A MICROCOMPUTER CONTROLLED LIQUID CONCENTRATE SYSTEM FOR AGRICULTURAL AIRCRAFT

By

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A MICROCOMPUTER CONTROLLED LIQUID CONCENTRATE SYSTEM FOR AGRICULTURAL AIRCRAFT

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PREFACE

The author wishes to express appreciation and gratitude to Dr. Lawrence O. Roth and Dr. Richard W. Whitney for their guidance and encouragement throughout this work. Appreciation is also expressed to committee member, Dr. Marvin Stone and the entire faculty and staff of the Agricultural Engineering Department.

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TABLE OF CONTENTS

TABLE

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Agricultural aviation in the United States has become a billion dollar industry treating over 180 million acres annually. The current world fleet consists of over 24,000 aircraft predominantly in the USA and the USSR (Kuhlman and Mock, 1981). Over 900 new planes are being built each year in the U.S. alone. Most of these new planes are being equipped with basically the same spray system which consists of a hopper, spray valve, pump, and distribution system.

The application of insecticides comprise the major portion of aerial application of all materials in the United States. Since insecticides contain chemicals that are toxic to humans, safety is an important aspect in handling and applying these chemicals. In recent years there has been a shift from the use of persistent pesticides to the short-term, non-persistent, but highly toxic insecticides such as organic phosphates. This trend has given rise to a increase in operational pesticide intoxication in the last 10 years (Roan, 1982). In the ten year period from 1970 to 1980, twenty-two percent of all operators experienced intoxication sufficient to require medical attention and/or a loss of work time. In a study at the University of Arkansas, it was shown that exposure to toxic pesticides is most likely to occur during handling and mixing concentrates (Lavy, 1982). The second highest exposure level occurred with those involved with unplugging nozzles, with flagmen and pilots receiving the lowest degree of exposure. Worker illnesses resulting from exposure and public concerns about the environment have led to new legislation and regulations for the pesticide application industry.

The California Department of Food and Agriculture in 1974 developed a set of pesticide worker safety regulations calling for the development of a closed system for handling pesticides in toxicity category I and certain category II materials (Yates, 1974). The California law, however, was pre-mature for the state of the art (Dewey, 1980). Dewey reported that the systems he observed appeared generally to be too complex, lacked durability, took too much time to carry out the operation and were expensive. Several states are considering laws directed toward safer handling of pesticides and their containers.

Sprayer calibration is essential to correct application of pesticides from agricultural aircraft. Calibration is most commonly accomplished using nozzle size and operating pressure tables. However, when nozzles become worn a potentially hazardous over application will occur if boom pressure is maintained at the calibration level. A flow rate metering system installed in a spray system can help a pilot to maintain an accurate application by monitoring the rate of application.

The addition of a flowmeters to the basic spray system can increase application accuracy, but the inherent problems of worker exposure during mixing and left-over tank mixtures still exists. The production flow monitoring devices are used to measure the application of the premixed solution.

Many pesticides deteriorate with time once diluted and they may not be used in the necessary time period once diluted. Left over tank mixtures may require special handling and federally supervised bookkeeping if disposed in any other way than application. The elimination or reduction of these left over chemicals would potentially result in significant savings and increased worker safety.

This study involved development of a system to eliminate pre-mixing of pesticide solutions by storing the diluent and concentrate in two separate containers on-board the aircraft. The concentrate was metered into the diluent stream in the boom supply line and the resulting mixture discharged through the nozzles. A microcomputer was used to control the concentrate metering rate in response to signals from a turbine flowmeter.

CHAPTER II

OBJECTIVES

The objectives of this study were:

1. To design and construct a microcomputer-controlled metering system suitable for injecting chemical concentrate into the high pressure diluent supply line of an aircraft spray system.

2. To evaluate the designed system under simulated field conditions.

CHAPTER III

REVIEW OF LITERATURE

State of the Art

The first research in developing the concept of separate containers for concentrate and diluent within the spray system was conducted at Oklahoma State University. The system developed (Nelson and Roth, 1973), metered wettable powders from a separate container mixing them with a diluent in the boom supply line. The wettable powder was metered into a mixing chamber where it was mixed with water forming a slurry. The slurry was then inducted into the boom supply line through a jet pump. The jet pump was successful in introducing the concentrate into the diluent line but the head loss across the jet pump was substantial. Peck and Roth (1975) modified the earlier spray system for use with liquid concentrates as well as wettable powders, and field tested the sprayer. The concentrate metering rate was controlled by a ground driven wheel which metered the concentrate proportional to ground speed thus the spray system automatically compensated for changes in the ground speed.

Harrell (1973) developed a spray system that metered wettable powders into a mixing tank and then inducted them into the diluent stream at the suction side of the centrifugal spray pump. A pressure regulated bypass was used to agitate the wettable powder in the mixing tank. The system was later modified by using a piston metering pump to inject liquid concentrates into a pressure regulated bypass which recirculated 88% of the mixture through the spray pump to insure complete mixing. This modified sprayer was field tested on sweet corn and no significant difference between the conventional sprayer and the experimental sprayer was detected (Hare and Harrell, 1976).

Problems with a delay between sensing a change in speed by the ground wheel and the corrected concentration reaching the nozzles was investigated by Vidrine (1975). He observed that two ways to reduce the delay were to place the point of injection close to the nozzles and maximize total flow rate. He noted that the concentrate application rate is independent of the total flow rate by using concentrate injection therefore the optimum distribution and droplet size could be achieved by adjusting the boom pressure.

Kansas State University developed a sprayer in which the chemical concentrate was injected directly into the nozzle housing (Larson, 1982). The system used a positive displacement pump powered by a ground wheel to meter the concentrate. The spray system was mounted on a Hesston 500 swather and field tested with encouraging results. Moving the point of injection to the nozzle housing reduced the the delay inherent with a previous systems. However, this type of system would be impractical for aerial application. A constant speed maintained by aircraft throughout a spraying swath and no spraying is done during turns. Therefore a system which continually adjusts for changes in ground speed would be unnecessary.

The first patented spray system using separate containers for concentrate and diluent was patented in the United States by Mihara (1973). His design used orifice plates to meter the concentrate and diluent. A pressure regulator was used to keep the concentrate line pressure equal to the pressure in the diluent line thus maintaining proportional output. The concentrate system was powered by a positive displacement pump with a pressure relief bypass. An automatic shut off valve in the concentrate line was closed by a signal from a flowmeter in the diluent line when the diluent flow line was shut off.

EVRARD, a French company is manufacturing a ground sprayer for injecting concentrate liquids into the high pressure diluent supply line using a piston metering pump in response to travel speed. A ground wheel drives the concentrate metering pump through a clutched power drive, which is engaged when the diluent system is operating. An in-line mixing section between the point of injection and the booms is used to enhance mixing (Ets Evard, 1973).

The research and development in this area has been confined to ground based sprayers. The concentrate systems use a positive displacement pump to inject the concentrate in response to ground speed. A positive displacement pump of sufficient capacity to deliver the high volume of concentrate required with aerial application would require a power source which would be taxing to the aircraft operations. Gebhardt (1974) developed a spray system in which a pre-mixed solution was forced from the pressurized storage tank with regulated compressed air. The application rate was controlled by using a flowmeter and motorized metering valve. For using this type of system on a aircraft, bottled compressed air could be stored on-board to pressurize the tank.

Flowmeter

Monitoring the concentrate flow rate can be accomplished by using one of several types of flowmeters. A drag-body flowmeter was tested by Gebhardt (1983). Five different commercial formulations of pesticide concentrates were tested with the flowmeter. It was discovered that four of the formulations tested were non-Newtonian and the flowmeter response was non-linear over a 22°C temperature change. The one Newtonian formulation performed linearly over the 22°C temperature change. The conclusions drawn from this research were that a drag-body flowmeter must be calibrated for a particular pesticide, and that it may be necessary to control the temperature of the pesticide to a range within which the flow rate can be accurately measured with this type of flowmeter.

Turbine flowmeters are used extensively in the aircraft industry. They have the advantage of simplicity, small size, accuracy, fast response, and a digital output. They are the most accurate flow monitoring device in common use. They are relatively immune to viscosity changes but should be calibrated over the expected range of viscosities to be metered.

Microcomputer

The use of microcomputers in agricultural aircraft was studied by Orchard (1977). In this study, the pilot was able to concentrate on his flying mission while the computer monitored (1) boom spray pressure; (2) flow rate; (3) total gallons sprayed; (4) elapsed spray time; (5) number of spray passes; (6) air temperature and relative humidity; and

(7) liquid temperature at the spray pump. The computer continually monitored these spraying parameters notifying the pilot of any changes.

In the field test of the monitoring equipment it was noted that the flow rate from a wind driven spray pump was highly variable with pressures ranging from 27-69 psi and flow rates from 15-26 gpm. With these ranges in flow rates metering the concentrate independent of the diluent flow rate is desirable. Precisely metering the concentrate against the varying head in the boom supply line requires constant adjustments. A microcomputer when used in conjunction with monitoring devices can make the adjustments necessary in the concentrate system to compensate for changes in flow rate, temperature, and pressure.

CHAPTER IV

DESIGN AND CONSTRUCTION

The concentrate injection system was designed as a subsystem of a conventional agricultural aircraft spray system. All the components fit within or were attached to the spray system. The system was developed in two phases. The concentrate subsystem was first developed as an independent unit. It was then incorporated into a laboratory mockup of an aircraft spray system and evaluated.

Concentrate Subsystem

The concentrate subsystem consisted of a concentrate storage tank, flowmeter, DC motor and gear train, needle and seat valve, solenoid valve, pressure regulator, injection chamber, and microcomputer with associated electronic components. Figure 1 shows the physical layout of the concentrate subsystem in the developmental arrangement.

Concentrate Storage Tank

The concentrate storage tank (Figure 2) was constructed from 3.2 mm steel plate with a volume of 83.3 L. It was designed as a pressure vessel to hold internal pressures in excess of 415 kPa. The tank was cylindrical with a cone shaped bottom to allow for complete removal of the liquid chemicals. The tank was baffled with three bands around the inner circumference of the tank to reduce sloshing of the liquid during

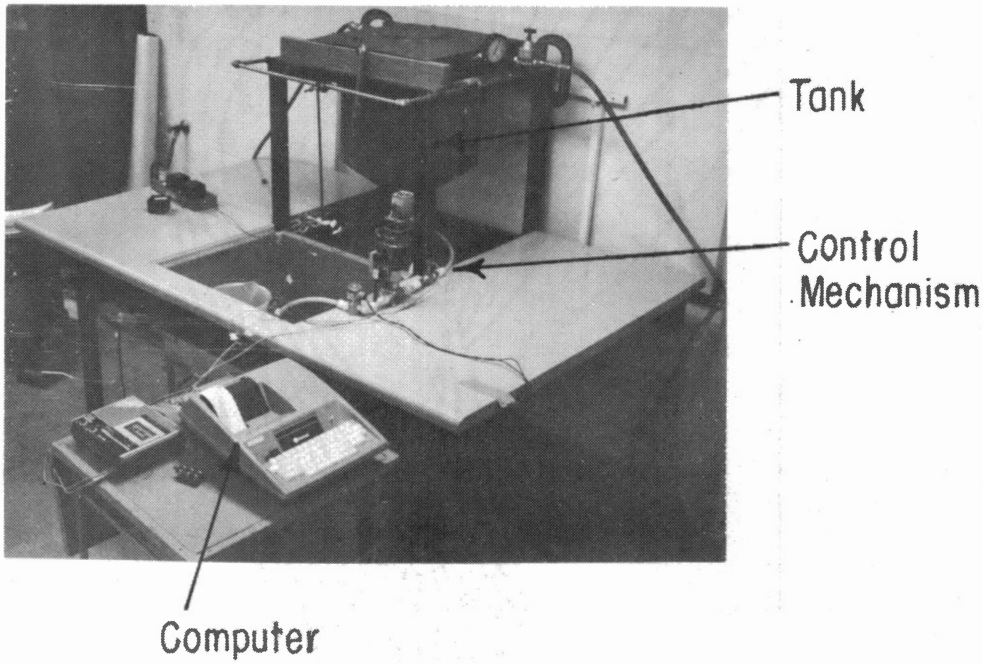

Figure 1. Top view of concentrate subsystem during development.

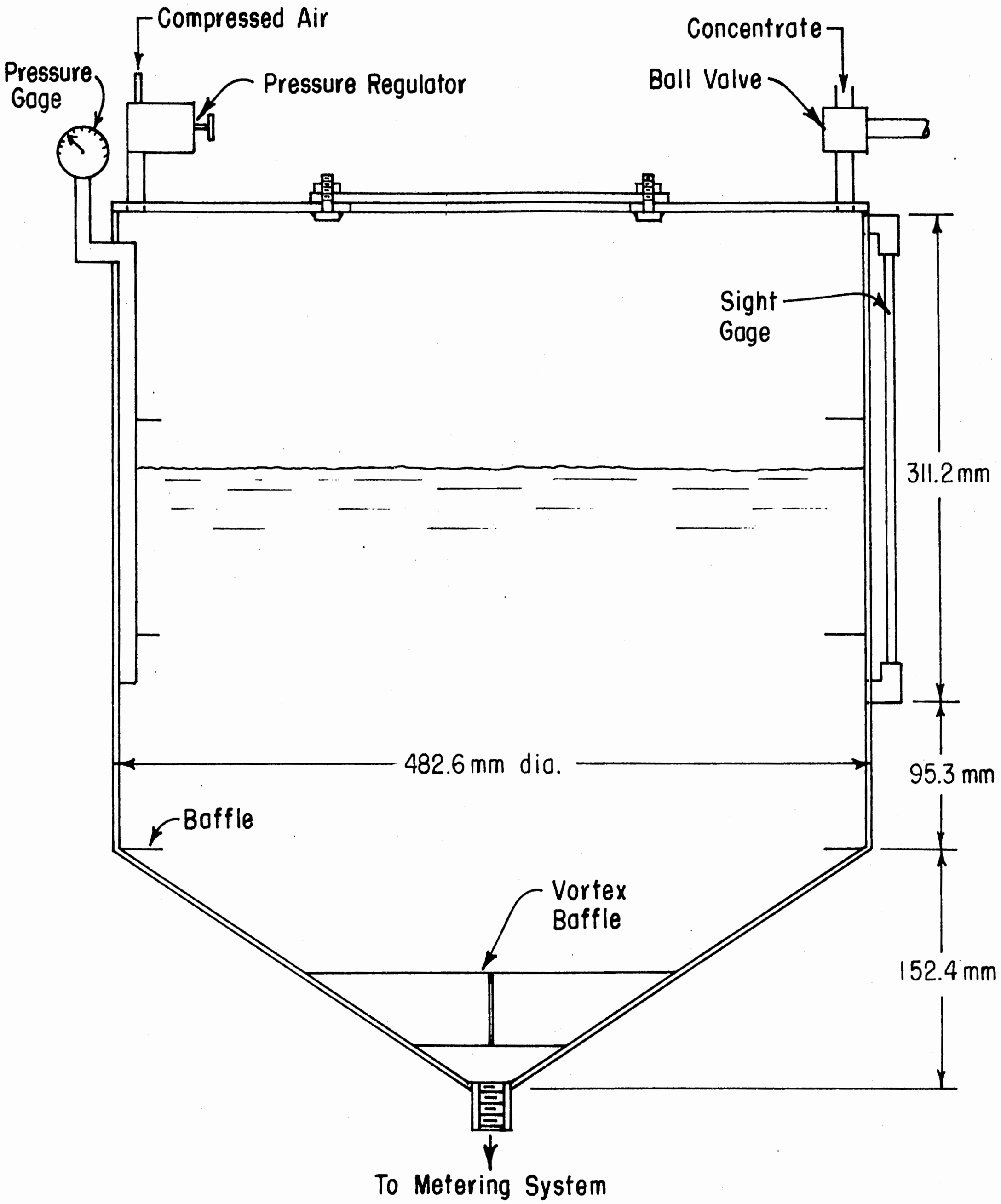

Figure 2. Schematic of the concentrate storage tank.

flight. An anti-vortex baffle was placed in the cone section to prevent air from entering the line as the liquid was forced from the tank by regulated compressed air. A 178 mm port in the top of the tank allowed for tank inspection.

The tank was placed inside the aircraft hopper through the hopper lid opening. A 13 mm ID plastic tube connected the concentrate storage tank to the controlling mechanisms through the hopper wall. This small diameter tubing would require a minimum amount of concentrate in the line. The tank was loaded through a ball valve at the top of the tank with a sight gauge constructed of plastic tubing indicating liquid level in the tank. A pressure relief valve was set at 380 kPa to protect the tank from excessive pressures.

A high capacity Nullmatic model 40-50 pressure regulator was used to maintain a constant pressure in the tank and a 0-416 kPa pressure gauge was used monitor tank pressure.

Concentrate Mixing

Complete mixing of the concentrate and diluent is necessary in chemical application. Inadequate mixing would result in a non-uniform application. Therefore, applying the same amount of chemical with each nozzle is critical to achieving a uniform spray pattern. Since turbulent flow exists in the boom supply line, complete mixing would eventually take place given an adequate length of pipe. In order to reduce the delay between injection of the concentrate and application by the nozzles, the amount of concentrate in the boom supply line it was desirable to position the point of concentrate injection as close to the booms as possible. An injection chamber was designed to enhance the mixing process without introducing a significant head loss in the supply line.

The chamber was designed with an internal annular passage with six 3.2 mm entry holes for the concentrate to enter and mix into the diluent stream (Figure 3). Plexiglass was used to construct the chamber to allow a visual check of mixing. The chamber was placed up stream from the system flowmeter and pressure gauge. The changes in the inside diameter of the pipe through these devices enhanced complete mixing of the concentrate and the diluent.

Metering Valve

The metering valve regulated the concentrate flow via commands from the microcomputer. This was done by using a 12-volt DC reversible motor and a needle and seat metering valve (Figure 4). The high speed motor was geared through a 374:9 transmission and connected to the valve. Limit switches were mounted to the frame which held the valve assembly preventing complete opening or closing of the valve, by turning off the motor due to the motor's inability to produce torque sufficient to turn the valve at these limits. The microcomputer could actuate the motor in the clockwise direction or counter clockwise direction, thus closing or opening the valve or it could turn the motor off.

Flowmeters

Flowmeters were used to monitor flow rate of the concentrate and diluent. A turbine flowmeter was used to measure the concentrate flow rate and a paddle wheel flowmeter was used to measure total flow of the

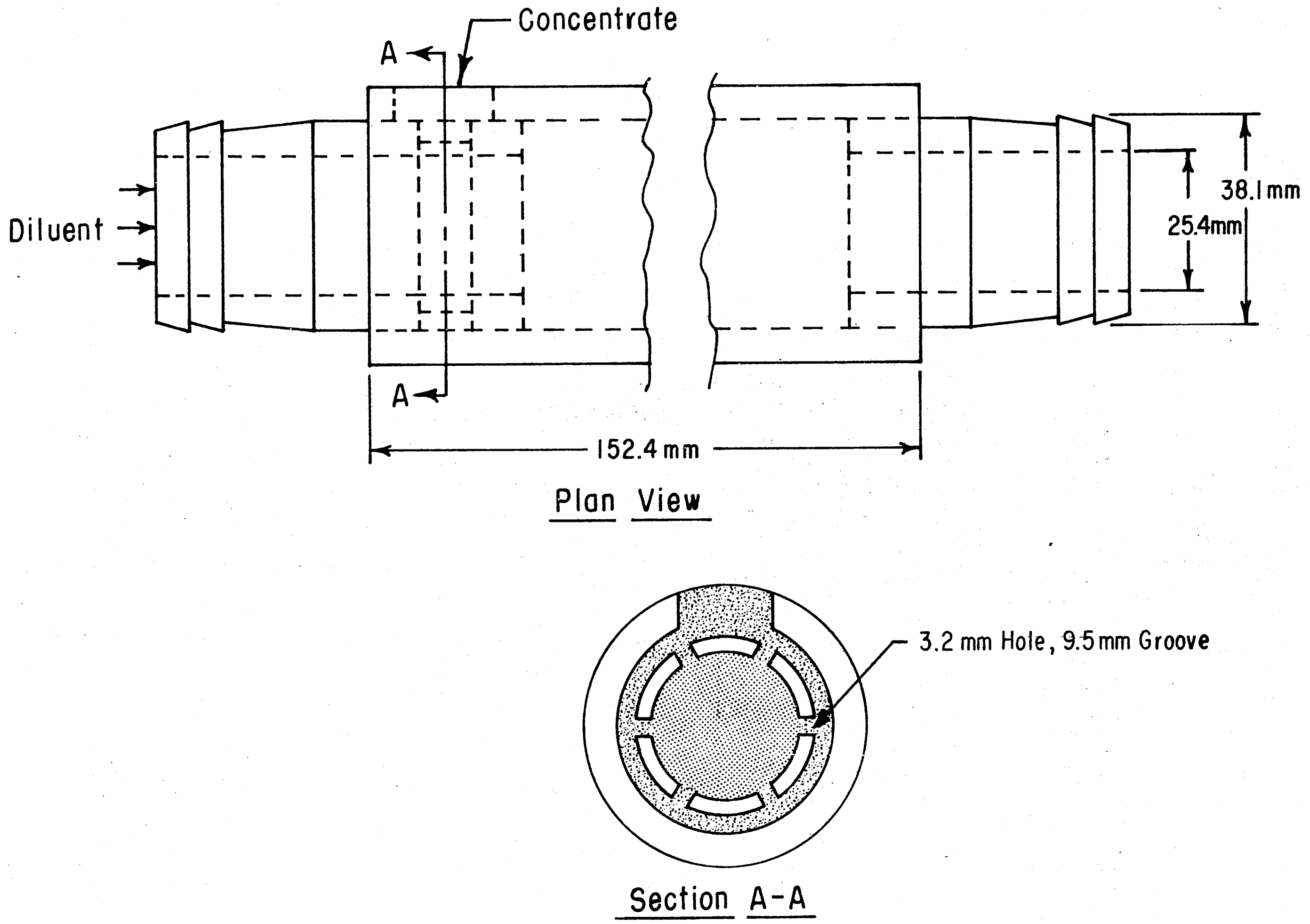

Figure 3. Schematic of the mixing chamber.

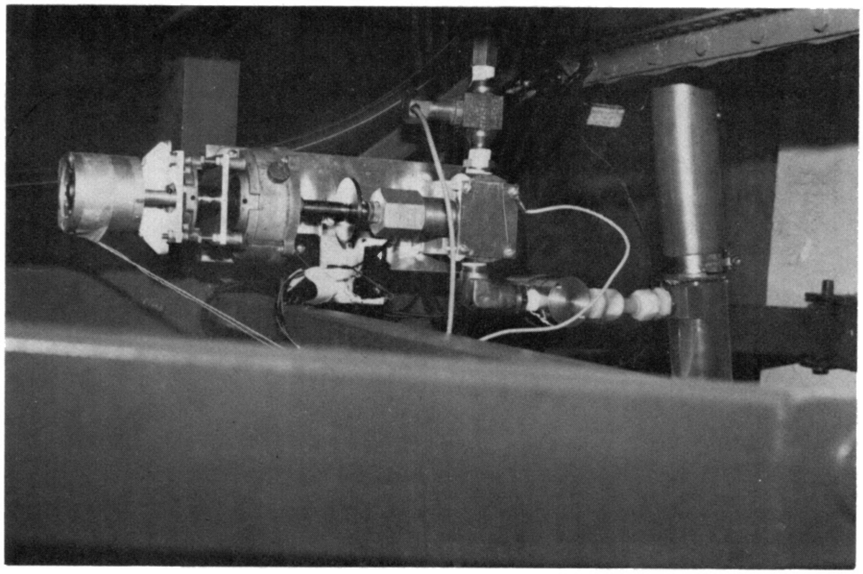

Figure 4. Metering valve mounted on the laboratory spray system.

concentrate and diluent. The paddle wheel meter consisted of a six bladed paddle wheel with its axis perpendicular to the direction of flow, and a magnetic pickup which output a pulse as each paddle blade passed in response to liquid flow. An SED System Monitor, which consisted of a paddle wheel flowmeter, microprocessor based signal processor, and digital readout, was used to measure total flow. The flowmeter fit within a 25.4 mm diameter pipe housing which was inserted into the delivery system between the injection chamber and the Y-strainer.

A turbine flowmeter was used in the concentrate subsystem due to its precise measurement and rapid response. Through the use of a magnetic pickup and proper circuitry, the turbine flowmeter translated the rotation of the six bladed turbine into a square wave output. Static calibration of the turbine meter was performed by using the microcomputer to measure the output wavelength and a container and stopwatch to measure flow. Three equations were derived for three flow ranges using a least square regression geometric model (Table I). Since the turbine was constructed with six blades, the variable name PERIOD represents the time for six consecutive waves from the flowmeter.

Microcomputer

The "brain" of the concentrate subsystem is the microcomputer. A Rockwell R6500 Advanced Interactive Microcomputer AIM65, a complete general purpose microcomputer having advanced hardware and software served as the controller and monitor of the subsystem. The computer was equipped with a 120 line per minute, 20 column dot matrix thermal

TABLE I

EQUATIONS FOR THE FLOWMETER WAVELENGTH

Flow Rate (RATE), L/s	Wave Length (PERIOD), µs
RATE < 0.12	PERIOD = EXP(LOG(865.79)-1.177*LOG(RATE))
0.12 ≤ RATE ≤ 0.2	PERIOD = EXP(LOG(1186.1)-1.034*LOG(RATE))
0.2 ≤ RATE	PERIOD = EXP(LOG(1526.4)-0.871*LOG(RATE))

printer, a 20 character 16-segment alphanumeric LED display, and a 70 function keyboard.

The Central Processing Unit (CPU) was the R6502 8-bit microprocessor which operated at 1 MHz. The AIM65 was equipped with 4K bytes of Random Access Memory (RAM) and 20K bytes of Read Only Memory (ROM) (8K Monitor, 4K Assembler, 8K BASIC).

A ROM-resident 8K monitor controlled AIM65 operations which simplified use of the CPU, memory, and Input/Output (I/O) devices. The monitor executed functional commands in machine code which made development faster. An Editor program was part of the Monitor. It allowed entry, editing, and listing of the R6502 source instructions, data, and general text. The R6502 Assembler was used for converting R6502 source instructions into object code using symbolic labels and operands. The AIM65 BASIC Interpreter was installed to allow the BASIC computer language to be used.

A R6522 Versatile Interface Adapter (VIA) which had 16 bidirectional Input/Output lines, four control lines, and two timers was used to interface the peripheral equipment to the AIM65. A cassette recorder was connected to the AIM65 through the VIA for loading and storing programs.

Programming the Microcomputer

The microcomputer was programmed using two computer languages, BASIC and assembly language. The BASIC program served as a main program, with the assembly language programs as subroutines. BASIC language, although a relatively slow computer language, contains

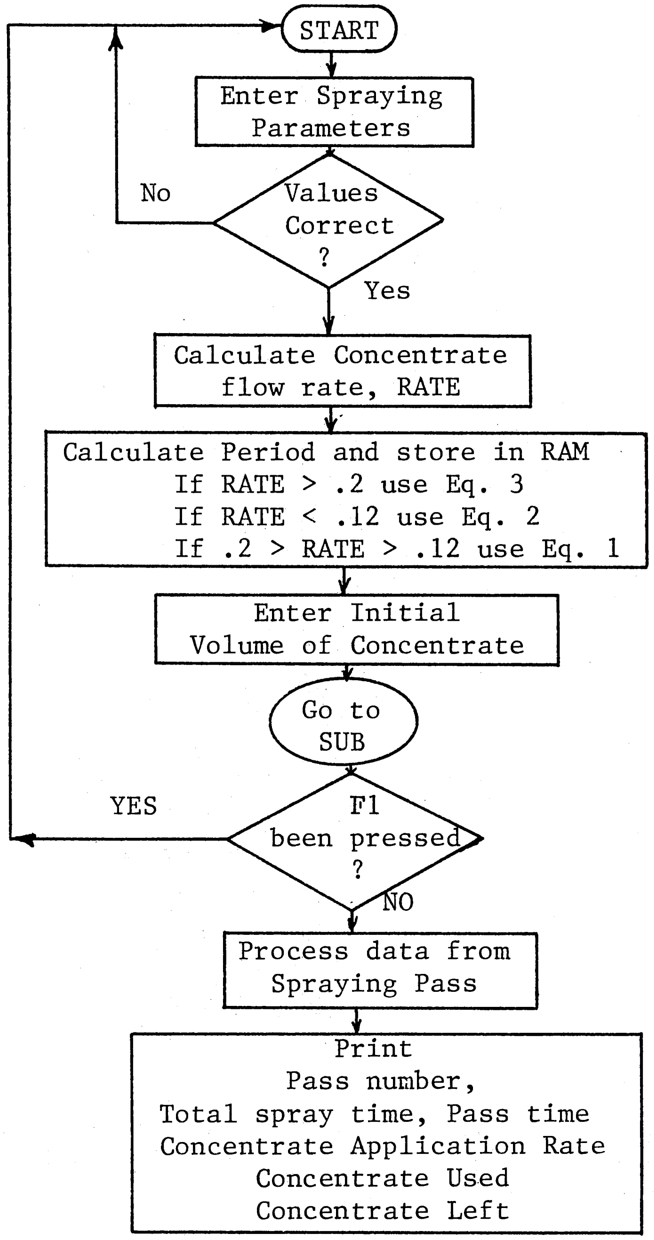

Figure 5. BASIC language main program flow chart.

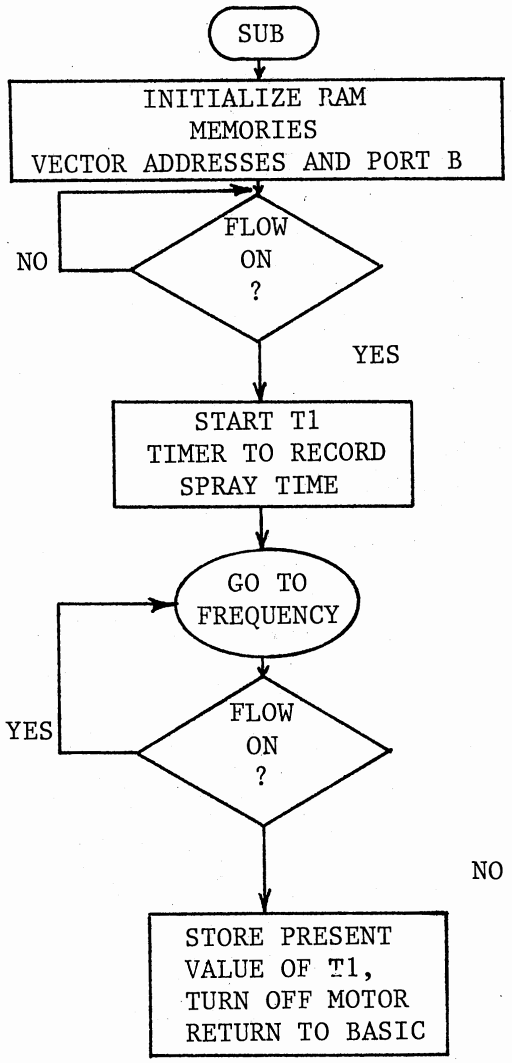

Figure 6. Assembly language subroutine flow chart.

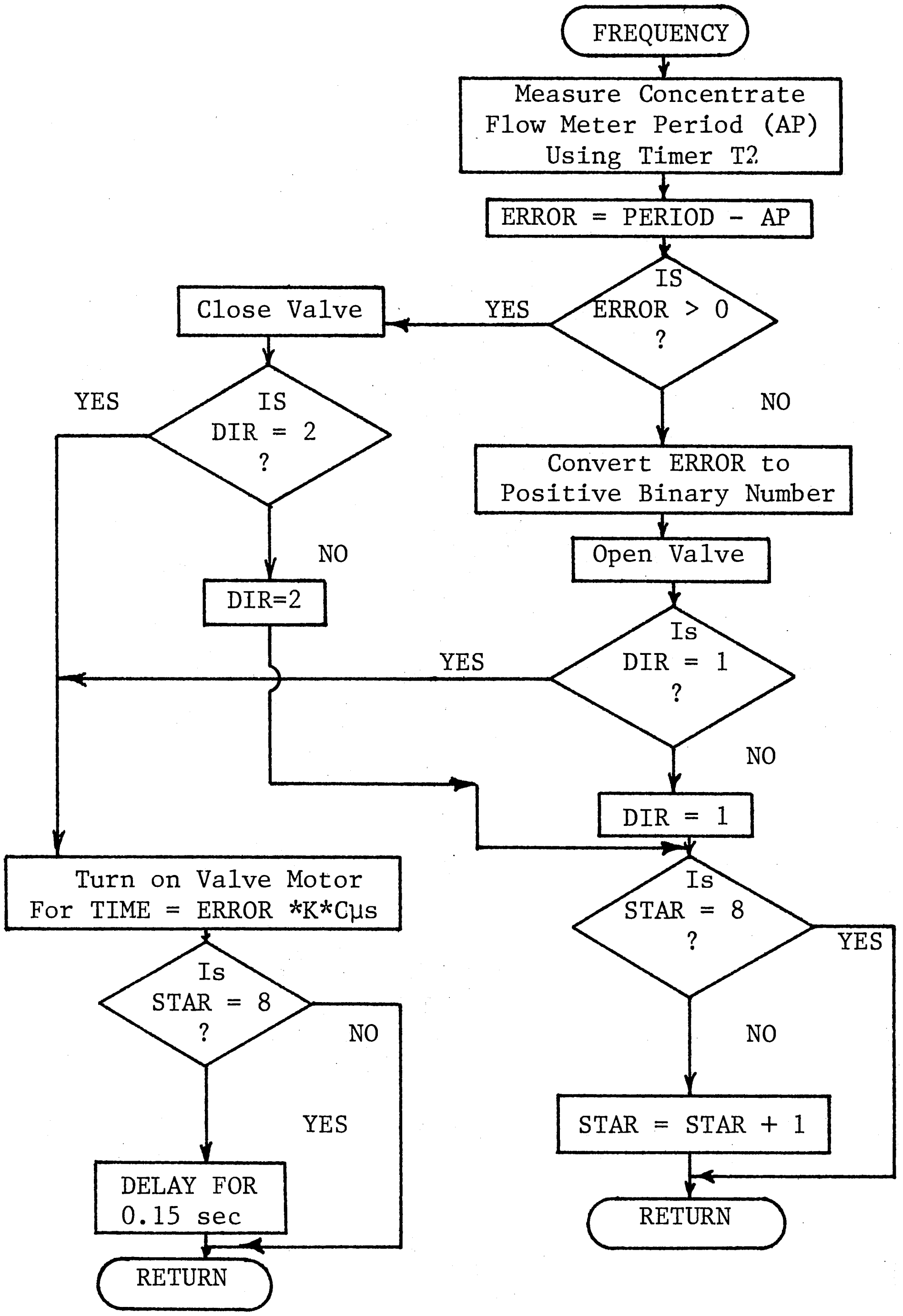

Figure 6. (Continued)

commands which simplify mathematical operations and allow direct communication with the program through the keyboard. Assembly language is ideally suited for controlling peripherial operations through the use of the computer I/O ports.

In Assembly language all the computer operations are programmed directly, whereas BASIC command words are programmed and the computer must decode these words to perform an operation. Therefore program execution is considerably faster in an assembly program allowing rapid control of the metering process.

Control System Development

A programmable microcomputer was used as a device for controlling concentrate metering. The programs for the computer monitored a microswitch and a flowmeter, for controlling the motorized metering valve, and for processing pertinent data for spray mission bookkeeping. Figure 5 shows the flow chart used in the main program and Figure 6 is the flow chart for the subroutine.

The system was initialized by entering the spray parameters of swath width (SW), m, ground speed (GS), km/hr, and concentrate application rate (CAR), L/ha. From these parameters the concentrate flow rate (RATE), L/s, was computed using equation (4-1).

$$\text{RATE} = \frac{\text{SW x GS x CAR}}{36000} \tag{4-1}$$

The computer then decided which flowmeter equation to use to calculate PERIOD by fitting RATE into the proper flow range (Table I). PERIOD and the adjustment gain factor (GAIN) for that flow range were then stored in RAM for use in the subroutine. The microcomputer then prepared to begin the controlling process by jumping into the subroutine and entering a loop which monitored a microswitch connected to the spray valve which indicated the status of the spraying operation.

When the spray valve was opened the microswitch generated a high reading at an I/O port of the microcomputer indicating that spraying had begun and the program should begin the controlling sequence. Another microswitch on the spray valve responded by opening the solenoid valve in the concentrate line. The computer then entered a timing loop which counted six waves from the turbine flowmeter to obtain the actual period (AP). The program started Timer T2 on the falling edge of a flowmeter wave then read T2 on the falling edge of the sixth wave. The actual period was then subtracted from the computed period to obtain ERROR, which was a factor in determining the amount of adjustment to be made in the metering valve (4-2).

$$\text{ERROR} = \text{PERIOD} - \text{AP} \tag{4-2}$$

If ERROR was positive the flow was restricted by closing the valve or if ERROR was negative the valve was opened increasing the flow rate. The valve adjustment was then made by leaving the valve motor on in the proper direction for a computed length of time, (TIME) μs (4-3).

$$\text{TIME} = 8*\text{ERROR}*\text{GAIN}*\text{C} \tag{4-3}$$

Where GAIN was dependent on the flow range and C was the number of computer processing steps used in the timing loop. The general equation for this integral control mode is:

$$\text{FR} = \text{K}*\text{ER} \tag{4-4}$$

where FR is the change in flow rate needed, K is a constant, and ER is the deviation from the set flow rate. After the valve adjustment direction had changed 8 times, a delay was added between flow rate adjustments to allow the concentrate flow to stabilize before a new reading is taken, thus reducing the tendency for the valve to oscillate.

During initial development of the control system it was apparent that electronic noise in the flowmeter circuitry was generating incorrect flowmeter readings causing the computer to make incorrect adjustment in the valve. It was noted that a change in the valve adjustment direction normally accompanied a gross over adjustment, therefore a filter was added to the program. The filter required two consecutive readings dictating a change in direction be necessary for a valve adjustment to be made. This virtually eliminated all of the erratic behavior of the controlling system.

The sequence of read the flow rate, calculate the valve adjustment needed, make the adjustment, and the flow rate changes, continuously occurred while spraying. When the spray valve was closed the microswitches on the spray valve linkage prompted the subroutine to return to the main program by inputting a 0 to PB7 and turned off the concentrate flow by closing the solenoid. The main program then checked the recalculate flag, calculated and updated all bookkeeping data, printed data from the last spraying operation, and returned to the subroutine.

The bookkeeping and system operational data monitored by the microcomputer were spraying passes completed, time elapsed during a pass, total spraying time, concentrate application rate, concentrate used, concentrate left in tank. Spraying time was recorded by initializing Timer T1 immediately after the spray valve was opened. The Timer used the Interrupt Request (IRQ) pin on the microprocessor to generate an interrupt every 65.535 milliseconds. Figure 7 is the flow chart of the

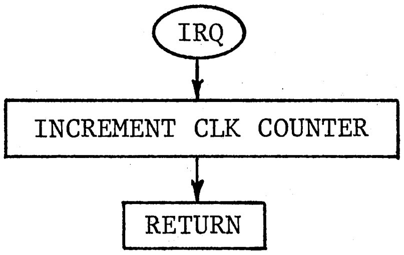

Figure 7. Flow chart for the Interrupt Request (IRQ) service routine.

interrupt service routine which serviced the IRQ interrupt by recording the time then returning to the subroutine.

User definable key F1 was used to generate an interrupt on the Non Maskable Interupt (NMI) pin on the microprocessor. The F1 key was used to signal the program that the spraying parameters needed to be changed upon returning to the main program. Figure 8 is the flow chart for the interrupt service routine which set a RAM memory to signal the main program to restart the program.

The amount of concentrate loaded into the tank is entered into the main program upon initialization. From the average flow rate measured in the subroutine, the amount of concentrate used during each pass is calculated, then subtracted from the remaining concentrate to maintain an update on the amount of concentrate remaining in the tank.

Laboratory Spray System

A complete spray system from an agricultural aircraft was assembled in the laboratory for simulation of field spraying operations. The laboratory spray system consisted of a 700 liter hopper, a Transland centrifugal pump, spray valve, Y-strainer and 3.7 m long 38 mm ID round booms having 16 Spraying Systems #4664 diaphragm teejet check valve bodies per boom at a spacing of 229 mm. To obtain a flow rate of approximately 1.9 L/s and 2.3 L/s at boom pressures of 138 kPa and 207 kPa respectively, D7-46 orifice and core were used in the spray nozzles.

The propeller shaft was connected to a Lincoln 7.5 kW, 1745 rpm, 3 phase electric motor through an adjustable speed gear train. Pump speeds sufficient to achieve pressures equal to those on an aircraft were obtainable. The spray system and power unit were mounted on a

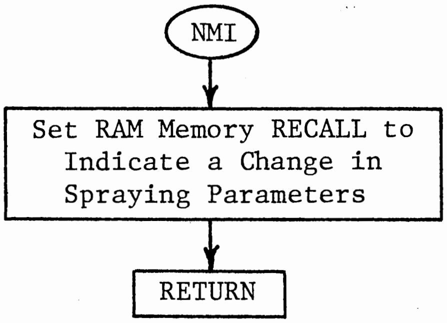

Figure 8. Flow chart for the Non-Maskable Interrupt (NMI) service routine.

particle board with framework constructed from steel tubing and angle iron (Figure 9). A collection system was constructed from 101 mm PVC pipe by drilling a hole in the pipe for each spray nozzle, mounting the pipe to the boom, and draining the pipe into the floor drains.

A SED Sprayer Monitor model 981 was used to record the total volume pumped through the boom supply line during spraying. The SED converted the 12 volt square wave from a paddle wheel flowmeter in the boom supply line into the volume of liquid pumped in liters. A pressure gauge was mounted in the boom supply line for monitoring boom pressure monitoring.

The concentrate subsystem was integrated into the laboratory spray system by placing the concentrate tank inside the hopper, inserting the mixing chamber in the boom supply line, and mounting the rest of the components on the hopper framework similar to what would be done on actual aircraft installation (Figure 10).

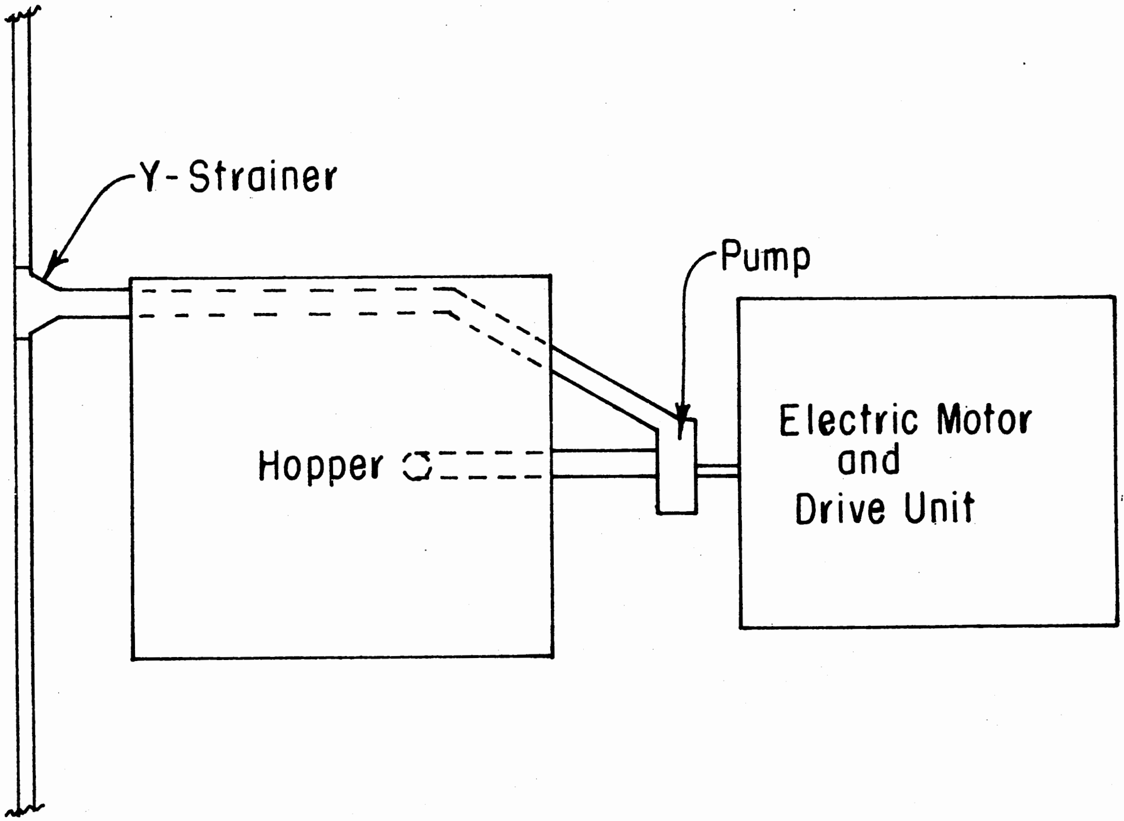

Figure 9. Schematic of the laboratory spray system.

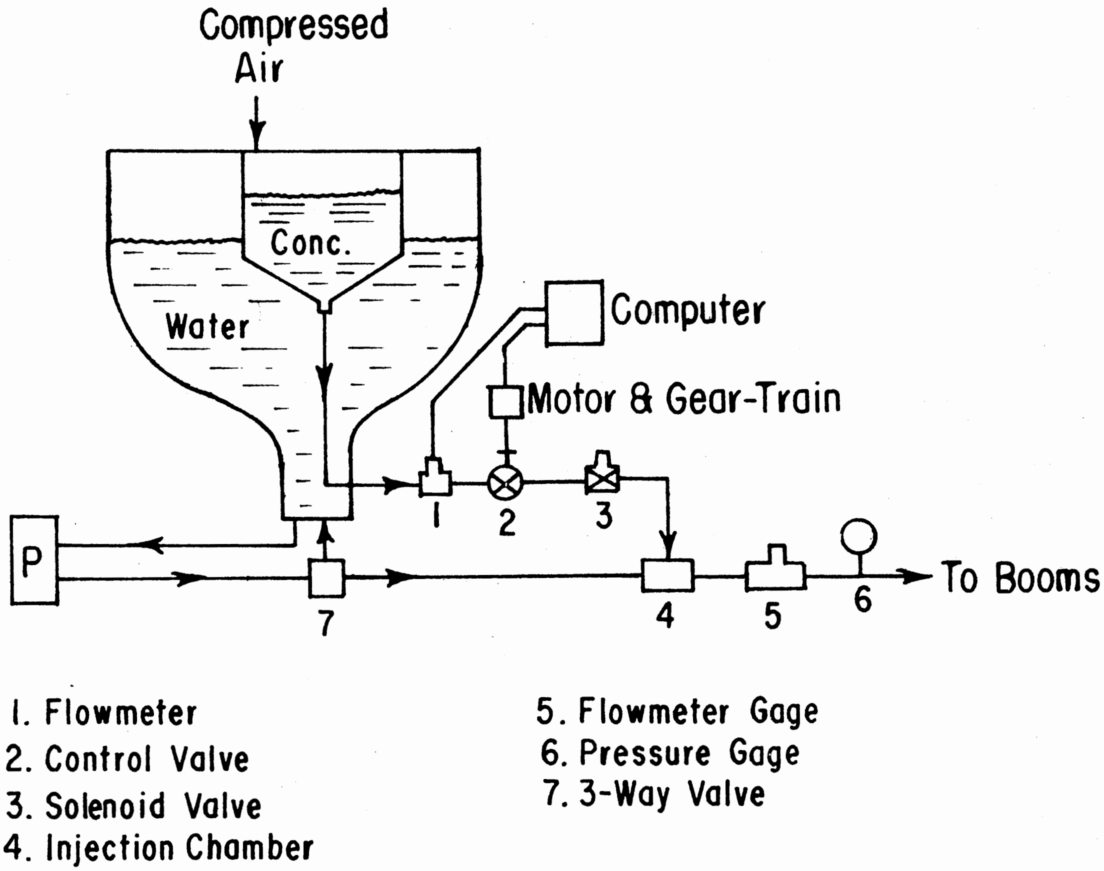

Figure 10. Schematic of the concentrate subsystem mounted on the laboratory spray system.

CHAPTER V

EXPERIMENTAL EQUIPMENT AND PROCEDURES

Experimental Equipment

The performance of the metering system was measured by the system's ability to mix the concentrate following injection and the accuracy and precision with which the concentrate was metered. These were evaluated in two separate experiments.

Spray parameters were 18.3 m swath width, 177 km/hr ground speed, and two concentrate applications rates 2.34 L/ha and 1.17 L/ha. The boom supply line was operated at 138 kPa.

In order to evaluate the performance of the metering system, it was necessary to measure the amount of concentrate distributed by each nozzle. Therefore it was necessary to use a concentrate which could be measured after it was mixed with the diluent to determine how much concentrate was being sprayed. A Rhodamine B dye solution was used as the chemical concentrate tap water was used as the diluent.

A model 112 Turner Filter Fluorometer, with excitation filter #546 and emission filter #590, a cuvette door, and a flow-through door were used in the experiment. The cuvette door was used for static measurements in the mixing evaluation and the flow-through door was used for dynamic measurements and in the metering rate evaluation.

An APPLE II PLUS computer equipped with an ADALAB analog to digital (A/D) interface and data acquisition system was used to record the analog signal from the fluorometer. The APPLE II PLUS was equipped with 64K RAM, silent type printer, 2 disc drives and a 40 character monitor. The A/D interface converted the 0-1 millivolt output of the fluorometer to a 1 to 4000 numerical input for the computer.

The fluorometer was calibrated using 3 standard solution of 05 grams of dye to one liter of distilled water and 3 standard solutions of .02 grams of dye to one liter of distilled water. These solutions were diluted and fluorometer voltage readings taken with the APPLE for each dilution level. Both the flow through and cuvette doors were calibrated by this procedure. Equations (5-1) and (5-2) were derived from these data using least square regression for voltage versus fluorescence. For the cuvette door

$$C = 5.48E\text{-}10 \times v^2 + 7.67E\text{-}7 \times v - 8.38E\text{-}5 \tag{5-1}$$

and for the flow through door

$$C = 1.9E\text{-}5 + 3.46E\text{-}7 \times v + 2.83E\text{-}10 \times v^2. \tag{5-2}$$

where v was the numerical voltage equivalent for the computer, and C was the dye concentration.

During initial experimentation rhodamine dye was discovered to react with tap water in a way which decreased its fluorescence. Fluorescence was stabilized by mixing a solution of 0.01 grams of dye per liter of tap water in 190 liter quantities and allowed to set for a minimum of 2 hours before being used.

Prior to loading the concentrate storage tank, a sample of the premixed dye solution was tested in the fluorometer to determine concentration. The concentrate storage tank was emptied following each replication so the tank could be filled with dye solution of a known fluorescence.

The nozzles and diaphragm check valves were removed from nozzle ports were samples were to be taken and replaced by a hose nipple and 4.8 mm ID Tygon tubing. The tubes were used to collect volume samples during the mixing evaluation and to direct the spray liquid through the flow through door for the metering rate evaluation.

Procedures for System Operation

A cold start of the spray system required programming the computers. The AIM65 was programmed by using a cassette recorder to load the machine code for the subroutine and BASIC language main program. The programs for the APPLE were loaded via the Disc Operating System (DOS). The program supplied with the A/D board was modified to record the fluorometer readings and then print the data on the thermal printer. For use the flow through door the program would take a reading every half second. After the sample run was completed the data array was printed then saved on disk.

Each data collection sequence was performed as follows:

1. The AIM65 was initialized by entering the spray system parameters.

2. Three samples were taken from the bulk tank of dye solution and evaluated to determine dye concentration.

3. The diluent tank was filled with water and the concentrate tank was charged with enough dye for one run using a sump pump.

4. A compressed air hose was attached to the concentrate tank and the pressure set.

5. The SED monitor was initialized to record total flow.

6. The spray system motor was started and the spray valve opened.

7. Cumulative flow was recorded every 15 seconds.

8. Upon completion of the 2 minute test, all the remaining dye was emptied from the concentrate tank and clear water was flushed through the booms in preparation for the next run. Figure 11 shows the laboratory setup for sprayer evaluation.

Mixing Evaluation

The level of mixing of the dye and diluent in the boom supply line was determined from simultaneously collected samples of spray from the sampled nozzle positions. Figure 12 shows the nozzle positions used for sampling. Nozzles 1 on each boom was used for comparing the concentrate distributed to the respective boom. The concentrate subsystem was allowed to reach a steady-state condition, samples were collected, poured into cuvets, and evaluated in the fluorometer using the cuvet door. The level of mixing was indicated by how close the fluorescence readings were to each other. Perfect mixing would result in equal readings.

Metering Rate Evaluation

Precision and accuracy of the metering system was determined by recording the dye concentrations with time as the system tried to reach and maintain the desired application rate. Two procedures were used for the metering rate evaluation. In one the system was allowed to adjust from one application rate to the another with the boom supply line pressure constant at 138.1 kPa. In the other the application rate

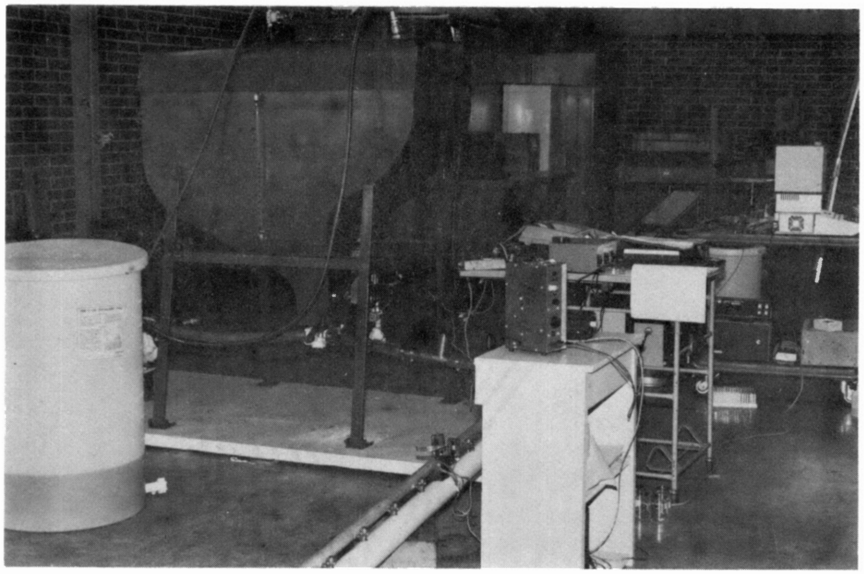

Figure 11. Laboratory setup during evaluation.

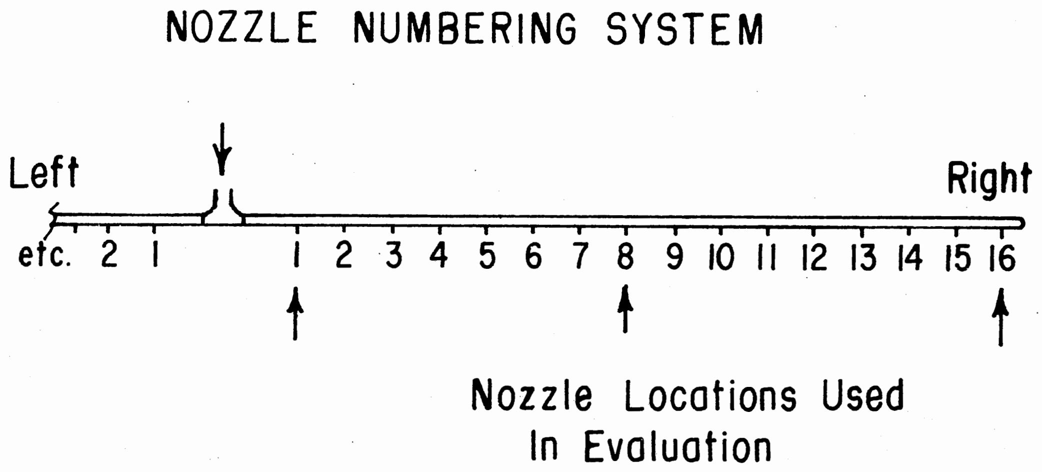

Figure 12. Nozzle ports where samples were taken.

remained constant and the line pressure was varied. The concentrate tank was maintained at 207.2 kPa for 1.168 L/ha application rate and 345.3 kPa for 2.337 L/ha to allow the metering valve to operate at approximately 50% open.

Each of the ports 1, 8 and 16 was connected to the flow through door on the fluorometer and the concentrations recorded during a test run. The application rate was alternated each replication to allow the valve to start in an incorrect position. Each application rate was replicated three times at each nozzle position. The flow rate through the fluorometer was measured with a stopwatch and graduated cylinder to determine the delay time between when the liquid reached the port and when it was recorded by the fluorometer.

Discharge from nozzle port 1 was used to evaluate the concentrate application rate as the boom pressure was varied from 172.7 kPa to 69.1 kPa in 34.5 kPa intervals. A one minute delay was maintained between spray valve adjustments to assure steady state conditions.

CHAPTER VI

RESULTS AND DISCUSSION

The level of mixing dye and water in the boom supply line was tested first. The data collected supported the hypothesis that equal amounts of concentrate were distributed to both booms. The least significant difference (LSD) at the 95% confidence level was 0.0028 g/L and the mean difference between the booms was 0.00217 g/L. Therefore the hypothesis at the 95% confidence level was not rejected and complete mixing was assumed. This assumption permitted only one boom to be used for measuring the concentrate metering rate.

The results of the metering rate evaluation indicated a bias of 12-15% below the set application rate. Figure 13 and 14 show typical response curves for the metering system at the three nozzle positions tested. At 1.17 L/ha set application rate the average bias was 0.17 L/ha and at 2.34 L/ha the bias was 0.28 L/ha. The systematic error comes from two possible sources.

The most likely source is the calibration procedures for the turbine flowmeter. The flowmeter was calibrated under a free flowing condition with no vibration, conditions which did not exist during operation. The use of a container and stopwatch to measure the flow during calibration would not be 10 times as accurate as the turbine meter which is recommended by Doeblin (1983).

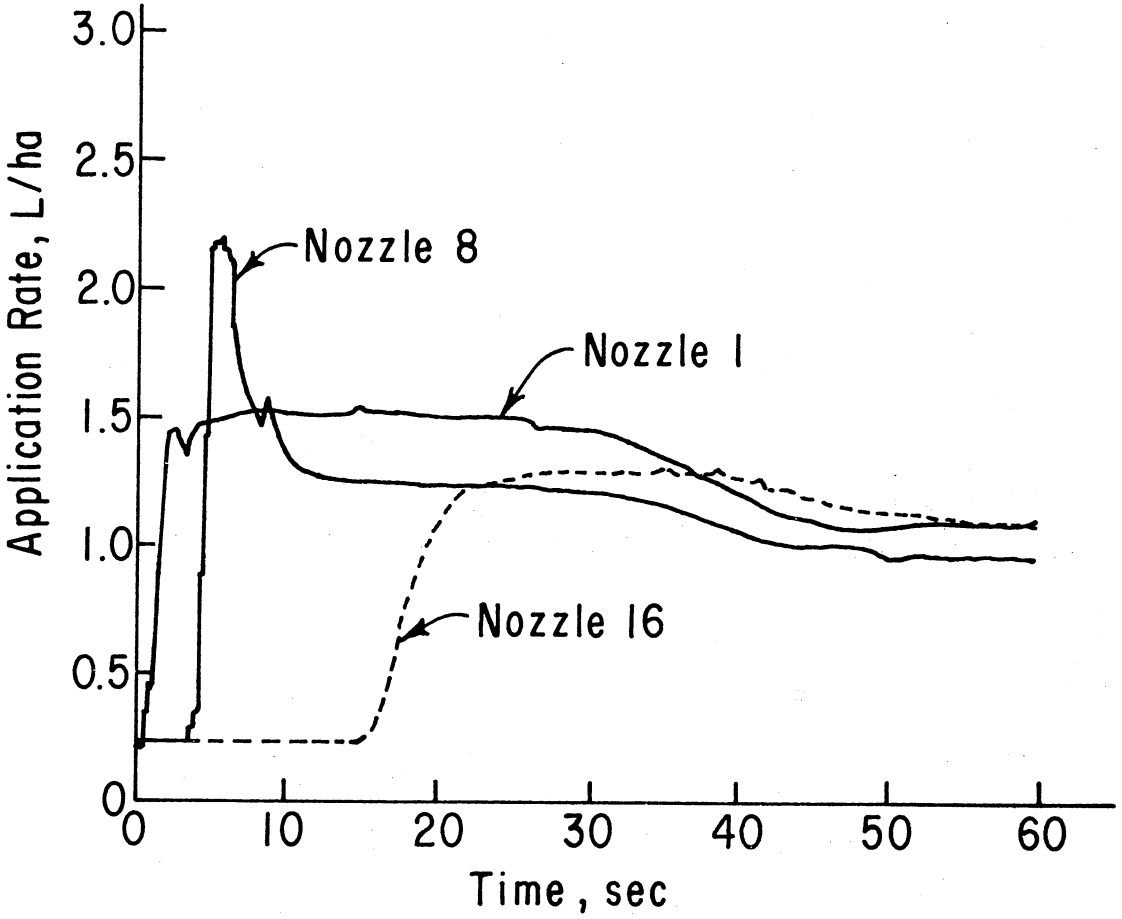

Figure 13. Typical response curves at 1.17 L/ha application rate.

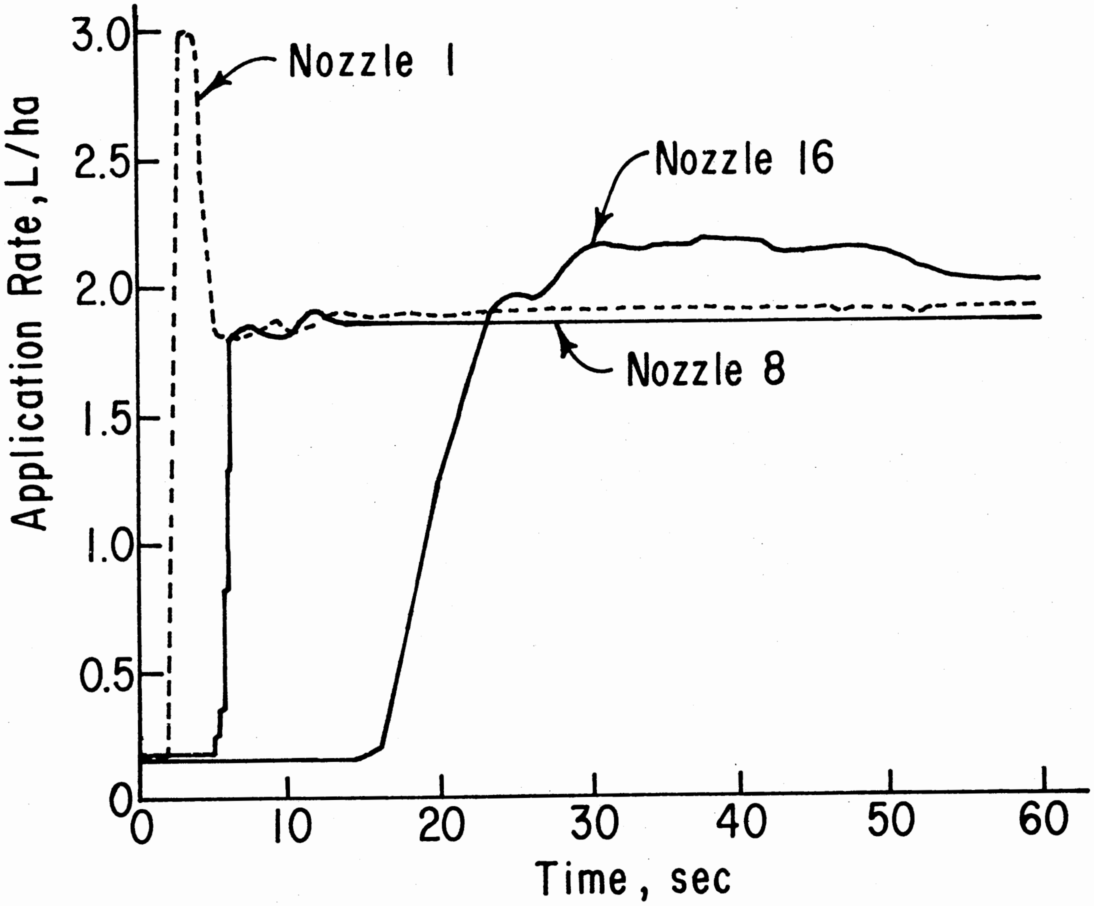

Figure 14. Typical response curves at 2.34 L/ha application rate.

The other source could be in the response of the dye to tap water. Since no testing was done to measure the rate of degradation under turbulent conditions the dye response is unknown. If any degradation occurred this would contribute to a negative bias. However, no apparent degradation occurred in the boom between nozzle 1 and nozzle 16. There was only a one second delay between injection and reading nozzle 1 while there was a 14 second delay between nozzles 1 and 16. Therefore the assumption was made that no degradation occurred in the distribution system.

The metering system was able to maintain a stable concentrate application rate once steady-state was reached. This is indicated by the straight line in Figures 12 and 13. The imprecision was ± 0.07 L/ha using three times the standard deviation for this measure of the random error. Therefore, 99.7% of the time the metering system will perform in the range of ± 0.07 L/ha of the mean application rate.

Figure 15 shows the response of the metering system to changes in the line pressure. Although the mean application rate changed with a change in line pressure the means fell within ± 0.07 L/ha of the overall mean. Therefore the line pressure does not have a significant effect on the metering rate. It should be noted that through observation there is a combination of tank pressure, line pressure, and flow rate, at which the metering valve performed best. Therefore in actual operation with the application rate and line pressure set, the tank pressure could be regulated for the valve to perform in the optimum range.

The curves at start up (Figures 13 and 14) exhibit the control valve adjusting from an incorrect flow rate to the set flow rate. The

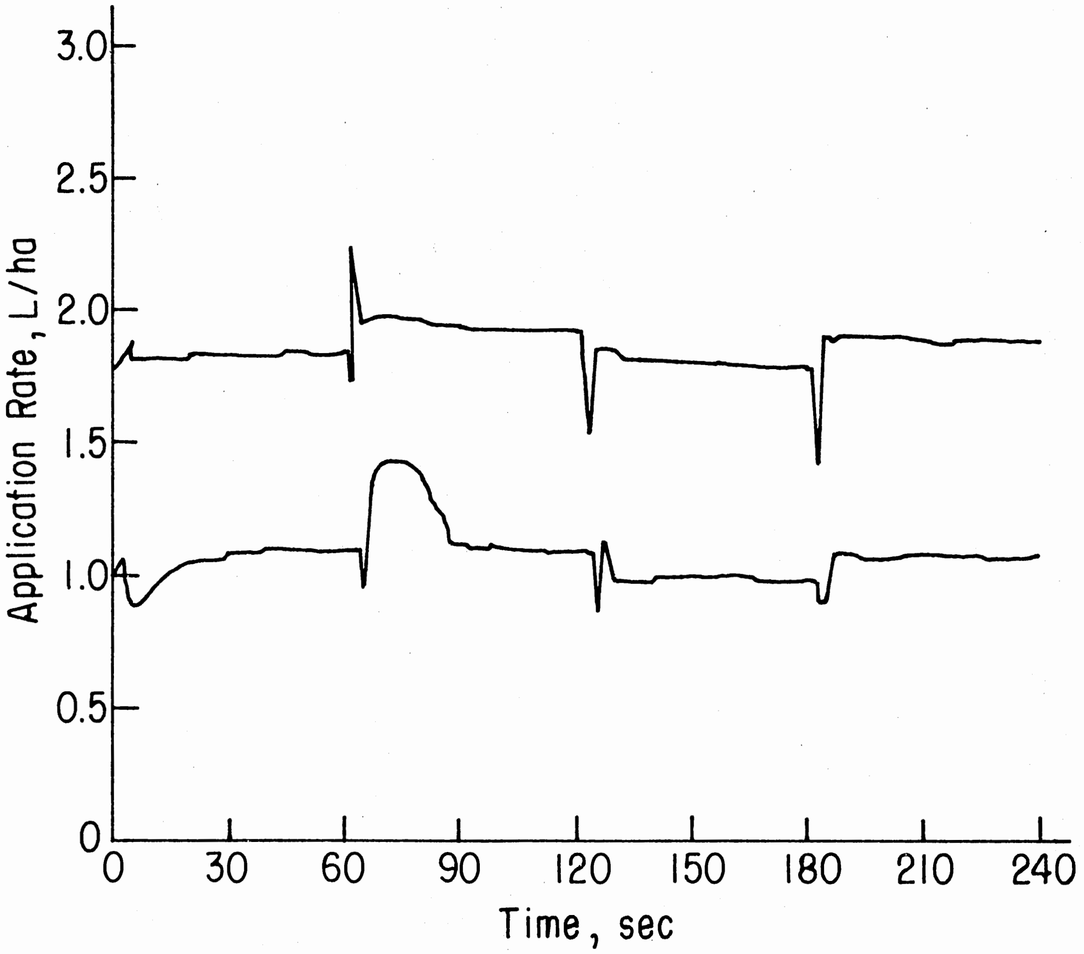

Figure 15. Response curves for the metering system as it adjusts for changes in line pressure.

average response time for the system to achieve steady-state was 35.8 seconds with response ranging from 7.5 to 84.5 seconds.

The straight line at the zero position, beginning each replication, (Figures 13 and 14) is time required for the dye mixture to travel from the point of injection to the nozzle port. This delay is shown as a curve in Figure 16. This delay can be reduced by decreasing the boom diameter or increasing the diluent flow rate.

A major problem encountered during evaluation was that the venturi in the spray valve sucked the mixed dye-water solution from the boom supply line into the diluent tank when the spray valve was closed. This problem was solved during testing by flushing the booms with diluent before the valve was closed.

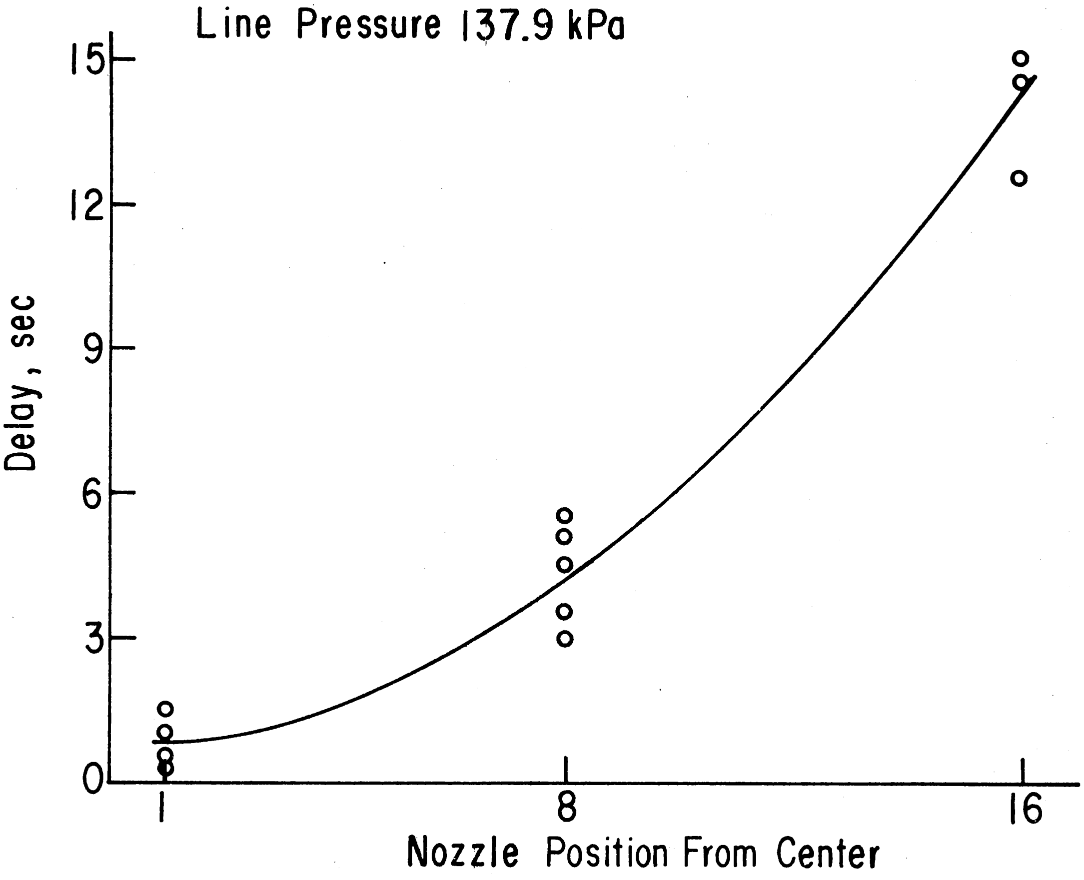

Figure 16. Time required for liquid to pass from point of injection to nozzle port at 18.9 L/ha application rate.

CHAPTER VII

SUMMARY AND CONCLUSIONS

Summary

A system was designed and constructed for metering chemical concentrates into the high pressure diluent supply line of an agricultural aircraft spray system. A microcomputer was used to control the metering rate of the chemical concentrate from the pressurized concentrate tank based on system operating parameters. Concentrate flow rate was measured by a turbine flowmeter and subsequently regulated by a motorized needle valve controlled by the microcomputer. An injection chamber was designed to enhance the mixing of the concentrate into the diluent stream near the point of injection.

The concentrate metering system was incorporated into an aircraft spray system for laboratory evaluation. A Rhodamine B dye solution was used as a chemical concentrate. The dye was injected into the diluent stream, distributed to the booms, passed through a fluorometer, then routed to the floor drains through a collection system. An APPLE II PLUS computer was used to read and record the dye concentrations monitored by the fluorometer. The operating parameters were 18.3 m swath width, 177 km/hr ground speed, and concentration application rates of 2.34 L/ha and 1.17 L/ha.

Conclusions

1. Concentrate metering is feasible for aerial spray systems using a microprocessor-controlled metering valve. Demonstrated imprecision of ± 0.07 L/ha shows the capability of such a system to deliver repeatable constant application rates with minimal error under significant changes in pressure.

2. The system bias of 12% to 15% is significant, but could be eliminated by recalibration of the turbine flowmeter.

3. Mixing of the concentrate and diluent liquids in the boom supply line can be obtained by using an injection chamber to distribute the concentrate symmetrically in the diluent flow regime.

4. Response time of the concentrate subsystem averaged 35.8 seconds. This represents a first time only adjustment and would not be a factor on subsequent spray passes.

5. There was a delay of 15 seconds between a change in concentration at the point of injection and application of the mixture at the last nozzle.

Suggestions for Future Study

1. Conduct an intensive study of different type flowmeters and their suitability for measuring pesticide formulations under actual operating conditions. Develop equations for the best suited flowmeter specifying the formulations and operating temperatures for which they apply.

2. Investigate the response of Rhodamine B dye with tap water to determine its suitability for quantitative studies.

3. Develop additional software and hardware to sense ground speed, diluent flow rate, concentrate temperature, operating pressure, and for transferring data to a ground based computer.

4. Modify the aerial spray valve to prevent the "suck back" feature from drawing the concentrate from the boom supply line into the hopper.

5. Examine the use of a linear actuator to control a metering valve. The response of this type of device would be superior if pressures in the concentrate supply line did not exceed its capabilities.

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APPENDIX

CONTROLLING PROGRAMS FOR MICROCOMPUTER

```
REM CONTROL PROGRAM FOR
REM CONCENTRATE METERED SPRAYER
REM WRITTEN BY
REM STEVEN C. KENNEDY
REM
100 PRINT "ENTER SWATH WIDTH,  IN METERS"
110 INPUT SW
120 PRINT "ENTER GROUND SPEED, IN KM/HR"
130 INPUT GS
140 PRINT "ENTER CONCENTRATE   APPL. RATE, IN L/HA"
150 INPUT CAR
REM
REM CHECK TO MAKE SURE ALL DATA IS CORRECT
151 PRINT TAB(20),"********************   "
152 PRINT "SWATH WIDTH ";SW,"METERS                 "
153 PRINT "SPEED ";GS,"KILOMETERS/HOUR       "
154 PRINT "APPL. RATE ";CAR,"LITERS/HECTARE         "
155 PRINT " "
156 PRINT "ARE THESE VALUES    CORRECT?"
157 PRINT "Y-N"
158 INPUT A$
159 PRINT TAB(20),"********************  "
160 IF ASC(A$)=89 GOTO 165
161 GOTO 100
REM
REM RATE IS IN LITERS/SECOND
165 RATE=SW*GS*CAR*.000027777778
REM
REM
REM PERIOD IS THE MICRO-SECONDS FOR SIX FLOW METER WAVES
REM DECIDE WHICH EQUATION TO USE
170 IF RATE>0.2 GOTO 190
175 IF RATE<.12 GOTO 200
REM
REM EQUATION 3
REM
REM CALCULATE PERIOD FOR FLOW RATE .12 - .20 L/S
180 PERIOD=EXP(LOG(1186.135)-1.0337*LOG(RATE))
REM STORE GAIN FACTOR FOR THIS RANGE
183 POKE 4079,4
185 EQ=3
187 GOTO 210
REM
REM EQUATION 1
REM
REM PERIOD FOR FLOW RATE > .2 L/S
190 PERIOD=EXP(LOG(1526.367)-.870512*LOG(RATE))
REM STORE GAIN FOR THIS RANGE
193 POKE 4079,8
195 EQ=1
197 GOTO 210
REM
REM EQUATION 2
REM
REM PERIOD FOR FLOW RATE < .12 L/S
200 PERIOD=EXP(LOG(865.79)-1.176836*LOG(RATE))
```

```
REM STORE GAIN FOR THIS RANGE
203 POKE 4079,1
205 EQ=2
REM
REM
REM STORE THE PERIOD LENGTH REQUIRED FOR THE APPLICATION
REM THE PERIOD HAS TO BE STORED IN TWO BYTES
210 LOW=PERIOD/255
220 HIGH=INT(LOW)
REM LOAD THE SET PERIOD LENGTH TO CONTROL THE CONCENTRATE
REM HIGH IS THE HIGH ORDER BYTE OF THE PERIOD
230 POKE 4081,HIGH
REM LOWW IS THE LOW ORDER BYTE OF THE PERIOD
240 LOWW=(LOW-HIGH)*255
250 POKE 4080,LOWW
REM
REM
260 PRINT "ENTER CONCENTRATE   LOADED INTO TANK,L"
270 INPUT C
291 PRINT TAB(20),"********************  "
REM PASS IS THE NUMBER OF PASSES
300 PASS=0
REM TIME IS THE TOTAL SPRAY TIME
305 TIME=0
REM
REM
REM ENTER THE ADDRESS OF THE CONTROL SUBROUTINE
310 POKE 4,00
320 POKE 5,10
REM GO TO THE MACHINE SUBROUTINE TO CONTROL CONCENTRATE FLOW
REM     AND MONITOR FLOWS
330 X=USR(W)
REM
REM
REM IF RECALCULATE(F1) HAS BEEN PRESSED, START OVER
335 RC=PEEK(4095)
336 IF RC=1 GOTO 100
REM
REM
REM N IS THE NUMBER OF FLOW READINGS TAKEN
340 N=PEEK(4091)
350 N=N*2
REM INITIALIZE CS
360 CS=0
370 FOR I=1 TO N STEP 2.0
REM CONCENTRATE READINGS START AT $200
REM SUM ALL THE CONCENTRATE PERIOD LENGTHS
REM CH IS THE HIGH BYTE OF THE PERIOD
REM CL IS THE LOW BYTE OF THE PERIOD
REM CR IS THE PERIOD LENGTH IN MICRO-SECONDS
380 CL=PEEK(3327+I)
390 CH=PEEK(3328+I)
400 CH=255*CH
410 CR=CH+CL
415 CS=CS+CR
470 NEXT
```

```
REM CALCULATE AVERAGE PERIOD LENGTH
480 ACR=CS*2/N
REM
REM
REM LOAD NUMBER OF TIMES T1 TIMED OUT, CL & CH
REM T1 COUNTED DOWN $FFFF OR ONCE EVERY .066 SECONDS
500 CH=PEEK(4086)
510 CH=CH*255
520 CL=PEEK(4085)
REM LOAD NUMBER IN T1 WHEN PASS WAS COMPLETED
530 TH=PEEK(4088)
540 TH=TH*255
545 TL=PEEK(4087)
REM CALCULATE PASS TIME IN SECONDS
550 SEC=((CH+CL)*65535. + TH +TL)/1000000.
REM
REM
REM CALCULATE THE AVERAGE CONCENTRATE FLOW RATE, LITERS/SEC
REM DECIDE WHICH EQUATION TO USE
555 IF EQ=1 GOTO 565
557 IF EQ=2 GOTO 570
REM
REM EQUATION 3
560 CRATE=EXP((LOG(1186.135)-LOG(ACR))/1.0337)
562 GOTO 580
REM
REM EQUATION 1
565 CRATE=EXP((LOG(1526.367)-LOG(ACR))/.870512)
567 GOTO 580
REM
REM EQUATON 2
570 CRATE=EXP((LOG(865.79)-LOG(ACR))/1.176836)
REM
REM
REM CALCULATE THE CONCENTRATE USED, LITERS
580 CUSED=CRATE*SEC
REM CALCULATE THE CONCENTRATE LEFT, IF NOT ENOUGH FOR
REM  ANOTHER RUN THE TURN ON WARNING LIGHT
590 C=C-CUSED
600 IF C<=CUSED THEN POKE 40961,11
REM
REM
REM COUNT PASS TO KEEP A TOTAL
650 PASS=PASS+1
REM PRINT OUT PASS DATA
655 PRINT TAB(20),"********************  "
660 PRINT "PASS  ";PASS
670 PRINT "PASS TIME, SEC ";SEC
675 PRINT "CON RATE, L/S";CRATE
680 PRINT "CON USED, L  ";CUSED
690 PRINT "CON LEFT, L  ";C
REM CALCULATE TOTAL SPRAY TIME
720 TIME=TIME+SEC/60
730 PRINT "SPRAY TIME, MIN ";TIME
735 PRINT TAB(20),"********************  "
740 GOTO 330
```

```
* ASSEMBLY SUBROUTINE FOR CONCENTRATE METERED SPRAYER
* WRITTEN BY STEVEN C. KENNEDY
A00B                        ACR       EQU    $A00B     :AUXILIARY CONTROL T1
                                                       & T2
A00E                        IER       EQU    $A00E     :INTERUPT REGISTER
A404                        IRQVL     EQU    $A404     :INTERUPT VECTOR LOW
A405                        IRQVH     EQU    $A405     :INTERUPT VECTOR HIGH
010C                        F1KEY     EQU    $010C
A000                        PORTB     EQU    $A000     :PORT B ADDRESS
A002                        PBDD      EQU    $A002
A004                        T1LL      EQU    $A004     :TIMER 1 LOW & HIGH
A005                        T1LH      EQU    $A005
A008                        T2LL      EQU    $A008     :TIMER 2 LOW & HIGH
A009                        T2LH      EQU    $A009
A495                        T0008     EQU    $A495
A496                        T0064     EQU    $A496     :INTERVAL TIMERS
A497                        T1024     EQU    $A497
A497                        STATUS    EQU    $A497     :STATUS OF THE TIMERS
0FE9                        X1        EQU    $0FE9     :NUMBER OF FLOW METER
                                                       WAVES
0FEB                        F1L       EQU    $0FEB     :PERIOD LENGTH
0FEC                        F1H       EQU    $0FEC
0FED                        EL        EQU    $0FED     :ERROR BETWEEN ACTUAL
                                                       AND COMPUTED
0FEE                        EH        EQU    $0FEE
0FEF                        K         EQU    $0FEF     :GAIN CONSTANT
0FF0                        SETL      EQU    $0FF0     :PERIOD OF CONCENTRATE
                                                        WAVE
0FF1                        SETH      EQU    $0FF1     :CALCULATED IN BASIC
0FF3                        DIR       EQU    $0FF3     :DIRECTION OF VALVE
0D00                        MEMC      EQU    $0D00     :CONCENTRATE PERIOD
0FF5                        CLKL      EQU    $0FF5     :INTERUPTS BY T1 ARE
0FF6                        CLKH      EQU    $0FF6     :COUNTED AND STORED
0FF7                        T1L       EQU    $0FF7     :T1 AT THE END OF PASS

0FF8                        T1H       EQU    $0FF8
0FF9                        STAR      EQU    $0FF9     :INDICATOR FOR COURSE
                                                       TUNING
0FFD                        CC        EQU    $0FFD     :CONCENTRATE INDEX
0FFF                        RECALL    EQU    $0FFF     :F1 HAS BEEN PRESSED
*START OF MAIN PROGRAM TO CALCULATE RATES
*SETUP SYSTEM
0A00                                  ORG    $0A00
0A00    D8                            CLD
0A01    A9      40                    LDA    #$40      :T1 FREE RUNNING MODE
0A03    8D    0BA0                    STA    ACR       :T2 SINGLE SHOT MODE
0A06    A9      00                    LDA    #$00      :ZERO MEMORIES
0A08    8D    F50F                    STA    CLKL
0A0B    8D    F60F                    STA    CLKH
0A0E    8D    FD0F                    STA    CC
0A11    8D    F90F                    STA    STAR
0A14    A9      03                    LDA    #$03      :INITIALIZE MOTOR
0A16    8D    F30F                    STA    DIR
0A19    A9      30                    LDA    #$30
0A1B    8D    04A4                    STA    IRQVL     :INTERUPT ROUTINE
0A1E    A9      0C                    LDA    #$0C      :TO RECORD T1 INTERUPT
```

```
0A20    8D     05A4                  STA     IRQVH
0A23    78                           SEI
0A24    A9       C0                  LDA     #$C0
0A26    8D     0EA0                  STA     IER          ;SET INTERUPT REGISTER

0A29    A9       03                  LDA     #$03
0A2B    8D     00A0                  STA     PORTB        ;TURN OFF MOTOR
0A2E    A9       0F                  LDA     #$0F         ;PB7-PB4 INPUTS
                                                          PB3-PB0 OUTPUTS
0A30    8D     02A0                  STA     PBDD
0A33    A9       80                  LDA     #$80
0A35    2C     00A0         START    BIT     PORTB        ;INPUT FLOW ON SIGNAL
                                                          PB7
0A38    F0       FB 0A35             BEQ     START        ;FLOW OFF LOOP
0A3A    A9       FF                  LDA     #$FF         ;FLOW STARTED
0A3C    8D     04A0                  STA     T1LL         ;LOAD $FFFF INTO T1
0A3F    8D     05A0                  STA     T1LH         ;INTO LATCH
0A42    58                           CLI
0A43    A9       06         AGAIN    LDA     #$06         ;TIME 6 WAVES
0A45    8D     E90F                  STA     X1
0A48    20     560A                  JSR     FREQ         ;GOTO SUBROUTINE TO
                                                          RECORD PERIOD
0A4B    A9       80                  LDA     #$80
0A4D    2C     00A0                  BIT     PORTB        ;IS THE FLOW STILL ON
0A50    D0       F1 0A43             BNE     AGAIN        ;YES, CONTINUE
0A52    20     2B0B                  JSR     RETURN       ;NO, RETURN TO BASIC
0A55    60                           RTS
*SUBROUTINE TO READ AND RECORD PERIOD LENGTHS
0A56    78                  FREQ     SEI                  ;PREVENT INTERUPTS
0A57    A2       00                  LDX     #$00
0A59    A9       40                  LDA     #$40         ;METER INPUT
0A5B    2C     00A0         ZERO     BIT     PORTB        ;WAVE LOW?
0A5E    F0       FB 0A5B             BEQ     ZERO         ;YES LOOP, NO CONTINUE

0A60    2C     00A0         ONE      BIT     PORTB        ;WAVE HIGH?
0A63    D0       FB 0A60             BNE     ONE          ;YES LOOP, NO CONTINUE

0A65    A9       FF                  LDA     #$FF
0A67    8D     08A0                  STA     T2LL         ;START T2 ON FALLING
                                                          EDGE OF WAVE
0A6A    8D     09A0                  STA     T2LH
0A6D    A9       40                  LDA     #$40         ;METER INPUT
0A6F    2C     00A0         LOW      BIT     PORTB
0A72    F0       FB 0A6F             BEQ     LOW          ;LOOP WHILE WAVE LOW
0A74    2C     00A0         HIGH     BIT     PORTB
0A77    D0       FB 0A74             BNE     HIGH         ;LOOP WHILE WAVE HIGH
0A79    E8                           INX
0A7A    EC     E90F                  CPX     X1           ;READ SIX WAVES
0A7D    D0       F0 0A6F             BNE     LOW
0A7F    AD     08A0                  LDA     T2LL         ;READ T2 ON FALLING
                                                          EDGE OF WAVE
0A82    8D     EB0F                  STA     F1L          ;STORE T2L &T2H
0A85    AD     09A0                  LDA     T2LH
0A88    8D     EC0F                  STA     F1H
0A8B    58                           CLI                  ;INTERUPT CLEARED
```

```
*FLOW CONTROL AND CONCENTRATE PERIOD RECORDING
0A8C     AD     EB0F                 LDA    F1L      ;CONVERT T2 TO ELAPSED
                                                      TIME
0A8F     49       FF                 EOR    #$FF
0A91     8D     EB0F                 STA    F1L
0A94     AD     EC0F                 LDA    F1H
0A97     49       FF                 EOR    #$FF
0A99     8D     EC0F                 STA    F1H
0A9C     38                          SEC
0A9D     AD     F00F                 LDA    SETL     ;SUBTRACT ACTUAL FROM
                                                     CALCULATED
0AA0     ED     EB0F                 SBC    F1L      ;TO OBTAIN THE ERROR
0AA3     8D     ED0F                 STA    EL
0AA6     AD     F10F                 LDA    SETH
0AA9     ED     EC0F                 SBC    F1H
0AAC     8D     EE0F                 STA    EH
0AAF     B0       20 0AD1            BCS    DOWN     ;ERROR POSITIVE BRANCH

0AB1     38                          SEC             ;NORMALIZE DIFFERINCE
0AB2     A9       00                 LDA    #$00
0AB4     ED     ED0F                 SBC    EL
0AB7     8D     ED0F                 STA    EL
0ABA     A9       00                 LDA    #$00
0ABC     ED     EE0F                 SBC    EH
0ABF     8D     EE0F                 STA    EH       ;OPEN VALVE
0AC2     A9       01                 LDA    #$01     ;COMPARE WITH PREVIOUS
                                                      DIRECTION
0AC4     2D     F30F                 AND    DIR
0AC7     D0       17 0AE0            BNE    DOWN2    ;BRANCH IF SAME
0AC9     A9       01                 LDA    #$01     ;STORE NEW DIRECTION
0ACB     8D     F30F                 STA    DIR      ;AND CONTINUE
0ACE     4C     2208                 JMP    UP1
0AD1     A9       02       DOWN      LDA    #$02     ;CLOSE VALVE
0AD3     2D     F30F                 AND    DIR      ;COMPARE WITH PREVIOUS
                                                      DIRECTION
0AD6     D0       08 0AE0            BNE    DOWN2    ;BRANCH IF SAME
0AD8     A9       02                 LDA    #$02     ;STORE NEW DIRECTION
                                                     AND CONTINUE
0ADA     8D     F30F                 STA    DIR
0ADD     4C     2208                 JMP    UP1
0AE0     8D     F30F       DOWN2     STA    DIR      ;TURN ON VALVE
0AE3     8D     00A0                 STA    PORTB
0AE6     AE     ED0F       ON2       LDX    EL       ;LEAVE VALVE ON FOR
0AE9     F0       0E 0AF9            BEQ    OFF1     ;T=8*ERROR*K*C MICRO
                                                     SECONDS
0AEB     AD     EF0F       ON1       LDA    K        ;K= METER CONSTANT
0AEE     8D     95A4                 STA    T0008    ;C=AIM PROCESSING TIME

0AF1     2C     97A4       WAIT      BIT    STATUS
0AF4     10       FB 0AF1            BPL    WAIT
0AF6     CA                          DEX
0AF7     D0       F2 0AEB            BNE    ON1
0AF9     AD     EE0F       OFF1      LDA    EH
0AFC     F0       0B 0B09            BEQ    OFF2
0AFE     CE     EE0F                 DEC    EH
0B01     A9       FF                 LDA    #$FF
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0B03   8D    ED0F                STA    EL
0B06   4C    E60A                JMP    ON2
0B09   A9      03       OFF2     LDA    #$03         :TURN OFF MOTOR
0B0B   8D    00A0                STA    PORTB
0B0E   AD    F90F                LDA    STAR         :CHECK TO SEE IF DELAY
                                                      SHOULD
0B11   C9      08                CMP    #$08         :BE ADDED
0B13   D0      12  0B27          BNE    NOD          :NO, LOOP AROUND DELAY

0B15   A9      90                LDA    #$90
0B17   8D    97A4                STA    T1024
0B1A   2C    97A4       WAIT2    BIT    STATUS
0B1D   10      FB  0B1A          BPL    WAIT2
0B1F   4C    220B                JMP    UP1
0B22   C9      08       UP1      CMP    #$08         :DIR CHANGED 8 TIMES
0B24   D0      01  0B27          BNE    NOD          :NO, INCRIMENT COUNTER

0B26   60                        RTS                 :YES, RETURN
0B27   EE    F90F       NOD      INC    STAR         :INCRIMENT COUNTER
0B2A   60                        RTS
*RETURN SUBROUTINE
*WHEN FLOW IS TURNED OFF RETURN TO BASIC
0B2B   78               RETURN   SEI
0B2C   AD    04A0                LDA    T1LL         :STORE PRESENT T1
0B2F   8D    F70F                STA    T1L
0B32   AD    05A0                LDA    T1LH
0B35   8D    F80F                STA    T1H
0B38   A9      03                LDA    #$03         :TURN OFF MOTOR
0B3A   8D    00A0                STA    PORTB
0B3D   60                        RTS
*F1 SERVICE ROUTINE
*RECALCULATE APPLICATION RATE
0C20                             ORG    $0C20
0C20   78                        SEI
0C21   EE    FF0F                INC    RECALL       :RECALCULATE
0C24   60                        RTS
*INTERUPT SERVICE ROUTINE
*COUNT TIME TI TIMES OUT
0C30                             ORG    $0C30
0C30   78                        SEI
0C31   18                        CLC
0C32   A9      01                LDA    #$01
0C34   6D    F50F                ADC    CLKL         :T1 HAS DECRIMENTED
                                                     $FFFF TIMES
0C37   8D    F50F                STA    CLKL
0C3A   90      06  0C42          BCC    BRANCH       :IF LOW BYTE IS $FF
0C3C   6D    F60F                ADC    CLKH         :ADD ONE TO HIGH BYTE
0C3F   8D    F60F                STA    CLKH
0C42   AD    04A0       BRANCH   LDA    T1LL         :CLEAR INTERUPT FLAG
0C45   58                        CLI
0C46   40                        RTI
0C47                             END


TOTAL ERRORS           0
TOTAL LABELS          51
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VITA

Steven Charles Kennedy

Candidate for the Degree of

Master of Science

Thesis: A MICROCOMPUTER CONTROLLED LIQUID CONCENTRATE METERING SYSTEM FOR AGRICULTURAL AIRCRAFT

Major Field: Agricultural Engineering

Biographical:

Personal Data: Born in Muskogee, Oklahoma, June 25, 1958, the son of Mr. and Mrs. Robert A. Kennedy.

Education: Graduated from Sooner High School, Bartlesville, Oklahoma, in May, 1976; received Bachelor of Science degree in Agricultural Engineering from Oklahoma State University in December, 1980; enrolled in Master's Program in August, 1981 at Oklahoma State University; completed requirements for the Master of Science degree at Oklahoma State University in December, 1983.

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