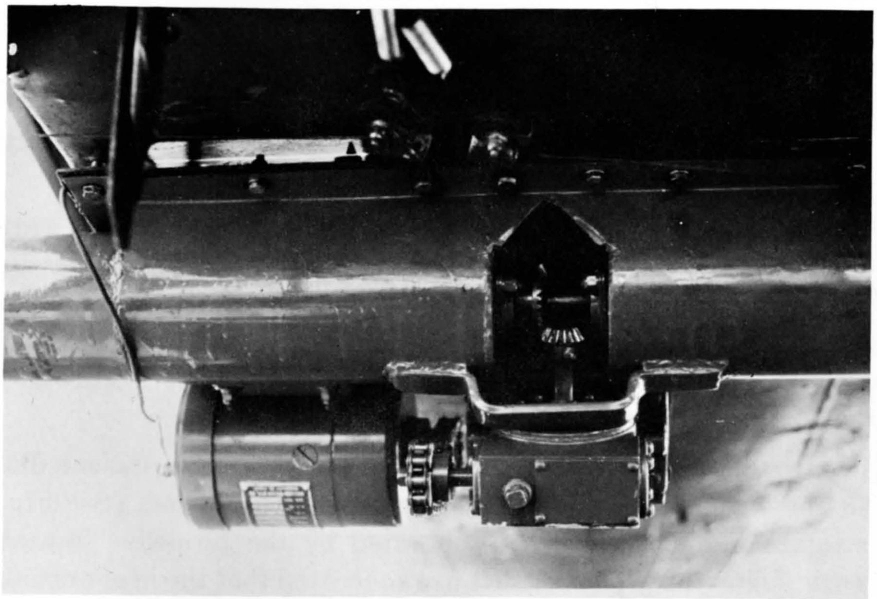


Figure 16. Sprocket drive and gear drive.

Propeller brakes. As a safety measure, brakes have been placed on each of the propellers located at the ends of the auger tubes and also on the propeller which turns the agitator hopper. The brakes are operated from the cockpit, thereby allowing the pilot to keep the propellers from rotating until they are needed during the dispensing of the evaporation-reducing materials.

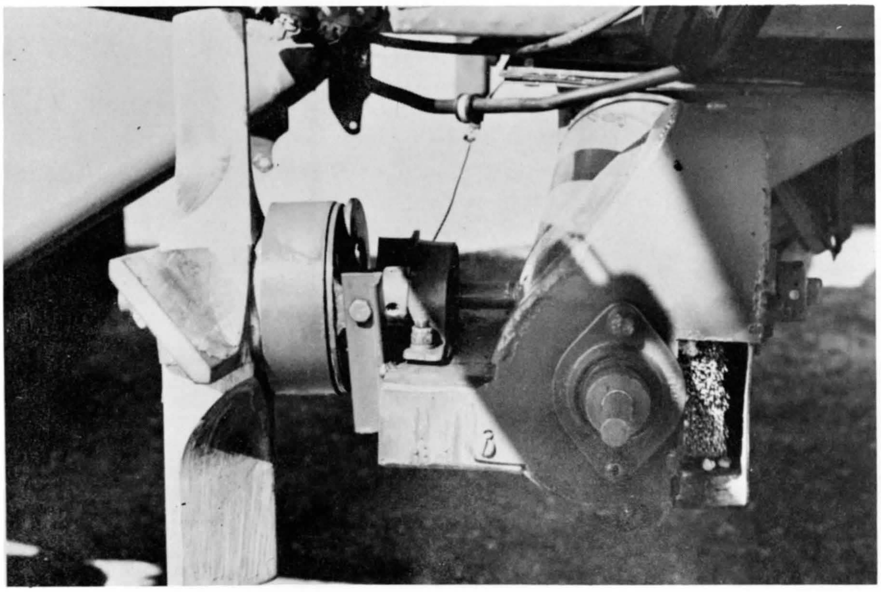


Figure 17. Steel-wire brush on left side of new powder dispensing unit.

Agitator. An agitator has been placed inside the hopper to help prevent bridging of the material and to facilitate the feeding of the material to the augers. Bridging sometimes occurs when air temperatures are high and the material becomes sticky and lumps are formed. The shaft of the agitator is rotated by the action of the propeller located on the left side of the fuselage above the dispensing unit. (See Figures 18 and 19.) A right-angle drive transmits the power from the propeller shaft to the agitator shaft. A built-in safety device has been incorporated so that if the agitator shaft should have a high torque applied to it, the shaft will uncouple, thus preventing serious damage to the aircraft.

Figure 18. Brakes, operated by cables, have been installed on the agitator propeller (upper) and steel-wire brush propeller (lower).

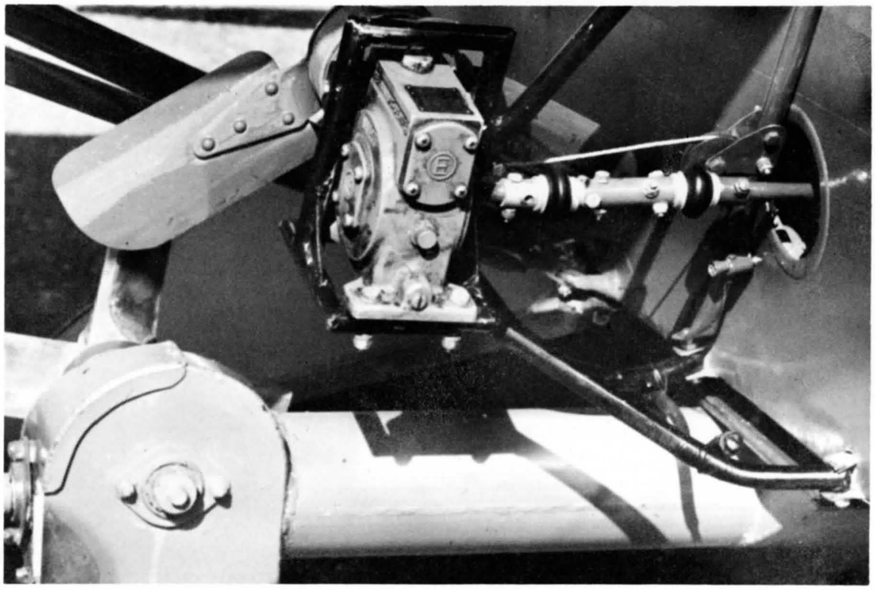


Figure 19. Agitator propeller, gear box, and shaft.

Hopper. A hopper with a capacity of approximately five hundred pounds of powdered alcohol has been installed in the Piper Super Cub. As reported previously (5), an air scoop located on the hopper lid and directed forward in the direction of flight (See Figure 22) has been found necessary. The air scoop partially pressurizes the hopper and thus aids in feeding the material to the augers. Since difficulty has been encountered with bridging of the material in the hopper, the agitator has been installed in the hopper along with the air scoop on the hopper lid. The hopper has also been lined with 2-mil teflon tape, thus providing a very smooth surface inside the hopper.

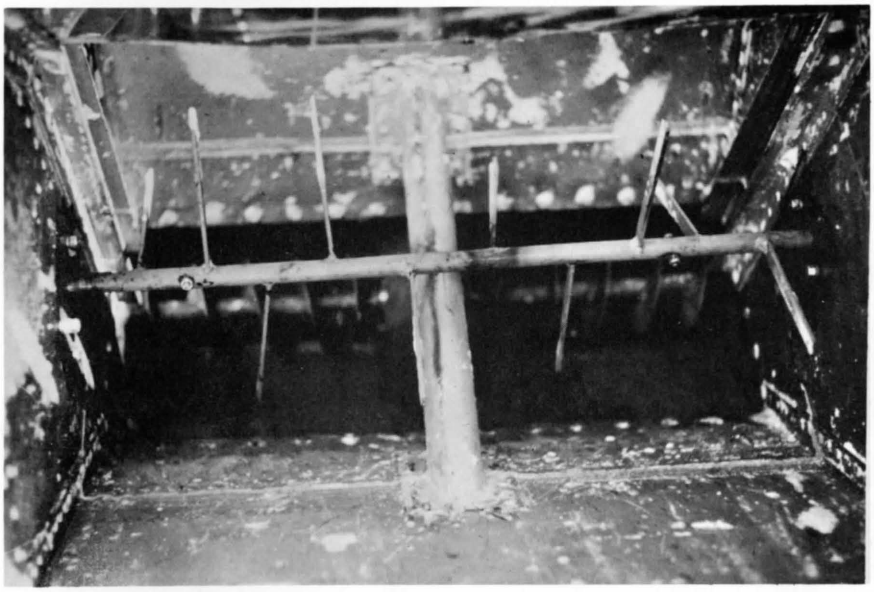


Figure 20. View inside hopper showing agitator with augers in background.

Figure 21. Hopper is located immediately behind pilot's seat.

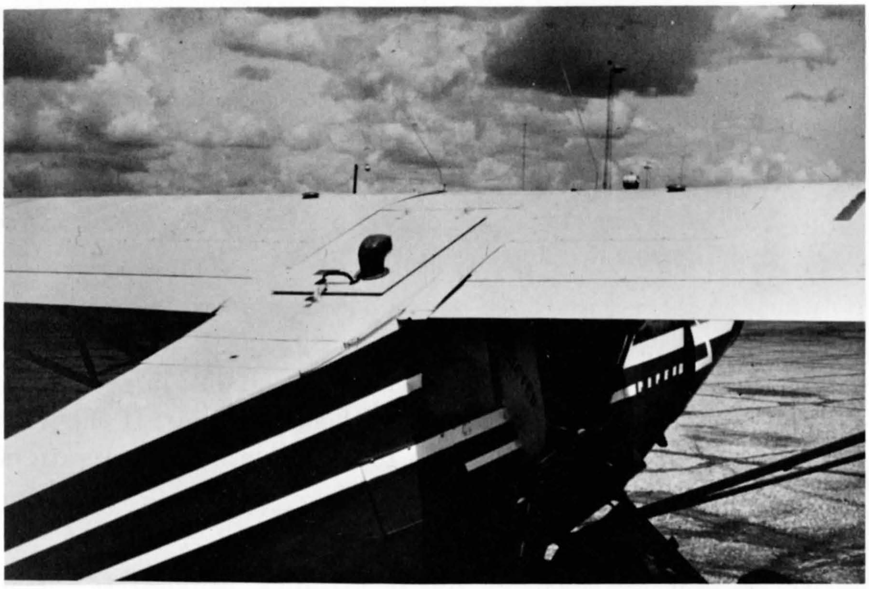


Figure 22. Air scoop is located on hopper lid.

Figure 23. Loading hopper with powdered alcohol.

OPTIMIZATION OF AERIAL APPLICATION PARAMETERS

The testing programs conducted at various lakes and reservoirs have provided information regarding many of the parameters involved in developing aerial techniques for applying evaporation-reducing, monolayer-forming materials to large bodies of water. The information gleaned from these tests has provided the basis for a number of recommendations concerning aerial application techniques.

Wind, Altitude and Application Rate

As a result of the analysis of quantative and qualitative data derived from the various testing programs, certain guide lines have been developed for the aerial application of powdered alcohol having an average particle diameter of 100 microns.

An application rate of 0.15 lb/acre is recommended when very calm wind conditions exist and for the patching of uncovered areas on a water surface after an initial heavy dosing, during a sustained application. An application rate between 0.20 lb/acre and 0.25 lb/acre is the optimum range for placing a monomolecular film on an uncovered body of water. If the wind speed should become greater than 8 mph, it is then advisable to use an application rate of 0.30 lb/acre.

It is recommended that the altitude of flight be varied as follows:

a. Calm wind conditions. An altitude of flight of 150 feet should be used for wind speeds less than 3 mph.

b. Moderate wind conditions. If the wnd speed is between 3 mph and 7 mph, an altitude of flight of 100 feet should be used.

c. Turbulent wind conditions. For wind speeds above 7 mph, the plane should be flown at an altitude less than 100 feet. The degree of air turbulence will govern the choice of altitude for safe flying.

Aircraft Speed and Dispensing Rate

The dispensing rate is defined as the rate at which the evaporation retardant is moved by the augers to the auger tube outlets and will be expressed in lb/minute. The dispensing rate can be varied by changing the sprockets on the 1/4-h.p., 12-vdc motor and gear reductor. For any particular type of aircraft, the ground speed can be varied over certain limits. Utilization of the various combinations of sprockets in conjunction with allowable changes in ground speed permits a wide latitude in discharge rates that can be employed.

The relationships between aircraft ground speed, swath width, rate of coverage, application rate, and dispensing rate are plotted in Figure 26. The recommendations regarding wind, altitude of flight, and application rate in the previous section can be followed in arriving at a desirable application rate. If data are not available for determining swath widths at the particular body of water in mind, then a swath width of 500 feet can be used. An estimate of 500 feet should be conservative except under cold water conditions. With a knowledge of the desired application rate and possible swath width it is possible to determine the set of sprockets to be utilized for a particular dispensing rate and the required aircraft ground speed.

Figure 24. Test strips at Utah Lake.

Figure 25. Effect of wind on placing test strips.

Particle Size

Evaporation-reducing, monolayer-forming materials have been tested which have an average particle size ranging from 50 microns to 380 microns. Evidence has been presented by previous researchers to indicate that the smaller particle sizes will spread faster for any particular material. Generally, during aerial application tests, a particular material has spread faster for the smaller particle sizes. During the Scofield Reservoir tests, an evaporation retardant having an average particle size of approximately 100 microns was used. The tests clearly showed that some of the material, after being discharged from the aircraft, would almost "hang" in the air and slowly drift away much like a cloud. Observations of the drift loss and a knowledge of the particle size gradation of the material used has led to the hypothesis that the drifted material consisted of particle sizes less than 50 microns.

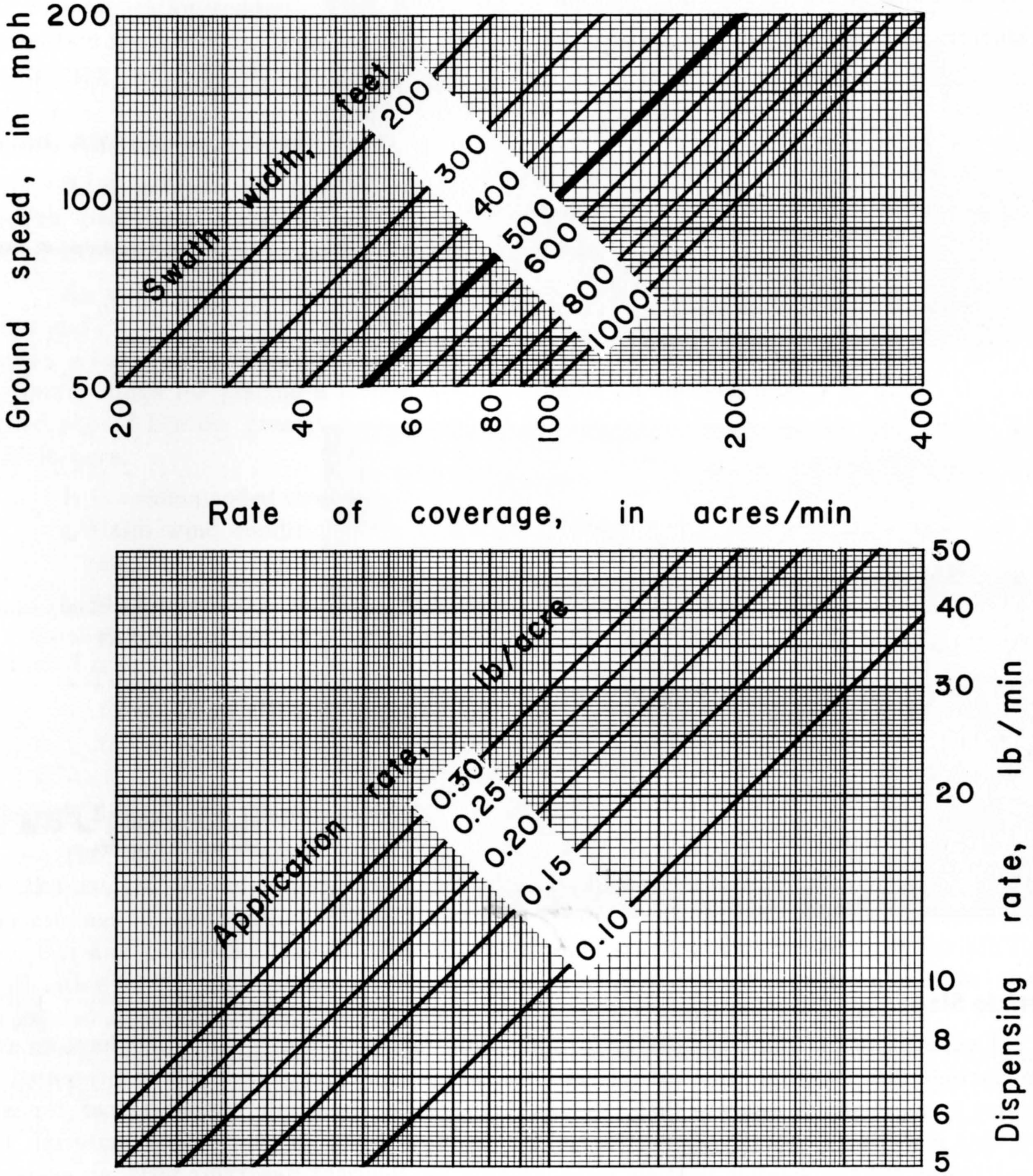


Figure 26. Relationship between ground speed, swath width, application rate, and dispensing rate.

The observations were made during nearly calm wind conditions. Since measurements were not possible, it is quite probable that the maximum particle size of the drifted material was much less than 50 microns, say 30 or 40 microns. The results of the Scofield Reservoir tests pointed out the necessity for using evaporation retardants with particle sizes greater than 50 microns if drift loss is to be minimized.

Evaluation of Evaporation Retardants

An effort has been made to determine the suitability of various chemical compositions and particle size gradations for aerial application. As mentioned previously, the evaluation of various chemical compositions was accomplished at Utah Lake in conjunction with the evaluation of the dispensing equipment. A variety of materials of different chemical compositions was obtained from a number of sources. The materials were mixed in a number of combinations to arrive at the desired chemical compositions. Much of the material was ground to powder in a micro-pulverizing machine at the University's River Laboratory. The chemical compositions of the materials tested at Utah Lake are listed in Table 2.

The results from testing the various chemical compositions were very surprising in that the longer chain lengths, C_{20} and C_{22}, spread very well. The spreading rate of the longer chain lengths was slow but the total width of spread was very satisfactory. Based on the results of these tests, and taking into account manufacturing techniques, it is felt that an evaporation retardant containing between 20 percent and 40 percent of C_{20} and/or C_{22}

Table 1. Chemical compositions of materials tested on Utah Lake.

No.	Chemical Composition of Powdered Evaporation Retardant	No.	Chemical Composition of Powdered Evaporation Retardant	No.	Chemical Composition of Powdered Evaporation Retardant
1	C_{16} - 35 % C_{18} - 65 %	6	C_{16} - 25 % C_{18} - 46.4% C_{20} - 28.6%	11	C_{16} - 15 % C_{18} - 27.8% C_{20} - 57.2%
2	C_{14} - 2 % C_{16} - 30 % C_{18} - 60 % C_{20} - 8 %	7	C_{14} - 1.3% C_{16} - 20 % C_{18} - 40 % C_{20} - 38.7%	12	C_{16} - 15 % C_{18} - 27.8% C_{20} - 57.2%
3	C_{14} - 1 % C_{16} - 26 % C_{18} - 73 %	8	C_{16} - 20 % C_{18} - 37.1% C_{20} - 42.9%	13	C_{20} - 95 % (commercially pure)
4	C_{14} - 1.7% C_{16} - 25 % C_{18} - 50 % C_{20} - 23.3%	9	C_{16} - 20 % C_{18} - 37.1% C_{22} - 42.9%	14	C_{22} - 95 % (commercially pure)
5	C_{16} - 25 % C_{18} - 46.4% C_{20} - 28.6%	10	C_{14} - 1 % C_{16} - 15 % C_{18} - 30 % C_{20} - 54 %		

would be desirable for aerial application. The longer chain lengths, of course, have the advantage of being more effective in retarding evaporation.

Additional research is required in order to determine a balance between the added effectiveness of an evaporation retardant due to the longer chain lengths, cost of materials, durability of monomolecular film containing longer chain lengths, and if more or less material is required to maintain a film using the longer chain lengths.

Indications, at present, point toward the use of longer chain lengths for aerial application with a resultant increase in evaporation savings. In addition, it is felt that the added cost of including the longer chain lengths will be very slight and the possibility is that the cost will not be increased at all. This assumption is based on personal communications with representatives of The Proctor and Gamble Company.

Quantity of Material

Fitzgerald and Vines (2) have reported on the effects of wind on the amount of material required to maintain a monomolecular film. Again, their work has been with cetyl

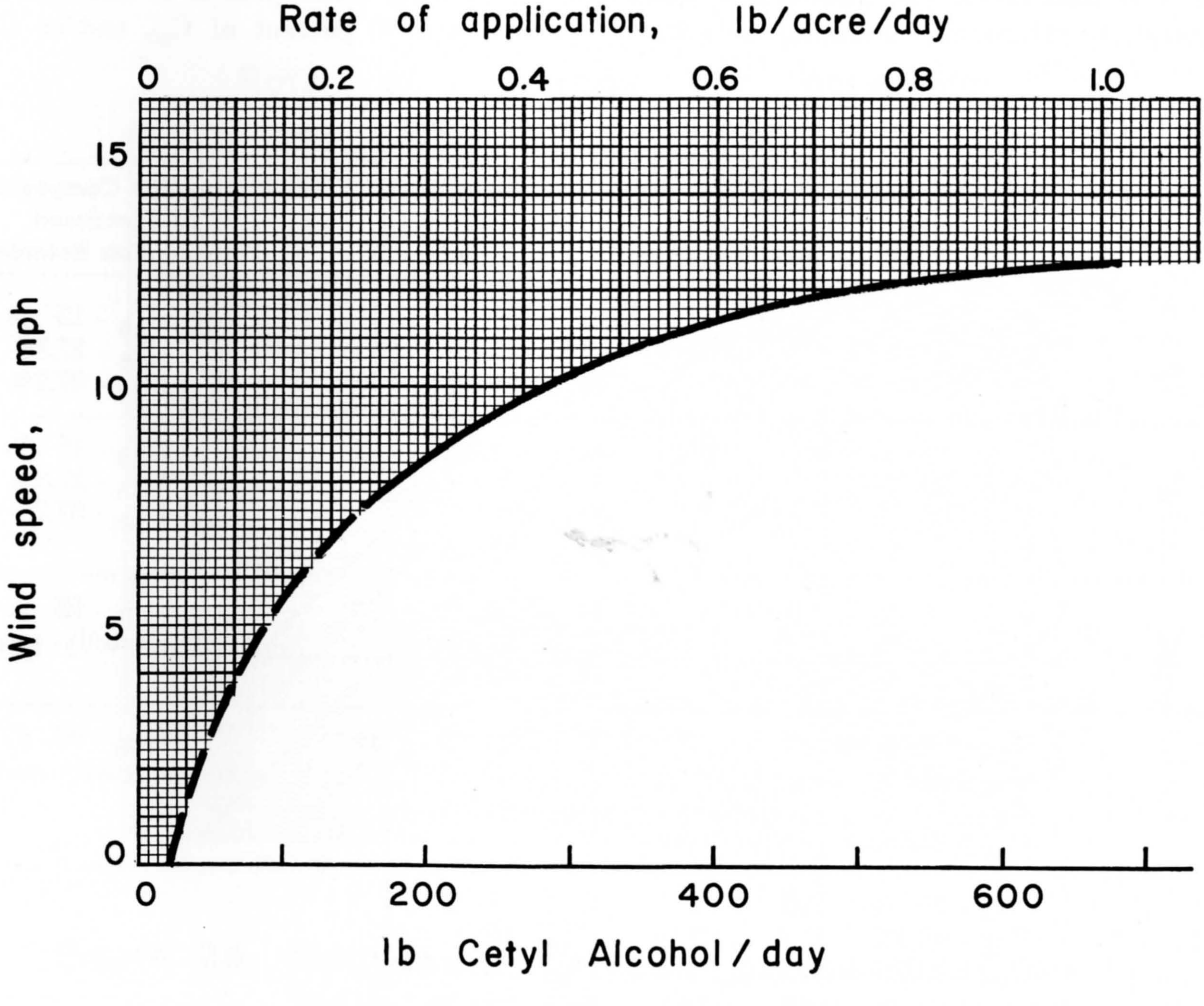


Figure 27. Effect of wind on quantity of material.

alcohol. Measurements were made which disclosed that 150 pounds of cetyl alcohol were required per day for an area of one square mile with winds of 7½ mph. For winds of 12½ mph, 650 lb/day for a one-square-mile area were required. Previously, Vines (6) had estimated that 15 pounds of material per day would be required in the absence of wind to maintain a film on a water surface area of one square mile. This information has been plotted in Figure 27 (2).

Possible Evaporation Savings

The difficulty in evaluating the cost per acre-foot of water saved on any reservoir is in determining the amount of water that is saved. Extensive instrumentation and calibration procedures are required in order to ascertain with any reasonable degree of accuracy the amount of water that is evaporating during the periods of time that a monomolecular film is present and the amount of water that would have evaporated if the film were not present.

Fitzgerald and Vines (2) have made some general statements regarding evaporation savings. These statements are the results of three years of study whereby cetyl alcohol was applied by means of a Robertson grinder located in a boat to a number of reservoirs in Australia. The water surface area of these reservoirs was 1,000 acres or less.

(A) Savings of 40 percent, or more, can be expected with winds up to approximately 5 mph.

(B) Savings of 10 to 20 percent can be expected with winds up to approximately 10 mph — though occasionally the savings may be somewhat less, depending upon prevailing conditions.

(C) With winds persistently in excess of 15 mph, the savings approach zero.

Water Surface Area

A number of methods have been developed for applying monolayer-forming materials to water surfaces. The methods developed include stationary drip-type dispensers, dispensers mounted on rafts, wind-controlled automatic dispensers, and boat-mounted liquid and powder dispensers. Although these methods have proved quite successful for use on small lakes and reservoirs, they are quite inefficient for covering large bodies of water.

Wind is the greatest detriment to maintaining a monomolecular film on a water surface. As an example, winds in excess of 10 mph are likely to completely remove the film cover from a water surface area of 2,000 acres in a few hours. As the water surface area increases, greater periods of time are required to completely remove the film cover for any particular wind speed. Consequently, the evaporation savings per unit area can be expected to increase with the size of reservoir.

An index of the degree of evaporation savings that can be expected is the amount of film coverage maintained on a particular body of water. The amount of film coverage is only a qualitive, rather than a quantitative, index of evaporation savings. Under similar meteorological and climatological conditions, evaporation savings from a water surface whereby a 50 percent film coverage is maintained can be expected to be twice the evaporation savings when only a 25 percent film coverage is maintained.

The relationships between water surface area, wind speed, and film coverage are depicted in Figure 28. Many simplifing assumptions had to be made in order to arrive at these relationships. For the method of analysis employed, the length of reservoir in the direction of the prevailing winds, rather than water surface area, is the pertinent parameter. The relationships have been developed assuming that an application is made once each day which results in 100 percent coverage. Immediately after complete coverage has been obtained, the average daily wind acts upon the film causing the film to retract from the water surface. The analysis has been made assuming that the film retracts at a speed of $\frac{1}{3}$ of the average daily wind speed. Fitzgerald and Vines (2), and also Meinke and Waldrip (7), have reported a ratio of film velocity to wind velocity of 1/30. Average daily wind speeds of 4 mph and 6 mph may very likely contain winds during some portion of the day in excess of 15 mph, which would completely disrupt the film and thereby make it ineffective in retarding evaporation during this time period. Computation of the average daily film coverage has not taken into consideration the effect of wind variations throughout the day. Also, the degree of film recovery which may occur on any body of water has not been taken into consideration. Film recoveries of nearly 100 percent of the uncovered area have been reported by Fitzgerald and Vines (2) for reservoirs in Australia during calm conditions following periods of moderate winds. Film recovery would conceivably materially increase the degree of film coverage.

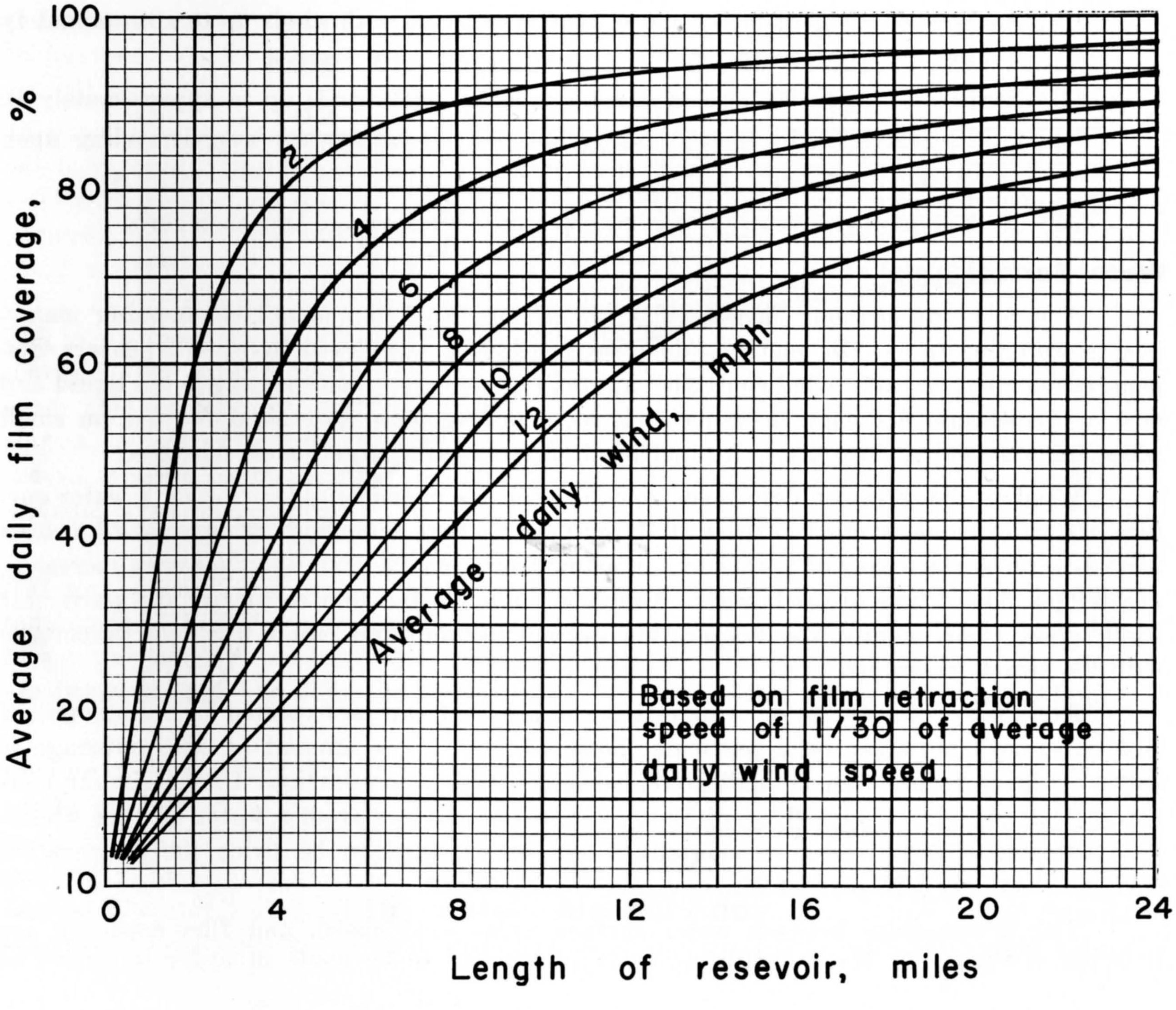


Figure 28. Relationship between reservoir length, wind, and film coverage.

ECONOMIC ANALYSIS

Economic Factors

Recommendations and guidelines regarding flight conditions during aerial application have been listed under "Optimization of Aerial Application Parameters." These guidelines show the interrelationship between aircraft groundspeed, dispensing rate, swath width, application rate, and coverage. (See Figure 26.) Also, recommendations regarding application rate and altitude of flight for various wind conditions have been listed. The effect of wind on quantity of material required and evaporation reduction has been described.

Type of aircraft. The aircraft presently being used is a Piper Super Cub, which has a flying speed of approximately 90 mph and a hopper capacity of 500 pounds of material. Flying at a speed of 90 mph, assuming a swath width of 500 feet, a coverage rate of 90 acres/minute will result. An application rate of 0.20 lb/acre used in conjunction with a hopper capacity of 500 pounds will allow the aircraft to cover 2,500 acres per load. Thus, the aircraft can dispense a load of powdered alcohol in approximately one-half hour. Allowing another half hour for ferrying flying time (assuming the airstrip is adjacent to the reservoir) and loading of the hopper, an hour would be required for each round trip. The flying time between each loading of the hopper, excluding the time in which the material is actually being dispensed, is the ferrying flying time per trip. If the aircraft could fly six trips a day, a coverage of 15,000 acres would be provided.

The use of aircraft larger than the Piper Super Cub will probably be economical for aerial application of evaporation retardants to very large water surfaces. A number of the existing agricultural aircraft could be adapted for this purpose. Agricultural aircraft have flying speeds of 90 to 160 mph and hopper capacities of 500 to 2,000 pounds. For example, an aircraft capable of flying at a speed of 160 mph and having a hopper capacity of 2,000 pounds could be used. Thus, the rate of coverage, for a swath width of 500 feet, would be 160 acres/min. The coverage for a 2,000-pound hopper capacity using an application rate of 0.20 lb/acre would be 10,000 acres/trip. The aircraft could dispense a load of material in approximately one hour. Such an aircraft, under ideal weather conditions would be able to make approximately 5 trips per day which would provide a coverage of 50,000 acres/day. Thus, this particular aircraft would be able to cover approximately 3 times the area covered by the Piper Super Cub in the same time period. Other agricultural aircraft would have capabilities intermediate between the two aircraft already described.

As this research program progresses, the economics of utilizing various aircraft should be investigated. The modifications required for such aircraft would be somewhat similar to the modifications required for the Piper Super Cub. The cost of modifying any of the suitable aircraft is very small when compared with the cost of long term sustained application tests.

Cost of flying time. Presently, the cost of flying the Piper Super Cub is $20 an hour when flying from the base station of the aircraft to the loading point in the vicinity of the body of water under study. The flying cost after loading has begun is $40 an hour. This cost rate would probably range between $30 and $40 for applications on large reservoirs. The use of aircraft larger than the Piper Super Cub will mean that the flying cost rate will be considerably higher, but such aircraft would be economically feasible on very large reservoirs

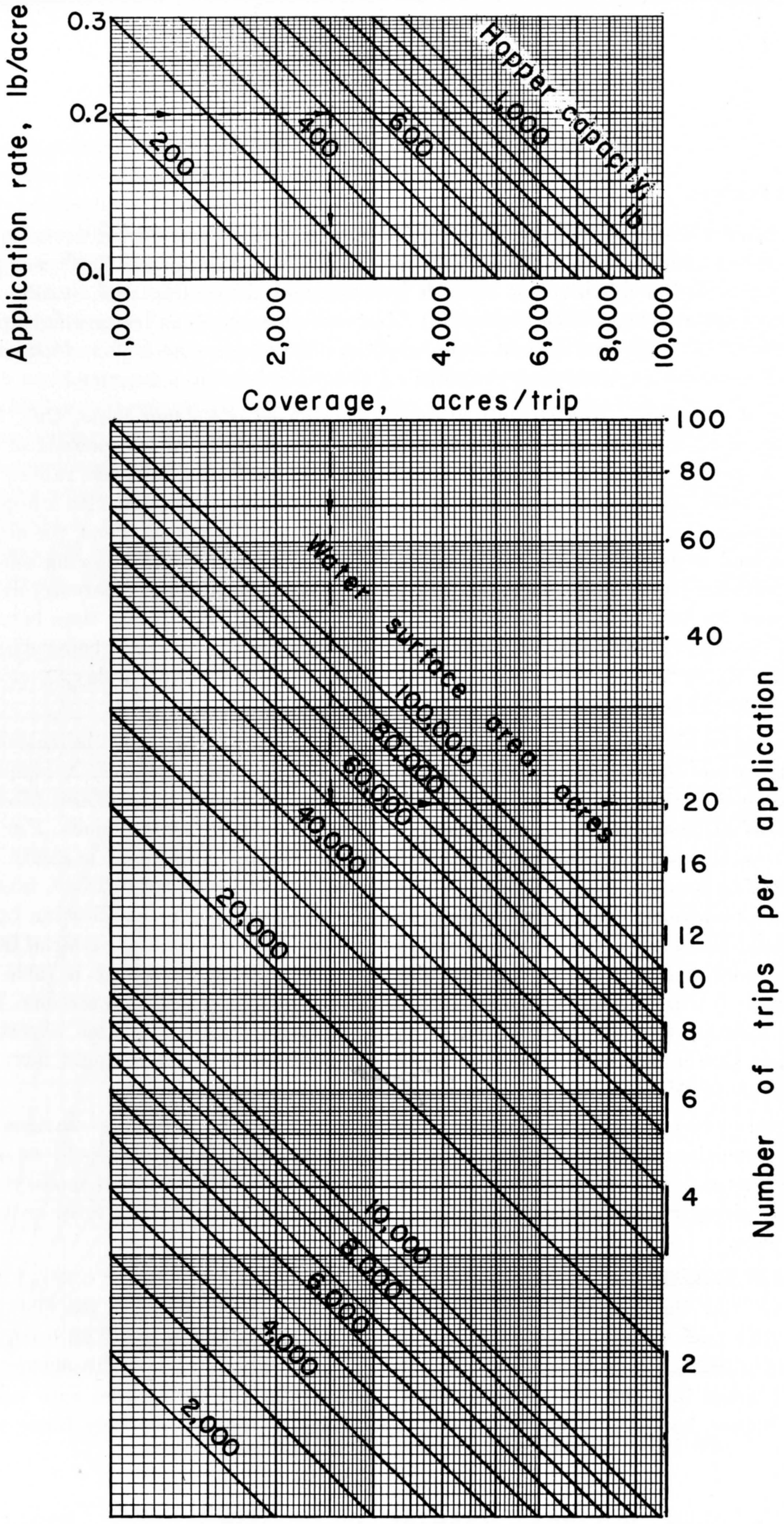


Figure 29 Number of trips per application

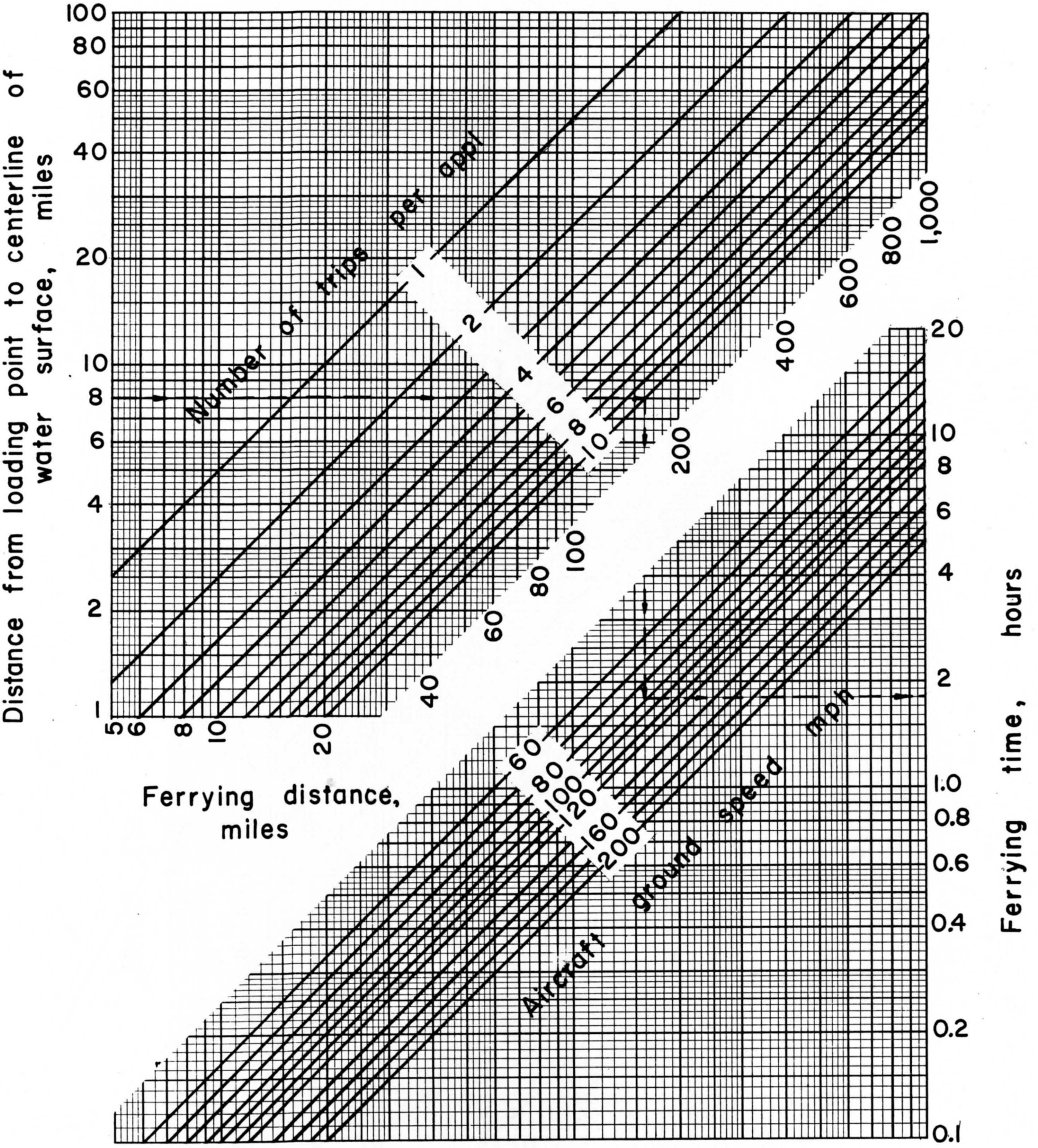


Figure 30. Ferrying time.

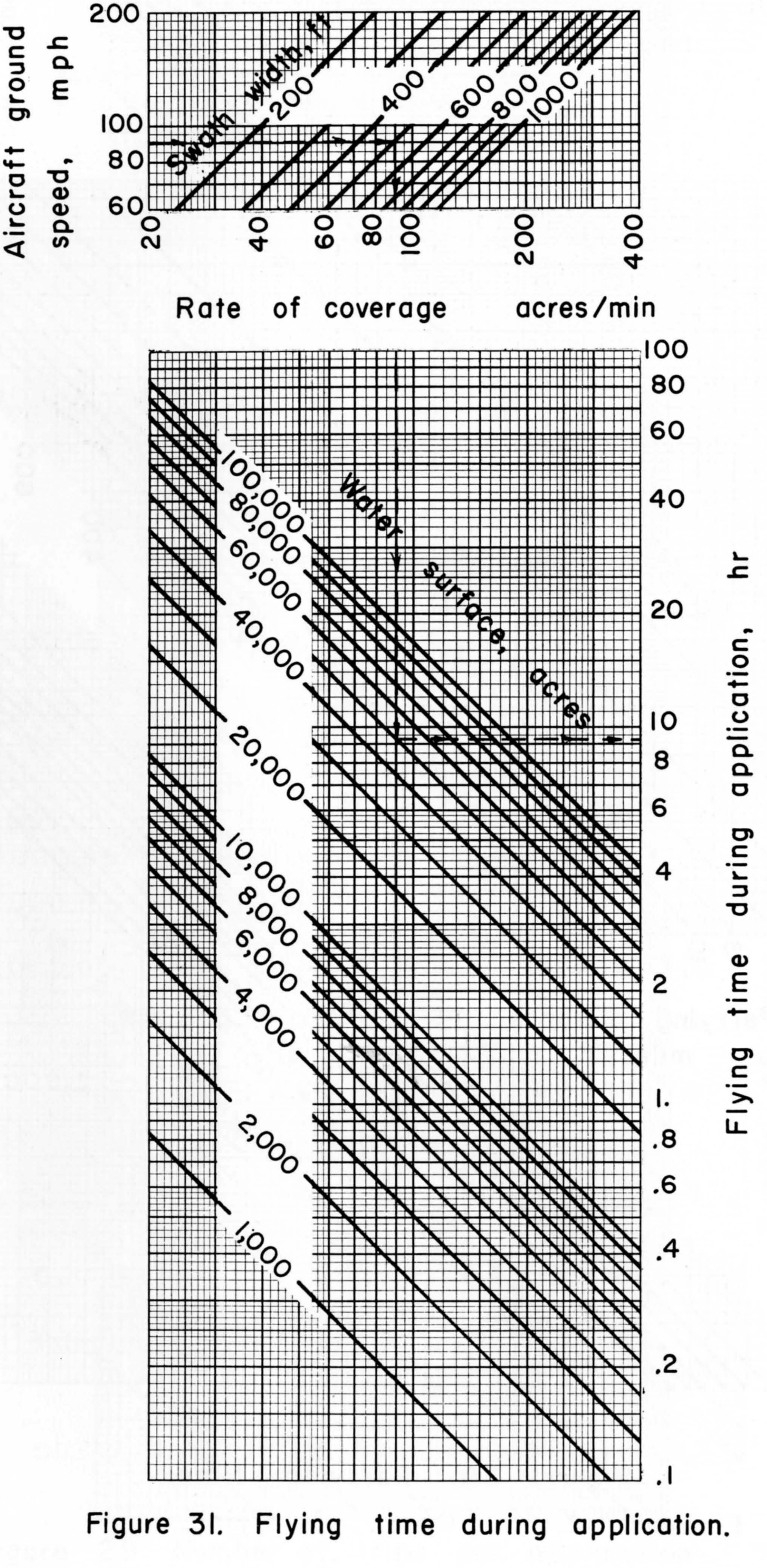


Figure 31. Flying time during application.

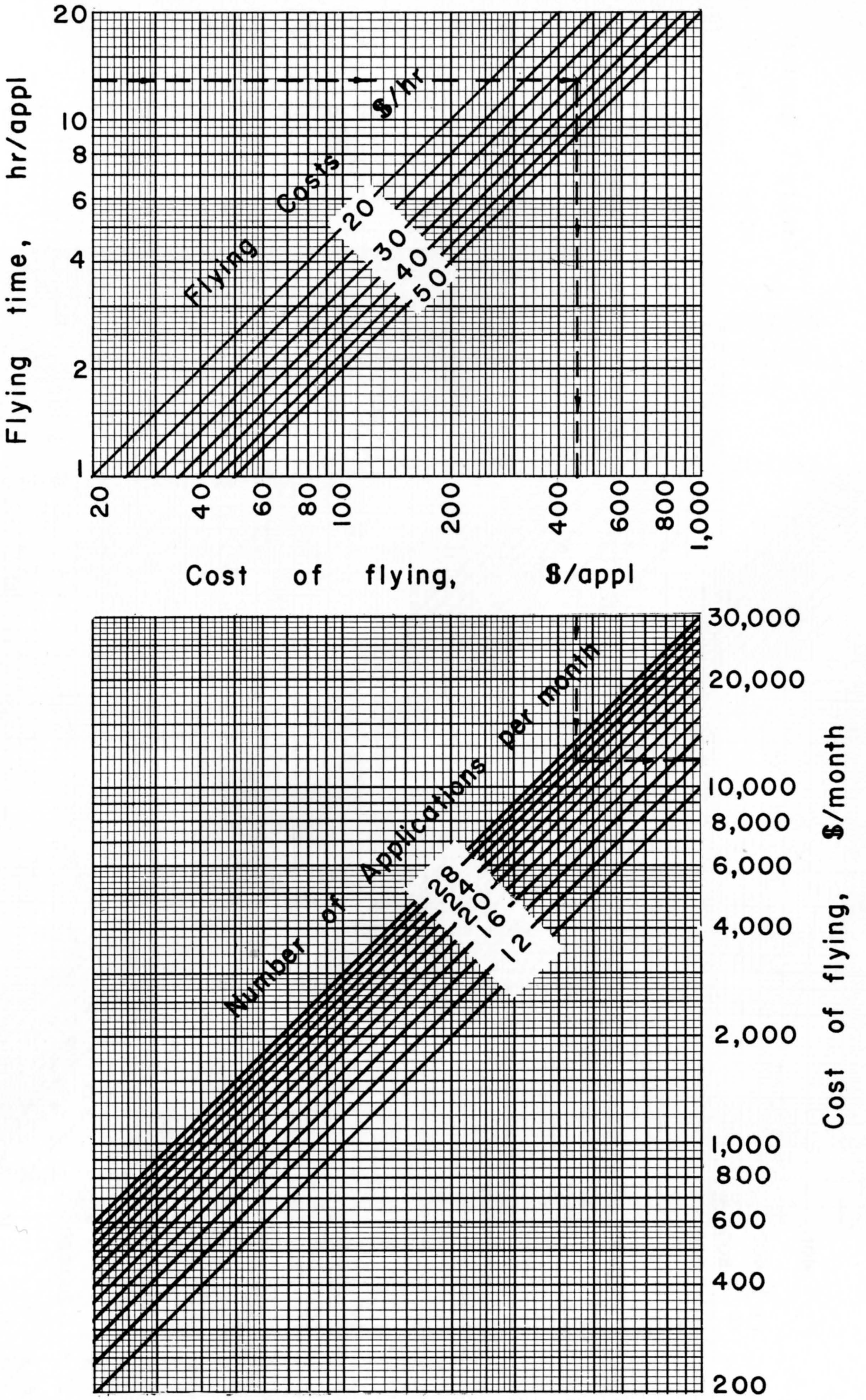


Figure 32. Cost of flying.

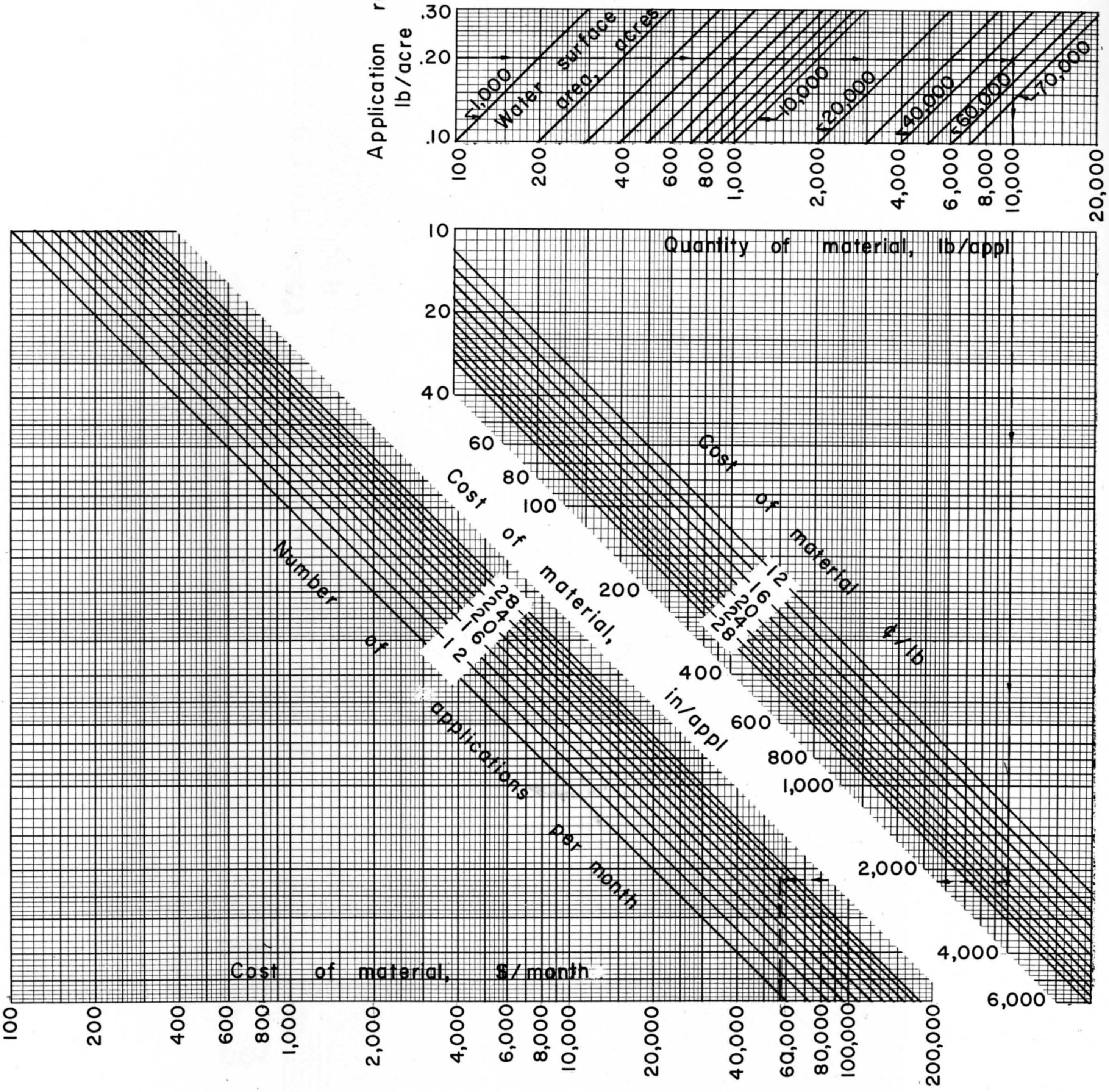


Figure 33. Cost of materal.

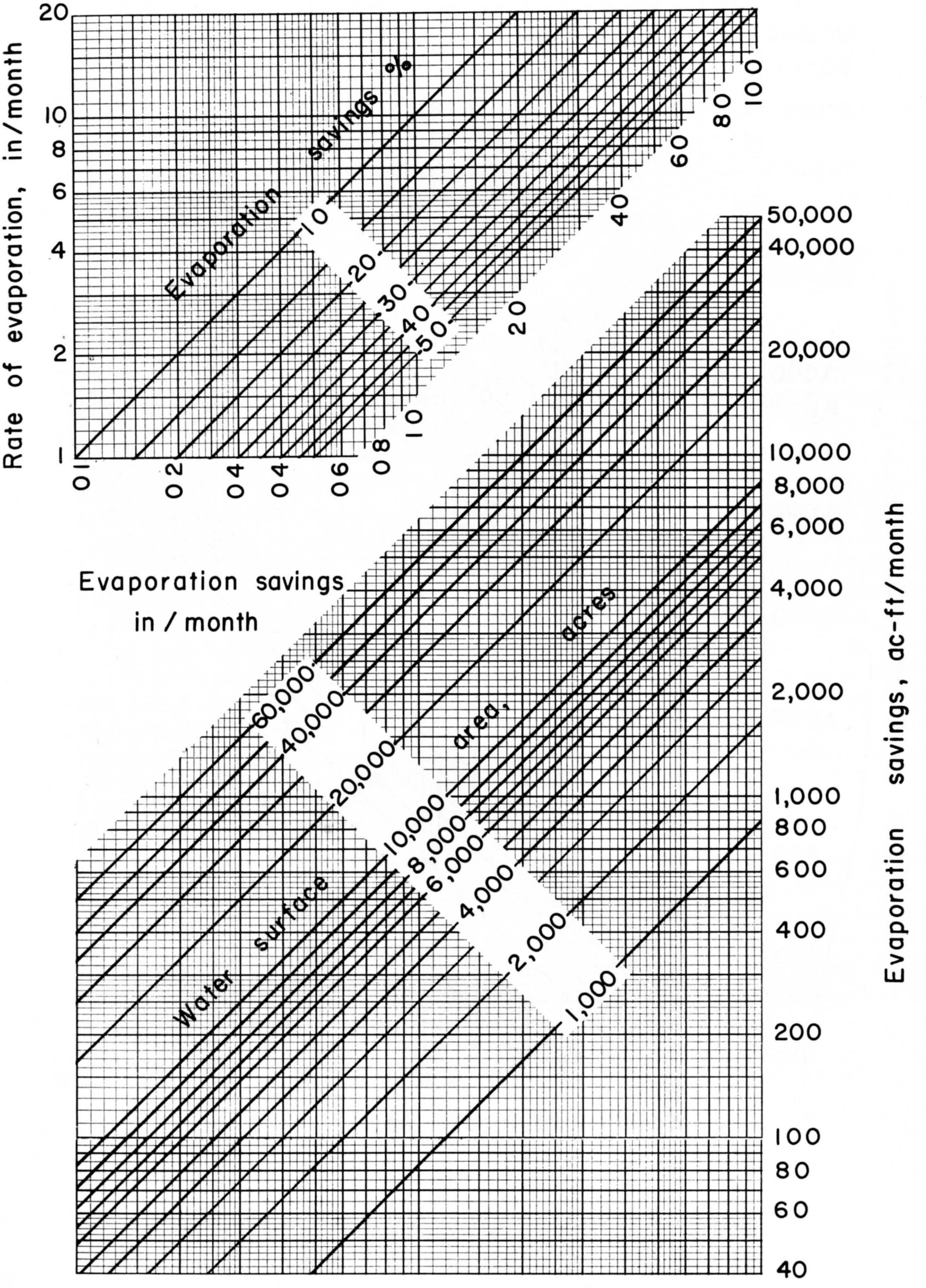


Figure 34. Evaporation savings.

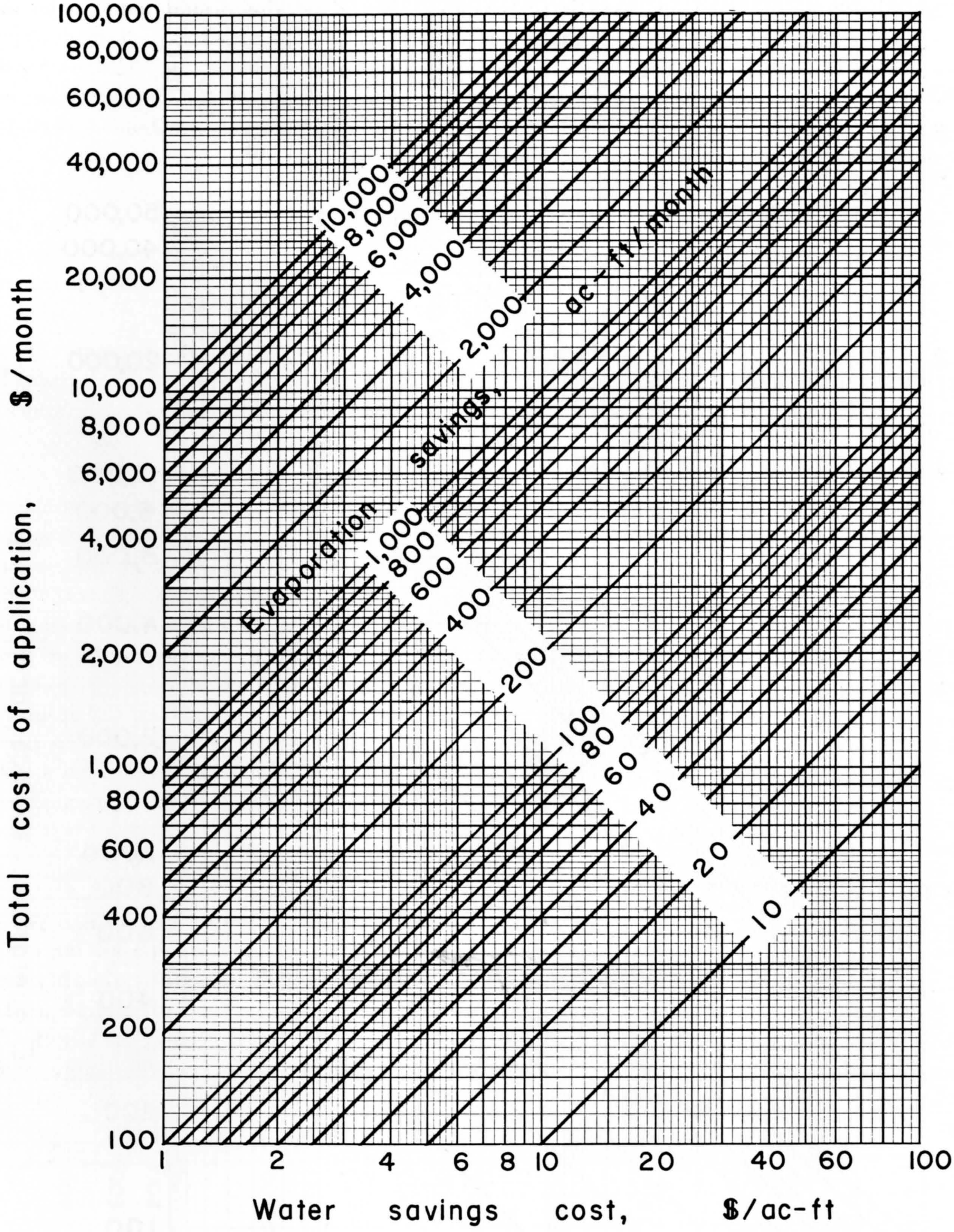


Figure 35. Cost of water saved.

because of the higher rates of coverage which would allow a single aircraft to cover a very large area in a single day. For the very large reservoirs, a decision would have to be made whether to use a number of small planes or a larger aircraft. Long-term, sustained application tests using an airplane, have not yet been made. Consequently, it is difficult to state with any degree of surety how much present flying costs might be reduced. Flying costs should be reduced considerable when applications are being made over extended periods of time because of the constant use of the aircraft.

Wind. The greatest single factor affecting the maintenance of a monomolecular film on a water surface is wind. The wind will either blow the film cover onto the shore or in winds of about 15 mph will completely disrupt the film. The wind affects greatly the quantity of material required to maintain a film on the water surface and also affects considerably the degree of evaporation reduction that takes place.

Evaporation savings. Evaporation reduction between 10 and 40 percent (2) have been obtained in field tests in the past. The research presently underway at Utah State University, involving the longer chain lengths, C_{20} and C_{22}, should provide larger evaporation savings than are presently being obtained by a combination of cetyl and stearyl alcohols (C_{16} and C_{18}).

Cost of material. The cost of the powdered alcohol will be affected by the chemical composition desired, the particle-size gradation employed, and the quantity of material used. The desired chemical composition and particle-size gradation will affect the manufacturing technique to be employed in preparing the material. Utilization of a number of chain lengths should allow for minimizing the cost of the material. Different manufacturing techniques are required for obtaining various particle-sige gradations. Consequently, a proper evaluation must be made between particle-size gradation and manufacturing techniques in order to develop the most economical material. As with most commodities, the greater the quantity of material being purchased the lower the unit cost of the material. The present outlook indicates that the cost of the material will be approximately 20 to 25 cents a pound. As evaporation reduction operations become widespread and are used on a commercial basis, the cost of the material might very well be reduced below these figures.

Hypothetical Example

A few hypothetical examples will illustrate the effect of water surface and percentage of evaporation reduction on the cost per acre-foot of water saved when applying evaporation-reducing, monolayer-forming materials by means of an airplane. Many simplifying assumptions are necessary in order to arrive at cost figures. The three water surface areas to be used as hypothetical examples are illustrated in Figure 36. In each case, the length of the area is twice its width. Prevailing wind direction was assumed to be over the length of each area.

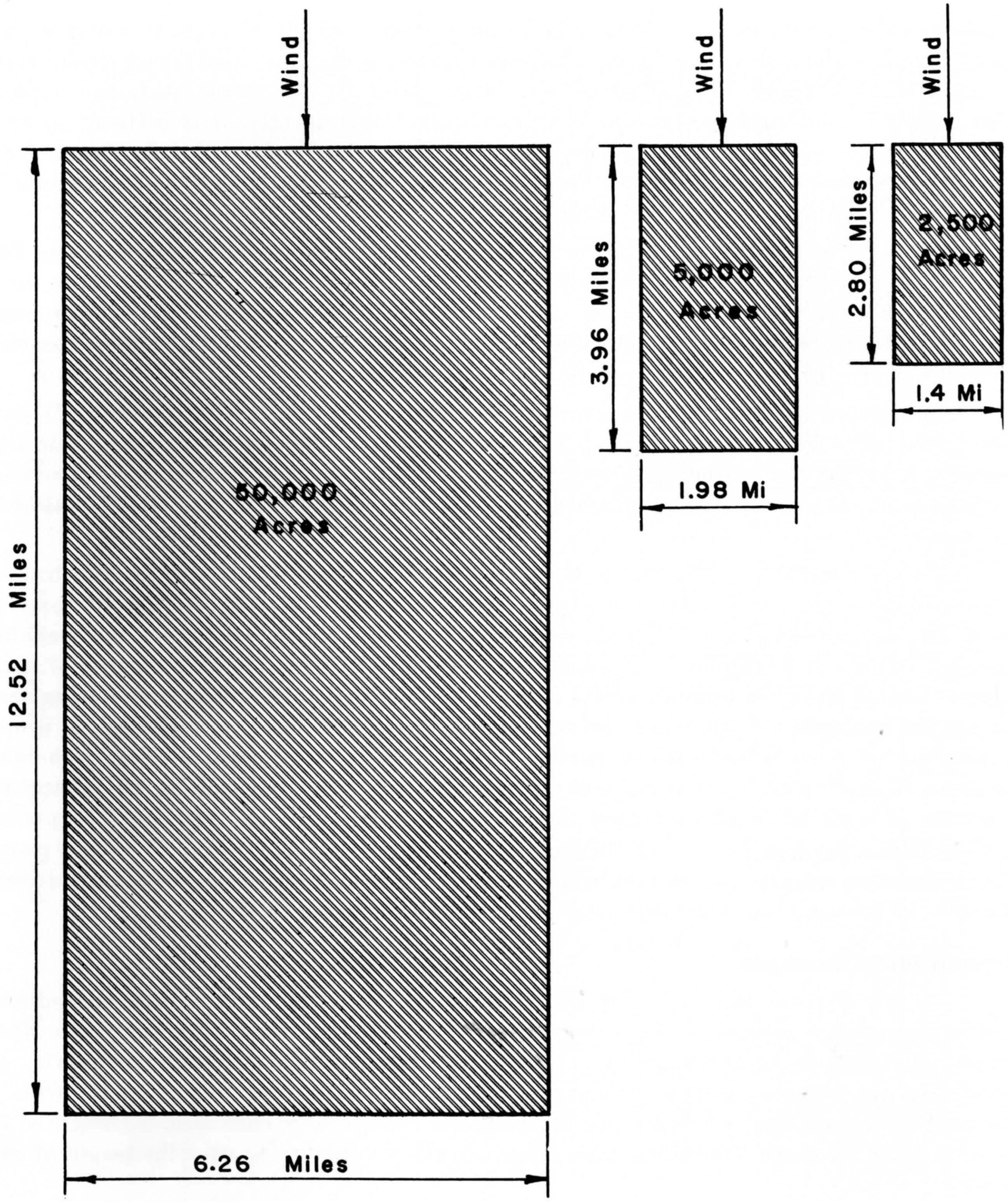


Figure 36. Resevoirs used in hypothetical example.

Part 1. A surface area, at the time of application, of 50,000 acres is assumed. Estimates of the monthly evaporation are as follows:

May	5.8 inches
June	7.0 inches
July	7.6 inches
August	6.7 inches
September	4.9 inches

The cost of applying the powdered alcohol is estimated to be $35 per hour during application and ferrying flying time. The speed of the aircraft is approximately 90 mph. The capacity of the hopper is estimated to be 500 pounds. A material cost of $0.22 per pound is assumed. The aircraft will be located at a small prepared airstrip in the vicinity of the reservoir. The distance from the airstrip to the center of the reservoir is 8 miles.

The application rate to be used is 0.20 lb/acre. Applications during 26 days of each month will be assumed. Application will begin May 1 and continue through September 30. Average daily winds of 6 mph will be assumed throughout the application period. The reservoir will be assumed to require complete daily coverage throughout the first month. Thereafter, the average daily winds of 6 mph will be assumed to retract the film at a speed of 6/30 mph. Thus, in 24 hours, a length of 4.8 miles, which is an area of 19,250 acres (4.8 miles x 6.26 miles x 640 acres per square mile), will be uncovered. Consequently, it will be assumed that a daily coverage of 20,000 acres will be required beginning June 1.

Figures 29 to 35 have been prepared to facilitate the rapid calculation of application costs and evaporation savings. To illustrate the use of these graphs, the computations for the month of May are described below. In addition, the computations for the month of May have been shown on the graphs by means of arrows which depict the sequence of the graphical analysis.

Enter Figure 29, (a) with an application rate of 0.20 lb/acre, (b) proceed to a hopper capacity 500 pounds, (c) read the coverage as 2,500 acres per trip, (d) proceed to a water surface area of 50,000 acres, and (e) read the number of trips per application as 20 (which will require 2 or 3 aircraft, say 2 aircraft).

Enter Figure 30, (a) with the distance from loading point to centerline of water surface of 8 miles, (b) proceed to 10 trips per application per aircraft, (c) read the ferrying flying distance as 160 miles per application per aircraft, (d) proceed to aircraft ground speed of 90 mph, and (e) read the ferrying flying time as 1.8 hours per application per aircraft, and a total flying time of 3.6 hours per application.

Enter Figure 31, (a) with an aircraft ground speed of 90 mph, (b) proceed to a swath width of 500 feet, (c) read the rate of coverage as 90 acres per minute, (d) proceed to a water surface area of 50,000 acres, and (e) read the application flying time as 9.3 hours per application.

Enter Figure 32, (a) with a total flying time per application of 12.9 hours (3.6 + 9.3), (b) proceed to a flying cost of $35 per hour, (c) read the flying cost for each application at $450, (d) proceed to 26 applications per month, and (e) read the flying cost per month as $11,700.

Enter Figure 33, (a) with an application rate of 0.20 pounds per acre, (b) proceed to a water surface area of 50,000 acres, (c) read the quantity of material as 10,000 pounds per application, (d) proceed to a material cost of 22 cents per pound, (e) read the material cost per application as $2,200, (f) proceed to 26 applications per month, and (g) read the material cost as $57,000.

The above figures apply to the month of May. During the months of June, July, August, and September only 20,000 acres will require material during each application. If the procedure described for the month of May is followed, (a) the number of trips per application is 8, (b) the ferrying flying time is 1.4 hours per application, (c) the application flying time is 3.7 hours per application, (d) the monthly flying cost is $4,600, and (e) the monthly material cost is $22,900.

The costs of saving the water for various assumed percentages of evaporation reduction have been evaluated in Table 2.

Table 2. Example of water savings costs for 50,000 acre reservoir.

Month	Application Costs, dollars	10% savings		20% savings		30% savings		40% savings	
		Savings, ac - ft	Cost $/a.f.	Savings, ac - ft	Cost $/a.f.	Savings, ac - ft	Cost $/a.f.	Savings, ac - ft	Cost $/a.f.
May	68,700	2,460	28.00	4,920	14.00	7,380	9.40	9,840	7.00
June	27,500	2,920	9.40	5,840	4.70	8,760	3.10	11,680	2.40
July	27,500	3,160	8.70	6,320	4.40	9,480	2.90	12,640	2.20
Aug.	27,500	2,800	9.80	5,600	4.90	8,400	3.30	11,200	2.50
Sept.	27,500	2,040	13.50	4,080	6.80	6,120	4.50	8,160	3.40
Totals	178,700	13,380	13.40	26,760	6.70	40,140	4.40	53,520	3.40

Assumptions:

1. Speed of aircraft is 90 mph, hopper capacity is 500 pounds, flying cost is $35 per hour, and distance from airstrip to center of reservoir is 8 miles.
2. Application rate is 0.20 lb/acre and 26 applications are made each month.
3. Entire 50,000 acres covered during each application in the first month.
4. Average daily winds of 6 mph result in an average film retraction speed of 0.2 mph, which requires that 20,000 acres be covered during each application beginning June 1.
5. The cost of the evaporation-reducing material is $0.22 per pound.
6. The effects of wind variations throughout the day, and also film recovery have not been taken into account.

Part 2. The conditions are the same as those for the previous reservoir except that the reservoir surface area is 5,000 acres; the distance from loading point to center of water surface is 5 miles; flying cost is $40 an hour; and the cost of material is $0.24 per pound.

The average daily winds of 6 mph will result in an average film retraction speed of 0.2 mph which will denude the reservoir for a length of 4.8 miles in 24 hours. Since the length of this reservoir is less thana 4.8 miles (See Figure 36), the entire reservoir will have to be covered during each application.

The graphical solution for each month shows (a) the number of trips per application is 2, (b) the ferrying flying time is 0.3 hour per application, (c) the application flying time is 0.9 hour per application, (d) the monthly flying cost is $1,300, and (e) the monthly material cost is $2,600.

The cost of saving the water for various assumed percentages of evaporation reduction has been evaluated in Table 3.

Table 3. Example of water savings costs for 5,000 acre reservoir.

Month	Application	10% savings		20% savings		30% savings		40% savings	
	Costs, dollars	Savings, ac - ft	Cost $/a.f.	Savings, ac - ft	Cost $/a.f.	Savings, ac - ft	Cost $/a.f.	Savings, ac - ft	Cost $/a.f.
May	7,500	250	30.00	490	15.30	740	10.10	980	7.70
June	7,500	290	25.90	580	13.00	880	8.50	1,170	6.40
July	7,500	320	23.40	640	11.70	950	7.90	1,270	5.90
Aug.	7,500	280	26.80	560	13.40	840	8.90	1,120	6.70
Sept.	7,500	200	37.50	410	18.30	610	12.30	820	9.20
Totals	37,500	1,340	28.00	2,680	14.00	4,020	9.30	5,360	7.00

Assumptions:

1. Speed of aircraft is 90 mph, hopper capacity is 500 pounds, flying cost is $40 per hour, and distance from airstrip to center of reservoir is 5 miles.
2. Application rate is 0.20 lb/acre and 26 applications are made each month.
3. Entire 5,000 acres is covered during each application.
4. The cost of the evaporation-reducing material is $0.24 per pound.
5. The effects of wind variations throughout the day, and also film recovery, have not been taken into account.

Part 3. The conditions are the same as those for the previous reservoirs except that the water surface area is 2,500 acres; the distance from the loading point to center of water surface is 4 miles; flying cost is $40 per hour; and the cost of material is $0.25 per pound as was the case for the 5,000 acre reservoir, the entire reservoir will have to be covered during each application.

The graphical solution for each month shows (a) the number of trips per application is 1, (b) the ferrying flying time is 0.1 hour per application, (c) the application flying time is 0.5 hour per application, (d) the monthly flying cost is $650, and (e) the monthly material cost is $3250.

The cost of saving the water for various assumed percentages of evaporation reduction has been evaluated in Table 4.

Table 4. Example of water savings costs for 2,500 acre reservoir.

Month	Application	10% savings		20% savings		30% savings		40% savings	
	Costs, dollars	Savings, ac - ft	Cost $/a.f.	Savings, ac - ft	Cost $/a.f.	Savings, ac - ft	Cost $/a.f.	Savings, ac - ft	Cost $/a.f.
May	3,900	120	32.50	250	15.60	370	10.60	490	8.00
June	3,900	150	26.00	290	13.50	440	8.90	580	6.70
July	3,900	160	24.40	320	12.20	480	8.10	640	6.10
Aug.	3,900	140	27.90	280	14.00	420	9.30	560	7.00
Sept.	3,900	100	39.00	200	19.50	300	13.00	410	9.50
Totals	19,500	670	2910	1,340	14.60	2,010	9.70	2,680	7.30

Assumptions:

1. Speed of aircraft is 90 mph, hopper capacity is 500 pounds, flying cost is $40 per hour, and distance from airstrip to center of reservoir is 4 miles.
2. Application rate is 0.20 lb/acre and 26 applications are made each month.
3. Entire 2,500 acres is covered during each application.
4. The cost of the evaporation-reducing material is $0.25 per pound.
5. The effects of wind variations throughout the day, and also film recovery, have not been taken into account.

Comparisons. The relative costs of water savings between the three reservoirs can be determined only by assuming similar meteorological and climatological conditions at the three sites and using the average percent of film coverage as an index of evaporation savings. Normally, it cannot be assumed that large water surfaces will have the same meteorological and climatological conditions as much smaller water surfaces. The percentages of film coverage for the three reservoirs can be obtained from Figure 28. An average daily wind speed of 6 mph has been used in these examples, and such an average wind speed usually contains periods during the day when the wind speed is in excess of 15 mph. Thus, during the periods of high wind, the film would be completely disrupted.

Water Surface Area	Average Film Coverage
2,500 acres	29%
5,000 acres	41%
50,000 acres	81%

The average film coverages are undoubtedly high because of the assumptions inherent in arriving at these quantitive values. Of importance, though, are the variations in average film coverage for the different water surface areas. The variations are indicative of the variations in evaporation savings that might be expected.

DEVELOPMENT OF RADIO ALTIMETER

Safety of Flight

Throughout this research program small aircraft have been used for dispensing the monolayer-forming materials. The dusting plane flies at altitudes between 50 and 200 feet above the water surface, depending upon wind conditions. Presently, a Piper Super Cub is being used. These small aircraft employ a pressure altimeter for indicating altitude of flight. Because the atmospheric pressure can change quite rapidly, and because pressure altimeters are sluggish in responding, this type of altimeter can indicate altitudes that are considerably in error. For this reason, the pilots flying the dusting planes during field tests have not relied on the altimeter. It is difficult, however, to judge altitude of flight by looking at a water surface. Consequently the pilot must rely either on boats on the water surface or on land forms surrounding the periphery of the lake or reservoir to keep the aircraft out of the water.

The conditions described above indicated clearly the necessity for developing a more accurate means of determing the altitude of the aircraft above the water surface. The importance of this development becomes even more evident when it is realized that the pilots used throughout this evaporation reduction research program have had considerable experience, and yet, on occasions, have had the aircraft came dangerously close to the water surface. The danger of aircraft flying into the water will be even greater when the technique of aerial application becomes more widely used and less experienced pilots are employed.

Figure 37. Pilot with life jacket and crash helmet.

Figure 38. Pilot and aircraft ready for flight.

Available Radio Altimeters

Considerable time and effort have been expended in locating an altimeter that could be used for low-flying aircraft. For this research effort, in particular, an altimeter which will warn the pilot when the aircraft is below, say 50 feet, is needed. The lower limit of 50 feet has been set for safety reasons.

In an endeavor to locate an accurate altimeter which could be used directly, or after modification, many research agencies, aircraft companies, and universities were contacted. The effort uncovered only one type of unit which could be economically used on small aircraft, a frequency-modulated radio altimeter (AN/APN-1), developed during World War II. A unit was located on the surplus market and purchased. Radio altimeters involving modern techniques which could possibly be adapted to aerial application are available commercially. The commercial models range in price from $5650 to $23,000. In addition to being expensive, the units lack resolution, and, in some cases, the accuracy required by pilots while flying at low altitudes over water. Modification of one of these units may be possible, but more work must be directed in this area to determine feasibility. The minimum cost of any of the commercial radio altimeters is $5650 plus the cost of necessary modifications. Thus, the cost of the radio altimeter would approach the cost of the aircraft itself.

Surplus Radio Altimeter

The frequency-modulated radio altimeter (See Figures 39 and 40) measures the altitude of the airplane by determining the time required for a radio wave to travel from the aircraft to earth and return. A method of time measurement, which depends on the observed difference in frequency between the transmitted and received energy, is employed. The frequency of the radio transmitter is varied rapidly at a constant rate, and the transmitter

Figure 39. Transmitter-Receiver on AN/APN-1 radio altimeter.

Figure 40. AN APN-1 radio altimeter, with auxiliary equipment.

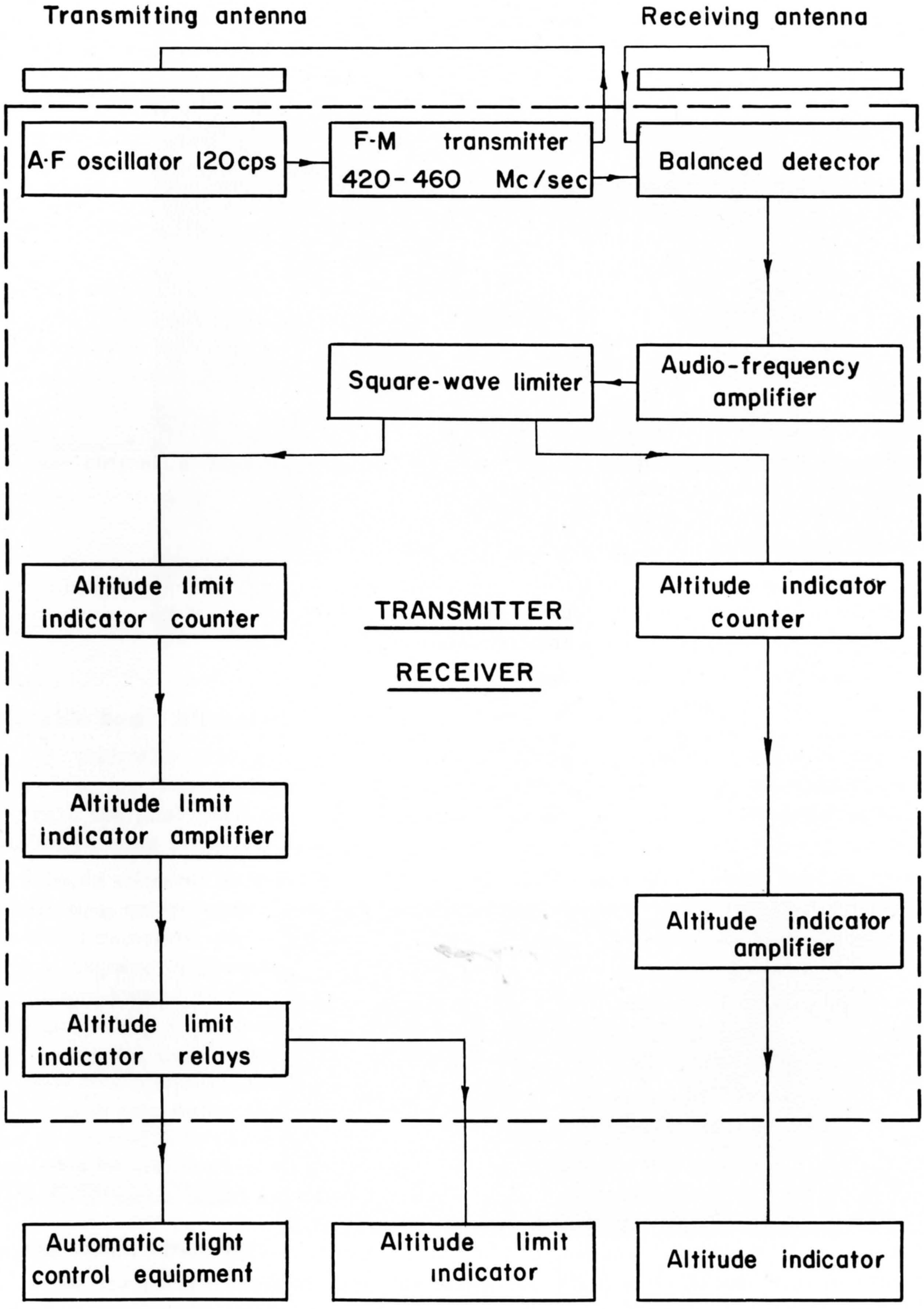


Figure 41. Block diagram of AN/APN-1.

changes frequency in the time period required for the radio wave emitted by it to travel to earth and return. The higher the airplane, the longer the time required for a round trip and the greater the difference between the transmitter frequency and that of the reflected wave when it arrives at the airplane. Thus, the frequency difference is directly proportional to the altitude of the airplane. The rate at which the transmitter frequency varies is known, and, therefore, the elapsed time corresponding to any observed frequency difference is established. Since this is a direct measure of the altitude, a circuit which provides a current proportional to the frequency difference is employed to operate a meter, which is calibrated in terms of absolute altitude. (See Figure 40.)

For low-altitude operation (0 to 400 feet), the frequency of the radio transmitter is varied sinusoidally between 420 and 460 Mc/s at a rate of 120 times per second. For simplicity of design, sinusoidal rather than linear variation of frequency has been employed. Sinusoidal variation does not affect the basic principle of the operation because the average frequency difference over a cycle of sinusoidal modulation is equivalent to that obtained from a linear variation of frequency with the same modulating period. Because the indicator circuits average the frequency difference over many modulation cycles, the transmitter may be considered to be frequency-modulated at a constant rate of 42 Mc/s in 1/240 of a second (one-half cycle of the modulating frequency) (3).

The output of the transmitter (about 0.1- watt) is radiated from a half-wave dipole transmitting antenna located on the underside of the airplane. A part of the reflected energy returns to a separate receiving antenna, which is also located underneath the airplane but at some distance from the transmitting antenna (3).

The weight of the transmitter-receiver unit of the surplus radio altimeter is 18.4 pounds. The weight of the auxiliary equipment, which includes the cabling, antennas, mounts, and indicator dials is 21.6 pounds. Thus, the total weight of the radio altimeter is 40 pounds. In many cases, where the aircraft must fly at high altitudes, the weight of the altimeter will reduce the weight of material that can be placed in the hopper. For example, during the tests at Scofield Reservoir, the quantity of material placed in the hopper for each trip was approximately 350 pounds. A limit of 350 pounds was necessary because of the high elevation (7,700 feet) and the runway conditions. If the surplus radio altimeter had been installed in the aircraft prior to this time, the quantity of material carried during each trip would have had to be reduced to approximately 310 pounds.

The radio altimeter received from surplus has been tested on the ground, and its performance appears to be satisfactory. A difficulty that will soon be encountered with this altimeter is that it operates in the frequency band 420 to 460 Mc/s. The Federal Communications Commission Rules and Regulations, Section 2. 106, footnote US6, states that:

> Radio altimeter will not be permitted to use the band
> 420-460 Mc/s, after February 15, 1968.

The above regulation rules out the possibility of using the radio altimeter on a commercial basis. Inquiries have pointed out the difficulty of obtaining parts for additional surplus altimeters. Also, the surplus unit has the disadvantages of being bulky and heavy, and of requiring considerable heavy cabling and frequent calibrations. The F.C.C. regulation and the other disadvantages inherent in this unit point out the need for a radio altimeter based on methods of modern circuitry.

RECOMENDATIONS FOR FUTURE STUDY

Large-Scale Application Tests

The need for large-scale, long-term, sustained application tests for gaining the additional knowledge required regarding aerial application is readily apparent. Primarily, knowledge concerning the recovery of monomolecular film after being retracted by the wind is important. The importance of film recovery can be seen from the work of Fitzgerald and Vines (2) in Australia, where remarkable film recoveries were observed during calm conditions. The low application rates of 0.075 lb/acre used in Australia after an initial heavy dosing of material is evidence of the importance of film recovery during sustained application periods.

Fitzgerald and Vines (2), using evaporation retardants consisting of cetyl and stearyl alcohols, have obtained evaporation savings of 15 to 20 percent over extended periods of time. Long-term application tests in the United States should produce similar results, if not better. Particularly, evaporation savings should be improved if longer-chain alcohols (C_{20} and/or C_{22}) are incorporated with the cetyl and stearyl alcohols (C_{16} and C_{18}). Also, the employment of an airplane rather than a boat allows more rapid replenishment of uncovered areas and thus increases the average percentage coverage of a water surface with a resultant increase in evaporation savings. Large-scale application tests would provide information necessary to more accurately assess the economics of aerial application.

Evaporation Retardants

A research program should be initiated which would give immediate attention to the development of an efficient and economical evaporation retardant suitable for aerial application techniques. Research, to date, at Utah State University has shown, contrary to some previous reports, that the longer chain alcohols (C_{20} and/or C_{22}) can be incorporated into the evaporation-reducing, monolayer-forming materials in significant amounts. A recommendation has been made to incorporate between 20 and 40 percent of C_{20} and/or C_{22} into the evaporation retardant to be employed in aerial application. The use of the longer chain lengths will increase the effectiveness of the material in retarding evaporation. The increase in effectiveness for various chemical compositions should be determined in conjunction with the behavior of the material under field conditions and taking into account the cost of such materials.

Radio Altimeter

Some effort has been expended on developing a radio altimeter. Additional efforts are necessary to complete the needed development. The importance of this research effort cannot be too strongly stressed. The problems encountered during past aerial application tests will become critical when less experienced pilots are used or when flights are made over larger water surfaces than has been the case in the past. Flights over very large bodies of water would prevent the pilot from judging his altitude by looking at land forms surrounding the periphery of lakes and reservoirs. The pilot could judge altitude if a large number of boats were on the water surface, but such an event cannot be relied upon. A pilot does not rely upon a pressure altimeter when flying at an altitude of 50 feet above the water surface. Consequently, if aerial application techniques are to be applied to very large water surfaces in the future, improved methods of determining altitude of flight must be developed and incorporporated into the aircraft.

Evaporation Savings

The application of evaporation-reducing, monolayer-forming materials to water surfaces on a commercial basis will require improved methods of determining evaporation savings. Primarily, any individual or group considering retarding evaporation on a water suface by means of monolayer-forming materials will want to know how much water is being saved or can be saved. A determination of the costs of application will then indicate the cost of saving such an amount of water and will make possible a decision regarding the feasibility of applying evaporation retardants on a particular water surface, or the more usual case, make possible a decision as to which months of the year are feasible for applying evaporation retardants.

Utah State University, because of the need for improved methods of determining evaporation savings, has developed a laboratory model of a long-path hygrometer with state funds. The development of the long path moisture flux meter should be continued and field instruments developed.

REFERENCES

1. Decker, J. P., W. G. Gaylor, and F. D. Cole. Measuring transpiration of undisturbed tamarisk shrubs. Plant Physiology 37:393-397. 1962.
2. Fitzgerald, L. M. and R. G. Vines. Retardation of evaporation by monolayers: practical aspects of the treatment of large water storages. Australian Journal of Applied Science, 14(4): 340-346. December 1963.
3. Hall, John S., editor. *Radar Aids to Navigation.* First Edition, McGraw-Hill. December 1963.
4. Hodges, C. N., D. N. Yarger, and W. D. Sellers. A new approach to the measurement of evaporation rates and the sensible heat flux from bare soil or short grass. 193rd National Meeting, American Meteorological Society, Davis, California. 1961.
5. Israelsen, C. Earl and Vaughn E. Hansen. Aerial application of evaporation-reducing chemicals: development and evaluation of equipment and techniques. Report PR-EC47-3, Engineering Experiment Station, Utah State University, Logan, Utah. July, 1963.
6. LaMer, Victor K., editor. *Retardation of Evaporation by Monolayers: Transport Processes.* Academic Press, 1962.
7. Meinke, Wilmon W. and William J. Waldrip. Research on evaporation retardation in small reservoirs. 1958-1963. Texas Water Commission, Bulletin 6401, March, 1964.
8. Stringham, Glen E. Hexadecanol monolayer films on storage reservoirs applied to aerial spraying equipment. Report PR-EC47-1, Engineering Experiment Station, Utah State University, Logan, Utah. August, 1961.
9. Stringham, Glen E. and Vaughn E. Hansen. Aerial spraying equipment feasibility study applying hexadecanol monolayer films on storage reservoirs. Report PR-EC47-2, Engineering Experiment Station, Utah State University, Logan, Utah. September, 1961.
10. U. S. Bureau of Reclamation. Aerial application technique development and monoloyer behavior study Elephant Butte Reservoir - 1962. Water Conservation Laboratory Report No. WC-1, Denver, Colorado. March 27, 1963.