DATA ACQUISITION SYSTEM FOR AERIAL APPLICATION AIRCRAFT MISSION ANALYSIS

By

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ANALYSIS

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PREFACE

Due to increasing material and labor costs along with increasing legal constraints in the aerial application industry, research was conducted to develop a data acquisition system to assist applicators in analyzing their operations.

I would like to express my gratitude to my major adviser, Dr. Richard W. Whitney, for his guidance, support and encouragement throughout my stay here at Oklahoma State University. I wish to thank Dr. Larry O. Roth for his encouragement and infinite wisdom. I would also like to thank committee member Dr. James D. Summers for his support and advice throughout this work.

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CHAPTER I

INTRODUCTION

Chemical application aircraft play a vital role in today's agricultural industry. According to a survey done by the Econ Corporation (1978) more than 12000 fixed and rotary winged aircraft were in operation in the United States at the time the survey was conducted. These aircraft log more than 2.5 million hours and treat about 180 million acres annually. Furthermore, gross annual revenues (including material costs) total approximately 1.1 billion dollars in the agricultural aviation industry. Due to the economic state of the agricultural industry, current figures are estimated to be less than those quoted above. Rising chemical, fuel and operational costs are threatening many operations to the point of nonexistence. Along with rising costs, are rising concerns of environmental damage and pollution caused by chemical drift and misapplication. Many of these concerns ultimately result in litigation against the applicator. Therefore it could be of great benefit to an aerial applicator to have post-mission data related to individual missions which he has flown. Not only would such data be of importance to the applicator but would also be useful in evaluating existing equipment resulting in improved designs for future equipment. Owing to the present availability and popularity of microcomputers, the benefits to the applicator of a microprocessor-based system become quite clear. The applicator would have access to immediate post-mission statistics along with permanent and compact storage on floppy disks. While applying a chemical to a field, the applicator must concern himself with keeping his aircraft on line and in the air. Therefore, except for split second glances, very little time exists for monitoring pertinent mission variables. For this reason, post-mission data analysis was chosen over real time in flight data analysis. Post-mission data analysis has the potential for providing factual information, derived from real time data, which can be used in decision making processes.

Objectives

The following objectives were formed for this project:

1) Develop and evaluate an on-board microprocessor-based, data acquisition system to record pertinent mission parameters of a fixed wing agricultural aircraft.
2) Develop appropriate software to read recorded measurements into a computer, and to evaluate, summarize and display appropriate mission statistics.

CHAPTER II

REVIEW OF LITERATURE

Monitoring systems for agricultural aircraft have in the past used chart recorders to record pertinent mission parameters. Both the VGH recorder developed by NACA, presently NASA, and a system developed for the USDA used galvanometric strip chart recorders.

The National Advisory Committee For Aeronautics developed an instrument for the collection of gust-load data on aircraft. Richardson (1950) states that this instrument, designated as the NACA VGH recorder, provides continuous records of airspeed, normal acceleration and altitude for long periods of operational flight. The recorder employed a tilting mirror and lens which focused the image of a straight-filament lamp on moving record paper. Airspeed and altitude were measured with diaphragms which were connected to the aircraft's pitot-static lines. A reflecting galvonometer movement was used to receive electrical signals from the accelerometer. The static accuracy of each element in the recorder was within one percent of full scale.

In 1962 the National Aeronautics and Space Administration installed VGH recorders on eight different types of aircraft (Jewel et al., 1975). The eight classes of aircraft studied were: twin-engine executive, single-engine executive, personal instructional, commercial survey, aerobatic, commuter and aerial application. Gust velocities were derived for all eight categories of aircraft. Aerial application aircraft were found to encounter gusts relatively infrequently due to operations in calm air. However, aerial application aircraft were found to be subject to the most severe landing accelerations of all the general aviation operations. This was attributed to two factors; the aerial application aircraft were flown from rough surfaces such as fields, roads and dirt strips and a high ratio of night landings were made by the airplanes involved in the data sample.

Jewel (1982) studied time characteristics of agricultural aircraft using data obtained from NASA VGH recorders. Mission parameters recorded included flight time, ferry time, spreading time, turning time, the number of spreading runs and the number of turns between spreading runs. Jewel concluded that agricultural airplanes spend the smallest amount of their flight time, 25 to 29 percent, actually spreading seed or chemical. Operator experience and fatigue were found to play an important role in the reduction of turning times. As the operators' experience in a new airplane increased, the turning times decreased. Furthermore, Jewel determined that the percent of flight consumed in turns was between 15 to 70 percent and averaged 40 percent.

Orchard (1979) developed an on-board monitoring system for recording aerial spray application parameters. This system used integrated circuits instead of transistors which had been used in the past. However, recording of the data was done on galvanometric strip chart recorders. Two basic modules were built. The first module, designated module A, recorded spray pressure, flow rate, total flow, elapsed spray time and total spray passes. The system was initiated through the use of a pilot-actuated spray switch which provided a control signal. The second unit, designated as module B, recorded relative humidity and liquid or air temperature. In 1976 the prototype model was installed on a Cessna Ag-truck and later on a Hiller 12E and a Bell 206 turbo-jet helicopter. A wind-driven pump was installed on the Ag-truck and an electrically powered pump was installed on the Bell 206. Results from the collected data showed that the electrically powered pump produced a very constant boom pressure, whereas the wind-driven pump produced a highly-variable pressure.

Whitney et al. (1985) used on-board data acquisition equipment to monitor temperature and pressure changes of an aerial application system while using soybean oil as a spray diluent. The authors stated that if significant temperature decreases occurred, viscosity reduction could cause a significant increase in flow rate. This in turn could cause misapplication of chemical due to the system being calibrated at ambient temperatures. Temperature measurements were used to ascertain liquid temperature rise in the tank as a function of fan blade angle and the elapsed spray time. Temperature measurements were also used to determine temperature gradients along the spray boom. Thermocouples were installed in the spray tank, along the spray boom and outside the aircraft for ambient air temperature measurements. A Hall Effect switch was mounted on the pump shaft to record rotational velocity. Pressure transducers were installed at the pump outlet and on the spray boom. A data logger and cassette tape recorder were used to record all measurements. Pump speeds in excess of those required for normal agitation were found to increase spray diluent temperatures. The maximum temperature gradient along the spray boom was found to resemble that of the temperature difference between the tank and ambient air temperature. No significant differences were found in deposition patterns using water vs. soybean oil.

Most spray systems use diaphragm check valves at the nozzles to prevent dripping. These check valves open only when a set pressure is reached. Pekrul et al. (1983) conducted a study of pressure transients of an aerial application system. The study was conducted using two pressure transducers interfaced with a microcomputer. One transducer monitored boom pressure while the second transducer monitored nozzle pressure. The study showed that if a leaking diaphragm is located on the boom, it will take longer for the check valve to open. This is due to the fact that a leak in the boom allows fluid to be drawn back into the tank by venturi action. Air enters the boom during the period when the suck-back valve has reduced the boom pressure. This in turn requires more fluid to be pumped into the boom before pressure can be built up for the check valves to open. Boom operating pressure was also found to affect the opening and closing times of the check valve.

Razak and Snyder (1977) developed a computer program which actually "flies" an aerial application mission. The program compares productivity and profitability of agricultural aircraft with respect to various design parameters. Various mission, airplane and economic variables are input into the program. The program then outputs airplane performance with respect to productivity and profit. Design factors which were found to be crucial to profitability and productivity included aircraft size, payload and ejection rate.

CHAPTER III

HARDWARE AND INSTRUMENTATION

An applicator in Junction City, Kansas agreed to the installation and testing of this system on his aircraft. The aircraft used was a Cessna Ag-truck (Figure 1) equipped with a 1060 liter (280 gallon) hopper and a hydraulically driven pump. The Ag-truck has an average swath width of 18-21 meters (60-70 feet) and a maximum speed of 195 km/h (121 mph) (Econ Corp., 1978).

Figure 1. Cessna Ag-Truck.

The data storage system was chosen on the basis of mass, portability, memory space and ease of interfacing. A variety of circuitry was examined and evaluated. Common problems found were lack of memory space and power requirements. A minimum of 512K bytes of memory was required. This requirement was due to the sampling rate and amount of data taken per sample. The sampling rate was chosen as one reading per second. This rate was chosen as the maximum acceptable rate which could adequately represent parameter changes during a mission. This decision was based on aircraft speed, operator response time and the fact that the system was to measure parameters on an overall mission basis rather than instantaneous parameter transients. Furthermore, the sample rate was directly proportional to the amount of computer memory needed to store the raw data. Each reading required 69 bytes of memory space. At a rate of 69 bytes per second a 512K byte RAM will fill in approximately 2 hours. Because most application missions do not exceed 2 hours in length 512K bytes of accessible memory is an acceptable amount. The data storage system chosen was a Apple IIc microcomputer installed with a Z-Ram card and an expanded memory. The expanded memory emulates three separate disk drives. Therefore, instead of actually writing data to a floppy disk while the aircraft is in the air, and consequently risking system damage due to vibration, the data is written to an emulated disk drive in the RAM space of the computer. When the aircraft returns from a mission the data can be transferred to disk safely. Power for the computer was provided by a 12 VDC gel type battery.

Signal inputs and analog to digital conversions were handled through the use of a Campbell Scientific model 21X data logger (Figure 2) which was interfaced to the Apple IIc through a serial link.

Four separate transducers were monitored by the data logger. Boom pressure was monitored through the use of a Setra Systems model 205-2 variable capacitance pressure transducer. The transducer was mounted to a nozzle outlet at the boom entrance (Figure 3). Output from this pressure transducer was sent to the data logger as a differential voltage between 0 and 5 VDC, proportional to 0 to 689.4 kPa (0 to 100 psia). This transducer had an accuracy to within plus or minus .11% full scale. Furthermore, acceleration response of the transducer was .05 psi/g. This acceleration response was acceptable due to the fact that most agricultural aircraft are not subjected to great lateral or normal accelerations. The data logger was programmed to receive input voltages from the boom pressure transducer of up to 5 volts. Within this range the data logger has a resolution of 666 microvolts. Excitation for this transducer was provided by a 12 VDC gel battery. An internal regulator eliminated the need for external voltage regulation and reduced the error due to excitation variation.

Figure 2. Campbell Scientific model 21X data logger.

Figure 3. Differential pressure transducer mounted on the spray boom.

Indicated airspeed measurements were made with a Setra Systems model 261-1 single ended output voltage, differential pressure transducer. Pressure differentials were measured between the static and ram air ports of the aircraft. Pressure differentials of 0 to 25.4 cm (0 to 10 inches) of water could be measured by the transducer. The transducer has an accuracy of plus or minus 1.0 %. Output voltages for this transducer were 0 to 5 VDC which were proportional to the measured pressure differential. The excitation requirement was 12 VDC. The output of this pressure transducer was read as a single ended voltage by the data logger and had a resolution of 333 microvolts. The transducer was installed behind the aircraft instrument panel. A maximum error of 4 % of full scale per G is possible. Therefore special care was taken to isolate the transducer from vibration.

Flow measurements were made with an SED paddle wheel flow meter installed between the chemical tank and the boom. The flow meter consisted of a magnetic pick up and a six bladed paddle with its axis perpendicular to the direction of flow.

Ambient air temperature measurements were made with a copper-constantan thermocouple which was installed through the roof of the aircraft (Figure 4). The need for ice point reference was eliminated through the use of a thermistor, built into the input terminal of the data logger, which served as the junction temperature reference.

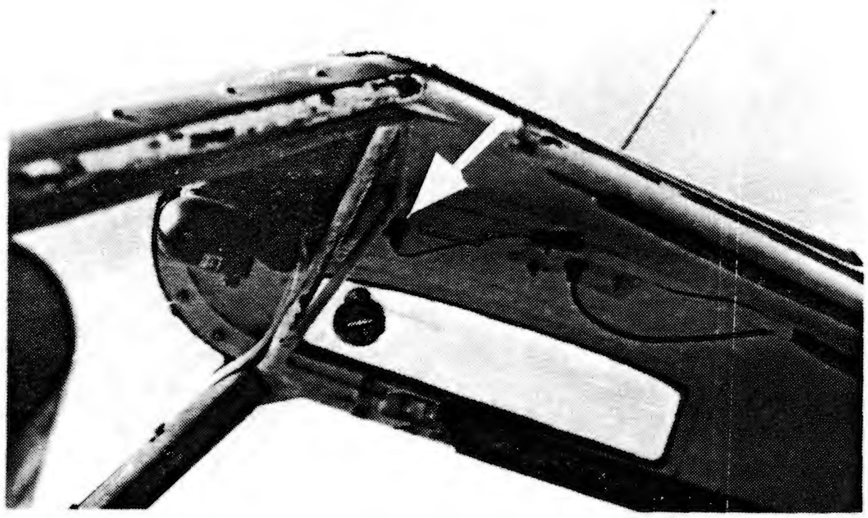

Figure 4. Placement of thermocouple.

Housings were constructed for both the computer and the data logger along with enclosures for two power supplies. Care was taken to isolate both data logger and computer from aircraft vibration. The data logger housing was installed behind the operator (Figure 5). The computer housing was installed beside the operator (Figure 6).

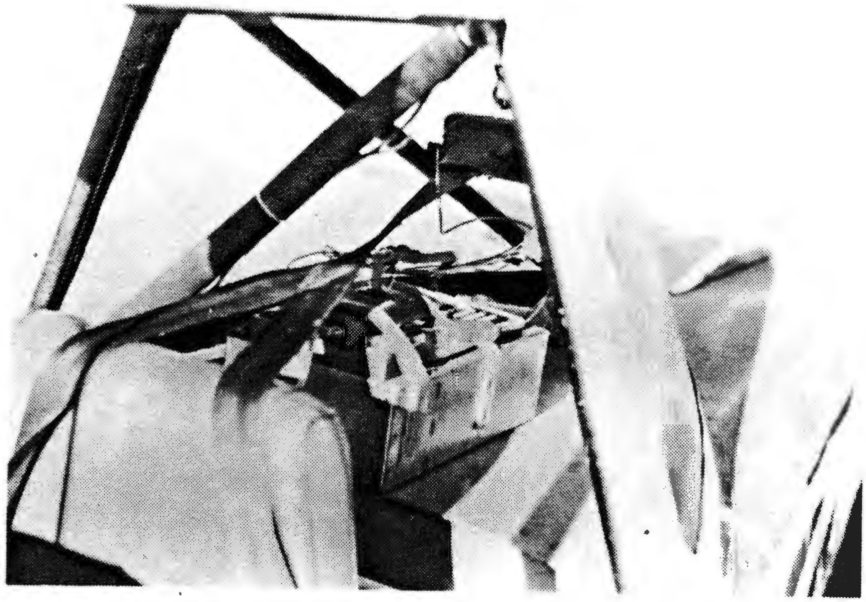

Figure 5. Data logger housing placement.

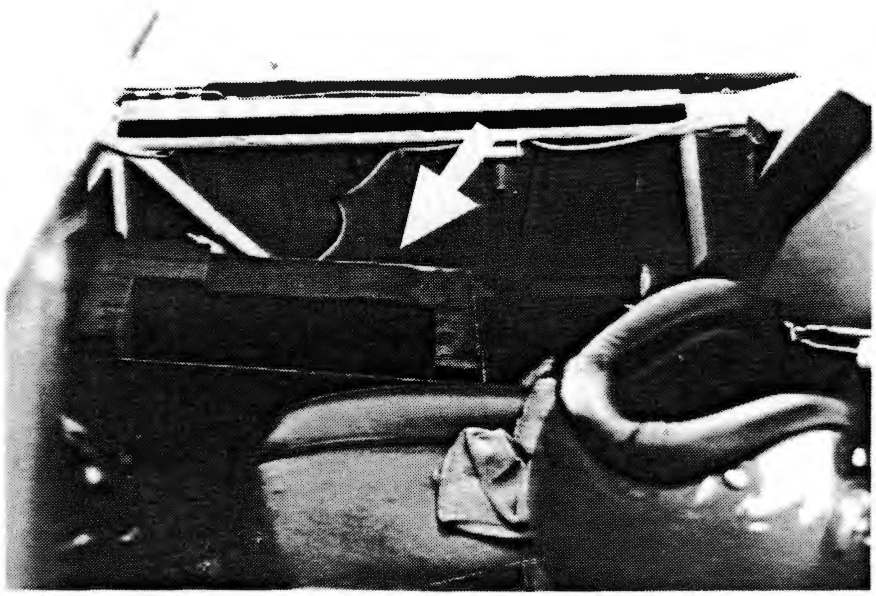

Figure 6. Computer housing placement.

CHAPTER IV

SOFTWARE DEVELOPMENT

The development of software for the acquisition system consisted of three separate components. These components consisted of 1) software for the data logger, 2) software for data transmission and collection for the on-board computer, 3) software for final data analysis.

Data Logger Software

The Campbell Scientific data logger required specialized processing instructions which were manually entered into the data logger. Table I lists the set of instructions which were used to collect and transfer data using the data logger. The specific instructions were obtained from the 21X operator's manual (Campbell Scientific, Inc., 1984). Two types of instruction sets are used with the data logger. The first set of instructions consists of input and temporary storage of signals received from the specific transducers. The second set of instructions relate to the output and processing of the collected data. The first instruction in Table I sets the sampling rate at one reading per second. The next set of instructions compare a predetermined voltage to the output

TABLE I

LIST OF ENTRIES FOR CAMPBELL SCIENTIFIC DATA LOGGER

INSTRUCTION LOCATION	PROGRAM NUMBER	ENTRY	DESCRIPTION
		1	Sampling rate.
1	P	89	Compare x with fixed value.
	1	3	Input location for x.
	2	3	Comparison code (if x greater or equal to fixed value.)
	3	300	Fixed value to be compared
	4	10	Set flag number 0 (the out put flag) causing output processing instructions to write to final storage.
2	P	17	Measures temperature of input panel for thermocouple reference.
	1	5	Location of temperature.
3	P	14	Differential voltage thermocouple temperature reading.
	1	1	Number of repetitions per reading.
	2	1	Range code (corresponds to slow integration and resolution of .33 microvolts.)
	3	1	Channel number to which the thermocouple is connected to.
	4	1	Thermocouple type code (corresponds to copper-constantan)
	5	5	Location of reference temperature.
	6	1	Storage destination location.
	7	1	Multiplier.
	8	0	Offset.
4	P	2	Differential voltage measurement for boom pressure measurements.
	1	1	Number of repetitions.
	2	5	Range code (corresponds to 5000 mV and slow analog to digital integration).

TABLE I (Continued)

INSTRUCTION LOCATION	PROGRAM NUMBER	ENTRY	DESCRIPTION
	3	2	Input channel of signal.
	4	2	Temporary storage location.
	5	1	Multiplier.
	6	0	Offset.
5	P	1	Single ended voltage measurement for differential pressure readings.
	1	1	Number of repetitions.
	2	5	Range code (corresponds to 5000 mV and slow analog to digital integration).
	3	7	Input channel of signal.
	4	3	Temporary storage location.
	5	1	Multiplier.
	6	0	Offset.
6	P	3	Pulse measurement for flowmeter readings.
	1	1	Number of repetitions.
	2	1	Pulse input channel number.
	3	0	Pulse count configuration (corresponds to high frequency pulse).
	4	4	Temporary storage location.
	5	1	Multiplier.
	6	0	Offset.
7	P	77	Real time output.
	1	11	Store hr.,min.,sec.
8	P	70	Output processing instruction to sample and store value from thermocouple reading.
	1	1	Number of repetitions.
	2	1	Starting input location.
9	P	70	Output processing instruction to sample and store value from boom pressure reading.
	1	1	Number of repetitions.
	2	2	Starting input location.
10	P	70	Output processing instruction to sample and store differential pressure readings.
	1	1	Number of repetitions.
	2	3	Starting input location.

TABLE I (Continued)

INSTRUCTION LOCATION	PROGRAM NUMBER	ENTRY	DESCRIPTION
11	P	70	Output processing instruction to sample and store pulse readings from flow transducer.
	1	1	Number of repetitions.
	2	4	Starting input location.

signal from the differential pressure transducer. If the output signal rises above 300 mV, which corresponds to approximately 60 km/h (37 mph), the output flag is set and processing of the data begins. The following four instruction sets are input instructions for the thermocouple, boom pressure, differential pressure and flow transducers, respectively. The next set in the series specifies the real time parameters to be stored. The final four instruction sets are the processing instructions. These commands specify the temporary location of the input data and transfer it to a final storage location which is specified in the instruction set. If, however, the data logger is interfaced to transmit serial data, permanent storage is bypassed and the data is sent directly through the serial port in ASCII code.

Data Acquisition Software

The data acquisition software was written using the BASIC computer language. A complete listing of this program can be found in Appendix A. BASIC was chosen over assembly language for the following reasons: 1) The Apple IIc contains no monitor routines for reading or writing to disk i.e. no ROM memory locations are accessible for this purpose. 2) The Apple IIc memory consists of two memory banks which must be continually switched depending on memory locations to be accessed. The ramdrive (disk emulator) complicates this situation further by adding 15 more banks to switch and to keep track of. 3) The BASIC interpreter was found to be fast enough to read and to store incoming data without overflowing the serial buffer.

The acquisition program initializes the disk drive emulators and reserves space for seven files in each of the three emulated disk drives. The program reads each set of ASCII strings sent from the data logger as one string and stores it in a file in the emulated disk drive. Each string sent from the data logger is 69 bytes long, this includes one byte for the ASCII return character. An example of the format of the transmitted data is given in Table II. The first two numbers of each column represent the corresponding data point identification. The first column lists a four digit number which represents the program table identification and the location of the output enable flag. The remaining five columns are self explanatory.

TABLE II

EXAMPLE FORMAT OF TRANSMITTED DATA

	HR-MIN	SECOND	TEMP	PRESS	SPEED	FLOW
01+0101.	02+0951.	03+011.1	04+6.162	5+668.7	06+591.9	07+25.00
01+0101.	02+0951.	03+012.1	04+6.145	5+0734.	06+630.8	07+22.00
01+0101.	02+0951.	03+013.1	04+6.136	5+0761.	06+0749.	07+22.00
01+0101.	02+0951.	03+014.1	04+6.136	5+0797.	06+0808.	07+20.00
01+0101.	02+0951.	03+015.1	04+6.138	5+0779.	06+0880.	07+18.00
01+0101.	02+0951.	03+016.1	04+6.139	5+0835.	06+0944.	07+16.00
01+0101.	02+0951.	03+017.1	04+6.164	5+0825.	06+1063.	07+13.00
01+0101.	02+0951.	03+018.1	04+6.164	5+0822.	06+1126.	07+07.00
01+0101.	02+0951.	03+019.1	04+6.164	5+0812.	06+1251.	07+4.000
01+0101.	02+0951.	03+020.1	04+6.164	5+0835.	06+1269.	07+3.000
01+0101.	02+0951.	03+021.1	04+6.173	5+0834.	06+1409.	07+1.000
01+0101.	02+0951.	03+022.1	04+6.167	5+0820.	06+1467.	07+0.000
01+0101.	02+0951.	03+023.1	04+6.184	5+0828.	06+1528.	07+0.000
01+0101.	02+0951.	03+024.1	04+6.201	5+0804.	06+1622.	07+0.000
01+0101.	02+0951.	03+025.1	04+6.192	5+0838.	06+1695.	07+0.000

The strings are stored in sequential text files by a loop in the program. Each time the loop is incremented a file byte pointer is incremented by 69 to place the following string at the end of the file. The maximum memory space of each emulated disk drive is 744 free sectors, each sector consisting of 256 bytes. The maximum memory space of a file is approximately 32K bytes. Thus the program loop was incremented 375 times to allow 25875 bytes to be stored per file. This amount of memory filled 103 sectors per file and also evenly distributed the data between the seven files in each drive. At a sampling rate of one reading per second, over two hours of data could be stored. Three loops are nested in the program, incrementing the drive number, file number and byte location within the file respectively. To use the system, the operator enters initial data which consists of the date, field identification, chemical being applied, aircraft number and pilot's name. The program then initializes the disk emulators and waits for the first input. The computer is then placed aboard the aircraft and is connected to the data logger. Since the data logger will not transmit serial data until the aircraft reaches approximately 60 km/h (37 mph) no transmission is encountered until the aircraft is in the air. When the aircraft returns from a mission transmission stops due to the airspeed reduction. The computer is removed from the aircraft and the operator has the option of storing the raw data on floppy disk or immediately processing the data and storing only the final results.

Data Analysis Software

Two primary choices are given to the user with respect to data analysis. The first choice is to analyze raw data which has been collected from a mission. In this mode the raw data must be already stored in the emulated disk drives or must be transferred there from floppy disks by the user. The alternative choice for the user is to have the computer display or print out final results which have previously been analyzed for a particular mission. In the latter case, the final statistics are stored and read from a separate floppy disk and the emulated disk drives are not required. A complete listing of the data analysis program can be found in Appendix B.

The data analysis program reads each set of readings from the emulated drives as a string. It then sorts the string into individual readings of hour, minute, second, pressure, flow, temperature and velocity. These readings are the raw data sent from the data logger and are converted from strings to numerics and assigned separate variable names. The raw flow readings are converted to gallons per minute based on the number of pulses counted during the reading. The pressure transducer outputs a voltage of 0 to 5 VDC. Therefore the pressure reading is converted to psi by multiplying it by .02 and subtracting the atmospheric pressure from this. If the user chooses to have the final data stored in SI units, the program converts these calculations to kPa and L/min. From this point the program decides, through a series of logic steps, at what point of the mission the current data reading was taken. This is done by checking both the pressure and the flow values and comparing them with the previous readings. A flag, CN, is set when the program encounters data in a spray pass. If a change in pressure of more than 20 psi or a change in flow of over 10 gpm occurs and CN is set to zero, a pass start flag, ST, is set. During the next reading, the ST flag is reset to zero but the CN flag remains set. When the program encounters a negative pressure, which indicates the spray has been shut off and the venturi action in the system is causing a suction in the boom, or when flow drops to zero the program sets an end of pass flag, EN. When EN is set, the CN flag is reset to zero and a TN flag is set indicating a turn. This process continues until the pressure no longer drops below zero after a pass. When the flow is shut off after the final pass, the pump is also shut off resulting in atmospheric pressure within the boom. This event marks the end of the spray pass and beginning of the return ferry time. All calculations within the program are based on the CN or EN flags or a combination of the two. Flow and pressure averages are calculated for each pass individually and a running average for the entire mission is also calculated. The first and last pressure and flow rate calculations of a pass are discarded from the pass averages. This is done to eliminate possible readings taken during transition conditions which could cause misleading results to be calculated. The first and final flow readings of a pass are used to calculate total flow and application rates.

Temperature averages are calculated for each pass and turn individually. Furthermore, an overall pass and turn temperature average is calculated using the entire temperature data base.

Calibrated airspeed is calculated using the differential pressure reading between the static and ram air ports of the aircraft. This calculation is based on the following equation for velocity of a fluid with respect to the difference in head:

$$V = \sqrt{\frac{2g(P_{ram}-P_{static})}{\rho}} \qquad 4.1$$

An atmospheric pressure is input by the operator for the specific day of the mission. Because the aircraft is relatively low to the ground during spray passes and turns, the assumption can be made that the atmospheric pressure remains constant. Therefore, according to the ideal gas law, the density of the air surrounding the aircraft can be assumed to be primarily a function of air temperature. The air density is calculated for each reading using the air temperature recorded at that particular time. Equation 4.1 is used to compute the calibrated airspeed. Using this velocity, the amount of time per pass, and a user entered swath width, the total area covered is calculated. The area is then used to calculate an application rate for each pass and an average application rate for the entire mission.

Final results are stored on disk and the raw data can then be discarded. Depending on user choice, the results are either displayed to the screen or printed in tabular form. Two tables are printed; the first table lists information regarding each pass and turn during the mission, the second table lists overall averages and final results for the entire mission.

CHAPTER V

EVALUATION AND RESULTS

The system was mounted on a Cessna Ag-truck for evaluation during actual spray missions. Four separate missions were flown and recorded. Custom software was used to convert the collected data into a format which was of benefit to the applicator. The following mission statistics were calculated:

1. Real time takeoff and landing times.
2. Percent of time spent ferrying, spraying and turning.
3. Flow rate of chemical during spraying.
4. Mean boom pressure during chemical application.
5. Total amount of chemical sprayed.
6. Application rate.
7. Ambient air temperature during spray passes and turns.
8. Mean aircraft velocity during spray passes.
9. Total area covered.

Tables III thru VI list the final mission statistics for all four missions.

TABLE III

FINAL STATISTICS FOR MISSION NO. 1

MISSION DATE	NOV/17/86
FIELD NUMBER	1
CHEMICAL	TORDON
AIRPLANE NO.	N9151R
MISSION INITIATION TIME	09:51:11.1
FIRST PASS INITIATION TIME	10:00:48.1
FINAL PASS COMPLETION TIME	10:16:42.1
MISSION COMPLETION TIME	10:27:27.1

% TIME			TOTAL AREA	TOTAL LIQUID SPRAYED	AVG. AIR TEMP (TURN)	AVG. AIR TEMP (PASS)	AVG. BOOM PRESS	AVG. FLOW RATE	APPL. RATE
ferry	turn	spray	ha	L	deg.C	deg.C	kPa	L/min	L/ha
56	32	12	18.9	449.9	8.17	8.37	123.5	111.7	23.8

TABLE IV

FINAL STATISTICS FOR MISSION NO. 2

MISSION DATE	NOV/17/86
FIELD NUMBER	2
CHEMICAL	TORDON
AIRPLANE NO.	N9195R
MISSION INITIATION TIME	10:55:48.1
FIRST PASS INITIATION TIME	11:02:31.1
FINAL PASS COMPLETION TIME	11:21:11.1
MISSION COMPLETION TIME	11:27:26.1

% TIME			TOTAL AREA	TOTAL LIQUID SPRAYED	AVG. AIR TEMP (TURN)	AVG. AIR TEMP (PASS)	AVG. BOOM PRESS	AVG. FLOW RATE	APPL. RATE
ferry	turn	spray	ha	L	deg.C	deg.C	kPa	L/min	L/ha
41	46	13	19.4	454.4	11.96	12.17	128.6	116	23.4

TABLE V

FINAL STATISTICS FOR MISSION NO. 3

MISSION DATE	NOV/17/86
FIELD NUMBER	3
CHEMICAL	TORDON
AIRPLANE NO.	N9151R
MISSION INITIATION TIME	11:48:59.1
FIRST PASS INITIATION TIME	12:11:26.1
FINAL PASS COMPLETION TIME	12:27:23.1
MISSION COMPLETION TIME	12:46:45.1

% TIME			TOTAL AREA	TOTAL LIQUID SPRAYED	AVG. AIR TEMP (TURN)	AVG. AIR TEMP (PASS)	AVG. BOOM PRESS	AVG. FLOW RATE	APPL. RATE
ferry	turn	spray	ha	L	deg.C	deg.C	kPa	L/min	L/ha
72	19	9	25.3	563.1	12.92	13.22	126.2	110.5	22.3

TABLE VI

FINAL STATISTICS FOR MISSION NO. 4

MISSION DATE	NOV/17/86
FIELD NUMBER	4
CHEMICAL	TORDON
AIRPLANE NO.	N1915R
MISSION INITIATION TIME	13:22:07.1
FIRST PASS INITIATION TIME	13:25:25.1
FINAL PASS COMPLETION TIME	13:44:51.1
MISSION COMPLETION TIME	::

% TIME			TOTAL AREA	TOTAL LIQUID SPRAYED	AVG. AIR TEMP (TURN)	AVG. AIR TEMP (PASS)	AVG. BOOM PRESS	AVG. FLOW RATE	APPL. RATE
ferry	turn	spray	ha	L	deg.C	deg.C	kPa	L/min	L/ha
24	60	16	18.6	449.3	17.95	18.17	128.5	112.9	24.1

Final mission statistics on a per pass basis along with examples of final statistics in English units can be found in Appendices C and D respectively. Occasionally an operator will apply chemical to a field with obstacles such as trees or ponds within the field. In such situations the operator will shut off the spray for a short period of time to avoid spraying these obstacles. The data analysis program interprets this sequence of events as a turn and consecutive spray pass. No computations are altered, however, an extra turn and spray pass is included in the computer output. This situation can easily be detected due to the short turn time displayed in the final results. An example of such a situation can be seen in passes number 18, 20, 22, 24 and 26 of mission number one in Appendix C. During each alternating pass the applicator turned off the spray to avoid a small pond in the field. This resulted in final statistics for two passes being printed for each of the actual passes in question.

Real time take-off and landing times were recorded and therefore total flight time was known. Figure 7 illustrates the percentage of time spent in each phase of the four missions. As can be seen from the figure, the operator spends only a small portion of his time actually applying chemical to a field. From a managerial standpoint the operator is providing income only during this small period of time.

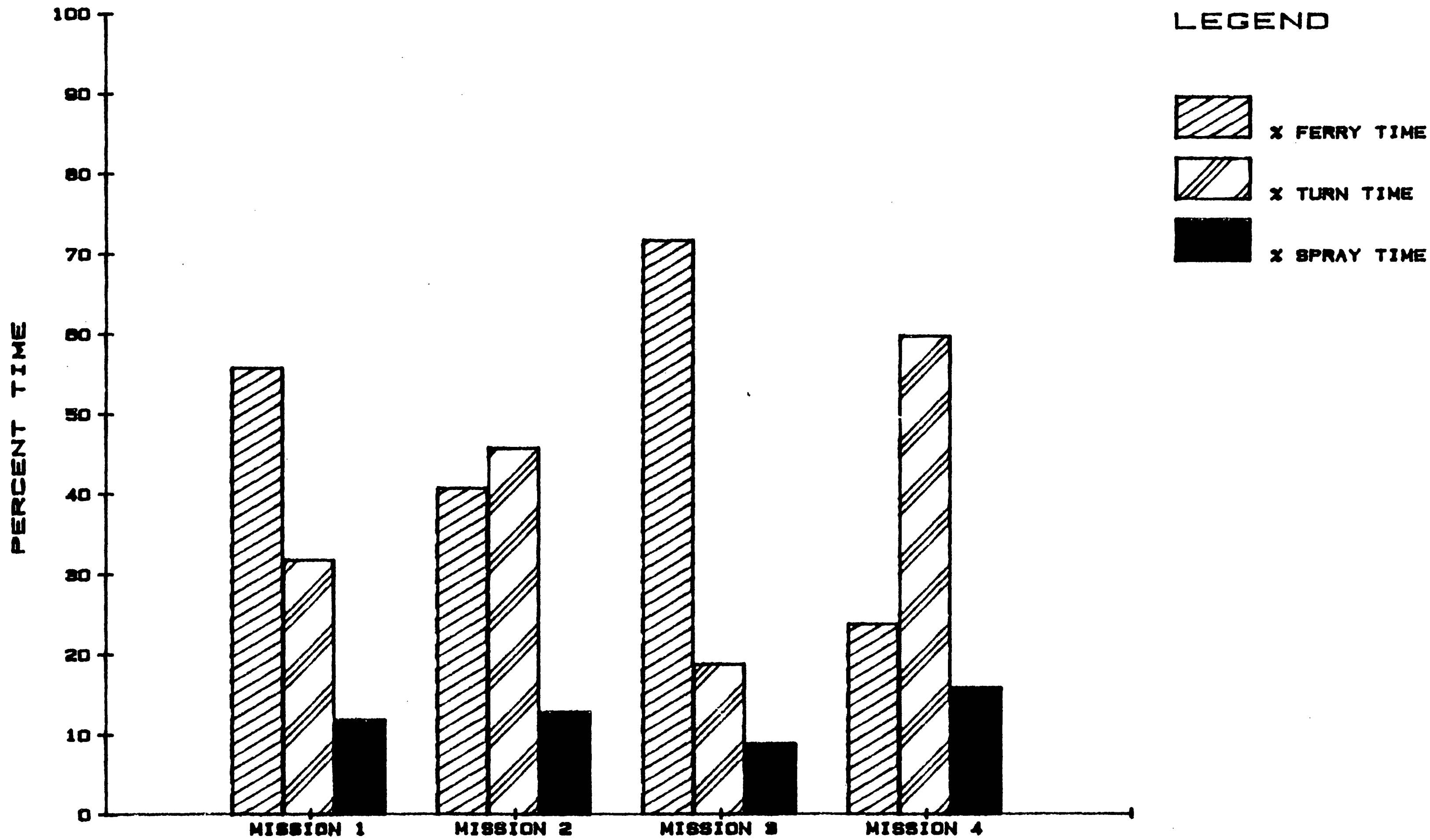

Figure 7. Percentage of time spent in each phase of four separate missions.

Air temperature measurements were intended for detecting the presence of a temperature inversion. A temperature inversion is an atmospheric condition consisting of a cool air layer at the earth's surface along with a layer of warmer air at a higher altitude. Yates et al. (1974) states that although many parameters affect chemical drift, the most undesirable condition for applying chemical exists during a temperature inversion along with very stable atmospheric conditions and low wind velocities. During such conditions droplets remain suspended in the air and may drift over excessive distances. Temperature measurements during a spray pass and consequently, during aircraft turns, are primary evidence of such atmospheric conditions. The aircraft gains altitude during a turn following a spray pass and then returns to a constant altitude during application. Therefore, temperature measurements, made during a turn, represent readings at a higher altitude than those made during a spray pass. Figures 8 thru 11 illustrate desirable atmospheric conditions for applying chemical. The figures show the air temperature readings during the spray passes were consistently higher than those during turns. If an inversion condition had existed Figures 8 thru 11 would be inverted. Such ambient air temperature data could serve as evidence in a contention over chemical drift.

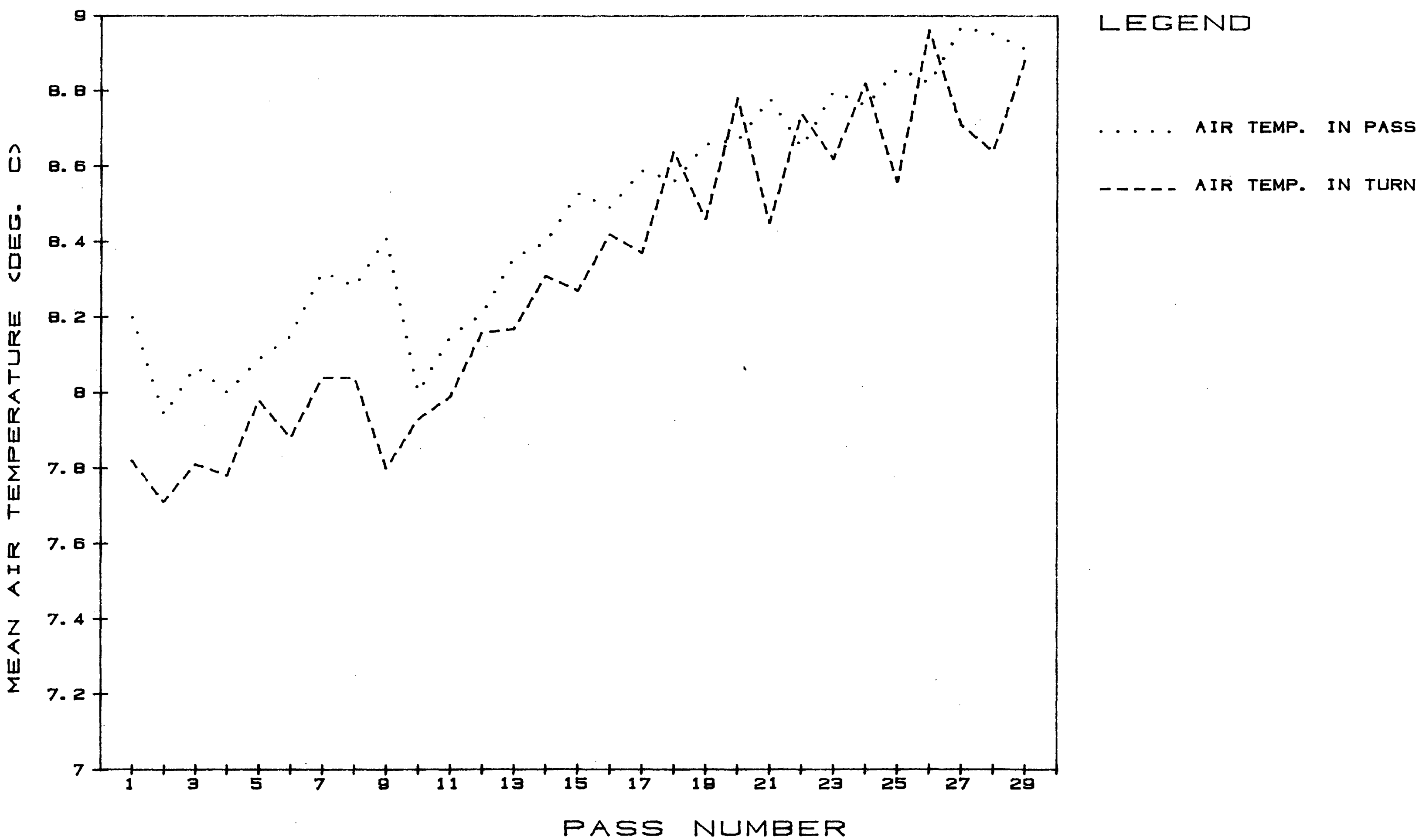

Figure 8. Ambient air temperature during spray passes vs. air temperature during turns for mission 1.

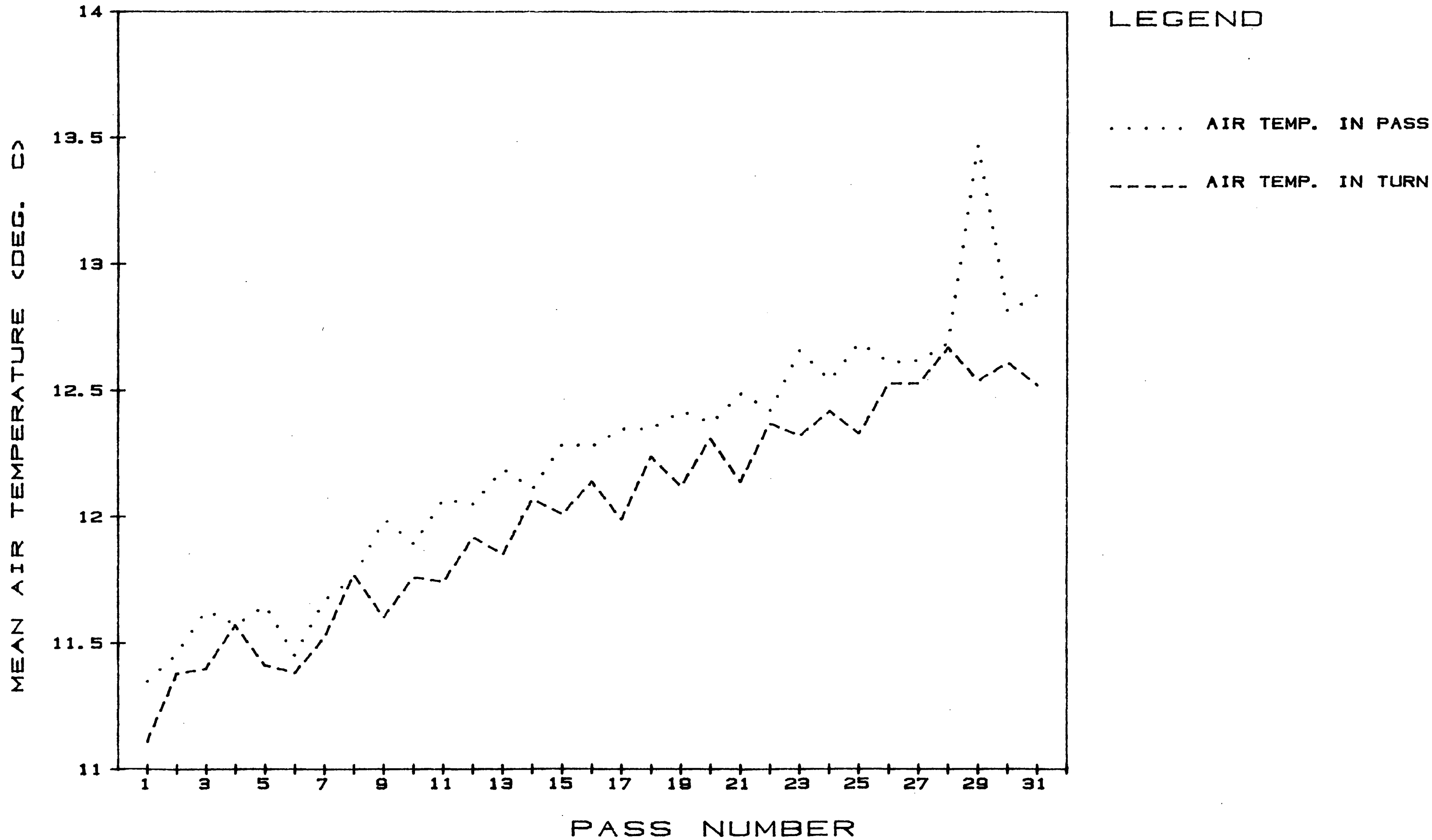

Figure 9. Ambient air temperature during spray passes vs. air temperature during turns for mission 2.

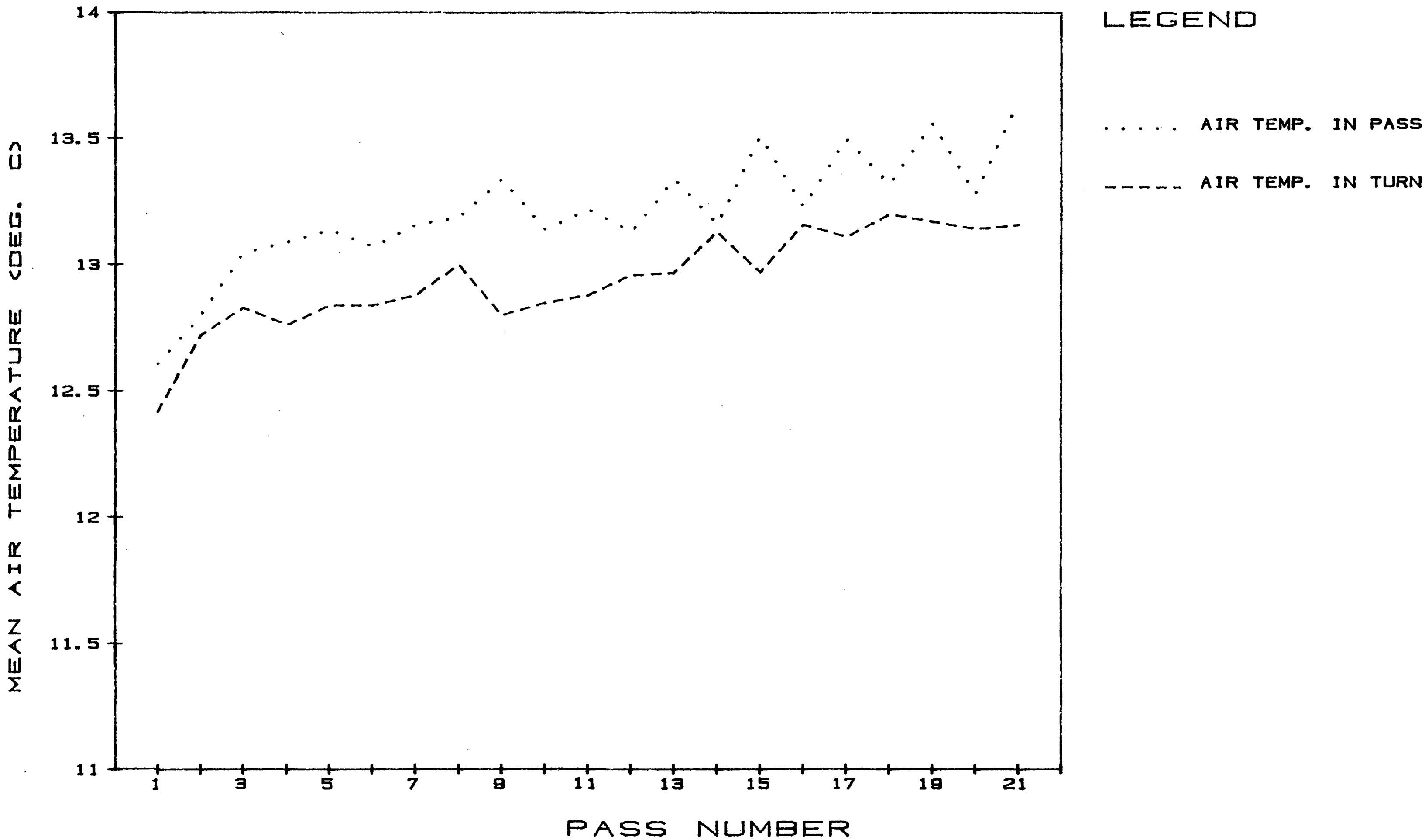

Figure 10. Ambient air temperature during spray passes vs. air temperature during turns for mission 3.

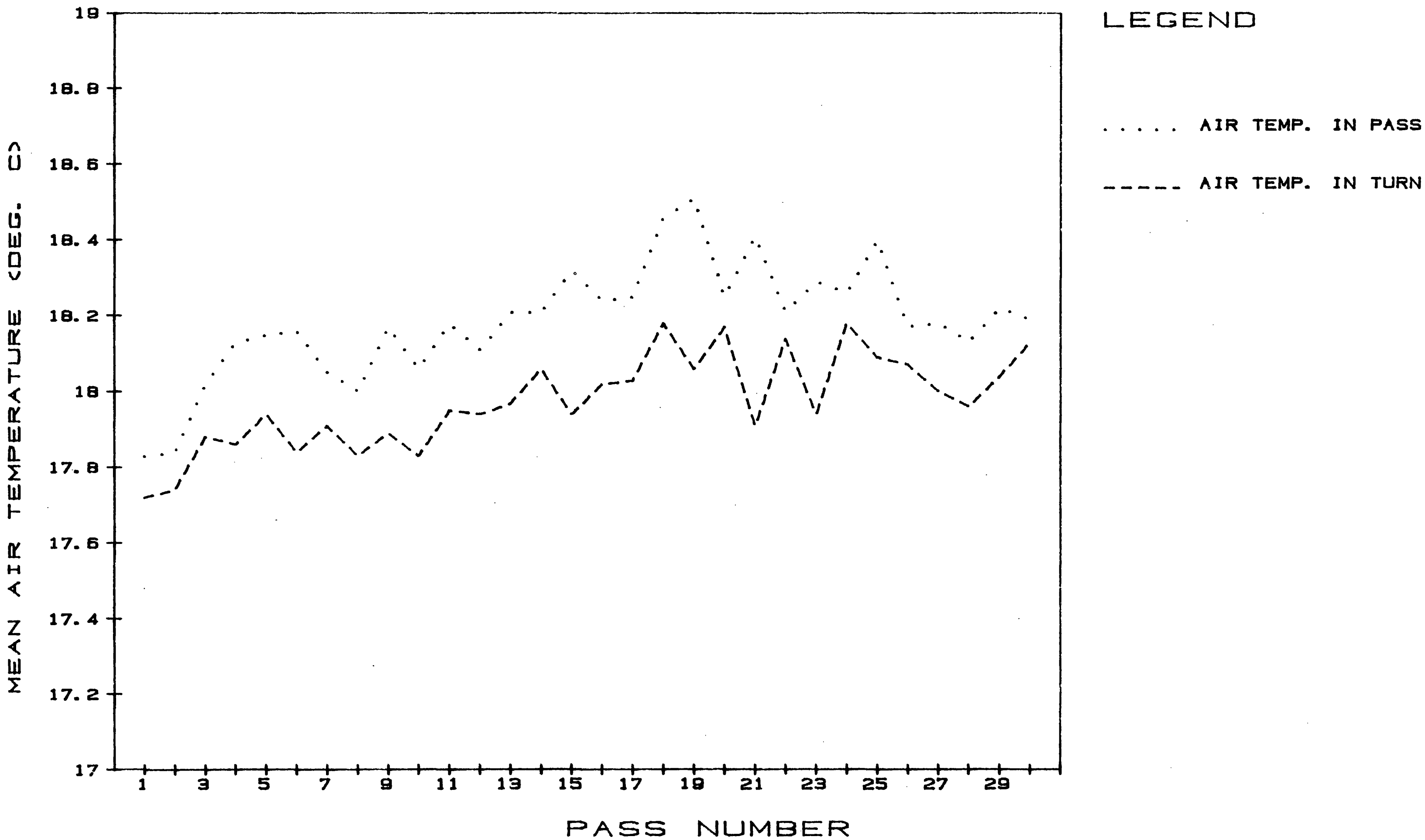

Figure 11. Ambient air temperature during spray passes vs. air temperature during turns for mission 4.

Pekrul et al. (1983) showed that within .5 seconds of flow turn on, one or more pressure spikes may be detected in the system. Furthermore, pressure pulse cycles due to pump frequency were shown to occur once the system reached steady state conditions. At an operating pressure of 207 kPa the amplitude of the pressure pulse cycles was observed to be within ten percent of the mean with a frequency of 44 Hz. The error which may have been caused by samples taken during a pressure spike was eliminated by eliminating the first pressure reading of each pass during calculations. However, the error caused by a one second sampling rate was not eliminated. It is not known at what frequency the pulse cycles on the aircraft were occurring. The same pump model was used by Pekrul as that which was installed on the Ag-Truck. Therefore, it can be assumed with a high degree of certainty that the cycles occurred at a frequency much higher than 1 Hz, the sampling rate. To reproduce a true mean, a sampling rate of twice the pulse frequency would have to be used. Due to the fact that the sampling rate was 1 Hz, the samples may have been taken at any point along the pressure cycle, consequently causing error in the mean pressure value calculations. Based on the observations of Pekrul et al. (1983) this error is on the magnitude of plus or minus ten percent of the true mean.

Figures 12 thru 15 show the correlation of flow and pressure for the four missions flown. The fluctuations of pressure averages among passes are thought to be due to the sampling rate error and are within plus or minus ten percent. Over longer periods of time, hardware problems could be detected in the spray system. Large deviations from these means over a spray season could indicate possible nozzle wear or leaks in the system.

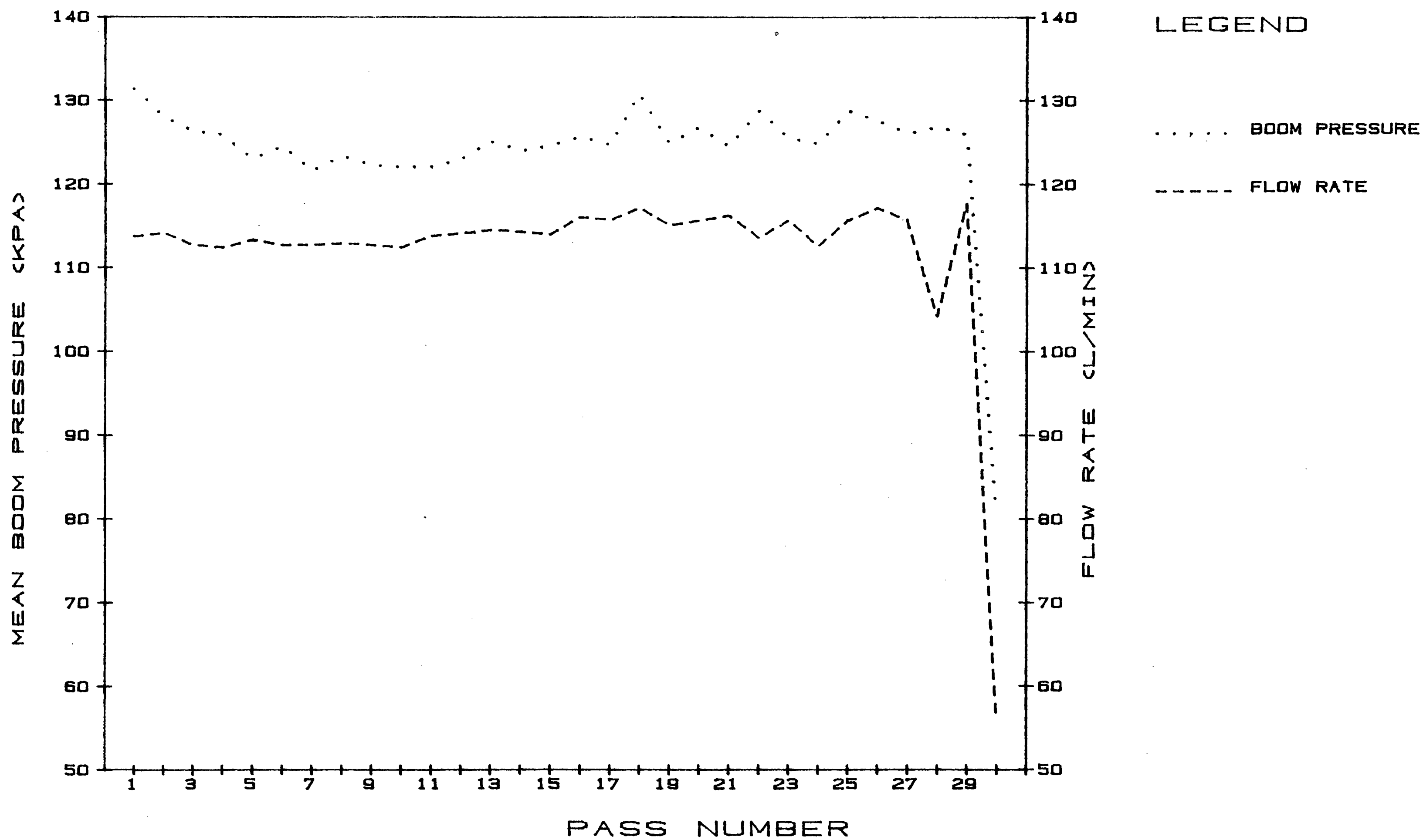

Figure 12. Flow vs. pressure characteristics for mission 1.

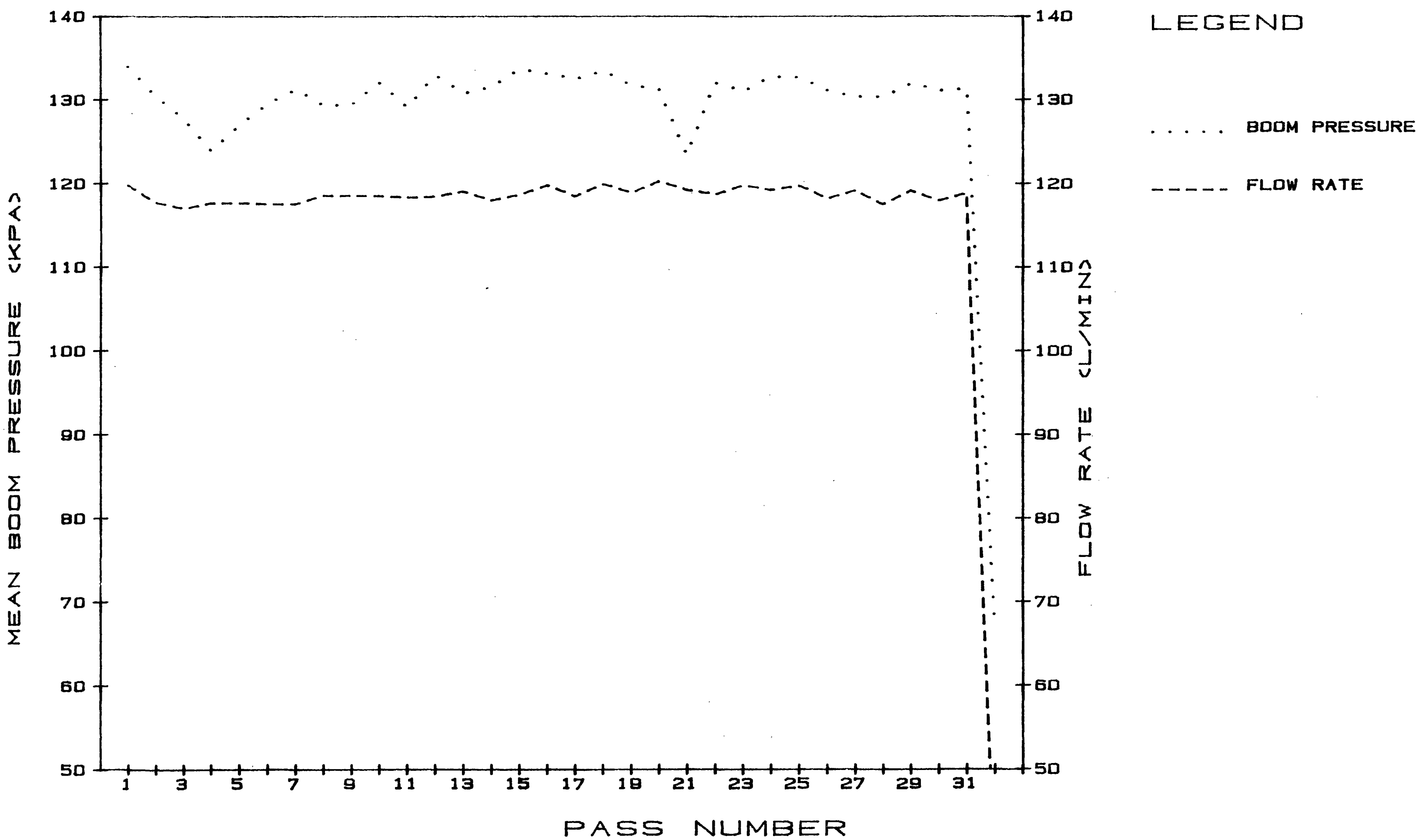

Figure 13. Flow vs pressure characteristics for mission 2.

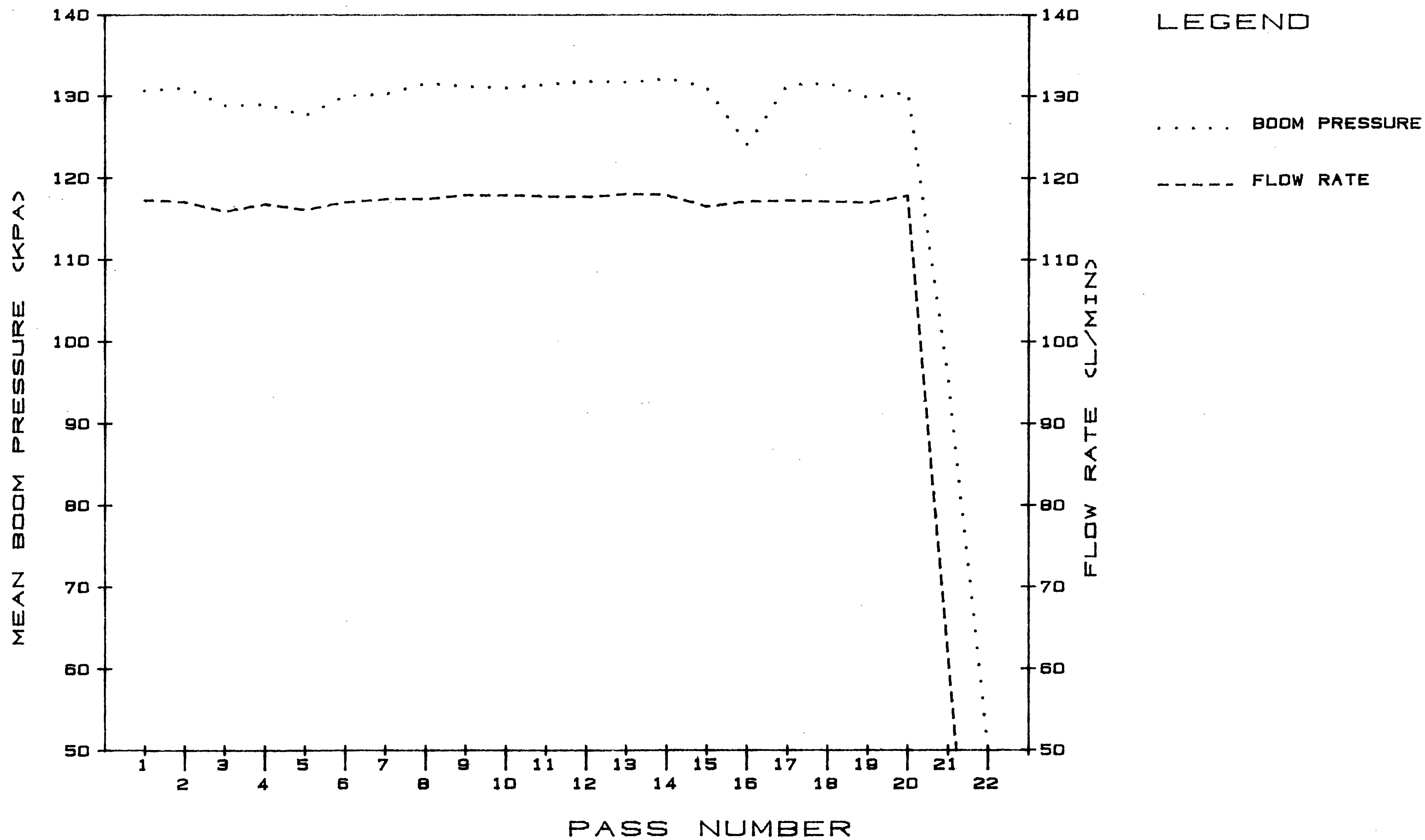

Figure 14. Flow vs pressure characteristics for mission 3.

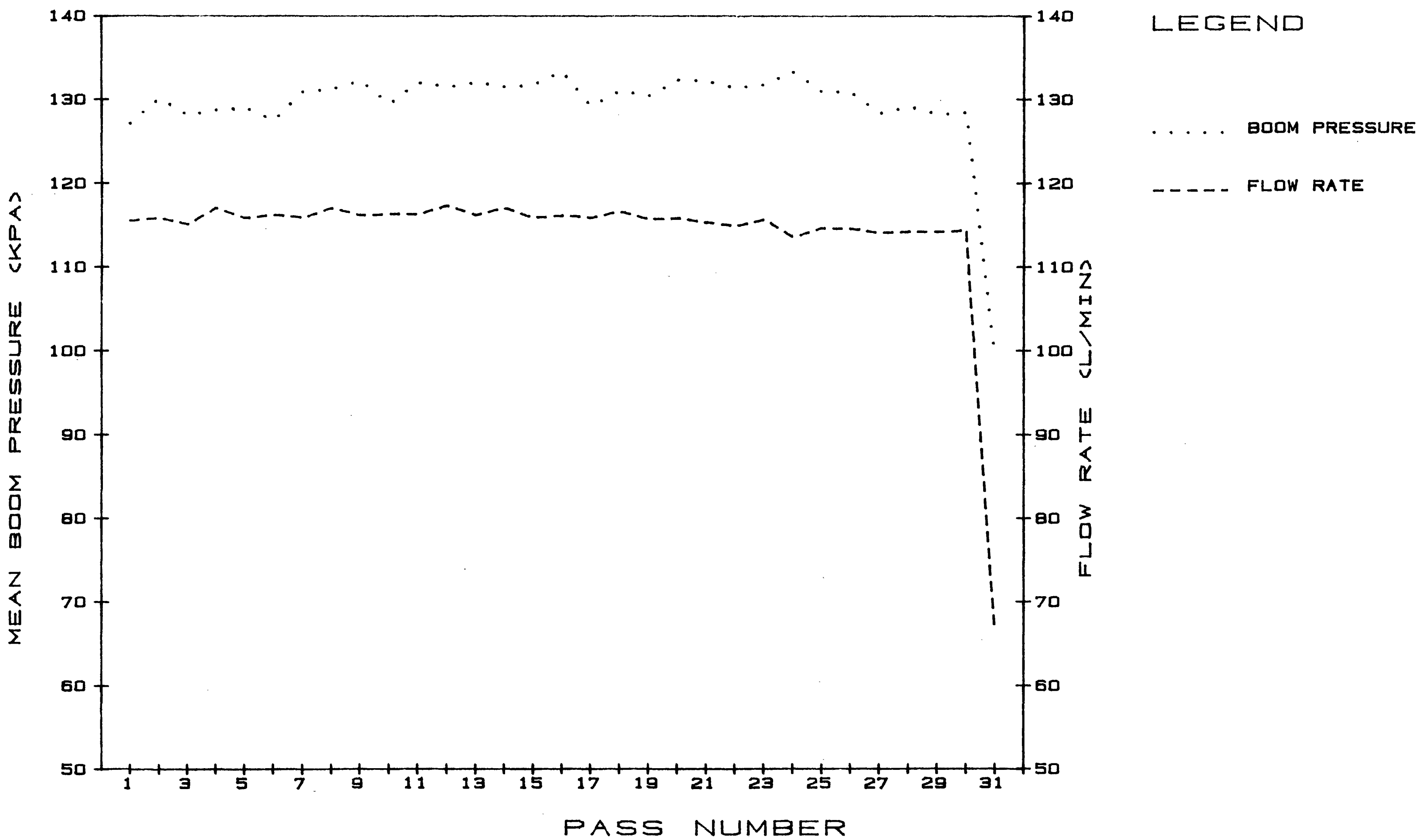

Figure 15. Flow vs pressure characteristics for mission 4.

CHAPTER VI

SUMMARY AND RECOMMENDATIONS

Summary

A data acquisition system was developed to measure pertinent agricultural aircraft mission parameters. Custom software was used to interpret collected data into useable form. The system performed well under actual spray conditions. Although concerns did arise about possible problems due to vibrations during flight, no problems were observed.

Aircraft velocity measurements are a source of error which must be recognized. Although velocities are also calibrated based on changing air density, they do not account for wind direction and speed. If a wind were to exist, the calibrated airspeed would still be a correct measurement but ground speed would be incorrect. Because the applicator applies chemical to a field in two opposing directions, the total area covered and overall application rate will not be significantly changed (assuming wind velocity and direction remain constant through the entire mission). Most chemical applications are performed in cross wind conditions and not in conditions in which the aircraft flies into or with the wind. Wind velocity and direction do change however, therefore, some error can be expected in these measurements. This problem may possibly be resolved through the use of radar or sonar units mounted on the aircraft itself. Accuracy of this system could be determined by applying chemical to a previously measured area and comparing results.

The error in the pressure calculations due to pressure pulses and a 1 Hz sampling rate could be eliminated in one of two ways. The sampling rate could be increased to twice that of the highest frequency of the pressure pulses. An assembly algorithm could be used to average and store these readings once per second and eliminate unwanted pressure peaks. A second alternative way of averaging the pressure signals would be to use an integrator op-amp circuit to average the signal from the pressure transducer to the data logger. Using a high pass filter along with the integrator would eliminate low frequency pressure spikes and allow only the higher frequency pulses as input into the integrator.

Recommendations

The system can be a very valuable tool to an applicator from a managerial standpoint. Over long periods of operation, an applicator has the option of retrieving data about a particular field to be sprayed. Consequently, he can obtain a general idea of what to expect during the mission and adequately plan for efficient application. A permanent record of such variables as total area covered and amount of liquid sprayed is a valuable asset for accounting purposes.

Although the system is relatively compact, it is too bulky for everyday use. Furthermore, it is unrealistic to assume that applicators will be willing to load and unload a computer from their aircraft before and after each mission. One solution to this problem may be to install a single board computer aboard the aircraft permanently and only transfer memory modules to a computer on the ground for analysis and permanent storage. The computer's clock rate and available memory space are two primary concerns. The amount of time required to process the collected data was found to be relatively long, approximately one half hour per mission depending on mission length. A faster microprocessor could help bring processing times down to reasonable lengths. Data analysis could take place during the mission. Because only final data must be stored, analyzing data during missions would significantly reduce the amount of memory space required. Because of the amount of logic involved however, a significantly faster microprocessor and possibly an assembly language program would have to be used to make decisions and still leave time for incoming data retrieval. This situation would be even more critical if more transducers were placed aboard the aircraft. Data was collected at a rate of 69 bytes per second. At this rate a 512K RAM will fill in approximately 2 hours. Because most application missions do not exceed 2 hours in length 512K bytes of available memory is an acceptable amount.

The addition of a fuel flow transducer aboard the aircraft could have great benefits to the applicator with respect to operational cost analysis. Incorporation of a fuel flow parameter into such a system along with custom software to interpret this data would allow an operator to perform a custom cost analysis of his operation.

Due to time constraints, only four missions were recorded and analyzed to test the system. Therefore, to further evaluate the effectiveness of such a system it is recommended that data be collected for an entire spray season. Through such an evaluation, the decision to continue the development of such a system could be made.

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APPENDIX A

DATA ACQUISITION SOFTWARE LISTING

```
]LIST

 10  REM  *** ACQUISITION OPENING ***
 30 D$ =  CHR$ (04)
 50 W$ =  CHR$ (23)
 70  HOME
 90  PRINT D$;"NOMON I,C,O"
 110  VTAB 3
 130  PRINT "      *****************************"
 150  PRINT "      *                           *"
 170  PRINT "      *    MISSION ANALYSIS FOR   *"
 190  PRINT "      *     AERIAL APPLICATION    *"
 210  PRINT "      *          AIRCRAFT         *"
 230  PRINT "      *                           *"
 250  PRINT "      *         CREATED BY        *"
 270  PRINT "      *                           *"
 290  PRINT "      *      THOMAS KACZYNSKI     *"
 310  PRINT "      *      GRADUATE STUDENT     *"
 330  PRINT "      *                           *"
 350  PRINT "      *        DEPARTMENT OF      *"
 370  PRINT "      *  AGRICULTURAL ENGINEERING *"
 390  PRINT "      *  OKLAHOMA STATE UNIVERSITY *"
 410  PRINT "      *    STILLWATER, OKLAHOMA   *"
 430  PRINT "      *                           *"
 450  PRINT "      *****************************"
 470  VTAB 24: PRINT "PRESS ANY KEY TO CONTINUE"
 490  GET P$: PRINT P$
 510  HOME
 530  REM  ** SET UP DRIVE EMULATOR **
 550  PRINT D$;"BLOAD RAMDRIVE,S6,D1"
 570  POKE 24579,0
 590  POKE 24580,0
 610  POKE 24591,2
 630  POKE 24592,1
 650  POKE 24593,1: CALL 24576
 670  DIM T$(0)
 690  PRINT D$;"BRUN SPEEDOS,S6,D1"
 710  HOME
 730  INPUT "INPUT AIRCRAFT NUMBER: ";AIRN$
 750  PRINT " "
 770  INPUT "INPUT YEAR ( FOUR DIGIT ): ";YR$
 790  PRINT " "
 810  INPUT "INPUT MONTH ( 3 LETTER ): ";MNTH$
 830  PRINT " "
 850  INPUT "INPUT DAY ( TWO DIGIT ): ";DAY$
 870  PRINT " "
 890  PRINT "INPUT CHEMICAL TO BE
 910  INPUT "USED ( UP TO 7 LETTERS ): ";CHEM$
 930  PRINT " "
 950  INPUT "INPUT FIELD ID: ";FLD$
 970  PRINT " "
 990  INPUT "INPUT APPROX. ACRES: ";ACR$
 1010  PRINT " "
 1030  PRINT "INPUT PILOTS NAME"
```

```
1050  INPUT "( UP TO 7 LETTERS ): ";NM$
1070  HOME
1090  PRINT "AIRCRAFT NUMBER......"AIRN$
1110  PRINT "YEAR................."YR$
1130  PRINT "MONTH................"MNTH$
1150  PRINT "DAY.................."DAY$
1170  PRINT "CHEMICAL............."CHEM$
1190  PRINT "FEILD ID NO.........."FLD$
1210  PRINT "ACRES................"ACR$
1230  PRINT "PILOT................"NM$
1250  PRINT " "
1270  PRINT "CORRECT ( Y OR N )"
1290  GET Y$: PRINT Y$
1310  IF Y$ = "Y" THEN  GOTO 1750
1330  HOME : PRINT "WHICH WOULD YOU LIKE TO CHANGE ?"
1350  PRINT " "
1370  PRINT "<1> AIRCRAFT NO."
1390  PRINT "<2> YEAR"
1410  PRINT "<3> MONTH"
1430  PRINT "<4> DAY"
1450  PRINT "<5> CHEMICAL"
1470  PRINT "<6> FIELD ID"
1490  PRINT "<7> ACRES"
1510  PRINT "<8> PILOT"
1530  PRINT " "
1550  PRINT "INPUT NUMBER TO CHANGE": GET N: PRINT N
1570  ON N GOTO 1590,1610,1630,1650,1670,1690,1710,1730
1590  HOME : INPUT "AIRCRAFT NUMBER ? ";AIRN$: GOTO 1070
1610  HOME : INPUT "YEAR ? ";YR$: GOTO 1070
1630  HOME : INPUT "MONTH ? ";MNTH$: GOTO 1070
1650  HOME : INPUT "DAY ? ";DAY$: GOTO 1070
1670  HOME : INPUT "CHEMICAL ?";CHEM$: GOTO 1070
1690  HOME : INPUT "FEILD ID ?";FLD$: GOTO 1070
1710  HOME : INPUT "ACRES ? ";ACR$: GOTO 1070
1730  HOME : INPUT "PILOT ? ";NM$: GOTO 1070
1750  REM
1770  PRINT D$;"OPEN DATAO,L180,S3,D1"
1790  PRINT D$;"DELETE DATAO"
1810  PRINT D$;"OPEN DATAO,L180,S3,D1"
1830  PRINT D$;"WRITE DATAO,R1"
1850  PRINT AIRN$: PRINT YR$: PRINT MNTH$: PRINT DAY$: PRINT CHEM$:
PRINT FLD$:
PRINT ACR$: PRINT NM$
1870  PRINT D$;"CLOSE DATAO"
1890 G =  FRE (0)
1910  REM  ** SET UP SERIAL PORT 2 FOR TRANSMISSION **
1930  PRINT D$;"IN#2"
1950  HOME
1970  REM  ** MANUAL SERIAL PORT INITIALIZATION **
1990  PRINT "TYPE CTRL(A) 0 8 B AND RETURN"
2010  PRINT "WAIT 15 SECONDS AND PUT COMPUTER"
2030  PRINT "ON THE PLANE"
2050  INPUT P$
2070  VTAB 24
```

```
2090  FOR I = 1 TO 7
2110  PRINT D$;"OPEN DATA"I",S3,D1"
2130  PRINT D$;"DELETE DATA"I
2150  NEXT I
2170  FOR I = 8 TO 14
2190  PRINT D$;"OPEN DATA"I",S3,D2"
2210  PRINT D$;"DELETE DATA"I
2230  NEXT I
2250  FOR I = 15 TO 21
2270  PRINT D$;"OPEN DATA"I",S3,D3"
2290  PRINT D$;"DELETE DATA"I
2310  NEXT I
2330  REM  ** THE ACQUISITION......
2350  REM  ** THE ACQUISITION......
2370  REM  ** BEGIN DATA ACQUISITION TO DRIVE 1 **
2390  FOR I = 1 TO 7
2410 X = 0
2430  FOR J = 1 TO 375
2450  INPUT T$(0)
2470  IF T$(0) = W$ THEN  GOTO 2550
2490  PRINT D$;"OPEN DATA"I",S3,D1"
2510  PRINT D$;"WRITE DATA"I",B"X
2530  PRINT T$(0)
2550  PRINT D$;"CLOSE DATA"I
2570  REM  ** X INCREMENTS BYTE LOCATION **
2590 X = X + 69
2610  IF T$(0) = W$ THEN J = 375
2630  IF T$(0) = W$ THEN I = 7
2650  NEXT J
2670  NEXT I
2690  IF T$(0) = W$ THEN  GOTO 3410
2710  REM
2730  REM  START ON DRIVE 2 *****
2750  REM
2770  FOR I = 8 TO 14
2790 X = 0
2810  FOR J = 1 TO 375
2830  INPUT T$(0)
2850  IF T$(0) = W$ THEN  GOTO 2930
2870  PRINT D$;"OPEN DATA"I",S3,D2"
2890  PRINT D$;"WRITE DATA"I",B"X
2910  PRINT T$(0)
2930  PRINT D$;"CLOSE DATA"I
2950 X = X + 69
2970  IF T$(0) = W$ THEN J = 375
2990  IF T$(0) = W$ THEN I = 14
3010  NEXT J
3030  NEXT I
3050  IF T$(0) = W$ THEN  GOTO 3410
3070  REM
3090  REM  ** START ON DRIVE 3 **
3110  FOR I = 15 TO 21
3130 X = 0
3150  FOR J = 1 TO 375
```

```
3170  INPUT T$(0)
3190  IF T$(0) = W$ THEN  GOTO 3270
3210  PRINT D$;"OPEN DATA"I",S3,D3"
3230  PRINT D$;"WRITE DATA"I",B"X
3250  PRINT T$(0)
3270  PRINT D$;"CLOSE DATA"I
3290 X = X + 69
3310  IF T$(0) = W$ THEN J = 375
3330  IF T$(0) = W$ THEN I = 21
3350  NEXT J
3370  NEXT I
3390  IF T$(0) = W$ THEN  GOTO 3410
3410  REM
3430  PRINT D$;"IN#0"
3450  HOME
3470  PRINT "PLEASE CHOOSE ONE"
3490  PRINT " "
3510  PRINT "<1> EXAMINE DATA"
3530  PRINT " "
3550  PRINT "<2> COPY DATA TO DISK"
3570  PRINT " "
3590  PRINT "<3> START ANALYSIS OF DATA"
3610  PRINT " "
3630  PRINT "<4> SEND RAW DATA TO PRINTER"
3650  GET N: PRINT N
3670  IF N = 1 THEN  PRINT "EXAMINE ?"
3690  IF N = 2 THEN  PRINT "COPY ?"
3710  IF N = 3 THEN  PRINT "ANALYZE ?"
3730  IF N = 4 THEN  PRINT "TO PRINTER ?"
3750  GET Y$: PRINT Y$
3770  IF Y$ = "N" THEN  GOTO 3450
3790  HOME
3810  ON N GOTO 3830,3850,3870,3930
3830  PRINT D$;"RUN BLOOKER,S6,D1"
3850  PRINT D$;"BRUN FID,S6,D1"
3870  HOME : PRINT "INSERT ANALYZING DISK AND HIT RETURN"
3890  INPUT RN:
3910  GOTO 3950
3930  PRINT D$;"RUN POUT,S6,D1"
3950  GOTO 3990
3970  GOTO 3990
3990  END
```

APPENDIX B

DATA ANALYSIS SOFTWARE LISTING

```
]LIST

5  REM  **************************************
6  REM  *                                    *
7  REM  *    DATA ACQUISITION ANALYSIS       *
9  REM  **************************************
10  REM  *** DATA ACQUISITION ANALYSIS *
30  REM
50  REM   ********* LIST OF VARIABLES *********
70  REM
90  REM    SE.........SECONDS
110  REM    TEMP.......TEMP. READING
130  REM   PRS........RAW BOOM PRESS. READING
150  REM   VEL........RAW VEL READING
170  REM   FLW........RAW PULSE COUNT (FLOW)
190  REM   HR.........HOUR READING
210  REM   MN.........MINUTE READING
230  REM   D..........INPUT TO DESIRE DECIMAL
250  REM   P..........USED TO CNVERT DECIMAL
270  REM   AIR$.......AIRCRAFT N NUMBER
290  REM   YR$........YEAR
310  REM   MNTH$......MONTH
330  REM   DAY$.......DAY DATE
350  REM   CHEM$......CHEMICAL USED
370  REM   FLD$.......FIELD I.D. NUMBER
390  REM   ACR$.......APPROX. ACRAGE SPRAYED
410  REM   K..........LOOP COUNTER FOR DRIVE NUMBER
430  REM   I..........LOOP COUNTER FOR FILE NUMBER
450  REM   L..........LOOP COUNTER FOR EACH READING
470  REM   ST.........MARKS START OF A PASS
490  REM    CN.........MARKS IF IN A PASS
510  REM    CH.........DIFF BETWEEN 2 CONSECUTIVE PASSES
530  REM    PH.........SAVES FLOW FROM PREVIOUS READING
550  REM   EN.........MARKS END OF A PASS
570  REM    TN.........MARKS IF IN A TURN
590  REM    GL.........CONVERTS RAW READING TO GAL/MIN
610  REM   FT.........TOTAL FLOW
630  REM    FP.........FLOW PER MINUTE
650  REM    FV.........AVERAGE FLOW RATE
670  REM    PS.........TOTAL BOOM PRES. USED TO AVERAGE
690  REM    PV.........AVERAGE BOOM PRESSURE
710  REM   N..........COUNTS READINGS DURING PASS
730  REM    SS.........COUNTS NUMBER OF PASSES
750  REM    TK.........INCREMENTED FOR EACH TURN
770  REM    RD........COUNTS EACH READING
790  REM    TM........TOTAL TEMP. USED TO AVG
810  REM    TT........TURN TEMPERATURE
830  REM     SB........SPRAY READINGS PER PASS
850  REM     TB........COUNTS READINGS/TURN
870  REM     XT........TURN TEMP AVG.
890  REM     XS........SPRAY TEMP. AVG.
910  REM     OS........TOTAL SPRAY TEMP (FOR AVG)
930  REM  FH........TEMPERATURE IN DEG. FAR.
950  REM  DN........DENSITY OF AIR PSF
```

```
970  REM  SP........CALIBRATED AIR SPEED
990  REM  AR........AREA COVERED
1010  REM  SW........INPUT SWADTH WIDTH
1030  REM  PC........DISTANCE TRAVELED PER READING
1050  REM  LN........DISTANC TRAVELED PER PASS
1070  REM  IV.......SAMPLING RATE
1090  REM  ME.......INCHES OF MERCURY
1110  REM  AP.......ATM. PRESSURE
1130  REM  EP.......INFORMATION ON PRINT OUT
1150  REM  SI.......UNITS DESIRED
1170  REM  SR.......SAVES PRESSURE FOR NEXT
1190  REM  CP.......CHANGE IN PRESSURE
1210  REM  HA.......HECTARES COVERED
1230  REM  CA.......APPLICATION RATE
1250  REM  R1$.......PRESSURE ARRAY
1270  REM  F1$.......FLOW RATE ARRAY
1290  REM  ZR$.......INDIVIDUAL APPL RATE ARRAY
1310  REM  FZ$.......INDIVIDUAL PASS VOLUME
1330  REM  FF$.......FINAL DATA ARRAY
1350  REM  S1$.......PASS BEGIN HOUR
1370  REM  S2$.......PASS BEGIN MINUTE
1390  REM  S3$.......PASS BEGIN SECOND
1410  REM  T1$.......PASS END HOUR
1430  REM  T2$.......PASS END MINUTE
1450  REM  T3$.......PASS END SECOND
1470  REM  PT$.......TURN TIME ARRAY
1490  REM  GB$.......USED TO CALC TURN TIME
1510  REM  ED$.......INDIVIDUAL PASS SPEED
1530  REM
1550  CLEAR
1570 D$ =  CHR$ (04)
1590  DIM TI$(12)
1610  DIM T$(0)
1630  DIM R1$(100),F1$(100),XS$(100)
1650  DIM LN$(100),ZR$(100),FZ$(100)
1670  DIM XT$(100),FF$(100)
1690  DIM S1$(100),S2$(100),S3$(100)
1710  DIM T1$(100),T2$(100),T3$(100)
1730  DIM PT$(100),GB(100),ED$(100)
1750  HOME
1770  ONERR  GOTO 4590
1790  REM
1810  REM
1830  PRINT " "
1850  PRINT "    ******************************"
1870  PRINT "    *                            *"
1890  PRINT "    *     AERIAL APPLICATION     *"
1910  PRINT "    *            DATA            *"
1930  PRINT "    *          ANALYSIS          *"
1950  PRINT "    *                            *"
1970  PRINT "    *        DEVELOPED BY        *"
1990  PRINT "    *                            *"
2010  PRINT "    *      THOMAS KACZYNSKI      *"
2030  PRINT "    *      GRADUATE STUDENT      *"
```

```
2050  PRINT "    *                               *"
2070  PRINT "    *        DEPARTMENT OF          *"
2090  PRINT "    *  AGRICULTURAL ENGINEERING     *"
2110  PRINT "    *  OKLAHOMA STATE UNIVERSITY    *"
2130  PRINT "    *    STILLWATER, OKLAHOMA       *"
2150  PRINT "    *                               *"
2170  PRINT "    *******************************"
2190  REM
2210  VTAB 23: PRINT "PRESS ANY KEY TO CONTINUE"
2230  GET A$: PRINT A$
2250  HOME
2270  PRINT "CHOOSE ONE OF THE FOLLOWING: "
2290  PRINT " "
2310  PRINT "(1) DATA ALREADY ANALYZED"
2330  PRINT " "
2350  PRINT "(2) ANALYSIS OF RAW DATA"
2370  PRINT " "
2390  INPUT W
2410  ON W GOTO 2430,2530
2430  INPUT "UNDER WHAT FILE NAME IS DATA STORED ? ";FI$
2450  PRINT "INSERT DATA DISK AND PRESS SPACE BAR "
2470  GET A: PRINT A
2490  REM  ** SET P5 FOR DATA ALREADY ANALYZED **
2510 P5 = 1
2530  HOME
2550  REM
2590  REM
2650  HOME
2670  IF P5 = 1 THEN  GOTO 2870
2690  INPUT "INPUT THE ATMOSPHERIC PRESSURE IN INCHES OF MERCURY:
";ME
2710  REM
2730  REM  **** CALCULATE ATMOSPHERIC PRESSURE BASED ON
2750  REM  *** INCHES OF MERCURY
2770 AP = ME * 144 * .491154
2790  HOME
2810  INPUT "INPUT YOUR DESIRED SWATH WIDTH IN FEET ";SW
2830  HOME
2850  INPUT "INPUT THE SAMPLE RATE IN SECONDS ";IV
2870  HOME
2890  PRINT "CHOOSE ONE OF THE FOLLOWING"
2910  PRINT " "
2930  PRINT " "
2950  PRINT "(1)  PRINT RESULTS TO PRINTER"
2970  PRINT " "
2990  PRINT "(2)  PRINT RESULTS TO SCREEN ONLY"
3010  PRINT " "
3030  PRINT " "
3050  INPUT W
3070  ON W GOTO 3090,3110
3090 EP = 1: GOTO 3130
3110 EP = 2: GOTO 3130
3130  HOME
3150  PRINT "PLEASE CHOOSE UNITS DESIRED"
```

```
3170  PRINT " "
3190  PRINT "(1) SI"
3210  PRINT " "
3230  PRINT "(2) ENGLISH"
3250  PRINT " "
3270  INPUT W
3290  ON W GOTO 3310,3330
3310 SI = 1: GOTO 3350
3330 SI = 0
3350  HOME
3370  IF P5 = 1 THEN  GOSUB 13070
3390  REM
3410  IF P5 = 1 THEN  GOTO 5410
3430  INPUT "DO YOU WANT FINAL RESULTS STORED ON DISK? ";DS$
3450  IF DS$ = "Y" OR DS$ = "YES" THEN  GOTO 3490
3470  GOTO 3590
3490  PRINT " "
3510  INPUT "STORE UNDER WHAT FILE NAME? ";FI$
3530  PRINT " "
3550  PRINT "INSERT STORAGE DISK AND PRESS SPACE BAR"
3570  GET A: PRINT A
3590  REM
3610  HOME
3630  IF EP = 2 THEN  GOTO 3710
3650  PRINT "TURN ON PRINTER AND PRESS SPACE BAR."
3670  GET A: PRINT A
3690  HOME
3710  REM
3730  REM  ** OPEN AND INPUT FIELD AND PLANE DATA **
3750  PRINT D$;"OPEN DATAO,L180,S3,D1"
3770  PRINT D$;"READ DATAO,R1"
3790  INPUT AIR$,YR$,MT$,DAY$,CHEM$,FLD$,ACR$,NM$
3810  PRINT D$;"CLOSE DATAO"
3830  REM
3850  REM  ***** DATA SORT ****************
3870  REM
3890 CC = 0
3910  FOR K = 1 TO 3
3930  IF CC = 1 THEN K = 3: GOTO 4050
3950  REM  ** K TRACKS EMULATED DISK DRIVES **
3970  REM  ** E1 AND E2 TRACK FILE NAMES **
3990  IF K = 1 THEN E1 = 1:E2 = 7
4010  IF K = 2 THEN E1 = 8:E2 = 14
4030  IF K = 3 THEN E1 = 15:E2 = 21
4050  REM
4070  FOR I = E1 TO E2
4090  IF CC = 1 THEN I = E2: GOTO 4290
4110  REM
4130  REM  ** CLEAR NON ESSENTIAL MEMORY **
4150 X =  FRE (0)
4170 ZZ = 374
4190 Q = 0
4210  REM
4230  IF K = 1 AND I = 1 THEN Q = 207
```

```
4250  IF K = 1 AND I = 1 THEN ZZ = 372
4270  REM
4290  REM  ** BEGIN LOOP READS STRINGS IN FILES **
4310  FOR L = 1 TO ZZ
4330  REM  ** CC MARKS ERROR HANDLING ROUTINE **
4350  IF CC = 1 THEN L = ZZ: GOTO 5270
4370  REM   ** RD TRACKS NUMBER OF READINGS **
4390 RD = RD + IV
4410  REM
4430  REM  ** READ FILES OFF OF RAMDRIVE **
4450  PRINT D$;"OPEN DATA"I",S3,D"K
4470  REM
4490  PRINT D$;"READ DATA"I",B"Q
4510  REM
4530  INPUT T$(0)
4550  REM
4570  GOTO 4730
4590  REM  ** ONERR ROUTED HERE ***
4610  REM  ** RESET ERROR SIGNALS **
4630  POKE 216,0
4650  PRINT D$;"CLOSE DATA"I
4670 CC = 1
4690 X =  FRE (0)
4710  GOTO 3910
4730  REM
4750  PRINT D$;"CLOSE DATA"I
4770  REM
4790  REM  *** PULL VALUES OUT OF STRING **
4810 S$ =  MID$ (T$(0),25,4):TMP$ =  MID$ (T$(0),34,5)
4830 P$ =  MID$ (T$(0),43,5):H$ =  MID$ (T$(0),14,2)
4850 V$ =  MID$ (T$(0),53,5):F$ =  MID$ (T$(0),63,5)
4870 MN$ =  MID$ (T$(0),16,2)
4890  REM  *** CONVERT STRINGS TO NUMERICS ***
4910 TEMP =  VAL (TMP$):PRS =  VAL (P$):VE =  VAL (V$)
4930 FLW =  VAL (F$)
4950  REM
4970  REM  ** CALL SUB TO CHECK IF IN PASS **
4990  GOSUB 5530
5010  REM  ** IF IN PASS CALL PRESSURE SUB **
5030  IF CN = 1 THEN  GOSUB 6850
5050  GOSUB 7110
5070  GOSUB 7750
5090  GOSUB 8110
5110  GOSUB 9110
5130  REM  ** PH AND SR SAVE FLOW AND PRESSURE
5150  REM     FOR NEXT PASS ****
5170 PH = FLW
5190 SR = PRS
5210  REM  ** INCREMENT BYTE LOCATION OF NEXT
5230  REM  ** STRING
5250 Q = Q + 69
5270  REM
5290  NEXT
5310  NEXT
```

```
5330  NEXT
5350  REM  ** ERROR HANDLING ROUTINE JUMPS
5370  REM  ** OUT OF LOOP TO HERE
5390  GOSUB 10270
5410  REM
5430  PRINT "DO YOU WANT MORE ?"
5450  INPUT Y$
5470  IF Y$ = "Y" THEN  GOTO 1530
5490  IF Y$ = "YES" THEN  GOTO 1530
5510  END
5530  REM  **** FLOW RATE CALCULATOR *****
5550  REM
5570  REM  ** CONVERT VOLTAGE READING TO PSI
5590 PRS = PRS * .02 - 14.696
5610  REM  ** CONVERT PULSE READING TO GAL/MIN
5630 FLW = FLW * .00450644 * 60 * IV
5650  REM  ** CALCULATE CHANGE IN PRESS. AND FLOW
5670  REM  ** FOR DETERMINING PASS OF TURN
5690 CH = FLW - PH
5710 CP = PRS - SR
5730  REM  ** SET START MARKER IF PASS IS ON
5750  IF ST = 1 GOTO 5870
5770  IF CH > 10 AND CN = 0 THEN ST = 1
5790  IF CP > 20 AND CN = 0 THEN ST = 1
5810  IF ST = 1 THEN SB = 0
5820  IF ST = 1 THEN KP = 0
5830  GOTO 5910
5850  REM  ** RESET START MARKER TO 0
5870 ST = 0
5890  REM
5910  REM  ** SET END OF PASS MARKER
5930  IF CH < 12 THEN EN = 0
5950  REM
5970  IF ST <  > 1 THEN  GOTO 6070
5990  REM  ** SET IN PASS, IN TURN AND PASS COUNTERS
6010 CN = 1
6030 TN = 0
6050 SS = SS + 1
6070  REM  ** CHECK ALL COMBINATIONS OF PASS AND TURN
6090  IF CN = 1 AND PRS <  - 1 THEN EN = 1
6110  REM
6130  IF CN = 1 AND FLW = 0 THEN EN = 1
6150  REM
6170  IF ST = 1 THEN EN = 0
6190  IF EN = 1 THEN CN = 0
6210  REM
6230  IF EN = 1 THEN TN = 1
6250  REM
6270  IF CN = 1 THEN N = N + 1
6290  IF TN = 1 AND PRS <  - 2 THEN XX = XX + 1
6310  REM
6330  IF TN = 1 AND PRS <  - 1 THEN TK = TK + 1
6350  REM  ** CALCULATIONS DURING PASS (CN=1)
6370  IF CN <  > 1 THEN  GOTO 6710
```

```
6390 SB = SB + 1
6410  REM  ** FLOW RATE CALCULATIONS **
6430  IF SI = 0 THEN GL = FLW / (60 * IV)
6450  IF SI = 1 THEN GL = FLW / (60 * IV) * 3.785412
6470 FT = FT + GL
6490 FZ =  INT (FT * 10 + .5) / 10
6495  IF ST = 1 THEN N2 = 0
6500  IF ST = 1 THEN  GOTO 6650
6510  REM  ** FLOW PER MINUTE TOTAL
6520 NNN = NNN + 1
6525 N2 = N2 + 1
6530 FP = FP + FLW
6550  REM  ** FLOW PER MINUTE AVERAGE
6570 FV = FP / NNN
6590  REM
6610  IF SI = 1 THEN FV = FV * 3.785412
6630  REM   ** AVERAGE PER PASS CALCULATIONS **
6650  IF ST = 1 THEN F1 = 0:L1 = 0
6655  IF CN = 1 THEN L1 = L1 + GL
6660  IF ST = 1 THEN  GOTO 6790
6690  IF CN = 1 THEN F1 = F1 + FLW
6710  IF EN <  > 1 THEN  GOTO 6790
6730 F1 = F1 / N2
6750  IF SI = 1 THEN F1 = F1 * 3.785412
6770 F1 =  INT (F1 * 10 + .5) / 10
6790  REM
6810  RETURN
6830  REM
6850  REM   **** PRESSURE   CALCULATOR *****
6870  REM
6890  REM  ** CALCULATE TOTAL AND AVG PRESSURE
6895  IF ST = 1 THEN R1 = 0
6900  IF ST = 1 THEN  GOTO 7050
6904  IF PRS < 5 AND CN = 1 THEN  GOTO 7050
6918 N1 = N1 + 1
6919 KP = KP + 1
6920 PS = PRS + PS
6930 PV = PS / N1
6950  REM  ** IF SI UNITS RECALCULATE
6970  IF SI = 1 THEN PV = PV * 6.894757
6990  REM  ** PRESSURE PER PASS CALCULATOR **
7030 R1 = R1 + PRS
7050  REM
7070  RETURN
7090  REM
7110  REM  ********** TEMPERATURE CALCULATIONS *****************
7130  REM
7150  REM  ** CHECK IF IN PASS OR TURN
7170  REM  ** RESET COUNTERS
7190  IF ST <  > 1 THEN  GOTO 7250
7210 XS = 0
7230 OS = 0
7250  REM
7270  IF EN <  > 1 THEN  GOTO 7350
```

```
7290 TB = 0
7310 XT = 0
7330 OT = 0
7350  REM  ** IF NOT IN TURN SKIP ****
7370  IF TN <  > 1 THEN  GOTO 7530
7390  IF PRS <  - 2 THEN UU = TEMP + UU:TV = UU / XX
7410 TB = TB + 1
7430 OT = TEMP + OT
7450 XT =  INT ((OT / TB) * 100 + .5) / 100
7470  IF SI = 1 GOTO 7530
7490 XT = (XT * 1.8) + 32
7510 XT =  INT (XT * 100 + .5) / 100
7530  REM  ** IF NOT IN PASS SKIP ***
7550  IF CN <  > 1 THEN  GOTO 7690
7570 YY = TEMP + YY:SV = YY / N
7590 OS = TEMP + OS
7610 XS =  INT ((OS / SB) * 100 + .5) / 100
7630  IF SI = 1 THEN  GOTO 7710
7650 XS = (XS * 1.8) + 32
7670 XS =  INT (XS * 100 + .5) / 100
7690  REM
7710  REM
7730  RETURN
7750  REM  ****** TIME CALCULATOR ******************************
7770  REM
7790  REM  ** IF FIRST READING SAVE THE TIME **
7810  IF RD > 1 THEN  GOTO 7870
7830 TI$(1) = H$:TI$(2) = MN$:TI$(3) = S$
7850  REM  ** SAVE TIME OF BEGINING OF FIRST PASS **
7870  IF SS = 1 AND ST = 1 THEN TI$(4) = H$:TI$(5) = MN$:TI$(6) = S
$
7890  REM  ** SAVE TIME OF END OF LAST PASS **
7910  IF EN = 1 AND PRS > 0 THEN TI$(7) = H$:TI$(8) = MN$:TI$(9) =
S$
7930  REM  ** IF IN PASS COUNT TIME
7950  IF CN = 1 THEN LQ = LQ + IV
7970  REM  ** IF IN TURN COUNT TIME
7990  IF TN = 1 AND PRS <  - 1 THEN TQ = TQ + IV
8010  REM  ** CALCULATE PERCENTAGE OF TIME
8030  REM  ** SPENT IN PASSES AND TURNS
8050 SU =  INT (LQ / RD * 100 * 1 + .5) / 1
8070 TU =  INT (TQ / RD * 100 * 1 + .5) / 1
8090  RETURN
8110  REM  ************* VELOCITY CALCULATOR *********
8130  REM
8150 P1 = P1 + 1
8170  IF ST = 1 THEN P1 = 1
8190  REM  ** RESET PASS LENGTH TO 0 **
8210  IF ST = 1 THEN LN = 0
8230  REM  ** SET TEMP TO FARENHEIT **
8250 FH = (TEMP * 1.8) + 32
8270  REM  ** CALCULATE AIR DENSITY **
8290 DN = AP * 28.97 / ((FH + 460) * 1545.31)
8310  REM  ** CALCULATE DELTA HEAD IN VELOCITY EQUATION **
```

```
8330 DH = .002 * VEL * 5.1929318
8350  REM  ** CALCULATE AIR SPEED  IN MPH **
8370 SP = ( SQR (64.4 * DH / DN)) * 3600 / 5280
8390  REM  ** CALCULATE SPEED AVERAGE PER PASS **
8410  IF ST = 1 THEN ED = 0
8430  IF CN = 1 THEN ED = ED + SP
8450  IF EN <  > 1 THEN  GOTO 8530
8470 ED = ED / SB
8490  IF SI = 1 THEN ED = ED * 5280 * .3048 / 1000
8510 ED =  INT (ED * 1 + .5) / 1
8530  REM
8550  REM  ******** AREA CALCULATOR ***********
8570  REM
8590  REM  ** CALCULATE PASS LENGTH AND AREA IF
8610  REM  ** IN A PASS
8630  IF CN <  > 1 THEN  GOTO 8950
8650  REM  ** CALCULATE LENGTH DURING READING **
8670 PC = (SP * 5280 / 3600) / IV
8690  REM  ** CALCULATE TOTAL PASS LENGTH **
8710 LN = LN + PC
8730  IF SI = 1 THEN MR =  INT (LN * .3048)
8750 LN =  INT (LN)
8770  REM  ** CALCULATE ACRES FROM SQUARE FEET **
8790 TR = SW * PC / 43560
8810  REM  ** KEEP TRACK OF TOTAL ACRES **
8830 AR = TR + AR
8850  IF SI = 1 THEN HA = AR * .4046856
8870 CA = FT / AR
8890  IF SI = 1 THEN CA = FT / HA
8910  IF ST = 1 THEN ZR = 0
8930 ZR = ZR + TR
8950  REM
8970  IF EN <  > 1 THEN  GOTO 9070
8990  IF SI = 1 THEN ZR = ZR * .4046856
9010  REM  ** CALCULATE APPLICATION RATE HERE **
9030 ZR = L1 / ZR
9050 ZR =  INT (ZR * 10 + .5) / 10
9070  REM
9090  RETURN
9110  REM  ** CONVERSION TO STRINGS AND ARRAY STORAGE **
9130  REM
9150  REM  ** DETERMINE WHEN TO STORE AND CONVERT **
9170  IF EN = 1 THEN  GOTO 9730
9190  IF ST = 1 THEN  PRINT " "
9210  IF ST = 1 THEN  PRINT " "
9230  IF ST = 1 AND SS > 1 THEN GT = 1
9250  IF ST = 0 OR SS < 1 THEN GT = 0
9270  IF GT = 0 GOTO 9550
9290  REM  **** TURN TEMP CONVERSION AND STORAGE **
9310 XT$(SS - 1) =  STR$ (XT)
9330  REM  *** TOTAL TURN TIME TQ **
9350 GB(SS - 1) = TQ
9370  REM  ** TURN TIME FOR EACH TURN ***
9390  IF SS = 2 THEN PT$(1) =  STR$ (GB(1))
```

```
9410  IF SS = 2 THEN  GOTO 9510
9430 VV = GB(SS - 1) - GB(SS - 2)
9450 VV =  INT (VV * 1 + .5) / 1
9470  REM  ** ROUND OFF AND STORAGE OF TURN TIMES **
9490 PT$(SS - 1) =  STR$ (VV)
9510  REM  ** PERCENT OF TIME IN TURNS CONVERTED"
9530 TU$ =  STR$ (TU)
9550  REM
9570  REM  ** IF NOT BEGINING OF PASS THEN SKIP **
9590  IF ST = 0 THEN  GOTO 9670
9610  REM  ** START OF PASS HERE, STORE VARIABLES IN ARRAYS **
9630  REM  ** STORE START TIME OF PASS ***
9650 S1$(SS) = H$:S2$(SS) = MN$:S3$(SS) = S$
9670  REM
9690  REM  ** IF NOT BEGINING OF TURN THEN SKIP **
9710  IF EN <  > 1 THEN  GOTO 10230
9730  REM  ** CONVERT AND STORE BOOM PRESSURE **
9750 R1 = R1 / KP
9770  IF SI = 1 THEN R1 = R1 * 6.894757
9790 R1 =  INT (R1 * 10 + .5) / 10
9810 R1$(SS) =  STR$ (R1)
9830  REM  ** CONVERT AND STORE FLOW **
9850 F1$(SS) =  STR$ (F1)
9870  REM  ** CONVERT AND STORE AIR TEMP IN PASS **
9890 XS$(SS) =  STR$ (XS)
9910  REM  ** CONVERT PERCENT OF TIME SPENT SPRAYING
9930 SU$ =  STR$ (SU)
9950  REM  ** CONVERT AND STORE PASS LENGTH **
9970  IF SI = 0 THEN LN$(SS) =  STR$ (LN)
9990  IF SI = 1 THEN LN$(SS) =  STR$ (MR)
10010  REM  ** CONVERT AND STORE APPLICATION RATE
10030 ZR$(SS) =  STR$ (ZR)
10050  REM  ** CONVERT AND STORE TOTAL VOLUME SPRAYED **
10070 FZ$(SS) =  STR$ (FZ)
10090  REM  ** CONVERT AND STORE AREA SPRAYED **
10110  IF SI = 0 THEN AR$ =  STR$ (AR)
10130  IF SI = 1 THEN AR$ =  STR$ (HA)
10150  REM  ** CONVERT AND STORE AIRSPEED **
10170 ED$(SS) =  STR$ (ED)
10190  REM  ** STORE AND CONVERT END OF PASS TIMES **
10210 T1$(SS) = H$:T2$(SS) = MN$:T3$(SS) = S$
10230  REM
10250  RETURN
10270  REM  ************ FINAL DATA ANALYSIS ****************
10290  REM
10310  REM  ** STORE THE END OF MISSION TIMES **
10330 TI$(10) = H$:TI$(11) = MN$:TI$(12) = S$
10350  REM  ** CONVERT AND ROUND OFF FINAL STATISTICS **
10370 FV =  INT (FV * 10 + .5) / 10
10390  IF SI = 0 THEN SV = (SV * 1.8) + 32
10410  IF SI = 0 THEN TV = (TV * 1.8) + 32
10430 SV =  INT (SV * 100 + .5) / 100
10450 TV =  INT (TV * 100 + .5) / 100
10470 FT =  INT (FT * 10 + .5) / 10
```

```
10490 PV =  INT (PV * 10 + .5) / 10
10510 CA =  INT (CA * 10 + .5) / 10
10530  IF SI = 0 THEN AR =  INT (AR * 10 + .5) / 10
10550  IF SI = 1 THEN AR =  INT (HA * 10 + .5) / 10
10570 SU =  INT (SU * 1 + .5) / 1
10590 TU =  INT (TU * 1 + .5) / 1
10610 FU = 100 - (SU + TU)
10630  REM
10650  REM  ** SAVE ALL FINAL STATS. IN FF$ ARRAY **
10670  FOR MM = 1 TO 12
10690 FF$(MM) = TI$(MM)
10710  NEXT
10730 FF$(13) =  STR$ (SV):FF$(14) =  STR$ (TV)
10750 FF$(15) =  STR$ (SU):FF$(16) =  STR$ (SS)
10770 FF$(17) =  STR$ (PV):FF$(18) =  STR$ (FV)
10790 FF$(19) =  STR$ (FT):FF$(20) =  STR$ (AR)
10810 FF$(21) =  STR$ (FU):FF$(22) =  STR$ (CA)
10830 FF$(23) =  STR$ (TU)
10850  REM  ***** TABULAR PRINT OUT ********
10870  REM
10890  IF EP = 1 THEN  PRINT D$;"PR#1"
10910  PRINT " "
10930  PRINT "________________________________________________________
_____________
   "
___
10950  PRINT " "
10970  PRINT "             DATE      FIELD      CHEMICAL      AIRPLANE
"
10990  PRINT "________________________________________________________
_____________
   "
___
11010  PRINT " "
11030  PRINT "          "MT$"/"DAY$"/"YR$"     "FLD$"        "CHEM$
"     "AIR$

11050  PRINT "________________________________________________________
_____________
   "
___
11070  PRINT " "
11090  PRINT "________________________________________________________
_____________
   "
___
11110  PRINT " "
11130  PRINT " PASS  AVERAGE   AVERAGE   PASS   TURN    PASS     AI
R   APL.  TU
RN"
11150  PRINT " NO.    BOOM      FLOW     TEMP   TEMP   LENGTH   SPE
ED  RATE  TI
ME"
11170  PRINT "       PRESS.     RATE                               AV
G.
  "
11190  PRINT " "
11210  IF SI = 1 THEN  GOTO 11270
```

```
 11230  PRINT "        psi        gpm       deg.F   deg.F   ft       mp
h  gal/ac   s
ec"
 11250  GOTO 11290
 11270  PRINT "        kPa       L/min      deg.C   deg.C   m        km
/h  L/ha    s
ec"
 11290  REM
 11310  PRINT "_____________________________________________________
____________
___"
 11330  PRINT " "
 11350  FOR H = 1 TO SS
 11370  HTAB 3: PRINT H;
 11390  HTAB 8: PRINT R1$(H);
 11410  HTAB 18: PRINT F1$(H);
 11430  HTAB 28: PRINT XS$(H);
 11450  IF H = SS THEN  GOTO 11490
 11470  HTAB 35: PRINT XT$(H);
 11490  IF SI = 1 THEN  HTAB 43: PRINT LN$(H);
 11492  IF SI = 0 THEN  HTAB 42: PRINT LN$(H);
 11510  HTAB 52: PRINT ED$(H);
 11530  HTAB 58: PRINT ZR$(H);
 11550  IF H = SS THEN  GOTO 11610
 11570  HTAB 65: PRINT PT$(H)
 11590  GOTO 11630
 11610  PRINT " "
 11630  REM
 11650  NEXT
 11670  PRINT "_____________________________________________________
____________
___"
 11690  PRINT " "
 11710  PRINT "                         FINAL ANALYSIS "
 11730  PRINT "_____________________________________________________
____________
___"
 11750  PRINT " "
 11770  PRINT "MISSION INITIATION TIME     _________ "FF$(1)":"FF$(2)
":"FF$(3)
 11790  PRINT "FIRST PASS INITIATION TIME _________ "FF$(4)":"FF$(5)
":"FF$(6)
 11810  PRINT "FINAL PASS COMPLETION TIME _________ "FF$(7)":"FF$(8)
":"FF$(9)
 11830  PRINT "MISSION COMPLETION TIME     _________ "FF$(10)":"FF$(1
1)":"FF$(12)

 11850  PRINT " "
 11870  PRINT "_____________________________________________________
____________
___"
 11890  PRINT " "
 11910  PRINT "    % TIME       TOTAL    TOTAL    AVG.    AVG.    AVG.
  AVG.   APP
```

```
L."
 11930  PRINT "                    AREA   LIQUID   AIR    AIR   BOOM
  FLOW   RAT
E"
 11950  PRINT "                           SPRAYED  TEMP   TEMP  PRESS
  RATE
"
 11970  PRINT "                                    (TURN) (PASS)

"
 11990  PRINT ""
 12010  IF SI = 1 THEN  GOTO 12070
 12030  PRINT "ferry turn spray  acre     gal   deg.F  deg.F   psi
  gpm gal/ac
"
 12050  GOTO 12090
 12070  PRINT "ferry turn spray   ha        L   deg.C  deg.C   kPa
  L/min L/ha
"
 12090  PRINT "_____________________________________________________
____________
___"
 12110  PRINT " "
 12130  PRINT " "
 12150  HTAB 2: PRINT FU;
 12170  HTAB 8: PRINT TU;
 12190  HTAB 13: PRINT SU;
 12210  HTAB 20: PRINT AR;
 12230  HTAB 27: PRINT FT;
 12250  HTAB 34: PRINT TV;
 12270  HTAB 42: PRINT SV;
 12290  HTAB 48: PRINT PV;
 12310  HTAB 56: PRINT FV;
 12330  HTAB 63: PRINT CA
 12350  PRINT "_____________________________________________________
____________
___"
 12370  PRINT " "
 12390  IF EP = 1 THEN  PRINT D$;"PR#0"
 12410  IF DS$ = "Y" OR DS$ = "YES" THEN  GOSUB 12450
 12430  RETURN
 12450  REM  *** DATA DISK WRITE SUBROUTINE *
 12470  REM
 12490  REM  ** FINAL STATS STORAGE FILE **
 12510  PRINT D$;"OPEN F"FI$",S6,D1"
 12530  PRINT D$;"WRITE F"FI$
 12550 SI$ =  STR$ (SI)
 12570  PRINT SI$
 12590  PRINT AIR$: PRINT YR$: PRINT MT$: PRINT DAY$
 12610  PRINT CHEM$: PRINT FLD$: PRINT ACR$: PRINT NM$
 12630  FOR H = 1 TO 23
 12650  PRINT FF$(H)
 12670  NEXT
 12690  PRINT D$;"CLOSE F"FI$
```

```
12710  REM
12730  REM  ** ACTUAL DATA FILE **
12750  PRINT D$;"OPEN "FI$",S6,D1"
12770  PRINT D$;"WRITE "FI$
12790  FOR H = 1 TO SS
12810  PRINT R1$(H)
12830  PRINT F1$(H)
12850  PRINT XS$(H)
12870  PRINT LN$(H)
12890  PRINT ED$(H)
12910  PRINT ZR$(H)
12930  IF H = SS THEN  GOTO 12990
12950  PRINT XT$(H)
12970  PRINT PT$(H)
12990  REM
13010  NEXT
13030  PRINT D$;"CLOSE "FI$
13050  RETURN
13070  REM  *** DISK READ SUBROUTINE **
13090  PRINT D$;"OPEN F"FI$",S6,D1"
13110  PRINT D$;"READ F"FI$
13130  INPUT UN$
13150 UN =  VAL (UN$)
13170  INPUT AIR$,YR$,MT$,DAY$,CHEM$,FLD$,ACR$,NM$
13190  FOR H = 1 TO 23
13210  INPUT FF$(H)
13230  NEXT
13250  PRINT D$;"CLOSE F"FI$
13270  REM  ** CONVERT STRINGS TO VALUES **
13290 SV =  VAL (FF$(13))
13310 TV =  VAL (FF$(14))
13330 SU =  VAL (FF$(15))
13350 SS =  VAL (FF$(16))
13370 PV =  VAL (FF$(17))
13390 FV =  VAL (FF$(18))
13410 FT =  VAL (FF$(19))
13430 AR =  VAL (FF$(20))
13450 FU =  VAL (FF$(21))
13470 CA =  VAL (FF$(22))
13490 TU =  VAL (FF$(23))
13510  REM
13530  REM  ** ACTUAL DATA FILE READ **
13550  REM
13570  PRINT D$;"OPEN "FI$",S6,D1"
13590  PRINT D$;"READ "FI$
13610  FOR H = 1 TO SS
13630  INPUT R1$(H)
13650  INPUT F1$(H)
13670  INPUT XS$(H)
13690  INPUT LN$(H)
13710  INPUT ED$(H)
13730  INPUT ZR$(H)
13750  IF H = SS THEN  GOTO 13810
13770  INPUT XT$(H)
```

```
13790  INPUT PT$(H)
13810  REM
13830  NEXT
13850  PRINT D$;"CLOSE "FI$
13870  REM
13890  REM  ** CHECK IF CONVERSIONS ARE NEEDED **
13910  IF SI = 0 THEN  GOTO 14770
13930  IF UN = 1 THEN  GOTO 15610
13950  REM  ** ENGLISH TO SI CONVERSIONS **
13970 SV = (SV - 32) / 1.8
13990 SV =  INT (SV * 100 + .5) / 100
14010 TV = (TV - 32) / 1.8
14030 TV =  INT (TV * 100 + .5) / 100
14050 AR = AR * .4046856
14070 AR =  INT (AR * 10 + .5) / 10
14090 FT = FT * 3.785412
14110 FT =  INT (FT * 10 + .5) / 10
14130 PV = PV * 6.894757
14150 PV =  INT (PV * 10 + .5) / 10
14170 FV = FV * 3.785412
14190 FV =  INT (FV * 10 + .5) / 10
14210 CA = CA * 9.353958
14230 CA =  INT (CA * 10 + .5) / 10
14250  FOR H = 1 TO SS
14270 LN =  VAL (LN$(H)) * .3048
14290 LN =  INT (LN * 1 + .5) / 1
14310 LN$(H) =  STR$ (LN)
14330 R1 =  VAL (R1$(H)) * 6.894757
14350 R1 =  INT (R1 * 10 + .5) / 10
14370 R1$(H) =  STR$ (R1)
14390 F1 =  VAL (F1$(H)) * 3.785412
14410 F1 =  INT (F1 * 10 + .5) / 10
14430 F1$(H) =  STR$ (F1)
14450 XS = ( VAL (XS$(H)) - 32) / 1.8
14470 XS =  INT (XS * 100 + .5) / 100
14490 XS$(H) =  STR$ (XS)
14510 ED =  VAL (ED$(H)) * 1.609344
14530 ED =  INT (ED * 1 + .5) / 1
14550 ED$(H) =  STR$ (ED)
14570 ZR =  VAL (ZR$(H)) * 9.353958
14590 ZR =  INT (ZR * 10 + .5) / 10
14610 ZR$(H) =  STR$ (ZR)
14630  IF H = SS THEN  GOTO 14710
14650 XT = ( VAL (XT$(H)) - 32) / 1.8
14670 XT =  INT (XT * 100 + .5) / 100
14690 XT$(H) =  STR$ (XT)
14710  REM
14730  NEXT
14750  GOTO 15610
14770  REM
14790  IF UN = 0 THEN  GOTO 15610
14810  REM  ** SI TO ENGLISH CONVERSIONS **
14830 SV = (SV * 1.8) + 32
14850 SV =  INT (SV * 100 + .5) / 100
```

```
14870 TV = (TV * 1.8) + 32
14890 TV =  INT (TV * 100 + .5) / 100
14910 AR = AR / .404685
14930 AR =  INT (AR * 10 + .5) / 10
14950 FT = FT / 3.785412
14970 FT =  INT (FT * 10 + .5) / 10
14990 PV = PV / 6.894757
15010 PV =  INT (PV * 10 + .5) / 10
15030 FV = FV / 3.785412
15050 FV =  INT (FV * 10 + .5) / 10
15070 CA = CA / 9.353958
15090 CA =  INT (CA * 10 + .5) / 10
15110  FOR H = 1 TO SS
15130 LN =  VAL (LN$(H)) / .3048
15150 LN =  INT (LN * 1 + .5) / 1
15170 LN$(H) =  STR$ (LN)
15190 R1 =  VAL (R1$(H)) / 6.894757
15210 R1 =  INT (R1 * 10 + .5) / 10
15230 R1$(H) =  STR$ (R1)
15250 F1 =  VAL (F1$(H)) / 3.785412
15270 F1 =  INT (F1 * 10 + .5) / 10
15290 F1$(H) =  STR$ (F1)
15310 XS =  VAL (XS$(H)) * 1.8 + 32
15330 XS =  INT (XS * 100 + .5) / 100
15350 XS$(H) =  STR$ (XS)
15370 ED =  VAL (ED$(H)) / 1.609344
15390 ED =  INT (ED * 1 + .5) / 1
15410 ED$(H) =  STR$ (ED)
15430 ZR =  VAL (ZR$(H)) / 9.353958
15450 ZR =  INT (ZR * 10 + .5) / 10
15470 ZR$(H) =  STR$ (ZR)
15490  IF H = SS THEN  GOTO 15570
15510 XT =  VAL (XT$(H)) * 1.8 + 32
15530 XT =  INT (XT * 100 + .5) / 100
15550 XT$(H) =  STR$ (XT)
15570  REM
15590  NEXT
15610  REM
15630  REM  ** CALL PRINT OUT ROUTINE **
15650  GOSUB 10850
15670  REM
15690  RETURN
```

APPENDIX C

FINAL STATISTICS FOR FOUR MISSIONS
ON A PER PASS BASIS

TABLE VII

MISSION NO. 1 PER PASS STATISTICS

PASS NO.	AVERAGE BOOM PRESS. kPa	AVERAGE FLOW RATE L/min	PASS TEMP deg.C	TURN TEMP deg.C	PASS LENGTH m	AIR SPEED AVG. km/h	APL. RATE L/ha	TURN TIME sec
1	131.4	113.8	8.2	7.82	742	206	22.7	26
2	128	114.2	7.94	7.71	708	183	24.1	34
3	126.3	112.7	8.07	7.81	734	177	25.2	28
4	125.9	112.4	8	7.78	696	180	25.3	26
5	123	113.4	8.09	7.98	784	177	23.7	25
6	124.6	112.7	8.15	7.88	686	177	24.6	30
7	121.6	112.8	8.32	8.04	746	180	24.3	23
8	123.4	113	8.28	8.04	734	177	24.1	24
9	122.3	112.7	8.41	7.8	734	177	24.3	76
10	122	112.4	8	7.93	399	206	19.3	29
11	122.1	113.9	8.15	7.99	398	180	23.2	25
12	123	114.2	8.21	8.16	356	161	25.8	30
13	125.2	114.6	8.36	8.17	332	171	26.1	24
14	124	114.3	8.4	8.31	357	162	24.8	30
15	124.7	114	8.53	8.27	377	170	25.5	24
16	125.7	116.1	8.49	8.42	354	160	28.2	29
17	124.7	115.7	8.59	8.37	420	169	24.9	26
18	130.8	117.2	8.56	8.64	133	161	19.5	1
19	124.9	115.1	8.66	8.46	226	164	24.7	27
20	126.8	115.7	8.67	8.78	228	165	27.3	1
21	124.5	116.3	8.78	8.45	185	167	25.9	26
22	128.8	113.6	8.65	8.74	92	168	21.9	2
23	125.5	115.7	8.8	8.62	189	170	24.5	26
24	124.8	112.6	8.76	8.82	142	171	23.5	3
25	128.8	115.7	8.86	8.56	92	167	26.6	23
26	127.6	117.2	8.82	8.96	138	167	19.4	4
27	126.1	115.7	8.97	8.71	94	171	25.3	26
28	126.9	104.2	8.95	8.64	490	177	21.8	22
29	125.9	117.7	8.91	8.88	376	170	24	26
30	80.6	56.4	9.01		394	178	12.3	

TABLE VIII

MISSION NO. 2 PER PASS STATISTICS

PASS NO.	AVERAGE BOOM PRESS. kPa	AVERAGE FLOW RATE L/min	PASS TEMP deg.C	TURN TEMP deg.C	PASS LENGTH m	AIR SPEED AVG. km/h	APL. RATE L/ha	TURN TIME sec
1	134	119.8	11.35	11.11	674	203	22.2	29
2	130.4	117.7	11.46	11.38	393	177	23.9	36
3	127.7	117	11.63	11.4	647	180	24.9	28
4	123.9	117.7	11.57	11.57	371	167	24.7	38
5	127.1	117.7	11.65	11.41	650	181	23.7	29
6	129.6	117.5	11.45	11.38	336	174	23.8	33
7	131.3	117.6	11.67	11.52	600	181	24.4	28
8	129.9	118.6	11.76	11.77	339	175	24.6	27
9	129.5	118.9	11.99	11.6	602	181	25.7	33
10	132.1	118.5	11.86	11.76	303	183	23.4	31
11	129.1	118.3	12.07	11.74	608	183	24.4	36
12	133	118.5	12.05	11.92	254	183	24.1	32
13	130.8	119.1	12.19	11.85	623	188	24.2	30
14	131.6	118	12.11	12.07	254	183	21.2	35
15	133.7	118.7	12.29	12.01	153	185	23.6	31
16	133.1	119.8	12.28	12.14	147	177	26.2	24
17	132.5	118.5	12.35	11.99	453	182	23.6	28
18	133.5	120	12.35	12.24	252	182	20.8	21
19	131.7	118.9	12.42	12.12	449	180	24	27
20	131.2	120.3	12.37	12.31	150	181	18	22
21	123.4	119.2	12.49	12.14	450	181	24.6	28
22	132.1	118.7	12.42	12.37	145	175	23.4	24
23	131	119.8	12.66	12.32	350	181	24.3	22
24	132.8	119.2	12.54	12.42	387	175	24.1	26
25	132.7	119.8	12.69	12.33	458	184	23.6	23
26	131.1	118.2	12.61	12.53	354	183	24.9	26
27	130.3	119.2	12.62	12.53	152	184	23	22
28	130.4	117.5	12.69	12.67	621	187	23.6	26
29	132	119.2	13.47	12.54	415	188	21.9	23
30	131.1	118	12.81	12.61	356	184	23.7	26
31	131.4	118.9	12.88	12.52	358	185	25.2	20
32	67.6	37.9	12.58		388	176	8.9	

TABLE IX

MISSION NO. 3 PER PASS STATISTICS

PASS NO.	AVERAGE BOOM PRESS. kPa	AVERAGE FLOW RATE L/min	PASS TEMP deg.C	TURN TEMP deg.C	PASS LENGTH m	AIR SPEED AVG. km/h	APL. RATE L/ha	TURN TIME sec
1	130.7	117.3	12.61	12.42	805	194	23.6	27
2	131	117	12.8	12.72	748	180	24.7	38
3	128.8	115.9	13.05	12.83	816	184	23.9	32
4	129.7	116.8	13.09	12.76	691	178	24.7	44
5	127.6	116.1	13.14	12.84	765	184	24.1	25
6	130.1	117.1	13.07	12.84	759	183	23.6	37
7	130.3	117.5	13.16	12.88	763	184	24.4	24
8	131.6	117.5	13.19	13	721	186	24.4	31
9	131.2	118	13.34	12.8	786	189	23.2	34
10	131	117.9	13.14	12.85	743	192	23.1	47
11	131.5	117.7	13.22	12.88	751	194	23.7	34
12	131.9	117.7	13.13	12.96	678	189	24.6	39
13	131.7	118.1	13.34	12.97	749	193	24.1	27
14	132.2	117.9	13.16	13.13	737	190	23.4	27
15	131	116.5	13.51	12.97	797	192	23.3	29
16	124.1	117.2	13.23	13.16	752	194	22.5	26
17	131.4	117.3	13.5	13.11	802	193	22.3	21
18	131.6	117.1	13.32	13.2	723	186	24	27
19	129.8	117	13.56	13.17	747	193	23.6	24
20	130.6	117.9	13.28	13.14	705	196	22.1	25
21	95.7	61.9	13.65	13.16	915	194	12.1	19
22	50.2	7.6	13.37		578	190	2.6	

TABLE X

MISSION NO. 4 PER PASS STATISTICS

PASS NO.	AVERAGE BOOM PRESS. kPa	AVERAGE FLOW RATE L/min	PASS TEMP deg.C	TURN TEMP deg.C	PASS LENGTH m	AIR SPEED AVG. km/h	APL. RATE L/ha	TURN TIME sec
1	127.2	115.6	17.83	17.72	579	190	24	28
2	130.2	115.9	17.84	17.74	477	172	25.3	39
3	128.1	115.1	18.02	17.88	505	166	25.5	27
4	128.8	117.1	18.13	17.86	434	174	23.7	47
5	129.1	115.9	18.15	17.94	422	169	26.3	30
6	127.5	116.3	18.16	17.84	458	166	26.6	38
7	131	115.9	18.05	17.91	244	176	22.8	26
8	131.3	117.1	18	17.83	447	162	27	38
9	132.5	116.2	18.17	17.89	247	179	23	27
10	129.5	116.4	18.06	17.83	432	174	26	37
11	132.1	116.3	18.18	17.95	192	174	21.5	28
12	131.5	117.4	18.11	17.94	396	179	25.6	35
13	132.1	116.2	18.21	17.97	151	182	21.3	27
14	131.5	117.1	18.21	18.06	436	175	24.3	34
15	131.8	115.9	18.32	17.94	459	184	24.1	26
16	133.4	116.2	18.24	18.02	330	170	25.5	33
17	129.2	115.9	18.25	18.03	293	177	23.6	30
18	131.1	116.7	18.46	18.18	237	171	26	29
19	130.4	115.7	18.51	18.06	302	182	21.5	30
20	132.4	115.9	18.25	18.17	274	165	24	32
21	132.2	115.3	18.41	17.91	201	182	23.9	27
22	131.4	114.9	18.21	18.14	239	173	22.7	32
23	131.8	115.7	18.29	17.94	207	187	20.6	30
24	133.4	113.6	18.26	18.18	195	176	24.4	22
25	130.9	114.7	18.4	18.09	531	175	25.1	22
26	130.3	114.6	18.17	18.07	510	168	24.9	29
27	128.3	114.1	18.18	18	657	170	25.7	24
28	129.2	114.3	18.13	17.96	472	171	25.8	30
29	128.2	114.2	18.22	18.04	645	179	23.9	26
30	128.5	114.5	18.19	18.13	538	177	24.5	29
31	99.3	66.8	18.31		677	188	14.6	

APPENDIX D

EXAMPLE FORMAT OF FINAL DATA OUTPUT IN ENGLISH UNITS

MISSION NO. 1 PER PASS STATISTICS
(ENGLISH UNITS EXAMPLE)

PASS NO.	AVERAGE BOOM PRESS.	AVERAGE FLOW RATE	PASS TEMP	TURN TEMP	PASS LENGTH	AIR SPEED AVG.	APL. RATE	TURN TIME
	psi	gpm	deg.F	deg.F	ft	mph	gal/ac	sec
1	19.1	30.1	46.76	46.08	2434	128	2.4	26
2	18.6	30.2	46.29	45.88	2323	114	2.6	34
3	18.3	29.8	46.53	46.06	2408	110	2.7	28
4	18.3	29.7	46.4	46	2283	112	2.7	26
5	17.8	30	46.56	46.36	2572	110	2.5	25
6	18.1	29.8	46.67	46.18	2251	110	2.6	30
7	17.6	29.8	46.98	46.47	2448	112	2.6	23
8	17.9	29.9	46.9	46.47	2408	110	2.6	24
9	17.7	29.8	47.14	46.04	2408	110	2.6	76
10	17.7	29.7	46.4	46.27	1309	128	2.1	29
11	17.7	30.1	46.67	46.38	1306	112	2.5	25
12	17.8	30.2	46.78	46.69	1168	100	2.8	30
13	18.2	30.3	47.05	46.71	1089	106	2.8	24
14	18	30.2	47.12	46.96	1171	101	2.7	30
15	18.1	30.1	47.35	46.89	1237	106	2.7	24
16	18.2	30.7	47.28	47.16	1161	99	3	29
17	18.1	30.6	47.46	47.07	1378	105	2.7	26
18	19	31	47.41	47.55	436	100	2.1	1
19	18.1	30.4	47.59	47.23	741	102	2.6	27
20	18.4	30.6	47.61	47.8	748	103	2.9	1
21	18.1	30.7	47.8	47.21	607	104	2.8	26
22	18.7	30	47.57	47.73	302	104	2.3	2
23	18.2	30.6	47.84	47.52	620	106	2.6	26
24	18.1	29.7	47.77	47.88	466	106	2.5	3
25	18.7	30.6	47.95	47.41	302	104	2.8	23
26	18.5	31	47.88	48.13	453	104	2.1	4
27	18.3	30.6	48.15	47.68	308	106	2.7	26
28	18.4	27.5	48.11	47.55	1608	110	2.3	22
29	18.3	31.1	48.04	47.98	1234	106	2.6	26
30	11.7	14.9	48.22		1293	111	1.3	

FINAL STATISTICS FOR MISSION NO. 1
(ENGLISH UNITS EXAMPLE)

MISSION DATE	NOV/17/86
FIELD NUMBER	1
CHEMICAL	TORDON
AIRPLANE NO.	N9151R
MISSION INITIATION TIME	09:51:11.1
FIRST PASS INITIATION TIME	10:00:48.1
FINAL PASS COMPLETION TIME	10:16:42.1
MISSION COMPLETION TIME	10:27:27.1

% TIME			TOTAL AREA	TOTAL LIQUID SPRAYED	AVG. AIR TEMP (TURN)	AVG. AIR TEMP (PASS)	AVG. BOOM PRESS	AVG. FLOW RATE	APPL. RATE
ferry	turn	spray	acre	gal	deg.F	deg.F	psi	gpm	gal/ac
56	32	12	46.7	118.9	46.71	47.07	17.9	29.5	2.5

VITA

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