UNIFORM AERIAL APPLICATION
USING COMPUTER SIMULATION

By

DENNIS K. KUHLMAN

Bachelor of Science
Kansas State University
Manhattan, Kansas
1970

Master of Science
Kansas State University
Manhattan, Kansas
1975

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Thesis Adviser

Dean of the Graduate College

PREFACE

The work reported in this thesis deals with the computer modeling of sprays released from agricultural aircraft. The major purpose of this study was to examine the existing technical knowledge pertaining to the aerial application of agrichemicals and to apply this information to obtain uniform field deposition through modification of boom and nozzle placement.

I wish to express my sincere gratitude to the faculty and staff of the Agricultural Engineering Department who assisted me in this work and during my stay at Oklahoma State University. My gratitude goes to Dr. Richard W. Whitney, my thesis adviser, for his encouragement, guidance, interest, and constructive criticism in the course of this work. I am also grateful to Dr. Whitney and Dr. Lawrence O. Roth for the teamwork, professional accomplishment, and worldly insights gained from their expertise.

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NOMENCLATURE

Ri	Richardson number
g	gravitational acceleration
T	absolute temperature
τ	adiabatic lapse rate
z	height
u	average velocity
wd	vortex decending velocity
Γ	circulation strength
b'	spacing between vortex centers
V	velocity
Zo	roughness height
Ux	friction velocity
ψ	stability parameter
k	VonKarman's constant
L'	scaling length
Cp	specific heat at constant pressure
Dv.1	droplet diameter at 10% cumulative volume
Dv.5	droplet diameter at 50% cumulative volume
Dv.9	droplet diameter at 90% cumulative volume
Vd	particle settling rate
n	viscosity
ρ	density

r	particle radius
p	static pressure
t	time
s	horizontal distance
d	droplet diameter
μ	dynamic viscosity

CHAPTER I

INTRODUCTION

The current world fleet of agricultural aircraft consists of an estimated 24,000. About 300 new agricultural aircraft are built each year in the United States and about 300 million crop acres are treated. Improvements in the design, comfort and safety of today's modern aircraft are evidenced by the declining rate of accidents and injuries. Many innovations have been incorporated into the aircraft designs since 1950. However, little has been done to improve the spray system being used on today's modern agricultural aircraft. The spray systems and spray technology being applied today are approximately the same as in 1950. The agricultural aircraft liquid spray boom and nozzle configuration used by many applicators is based on past experience, observation of other aircraft, hearsay, and trial and error test procedures.

Statement of Problem

The purpose of this study was to utilize existing and new information to formulate a computerized procedure which will predict the spray deposition position and amount of spray deposited from particular fixed-wing aircraft designs and predict the nozzle locations on the spray boom which will produce uniform spray deposition.

Objectives

The objectives of this study were to:

1. Predict the trajectory of spray particles released from an aircraft.

2. Predict the final deposition positions of the released spray particles.

3. Combine the information generated in objectives 1 and 2 to determine the correct nozzle placement on an aircraft boom to produce a uniform deposition.

Approach

The deposition characteristics of two different aircraft were determined. Tests were conducted to determine the location and shape of deposition of spray released from various points along an agricultural aircraft spray boom and their relationship to various physical and meteorological variables. This data was used to develop and/or verify the deposition model and to develop a deposition reference matrix.

The deposition reference matrix was used to predict the total deposition of the aircraft and to select the locations for nozzle placement along the spray boom to achieve a wide, uniform spray deposition. The predicted output was then compared with field data to determine the acceptability of the procedure.

CHAPTER II

REVIEW OF LITERATURE

Agricultural aviation is a growing, dynamic segment of the American Agricultural Industry. Its impact on United States farm production and the economy of the country is quite large, including seeding, fertilizing, insecticiding, herbiciding, and in various other forest and agricultural management techniques. The major contribution of aerial application is the support of agricultural production, primarily food production. The most scarce resource used in the production of food is land indicating that increased return per acre of land has and will continue to be of paramount importance in agricultural production. However, approximately 30 percent of the total agricultural yield is lost to pests each year. Improved aerial application techniques will help to recover some of this immense loss (1).

When using aerial application techniques, many physical and meteorological parameters can adversely affect the quantity of material deposited at the desired location. Since the first dry material was discharged from a Huf-Deland airplane shortly after World War I, a continuous effort has been made to predict the distribution of particles discharged from various kinds of devices mounted underneath agricultural aircraft. Hundreds of experiments have been conducted and thousands of swath distribution patterns have been measured, but no systematic variation of swath pattern has been attributed to any single factor, either aircraft design or operation. For example, swath patterns of an airplane operating at a given air speed at full gross weight and the same airplane operating at the same air speed with minimum gross weight, i.e., nearly empty hopper, have not differed sufficiently so as to make either one of the swath patterns unacceptable for commercial application. This implies that for any given airplane the factors which can be controlled by in-flight techniques or operating conditions are not sufficient by themselves to produce a commercially significant change in swath width or distribution pattern. The uniformity of material within a single swath is influenced strongly by the system set-up, boom and nozzle placement, the wing flow field, the propeller helix, ground speed, weight of the airplane, and flow rate of the spray material (2).

The basic objective of any application is to deposit the active material entirely on the target area. However, due to micrometeorological conditions, the dynamics of spray droplet behavior, the physical properties of the spray formulation, and the height at which the spray is emitted, the recovery of the active material on the target area will generally be less than one hundred percent (3).

Transport of particles by atmospheric movement is a direct cause of particle drift and varying rates of deposition. Measurements of these conditions and an understanding of their influence may result in meaningful improvements in spray deposition. Major factors limiting progress in the technology are the acquisition of knowledge concerning the biological factors involved, understanding the exact mechanics of transport of small particles to the target surface, and the complex interrelationships in this connection between the physical, biological, and meteorological factors (4). Even though all fundamental relationships for predicting spray deposition are not yet fully established, parametric studies of the major meteorological parameters can give considerable insight into the solution of this complex problem (5).

Turbulence

The main difficulty of analyzing the drift and deposition of particles in the atmosphere stems from the fact that the motion or spreading of any particles (solid or liquid) in the atmosphere takes place in a flow field that is almost invariably turbulent. Even though turbulence has proven to be an interesting subject in its own respect, it has proven to be one of the most untractable problems of the physical sciences and a complete understanding is still outside the grasp of technology. Turbulent motion of the atmosphere becomes even more so when there is particle interaction (5).

Turbulent atmospheric flow does affect the drift and deposition of materials but the effect depends on the particle concentration as well as the particle density, shape, and size relative to the characteristic scale (length) of turbulence in the atmosphere. Turbulence in turn is related to the ground surface roughness, temperature gradient with height, and the wind velocity gradient (wind shear) with height. The turbulence near the ground is partially induced by the surface roughness and is dependent on the size and distance between the surface roughness elements.

Vertical and horizontal eddies are mechanically produced as the airstream flows over and around the roughness elements. In addition, mechanically produced turbulence is induced by the gradient of wind velocity as it produces wind shear. The wind shear is generally greatest near the ground, increases with wind speed, and is also affected by the surface roughness elements. The temperature gradient is important since it represents the energy available for producing or suppressing eddies by bouyance forces. The temperature change with height, or thermal stratification, is one of the most critical factors that control atmospheric stability, turbulence, or vertical mixing. Temperature inversions are produced by several means. The most common is radiation inversion caused by heat transfer due to radiation from the ground to a cool sky (when the sun is low or below the horizon); this heat loss cools the ground and the air close to it. Another important inversion cause is the influx over land of a late afternoon sea breeze along coastal areas. This cold air pushes under the warm air and causes a temperature inversion condition. A third cause of temperature inversion conditions is subsidence, the phenomena by which air from a higher elevation is forced down into a lower level, such as a valley. This drop in elevation warms the air and places a warm layer of air over a valley to produce temperature inversion conditions.

The turbulent structure of the atmosphere is sometimes analyzed relative to atmospheric stability. The Richardson number, Ri, is frequently used to characterize stability conditions and is given by the following relationship (5):

$$Ri = g/t \; \{(\Delta T/\Delta z) + \tau\} \; / \; \{\Delta u/\Delta z\}^2 \qquad (1)$$

where g is the gravitational acceleration, T is the absolute temperature, τ is the adiabatic lapse rate, z is the height, and u is the average horizontal wind velocity. The Richardson number is a dimensionless parameter that relates the rate of bouyancy-produced turbulent energy to the rate of wind-shear-produced turbulent energy. Under stable conditions, turbulence is suppressed; whereas, with unstable conditions, turbulence is enhanced. It is, therefore, an indicator of the increase or suppression of turbulent motion in a variable height and density gradient. A large negative value indicates that convection predominates and is associated with strong vertical and lateral motion which would increase the rate of turbulent diffusion of the particles. Mechanically produced turbulence predominates as the Richardson number approaches zero. Large positive values represent conditions where the vertical or lateral motions are dampened, thus minimizing particle spread in other than the mean wind direction. However, the Richardson number applies mainly to a particular surface roughness and has limited usefulness for comparing measurements over surfaces of varying roughness. Quantitative calculations of the Richardson number also require sophisticated instrumentation to accurately measure wind velocity and temperature gradients. When such instruments are available, the Richardson number appears to be a good parameter or indicator for predicting dispersion of spray particles released from agricultural aircraft.

The Stability Ratio (SR), another measure of atmospheric stability, is a somewhat simplified index. Requiring less sophisticated instrumentation than the Richardson number, the SR has been satisfactorily correlated with drift deposit characteristics. It is given by the following relationship (1):

$$SR = \{(T_2 - T_1)/u^2\}\ 10^5 \qquad (2)$$

where T is temperature and u is average velocity measured at a height equal distance from locations two and one on a logarithmic scale, with position one being lower than position two.

The stability ratio is not affected as much by changes in surface roughness as the Richardson number. Also, average wind velocity can be measured more easily than a velocity gradient. Drift tests from previous investigations have established four general categories of atmospheric stability using the Stability Ratio:

Unstable	$-1.7 \leq SR \leq -0.1$
Neutral	$-0.1 \leq SR \leq 0.1$
Stable	$0.1 \leq SR \leq 1.2$
Very Stable	$1.2 \leq SR \leq 4.9$

With high wind velocities the stability ratio will tend towards low values for two reasons: the temperature difference between positions 1 and 2 will be less due to turbulent mixing and the square of the mean velocity will increase which in turn reduces the stability ratio. The stability ratio has its limitations and certainly cannot replace the close examination of such variables as wind direction, wind speed, thermal stratification, turbulence, relative humidity, etc. (5).

Another approach to characterizing the turbulent "state" of the atmosphere is to measure the three-dimensional variations of velocity. By observing the fine details of the atmospheric motion, the concept of turbulence "intensity" can be visualized. This approach requires a rather sophisticated instrument system to measure the three varying signals simultaneously without influencing any of the measurements by insertion of the probe into the flow field. It is important to recognize that the values of the turbulence intensities are dependent on averaging times and experience is required to select the appropriate averaging period for the type and scale of diffusion under consideration.

Temperature and Relative Humidity

Temperature and relative humidity may also affect the spray deposition. Relative humidity is defined as the ratio of the quantity of water vapor present to the quantity required for saturation at a given temperature and pressure. Caution must be used since the relative humidity involves the ratio of two vapor pressures, the actual and the saturation. The actual vapor pressure changes with the pressure, and saturation vapor pressure varies with temperature. Generally, effects due to humidity relate to evaporation rates. Solid and nonaqueous materials dispersed from agricultural aircraft may not be significantly affected by the humidity in the atmosphere. The drop size, after dispersal of an aqueous solution, will vary depending on the humidity and other related factors (temperature, relative velocity of the drop, etc.). As the particle evaporates, the diameter reduces which causes the terminal velocity to reduce. A reduction in size, therefore, increases the total suspension time of the drop for a given release height.

One important detail relating to evaporation is the relative velocity between drop and air. Both the rate of evaporation and the rate of conduction of the heat to a drop which is cooled by latent heat loss are increased when the drop experiences relative motion to the medium in which it is placed. The rate of mass and heat transfer then becomes convective in place of diffusive. No closed mathematical solution exists for the forced convective transfer because of the complex manner which the flow field past the drop changes with Reynolds number (5).

Aircraft Wake or Mechanical Turbulence

A significant amount of mechanical turbulence is produced by the physical forces involved in producing aircraft flight. A flow field is produced around each of the aircraft surfaces during flight. The wings generate turbulence as the air mass flows around the airfoil surfaces. To this turbulent wake, the turbulence generated by the fuselage, landing gear, pump, pump windmill, boom and boom hangers, elevator, rudder, aileron and flap control surfaces, and the propeller must be combined to form a three-dimensional mechanical wake which exists behind the aircraft in flight.

In close ground proximity, the ground exhibits a significant influence on the aircraft wake system by restricting normal vertical descent and inducing a rapid lateral outward movement of the system over the ground. The speed with which the lateral transport occurs is a function of the height of the aircraft over the ground and decreases as the height of the aircraft increases. In a relatively non-turbulent (stable) atmosphere where mechanical turbulence will dominate, the lift generated wing-tip vortex initially descends and then begins to move spanwise as it interacts with the ground. Lateral separation of the vortex pair increases. The vortex is predicted to reach a constant altitude by an inviscid mathematical prediction, while the viscous prediction is that the vortex will rise slightly as it moves along the ground. Vortex rebound has been observed in which the viscous action between the ground and the vortex system causes the primary vortex to "bounce" upward after it has come close to the ground. This indicates that a viscous prediction method may be more indicative of actual field conditions. Particle concentration patterns become increasingly more diffuse for the particles ejected from the more outboard locations because of the stronger influence of the tip circulation in these regions (6).

The distribution of velocity in the wing-tip vortices is primarily dependent on the aircraft weight distribution across the wing span. The circulation strength is a function of the aircraft weight, wing span, and indicated air speed. The vortex pair does not remain at the altitude of the wing but descends downward with a velocity given by:

$$wd = \Gamma/2\pi b' \qquad (3)$$

where b' is the spacing between the vortices and Γ is the circulation strength. For estimation purposes, the vortex center for airplanes with straight, untapered wings can be assumed to be located at the wing tips (7).

The swirling circulation velocities are significantly reduced by the presence of large (in relation to the aircraft wing span) canopies, as in application over forests. This effect is caused by the interference of the canopy with most of the wake vorticity. This effect is strong when the height of the canopy is of the same order of magnitude as the wing semispan (7).

When a cross shear is present near the ground, the symmetries of the secondary vortices generated by the interaction of the main vortices and the ground surface are distroyed. On the upwind side, the boundary layer interacts with the shear so that the main vortex rises but does not move outboard. On the downwind side, the vorticity in the shear and the boundary layer are of the same sign so that the boundary layer remains attached longer. Thus the secondary vortex is slow to form and the effect on the main vortex is to induce an outward motion but no upward motion. The vortex not interacting with the canopy continues to move as it slowly diffuses, while the vortex interacting with the canopy has little motion. The lateral motion of the vortex along the ground is slowed by the presence of a canopy (8).

In the region of outward particle transport, operation at a low lift coefficient decreases the amount of lateral transport with the influence increasing as the ejector location moves outboard. In the region of inboard transport, it is difficult to observe a significant effect due to the variation in operational lift coefficient. Qualitatively, operation of the aircraft closer to the ground allows less lateral transport to occur than when the aircraft operates at higher altitudes. The direction of the propeller rotation is clockwise (with a majority of engines) as viewed from the rear such that a right-hand helical flow-field is induced. This results in the rightward shifting of the more inboard particle trajectories (6).

While it has been definitely shown that liquid droplets can be entrained in tip vortex and that the vortex strength and position does influence liquid droplet drift, no such effect has been found in application of dry materials, where particle sizes range from 500 to 3500 microns. The trailing vortex velocity field behind existing airplanes is not strong enough to materially affect the lateral transport of large particles (9).

Wing Geometry

Wing geometry will also affect the deposition of materials. One wing geometry of interest in the analysis of particle trajectories is a wing with a partial-span flap. As bound circulation decreases progressively from the wing root to the tip, the shed circulation increases. The largest change in bound circulation occurs at the point of the largest change in wing lift. Thus, at the end of a deflected flap or at the wing tip, the large change in bound circulation produces a rolled-up vortex. The magnitude of shed vorticity is a function of wing loading and aircraft speed. A constant wing area with increased gross weight of the airplane must be reflected in increased power and stall speed. Wing loading, therefore, is not an independent variable and it cannot be changed without affecting major design parameters of the airplane, namely power-loading and stall speed (9).

The basic feature of the flow field behind a fixed wing aircraft is at least one pair of counter-rotating vortices which originates near the wing tips. There are vortices trailed from the lifting tail surfaces as well, but these are of lesser strength and influence the particle trajectories in only a minor way when the particles are released near the wing (7). The position of the shed vortex will also be influenced by wing twist. One way to secure aerodynamic wing twist is to deflect flaps.

When this is done the bound circulation is increased over the extent of flap span and decreased over the portion of the wing outboard of the flap. This is equivalent to a reduction in aerodynamic aspect ratio and the trailing vortex shed at the flap end is closer to the centerline. A discharged particle from the mid-semispan area will be closer to the vortex core and therefore will be in a higher velocity field. This particle is transported further laterally than when the vortex is disposed at or near the wing tip. From this it can be seen that increased particle transport from a given discharge point will occur when an airplane is flown with deflected flaps with the outboard wing panel unloaded. It is evident that the change in airplane weight, and therefore wing loading, between the first and last swath will affect particle transport. Thus some means of control of the effect of vorticity on particle transport would be required to maintain constant swath widths (9).

Wind Conditions

Under calm conditions of the surface layer of air (very unlikely), a drop or particle would fall vertically under the effect of gravity and there would be no drift. If there is wind during the settling time, droplets released will be carried a distance in the direction of the horizontal wind velocity component. The horizontal wind velocity, however, normally increases with altitude being effectively zero at the ground. Particles will be subject to different wind conditions as a function of height. The relationship between the horizontal wind velocity and altitude is generally a logarithmic profile. It should be noted that the wind profile is dependent upon where one measures the wind and the surface roughness.

Investigations have shown that the wind profile, near the surface of the earth, can be closely represented by an equation which is logarithmic and is expressed by (1):

$$V = U_x/k \left(\ln\{(z + Z_0) / Z_0\} + \psi (z/L')\right) \qquad (4)$$

where V is the velocity of the wind at some altitude z. V is also a function of surface roughness length, Zo; friction velocity, U_x ; a stability parameter, ψ; and k, Von Karman's constant which is generally taken as 0.4. The stability parameter is dependent on the altitude and a scaling length L' where:

$$L' = \{U_x T (\partial V/\partial z)\} / kg \{(\partial T/\partial z) + (g/Cp)\} \qquad (5)$$

where g is the gravitational acceleration, T is the absolute air temperature, k is von Karman's constant, V is the horizontal wind speed, and Cp is the specific heat at constant pressure.

Wind direction is a very obvious and easily recognized parameter which is important in the prediction of particle deposition. The mean wind direction can be used to predict the direction of particle deposition from the time it is released until it reaches the target.

The wind speed is a critical factor in determining transport distances. Under neutral and stable conditions the wind speed can provide an estimate of the drift distances before spraying begins (5).

Droplet Size

The uniformity of the droplet size spectrum is a major physical factor that affects both the biological efficacy and the environmental contamination from aerial application of pesticides. It is apparent that narrow droplet size spectrums are required if aerial applicators are to achieve precision target applications with a minimum loss due to drift and at the same time an optimum size that provides efficient coverage. It is also important to recognize that there is no single optimum spray system for all treatments. Thus it is important to understand the atomization characteristics and apply the information to each specific field condition.

The American Society of Testing Materials committee on liquid particle size measurement suggests the use of "Relative Span" as a general measure of the uniformity of a spray. The value is defined as:

$$\text{Relative Span} = (Dv.9 - Dv.1)/ Dv.5 \qquad (6)$$

where: Dv.9, Dv.5, AND Dv.1 refer to the drop diameter such that the cumulative volume fraction is less than 0.9, 0.5 and 0.1 respectively. The Relative Span can be readily calculated from the cumulative percent volume plot and represents the ratio of the range of drop sizes that contain 80 percent (from 10 percent to 90 percent) of the spray volume to the volume median diameter (10).

The use of droplet size information in field simulations poses sampling problems that can be encountered when using coated slides, cards, or water sensitive paper. With existing technology, accurate field image sizing is exceedingly difficult. Moreover, it appears that there are inconsistencies and a lack of information on the correction factors that must be applied because of droplet spreading or impact (11).

Droplet Dynamics

After leaving the aircraft, the velocity of the droplets is a vector quantity depending on nozzle orientation relative to the aircraft, the local flow velocity, and the initial particle velocity. This velocity is diminished by the resistance of the opposing airflow, the particle falls into the turbulent zone behind the aircraft, and then lags behind the aircraft. A rough estimate of particle trajectories from an aircraft can be made by using a number of simplifying assumptions. The particle is assumed to be spherical, to not experience rotational or oscillatory motions, and the air medium is assumed to be fixed. For a rough calculation of the vertical steady-state settling rate of fine particles assuming the above conditions, one can use Stoke's formula (1):

$$Vd = 4gr^2 \, (\rho_\ell - \rho_a) \; / \; 18\eta \tag{7}$$

where Vd is the steady state settling rate of the particle, g is the acceleration of gravity, η is the viscosity of air, ρ_ℓ is the liquid density, ρ_a is the air density, and r is the particle radius. The liquid density of water is much greater than air; consequently, the density of air can be ignored in the above equation. The settling velocity in the atmosphere is actually the particle velocity minus the wind velocity. Experimentally determined terminal fall velocities indicate that Stoke's law over-estimates the actual terminal velocity in air for droplets larger than 20 microns. The conditions for which Stoke's law may be accurately applied, in the case of water droplets in still air, is restricted to droplets less than 20 microns diameter.

Steady-state conditions are rarely present in the atmosphere. When turbulence and wind variation effects on the particle are taken into account, the governing equation of particle motion becomes a function of the velocities of the fluid and solid particle (the mean velocity of the fluid encountered by the particle, not the distributed fluid around the particle), the particle radius, densities of the fluid and solid particle, the external force due to the potential field, the static pressure, the time, the viscosity of the fluid material, and the time constant (inverse relaxation time) for momentum transfer due to drag force.

Along with consideration of the vertical settling rate of particles, there is also interest in the horizontal path over which the ejected particle can move until it is stopped by the opposing air current. The maximum horizontal path of a particle with an initial velocity (V) can be calculated by:

$$Smax = \rho_d \, d^2 \, V \, / \, 18n \qquad (8)$$

where Smax is the maximum horizontal path of the drop; ρ_d is the density of the drop; d is the drop diameter; and n is the absolute viscosity of the air (1). The initial horizontal velocity of a small particle is quenched in the air within a fraction of a second, and such a particle, even for large initial velocities, can move only small distances before it is stopped by the opposing air current (7).

In general, most environmental conditions applicable to particle drift will be such that the only other force, other than gravity, will be the force due to viscous drag. The viscous drag force is actually a nonlinear expression, but if Stoke's law is assumed, the equations of motion (vertical and horizontal) are given as (5):

$$dVpz / dt + A(Vpz) = g \tag{9}$$

and

$$dVpx / dt + A(Vpx - Vx) = 0 \tag{10}$$

where Vpz is the particle velocity in the z direction, Vpx is the particle velocity in the x direction, Vx is the wind velocity in the x direction, g is the acceleration due to gravity, and:

$$A = (9/2) \{Ug / (pp\ r_p^2)\} \tag{11}$$

where Ug is the dynamic viscosity of the gas medium (in this case, air), pp is the density of the particle, and r is the radius of the particle.

If the particle is assumed to be released at an initial height, Zi, and to have an initial velocity of zero in the vertical direction, solving Equation 9 for Z:

$$z = g/A \{t + 1/A\ e^{-At}\} + Zi - g/A \qquad (12)$$

In a similar manner the distance traveled downstream by the particle will be calculated from Equation 10. If the initial x position is assumed to be zero and the initial velocity of the particle in the x direction (Vpx) is zero, then x can be expressed as the double integral:

$$x = A\int_0^{t}\int_0^{t''} e^{A(t'-t'')}\ Vx_{(z_{(t)})}\ dt'\ dt'' \qquad (13)$$

where t in the outer integral of Equation 13 is determined from Equation 12 by setting z equal to zero and solving for t. The wind velocity profile for neutral stability conditions (Greek ψ =0) is given as:

$$Vx_{(z)} = (Ux\ /\ k)\ln \{(z + Zo)\ /\ Zo\} \qquad (14)$$

and z is given in Equation 12 as a function of time. The time required to reach the surface is dependent on the radius and density of the particle. These two parameters are combined in the constant A. As the density or radius increases, the value of A decreases which in turn reduces the drift time for a given release height (5).

CHAPTER III

PREDICTING DEPOSITION

An accurate method of predicting the final deposition location of spray released from specific nozzle locations has long been desirable. Manuals have been prepared for characterizing spray released from agricultural aircraft. The technology has not been available to determine spray characteristics and deposition amounts when released in and subjected to aircraft wake turbulence. A computer simulation of the spray deposition would enable manufacturers and users of their products to evaluate the effects of nozzle placement or configuration and could make possible a reduction in off-target chemical movement with wider swaths and better deposition uniformity. Aircraft manufacturers could potentially determine the most desirable nozzle and boom placements to achieve the optimum deposition for each airframe model. Presently, little or no test work is done prior to delivery of a new aircraft to insure uniform deposition of agricultural sprays.

Two approaches to the problem of predicting the final deposition of spray released from agricultural aircraft were considered. The first was to mathematically describe the aircraft in such a way that would allow the prediction of the aircraft wake profile that exists behind the aircraft in flight and to follow spray particle trajectories through that wake profile until impact with the ground. The second approach was to measure the actual deposition location and the independent variable values that existed at the time of the test with a sufficient number of replications to make the observations statistically credible. Statistical and numerical analysis was then applied to the data to examine the relationships between the independent and dependent variables to predict deposition locations. In short, the first approach was from the "aircraft to the ground" while the second approach was from the "ground to the aircraft".

A modular programing approach was utilized in the development of both algorithms to allow flexability within the program structure for ease of modification due to updated information. All modules resided and executed on an Apple II+ microcomputer with the exception of Module Two of the Aircraft to Ground algorithm which resided on a Digital Electronics Corporation PDP 11/34A minicomputer. The modular approach allowed the algorithms to be applied in remote locations. A complete listing of the Aircraft to Ground algorithm may be found in Appendix A, and the Ground to Aircraft algorithm in Appendix B.

Model Development - Aircraft to Ground

Module One

Operation of the model required that the physical simulation system including the aircraft and environmental factors be initialized. Module One prepared the input parameters into the format required for the execution of the remaining modules. Inputs requiring initialization included aircraft wing loading, height of the wing above the ground surface, flight speed of the aircraft, aircraft wing configuration, wing circulation strength (determined from aircraft weight, wing semi-span, air density, and flight speed), crosswind velocity, wind velocity measurement height, ground surface roughness, drag coefficient of the aircraft, planform area, propeller efficiency, propeller RPM, propeller blade radius, propeller shaft centerline distance above or below the particle release height, background turbulence velocities, maximum background turbulence macroscale, canopy plant area profile, particle release position, diameter of released particle, specific gravity of released particle, initial velocity vectors of released particle, wet-bulb temperature depression, and minimum particle size at which particle is assumed to have evaporated. The computer code was developed in Applesoft basic with input parameters in English units. A numerical solution, of the Lagrangian form particle dynamics equations, is then required.

Module Two

The development of a module two to predict the deposition position of spray released from specific nozzle locations on an agricultural aircraft was completed by modifying the NASA developed Agdisp computer simulation. The formated output of Module One remained compatable with Versions One and Two of the Agdisp simulation code. The modified code resides on a Digital Electronics Corporation PDP 11/34A minicomputer. The formated output of Module One was transfered directly via remote modum to the PDP 11/34A for execution of the numerical prediction of deposition. The modular format allowed the microcomputer equipped with a remote modum complete access to the faster, larger capabilities of the minicomputer from remote locations. The development of the NASA computer model for predicting the deposition and trajectory of spray particles released from an aircraft is beyond the scope and objectives of this thesis. However, a brief background is presented.

In an early attempt to quantify insecticide coverage while spraying for mosquito control, LaMer and Hochberg (22) observed that the deposition of acute material appeared to be an inverse exponential function of distance from the spray generator for droplet sizes less than 60 microns. Johnstone et al. (23) give relationships for vertical and horizontal penetration of an aerosol through a forest canopy. They also consider aerodynamic downwash effects on spray coverage. Sexsmith et al. (24) provide experimental spray deposit distributions for both on-target and off-target areas for a spray formulation having a spray droplet mass median diameter of 210 microns, and a range of 20 to 450 microns. Coutts and Yates (25) reported drift deposition data as a function of nozzle orientation in relation to the chord line of the wing. Umback and Lembke (26) presented a comprehensive wind tunnel study in an effort to quantify aerial drift by using dimensional analysis which related drift as a function of height of release, wind velocity, and spray droplet diameter for a specific system. Garrett (27) studied single particle dynamics and droplet drag characteristics in order to estimate distance to ground impact when droplets are released above ground level in a flowing air stream. Friedlander and Johnston (28) examined deposition of suspended particles in turbulent gas streams within enclosed ducts. Threadgill and Smith (29) determined the impact distance of various nonevaporating droplet sizes released from a height of ten feet in an airstream having a three mile per hour horizontal velocity. Lapple and Shepard (30) developed the equations of motion, describing single particle trajectories in still air, utilizing experimentally determined drag coefficients. Hughes and Gilliland (31) applied this work to their investigation of motion of small droplets in a gaseous medium.

Based on this work, a two-dimensional stream function model in terms of velocity and position in a fixed coordinate system was developed and simultaneously integrated to obtain the trajectory of a single particle. However, this procedure ignored any deposition velocity contribution due to inertial effects and diffusion. Other factors that must be considered include turbulence, changes in horizontal wind velocity with height above the grade, evaporation, coagulation, and deformation of particles. The NASA Agdisp model has expanded these basic models and developed the technology required to predict the deposition of sprays (or particles) released into the atmosphere from both fixed and rotary wing aircraft.

A dispersal code developed by Reed (32) demonstrated the importance of the vortex wake in establishing particle trajectories and hence deposition patterns. However, no consideration was given to the effects of dispersion of particles resulting from atmospheric and aircraft generated turbulence. The Reed model was added to by Trayford and Welch (33), by Bragg (34), by Bilanin (35), by Jordan (36), and by Morris (8). The Agdisp computer code has been developed to simulate the viscous, turbulent interaction of the multiple vortices in an aircraft wake. The code is a two-dimensional, unsteady, incompressible modeling of the Reynolds stress equations which initializes the computation downstream of the trailing edge of the wing. The two-dimensional approximation was justified for these flows since gradients in the flight direction are very small compared with the changes in the vertical and lateral directions. Therefore, the numerical simulation was equivalent to observing a wake flowfield in a plane which is both perpendicular to the aircraft's flight direction and fixed to the ground. Incompressibility was justified since the Mach number of the swirling velocities in the wake is small. Constants were evaluated by comparison with measurements of fundamental fluid laws. The computations idealized the neutral atmosphere by assuming constant shear and homogeneous turbulence in the absence of a vortex wake. The background turbulence levels were determined by the limit of the turbulent transport model. This limit was approached at high Reynolds number when time-rates-of-change and diffusion of second-order correlations were negligible. The numerical solution scheme was an Alternating Direction Implicit (ADI) technique. The mean equations were in stream function-vorticity variables, eliminating the need to compute the pressure. A direct solver calculated the stream function from which the velocity fields were determined. A uniform velocity gradient mesh was used except near the ground where additional resolution was needed to define the large gradients. To reduce grid point requirements, half-plane computations were made when possible. Initial distributions of vorticity were determined from experimental wake surveys or estimated based on measured or calculated wing span load (18).

The output of this module was the particle position at each small time increment in the aircraft wake which allowed the plotting of the particle trajectory, the final position of deposition at the ground, and the droplet diameter ratio which was an indication of the volume loss due to volatilization.

Module Three

One of the major shortcomings of the numerical solution of Module Two was that the solution could only be performed on one droplet size during each simulation. Sprays released from hydraulic atomization contain a spectrum of sizes. Therefore, multiple numerical solutions must be employed to adequately describe the trajectory and final deposition of the spray spectrum. A numerical solution was completed for three droplet sizes representing the droplet size at which 90 percent of the spray by volume was composed of spray droplets smaller than that size (V.9), the droplet size at which 50 percent of the spray by volume was composed of spray droplets smaller than that size (V.5), and the droplet size at which 10 percent of the spray by volume was composed of spray droplets smaller than that size (V.1) as illustrated on a logarithmic graph of the cumulative volume droplet size distribution shown in Figure 1. These droplet sizes were corrected by linear interpolation for simulated aircraft ground speed. Each of the numerical solutions resulted in the output of droplet

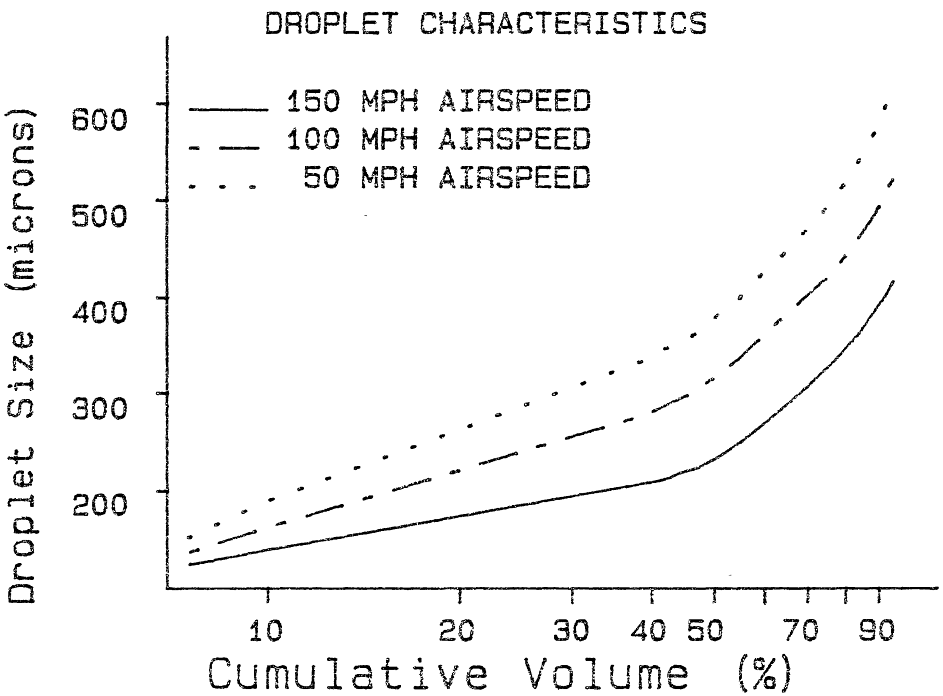


Figure 1. Droplet Size Distribution

diameter ratios, and deposition locations for each nozzle position.

The individual runs were then combined into a single nozzle deposition distribution by Module Three. Each of the three distributions was described as triangular in shape with the deposition span forming the base and the height being determined by the simulation predicted droplet deposit diameter ratio multiplied by the fraction of the theoretical flow rate of the nozzle tip represented by that respective droplet size range. The deposition span was assumed to be 25 feet as indicated by the mean of the deposition span of spray released from 125 nozzle positions on two aircraft. A final predicted spray deposition was then formed by adding the three triangular distributions as shown in Figure 2. The final deposition distribution was then placed into matrix form with the matrix elements representing the actual flow rate in gallons per minute for a six inch segment of the deposition span. When elements are totaled, the percent spray deposition based on the individual nozzle flow rate was computed. The final deposition matrix then contains the deposit start position in feet, the deposit stop position in feet, the deposition span in feet, and the deposit amounts (in gallons per minute) for each six inch increment starting at the start position up to a maximum of 60 matrix elements. In the event that the predicted deposition contained more than the allowable 60 elements, a routine was employed to center the deposition and to delete those elements that were beyond the matrix limits from both ends of the deposition. (This truncation procedure introduced an error into the actual deposition amounts that averaged 0.0001 gallons per minute.) A nozzle matrix is then formed and stored which contains the nozzle locations, and the deposition matrix for all of the individual nozzle locations.

Modules Four and Five

From the deposition matrix, all nozzles with positions between the 25 percent and 75 percent aircraft wingspan locations were turned "on" and a total deposition matrix formed by adding the individual amplitudes from each nozzle matrix position to the correct total deposition locations beginning with the start position and continuing for each of the matrix positions across the deposition span. The estimated swath width of the composite matrix was then calculated by determining the distance between left and right intercept points which were equal to one half the maximum deposition value as shown in Figure 3. The coefficient of variation was calculated for the deposition amounts found within the effective swath width just determined. Each nozzle position, beginning with the first nozzle left of the aircraft centerline, was then turned "on" or "off", depending on which state the nozzle was in before the process began, and a new coefficient of variation computed then compared to the original value. If

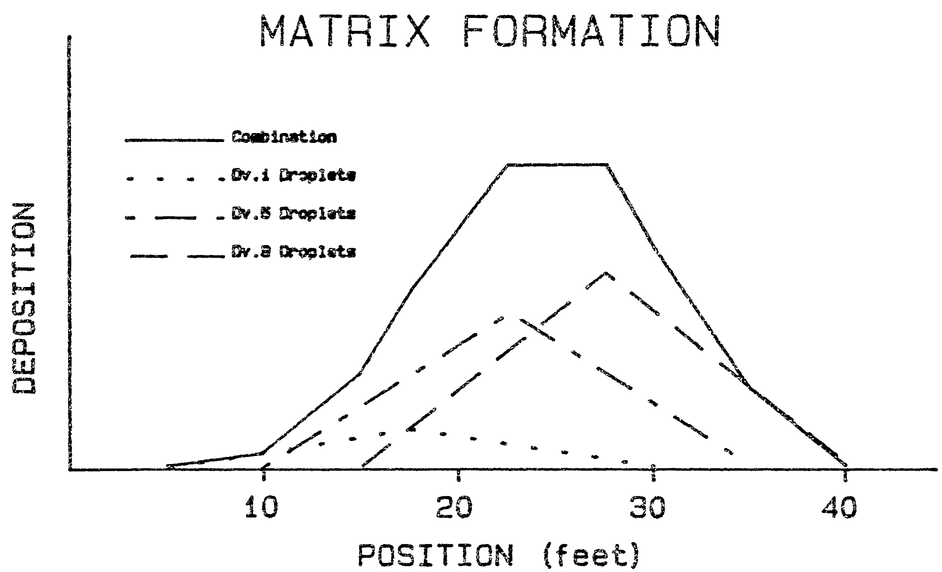


Figure 2. Formation of Predicted Deposition Matrix

the new coefficient of variation was less than the old coefficient of variation, then the new nozzle status became the standard for further comparison. If the new coefficient of variation was greater than the old, then the nozzle was returned to its original state and the process continued with the next nozzle. The testing sequence proceeded from the centerline outward on the left wing, then centerline outward on the right wing. Once this procedure was completed for all nozzle positions, a final deposition matrix was formed from which a predicted total deposition pattern was constructed, plotted, estimated percent deposition computed, effective swath width and estimated calibration computed, and predicted multiple swath deposition plotted.

Model Development - Ground to Aircraft

The development of a computer model to predict the final deposition of spray based on field data was completed by statistical and numerical analysis of field deposition data. The field deposition data was collected through a series of single nozzle spray tests to determine the deposition location from nozzle release points in a field situation. Only three nozzles, separated by enough distance to avoid deposition overlap, were operated during a minimum of four replications of each test series as illustrated in Figure 4. The spray solution, consisting of water and Rhodamine-B red fluorescent dye, was collected on a 100 foot paper strip supported by an aluminum test track. (Each replication was collected separately and analyzed for fluorescent dye by means of a Turner model 111 Filter Fluorometer, by feeding the continuous 100 foot length of paper tape containing the collected deposition and recording the levels of dye present as indicated by the Fluorometer output on a strip chart recorder.) The output signal of the Fluorometer was entered simultaneously into an Apple II+ microcomputer and the deposition analyzed to determine deposition location, amount, and deposit span. Test conditions for each replication were also recorded via a flight line computer which recorded the aircraft ground speed, wind direction, wind speed, and calculated crosswind component for each test replication, and dry and wet bulb temperatures for each test series. Height and centerline location of the aircraft above the collection surface was determined photographically. Deposition tests were completed on two airframes, an Agcat 164B+ and Melex M-18.

Emperical Relationship Development

The Statistical Analysis System (SAS) computerized analysis software was used to determine the characteristic relationships among the collected data. Variables involved in the analysis included spray deposit centroid, spray deposit span, spray deposit peak amplitude, aircraft load, nozzle location with respect to the aircraft centerline, crosswind component, relative humidity, aircraft altitude,

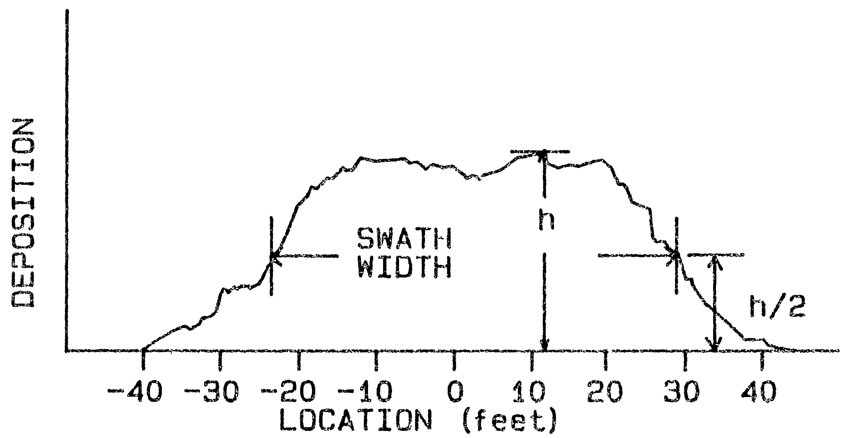


Figure 3. Effective Swath Width Determination

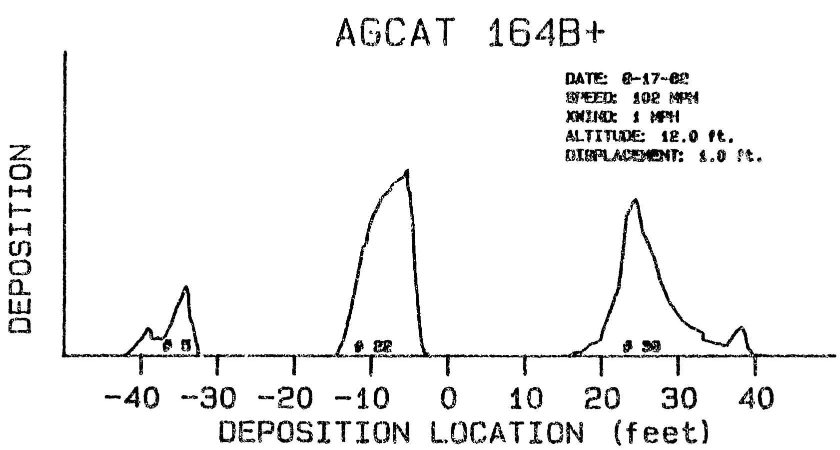


Figure 4. A Single Nozzle Test

lateral displacement, and aircraft speed. Statistical analysis was performed on the data in three sections: Agcat alone, Melex alone, and all data combined. Of particular interest was the determination of relationships among variables with respect to the deposition centroid and any characteristic shape of the deposition as a function of the spray deposition span and the spray deposition peak amplitude (or maximum deposit amount).

Using the variables of deposition centroid, span, and amplitude as dependent variables with the remaining variables of nozzle location, gross weight, crosswind, relative humidity, altitude, laterial displacement, and aircraft speed designated independent, the response characteristics of the data are shown in Table I. Nonlinear approaches were also explored with unfavorable results. In the case of the deposition centroid location, a strictly linear response is indicated as being the most favorable. The relatively high R-Square value of .94 indicates that a majority of the variation in the data can be attributed to a linear model response rather than to random error. The high F-Ratio also supports this conclusion by rejecting the hypothesis that all parameters in the linear model terms are zero. The addition of quadratic or crossproduct response models would not make a significant contribution as indicated by their low R-Square and F-Ratio values. In the case of deposit spray span, the linear response model produced a significant response at the .005 confidence level according to the F-Ratio with the remaining quadratic and crossproduct terms being rejected. However, the low R-Square value of .0837 indicated that while the linear response model was significant, it also accounted for a very small portion of the variation in the data. The same general trend was also apparent for the deposition peak amplitude with both linear and quadratic response models being significant at the .005 confidence levels, but both models exhibited low R-Square terms.

An additional indication of the model significance can be obtained by dividing the total error sum of squares into a lack of fit and pure error (SAS Lack of Fit test) and comparing the two values. When lack of fit is significantly different from pure error, then there is variation in the model not accounted for by random error. This analysis further supported the conclusion that the linear model was the best for the variable deposition centroid, and that any of the models for the deposition span and amplitude were extremely weak. Based on these conclusions, a multiple linear regression was performed on the data to further examine the linear response model. The results are shown in Table II. The R-Square and F-Ratio terms for the variable spray centroid were significant at the .001 confidence level for all three data sets; Agcat, Melex and total data.

The R-Square and F-Ratio terms for the variables spray span and peak amplitude were not significant at even the

TABLE I

DATA RESPONSE CHARACTERISTIC ANALYSIS

TYPE RESPONSE	VARIABLE	R SQUARE	F RATIO
Linear	Centroid	.9356	1323.86
Quadratic	Centroid	.0074	10.45
Crossproduct	Centroid	.0140	6.62
Linear	Spray Span	.0837	6.76
Quadratic	Spray Span	.0143	2.14
Crossproduct	Spray Span	.0283	3.69
Linear	Amplitude	.1452	16.24
Quadratic	Amplitude	.2091	23.40
Crossproduct	Amplitude	.1019	3.80

TABLE II

INITIAL REGRESSION RESULTS

Regression Input Source	Intercept	Nozzle Location	Gross Weight	Crosswind	Relative Humidity	Altitude	Lateral A/C Displacement	MPH	R Square	F Ratio
					REGRESSION FOR SPRAY CENTROID					
<u>Parameter Estimates</u>										
Total	20.03	2.10	.00172	2.56	.0003	.297	1.39	.336	.9346	941.9
AgCat	25.74	2.25	.0021	1.67	.079	.067	1.35	.107	.9501	733.2
Melex	42.17	2.03	.0086	3.46	.08	.24	1.31	.344	.9385	417.3
					REGRESSION FOR SPRAY SPAN					
<u>Parameter Estimates</u>										
Total	5.19	.0056	.00050	.038	.08	.54	.31	.15	.0837	5.926
AgCat	40.77	.069	.002	.019	.013	.90	.32	.15	.1108	5.786
Melex	45.43	.026	.006	.65	.73	.47	.20	.0017	.1386	5.381
					REGRESSION FOR DEPOSITION AMPLITUDE					
<u>Parameter Estimates</u>										
Total	229.73	.104	.002	.32	.96	1.27	1.49	1.11	.1320	11.013
AgCat	5.22	.23	.028	.14	.76	3.21	.70	.078	.1515	7.862
Melex	252.80	.04	.0032	.88	2.75	3.31	.54	.72	.2223	8.801

.005 confidence levels for any of the regression attempts. The low values of the R-Square terms indicated that a low portion of the variation in data response was attributed to the independent variables included in the analysis. The variables used in the regression were not indicative of and were not good indicators of the spray span and deposition amplitude. These results led to the conclusion that the possibility of predicting the shape of the deposition patterns from the approach of the "ground to the airplane" was not high when using only these independent measurements as the basis for future predictions. There may have been several reasons for this lack of deposition shape response.

(1) The Fluorometer "full-scale" response to the larger droplets may have minimized small droplet contributions to the shape response thereby masking the effects of the measured independent variables.

(2) The background turbulence was not measured in the field tests. This turbulence would have a strong influence on the span and deposition amplitude due the ease of movement of the small droplets.

(3) Evaporation would also be of major importance to span and amplitude due to the ease of movement of the smaller droplets; however, measurement of these effects would be minimized by the presence of the large drop size spectrum.

(4) The surface or canopy effects around the collection surface may have allowed the small particles to

skip or bounce over the deposit surface. Collection efficiency was not determined in these field tests to evaluate the deposit of the small droplets.

(5) The measurement of the independent variables may not have been of sufficient quality to adequately correlate with the collected data. More likely was the possibility that the most significant physical variable relating to the deposition span and amplitude simply was not measured.

Therefore, these values were set at constant values equal to the mean of all observations, 25 feet for deposition spray span and 51 units for peak amplitude.

A stepwise linear regression was performed to attempt to obtain the best linear model for the available independent variables and to include only those variables which contributed significantly to the model response. The results of that analysis are given in Table III. The best-fit model was the six-variable model:

$$Y = 20.06 + 2.10(LOC) + .0017(LD) + 2.56(CR) + .297(ALT) + 1.39(DSP) - .337(MPH) \quad (15)$$

where Y is the deposition centroid position (feet), LOC is the nozzle location (feet), LD is the aircraft gross weight (lbs.), CR is the crosswind component (MPH), ALT is the aircraft altitude (feet), DSP is the aircraft lateral displacement (feet), and MPH is the aircraft flight speed (MPH). This linear combination of variables was justified

TABLE III

BEST STEPWISE REGRESSION MODELS

Number Variables	Intercept	Location	Gross Weight	Crosswind	Lateral Displacement	MPH	Altitude	Relative Humidity	R Square	F Ratio
Parameter Estimates										
1	2.094	2.064							.9037	4316
2	1.849	2.068		2.41					.9210	2677
3	1.051	2.07		2.23	1.62				.9286	1984
4	26.70	2.09	.0019	2.76		.389			.9307	1533
5	28.84	2.09	.0016	2.55	1.319	.382			.9351	1313
6	20.06	2.10	.0017	2.56	1.39	.337	.2972		.9356	1101
7	20.03	2.10	.0017	2.56	1.39	.336	.2972	.00034	.9356	941

if some basic assumptions were made.

(1) The general wake resulting from the combination of wing, propeller, and fuselage interactions moved in one continuous direction in relation to a constant nozzle position. Therefore, a droplet released from a specific nozzle location continued to move in the same general direction in its path to deposition. The exception to this assumption would be those nozzles which released spray in the region of maximum wing-tip vortex circulation.

(2) The effect of the change in aircraft gross weight was a linear effect from full gross weight to basic empty weight. The gross weight affected the strength of the wake and the turbulent levels within the wake, but one would expect a linear relationship with each specific nozzle location.

(3) The effect of crosswind was a direct linear relationship based on the droplet mass, suspension time, and lateral movement. As the released spray from each nozzle position contained the entire spectrum of droplet sizes, the crosswind effect noted on the centroid position was the cumulative effect of all the evaporation, momentum, lateral velocity, and vertical velocity changes for all of the droplet sizes. Therefore, the relatively short suspension times of the larger droplets in the specific area of the centroid position tended to mask the nonlinear effects introduced by the other factors.

(4) Altitude was a linear function with the

assumption that each nozzle position had a unique and constant trajectory angle, θ, where θ was defined as the angle formed between a vertical vector directed downward and the trajectory vector after particle release, such that a change of altitude simply changed the base length of the right triangle formed with the constant angle, θ.

(5) Lateral displacement was expected to be a linear relationship as this variable was a direct correction for aircraft position error (pilot induced) relative to the fixed coordinates of the ground collection apparatus.

(6) Aircraft flight speed was a linear function assuming that increased speed caused a decrease in the trajectory angle, θ, that is unique to each nozzle position. This change was in response to the decreased angle of attack at the higher airspeed and the corresponding change in the velocity vectors in the trailing wake.

(7) Relative humidity was not a significant factor in the centroid model. This was explained by the facts that the field tests were carried out over a relatively narrow range of relative humidities and that the majority of the deposit in the centroid area was composed of the larger droplet sizes on which the relative humidity effect would have been minimized.

Module One

The computer algorithm prepared using the modular format and based on the relationship of equation 16 was used to predict the spray deposition locations. Module One interactively requested the needed simulation inputs and calculated the deposition centroids based on the input parameters. A deposition matrix was then formed by the assumpution of a triangular shaped pattern for each nozzle position with the span, fixed at 25 feet, forming the triangle base centered around the centroid predicted by equation 16, with the height being equal to the amplitude, fixed at 51 units. The matrix values represented theoretical maximum deposition, as the sum of the units under the triangular deposition pattern equaled the nozzle flow rate in gallons per minute. The deposition matrix contained the deposition start position, deposition end position, span, and amplitude values for each six-inch increment of the span.

Modules Two and Three

From the deposition matrix, all nozzle locations positioned between the 25 percent to 75 percent aircraft wingspan locations were turned "on" and a total deposition matrix formed by adding the individual amplitudes from each nozzle matrix position to the correct total deposition location starting with the start position and continuing for each of the matrix positions across the deposition span. The estimated swath width of the composite matrix was calculated by the determination of the distance between left and right intercept points which equaled one half the maximum deposition value as shown in Figure 3. The coefficient of variation was calculated for the deposition amounts found in the effective swath width as determined above. Each nozzle position, beginning with the first nozzle left of the aircraft centerline was turned "on" or "off", depending on which state the nozzle was in before the process began, and a new coefficient of variation computed then compared to the original value. If the new coefficient of variation was less than the old, then the new nozzle status became the standard for further comparison. If the new coefficient of variation was greater than the old, then the nozzle was returned to its original state and the process continued with the next nozzle. The testing sequence proceeded from the centerline outward on the left wing, then centerline outward on the right wing. Once this procedure was completed for all nozzle positions, a final deposition matrix was formed from which a predicted total deposition pattern constructed, plotted, swath width and estimated calibration computed, and predicted multiple swath deposition plotted.

CHAPTER IV

PRESENTATION AND ANALYSIS OF DATA

The ultimate usefulness of any computer simulation of field situations is determined by the accuracy and effectiveness of the predicted result. To evaluate these factors, the two predictive procedures were compared to actual field data from tests performed on two types aircraft; the Melex, M-18 and the AgCat, 164B+.

Particle Trajectory

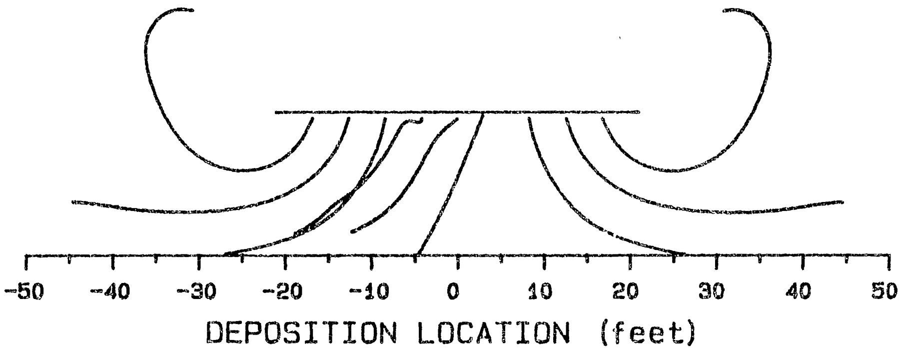
One of the advantages of the Aircraft to Ground method is the ability to track the particle as it passes through the wake following the aircraft. However, a disadvantage is that only one particle size may be followed during any individual simulation. Plots of the particle trajectories for each of the three droplet sizes, V.1, V.5, and V.9, and for each of the two aircraft types may be found in Figures 5 through 7. It is interesting to note the overall shapes of the trajectories and to note the areas of the most intensive wake/particle interactions, namely the wingtip and propeller helix areas. It was beyond the resources of the researcher to attempt to verify the actual track of particles suspended in the wake. Therefore, the usefulness of this portion of the modeling output is limited to explaining "what-if" situations or attempting to locate areas of greatest disturbances in the particle/wake interactions. It is significant to note that the movement of particles entrained in the vortex in a crosswind as observed by Morris (8) was predicted by the aircraft to ground method as shown in Figure 8.

Deposition Centroid Prediction

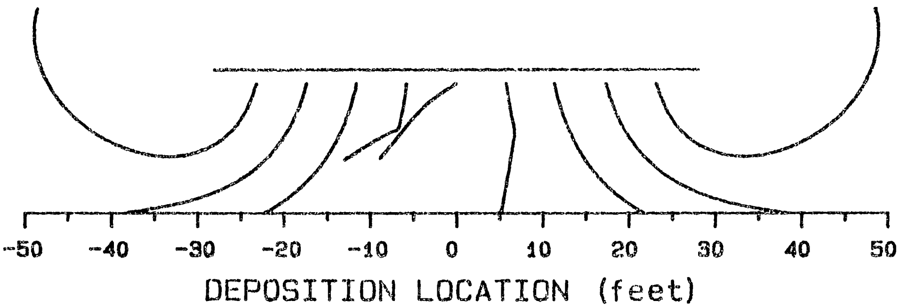
The effectiveness of the centroid position prediction algorithms can be evaluated by direct comparison of the predicted to the observed measured deposition centroid locations from the field tests for the two prediction algorithms. Figures 9 through 12 present the centroid positions predicted by the two modeling techniques and by actual measurement for the two aircraft types. The lines on the figures were drawn from the point of initial particle release to the position of final centroid deposition and do not represent the trajectory of the particles.

Aircraft to Ground Algorithm

It is difficult to compare the accuracy of modeling methods by direct comparison. An idea of the closeness of fit may be obtained by plotting the actual measured centroid location versus the predicted centroid location for both modeling methods. A plot of the predicted value

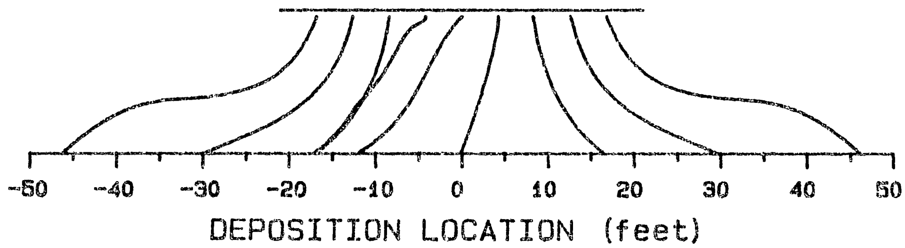


A. AGCAT, 164B+

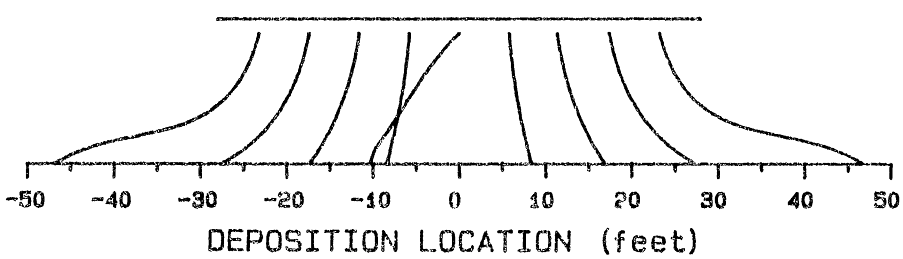


B. MELEX, M-18

Figure 5. Particle Trajectories for V.1 Droplets

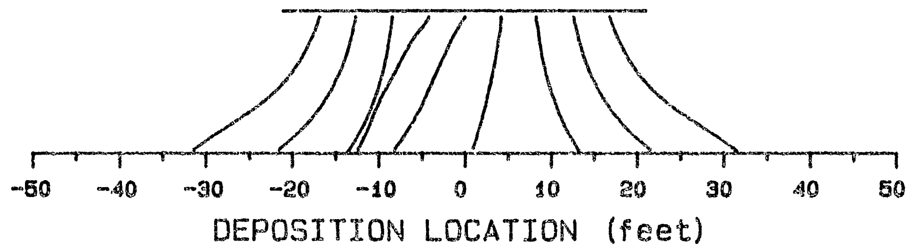


A. AGCAT, 164B+

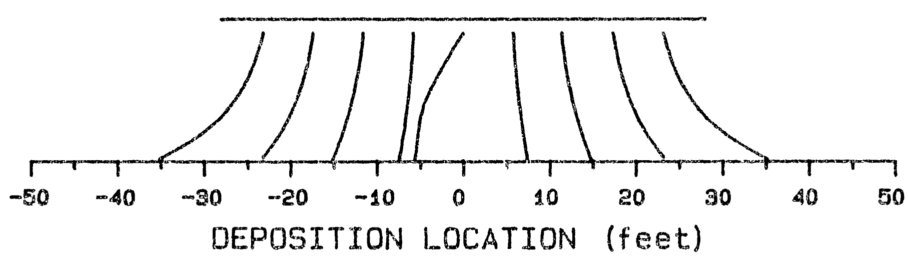


B. MELEX, M-18

Figure 6. Particle Trajectories for V.5 Droplets



A. AGCAT, 164B+



B. MELEX, M-18

Figure 7. Particle Trajectories for V.9 Droplets

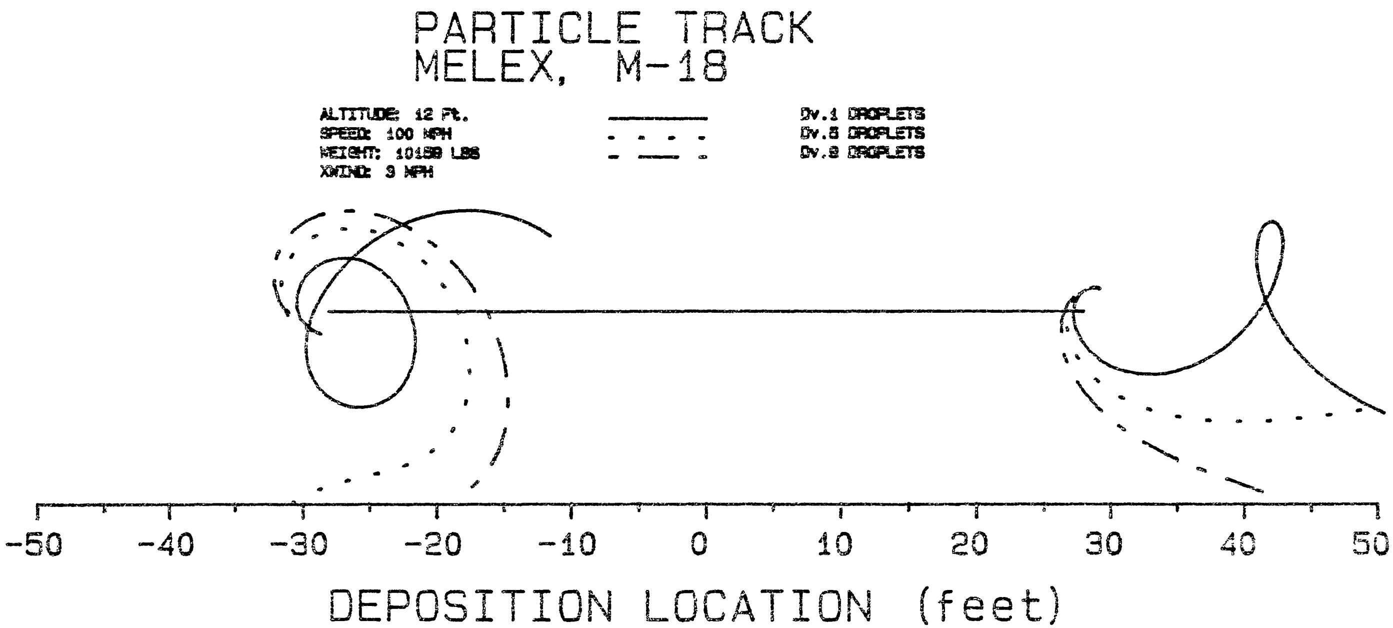
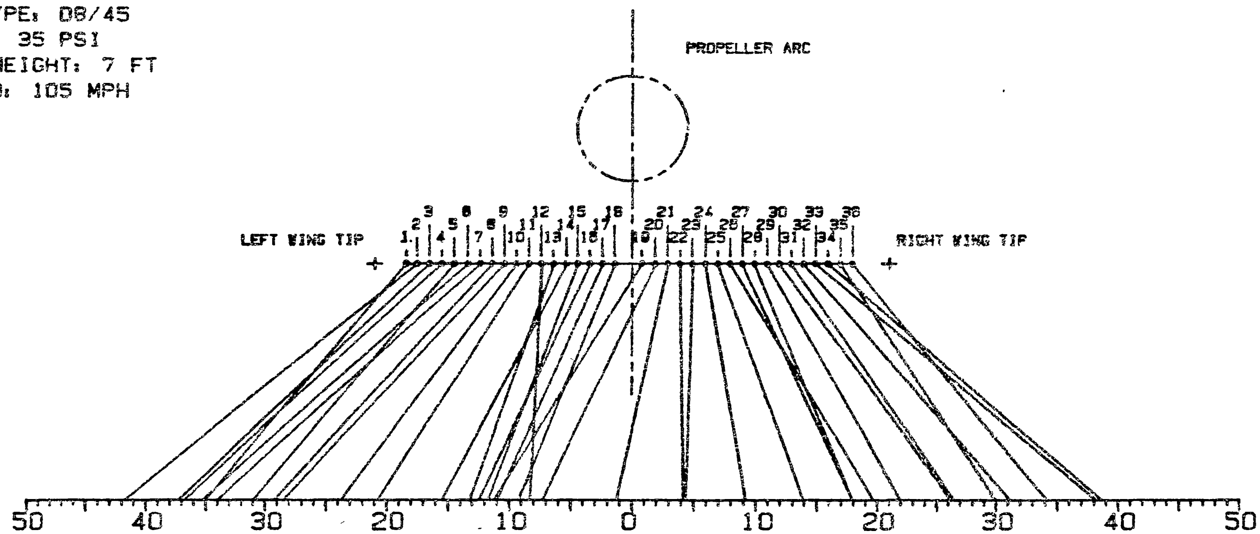


Figure 8. Vortex Movement in Crosswind

SINGLE NOZZLE ANALYSIS FOR AGCAT MODEL 164B+

DATE: 8/17/82
MAKE: AGCAT
MODEL: 164B+
NOZZLE TYPE: D8/45
PRESSURE: 35 PSI
PATTERN HEIGHT: 7 FT
AIR SPEED: 105 MPH



NOZZLE DEPOSITION PATTERN CENTROID LOCATIONS (FT)

Figure 9. Observed Centroid Deposition Locations, Agcat

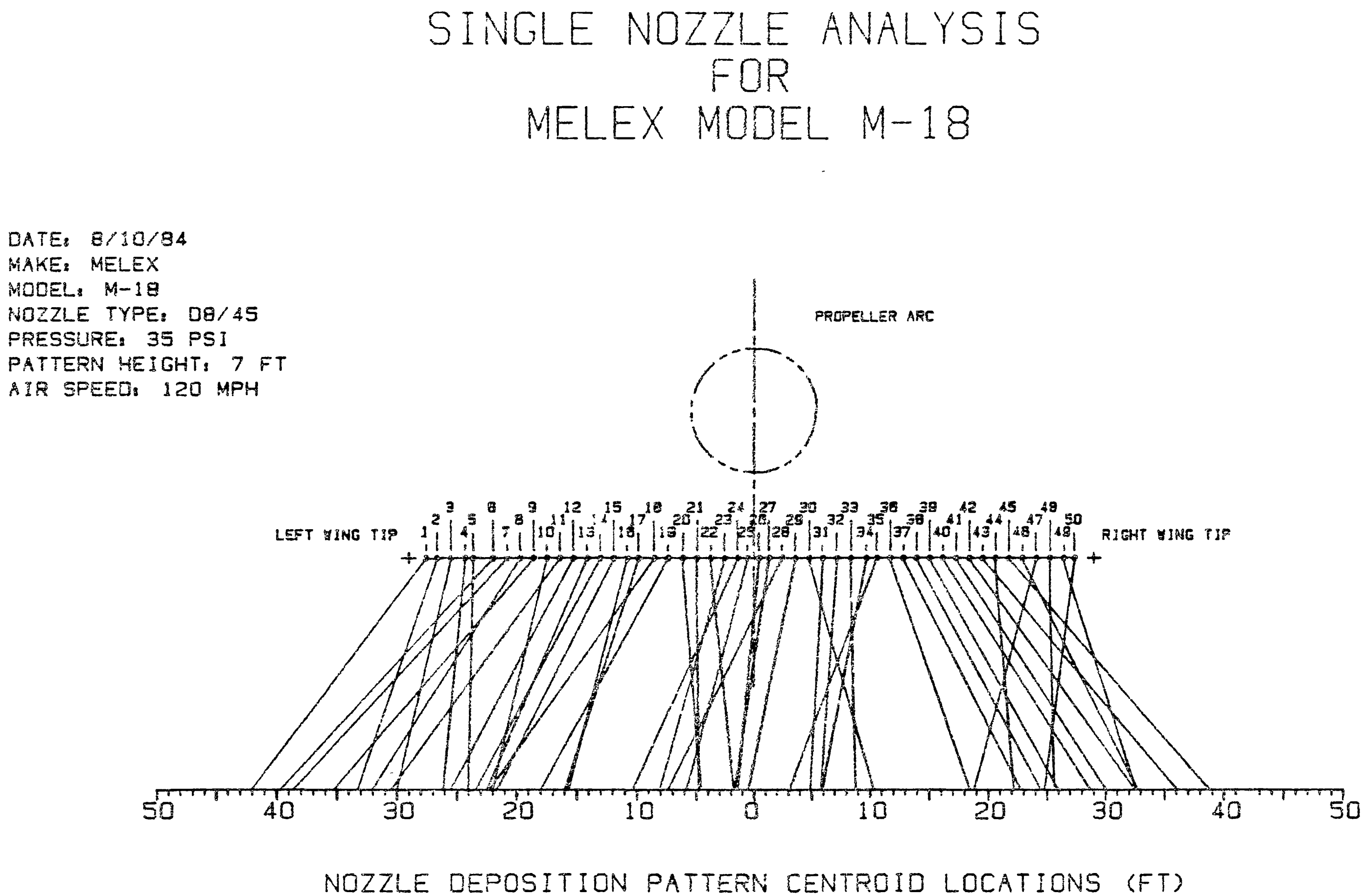
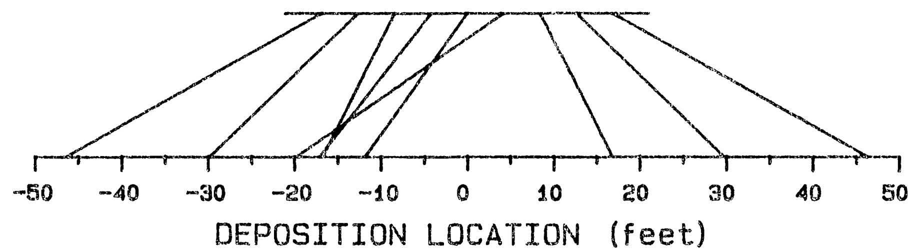
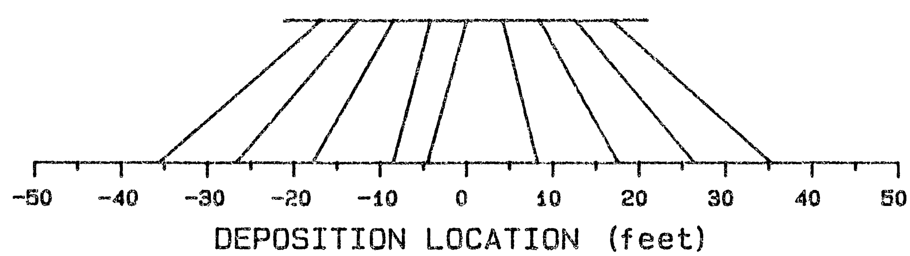


Figure 10. Observed Centroid Deposition Locations, Melex

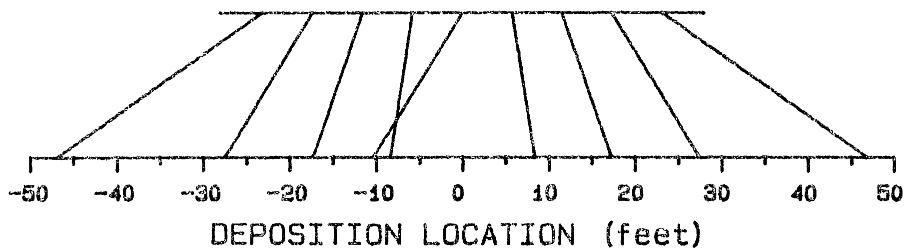


A. AIR TO GROUND ALGORITHM

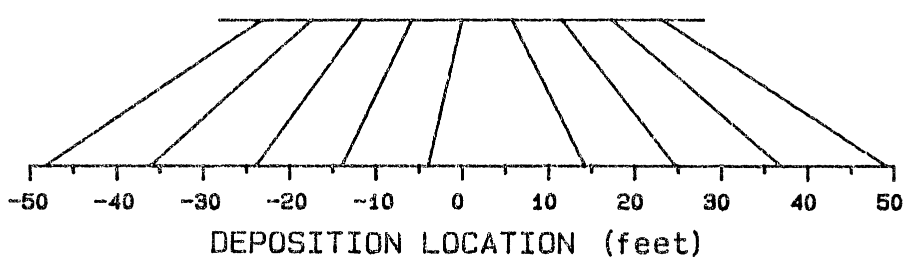


B. GROUND TO AIR ALGORITHM

Figure 11. Predicted Centroid Deposition Locations from Two Algorithms for Agcat, 164B+



A. AIR TO GROUND ALGORITHM



B. GROUND TO AIR ALGORITHM

Figure 12. Predicted Centroid Deposition Locations from Two Algorithms for Melex, M-18

versus the observed value for both aircraft using the aircraft to ground method is shown in Figure 13. As is readily apparent, the statistical relationship between predicted and observed values does not exhibit a particularly high correlation. The relationship between the predicted and observed values may be expressed by the equation:

$$\text{Predicted Value} = .6036\ (\text{Observed Value}) - 5.26 \qquad (16)$$

which exhibited an R-Square of .6619 and a standard error of 14.4 feet. This does not present a very strong indication of agreement. Removal of approximately ten percent of the prediction points which were in the greatest error increased the general agreement significantly (R-Square increasing from .6619 to .95). However, the removal of these points can not be justified. The points of largest error occurred during data runs on both types of aircraft and were inconsistent with respect to nozzle position.

The low correlation between the observed and predicted values in the aircraft to ground method should not be taken as an indication that the computer modeling algorithm is in error. Previous unpublished test data completed by Oklahoma State University on an Ayers Bull Thrush produced a predicted versus observed centroid location R-Square of .95. The inputs to this modeling method are such that many

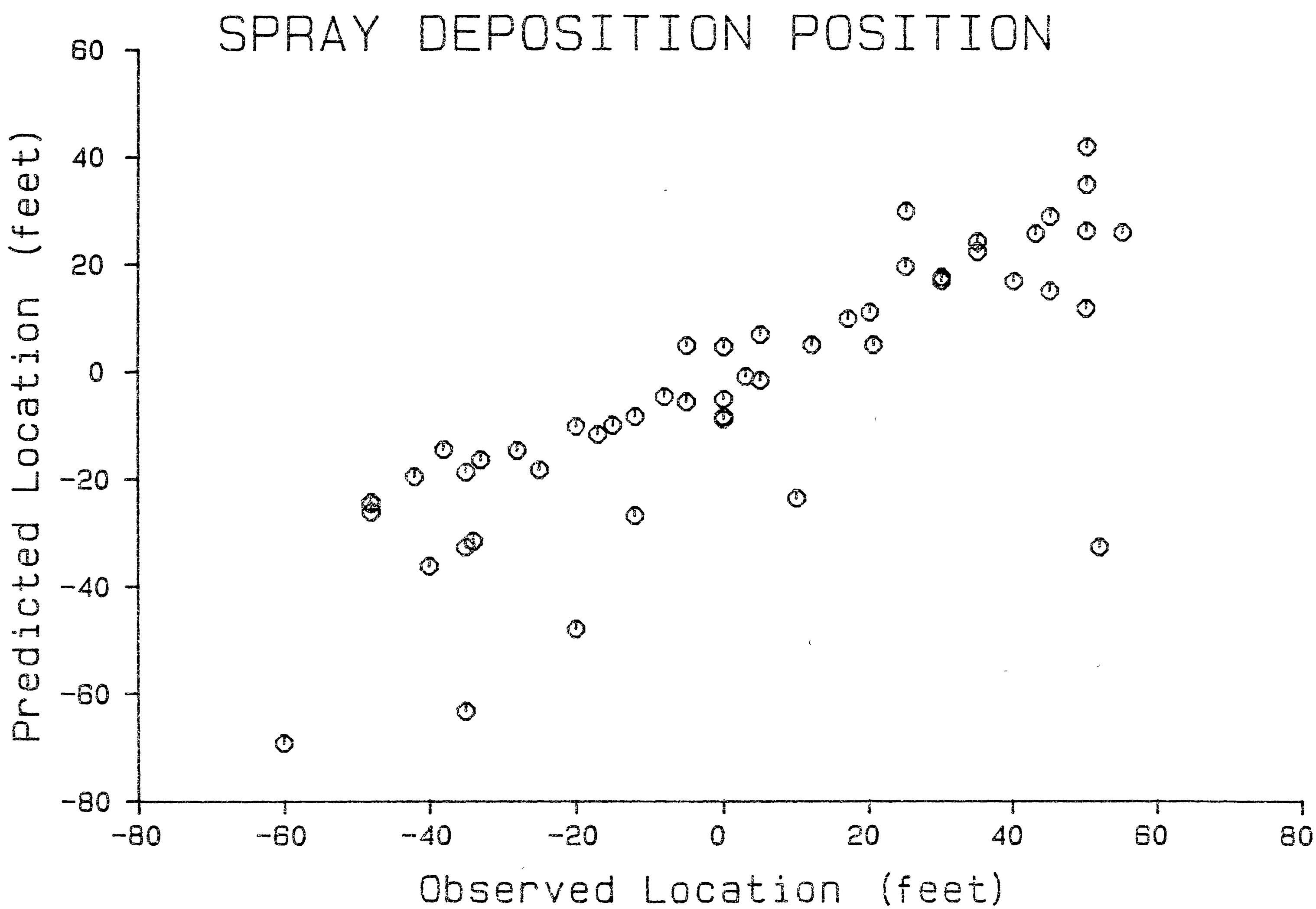


Figure 13. Aircraft to Ground Algorithm Accuracy

assumptions must be made. Possible input error sources include:

(1) The overall aircraft drag coefficient must be entered. When many components are combined on an aircraft, the projected frontal area is used for estimations rather than the wing surface area. The drag coefficient could have a significant amount of variation depending on the method used to estimate or evaluate variables.

(2) The propeller efficiency must be estimated. This value will change with respect to the flight characteristics being used. The propeller efficiency is also affected by the aircraft drag coefficient with an aerodynamically dirty aircraft producing a higher propeller efficiency (assuming other factors constant).

(3) An error in either the aircraft drag coefficient or the propeller efficiency will produce a change in the propeller disk swirl velocities which will in turn affect the turbulence levels in the wake due turbulent diffusion.

(4) The background turbulence was not measured in the actual field deposition tests. Therefore, the input values for background turbulence, and turbulence macroscale could have been significantly different than those actually encountered during the field tests.

(5) The input droplet sizes utilized by the modeling process may contain significant errors. The droplet data that is currently available is taken in steady-state airstreams at the reported slipstream velocities (forward

airspeed). However, preliminary unpublished data completed by Oklahoma State University (Effects of Soybean Oil on the Deposition from Agricultural Aircraft) on a Rockwell S2R-R600 Thrush flying at 120 miles per hour indicate that the actual airspeed across the boom ranged from 130 miles per hour at locations near the wingtips and increased at locations near the fuselage to a maximum airspeed in excess of 165 miles per hour at the left-fuselage-wing junction area. These boom location airspeed differences will introduce significant droplet size error using the present algorithm. Simulations for this work were completed using droplet size data presented by Yates (18) as being representative of droplet size characteristics of the D8/45 disc and core nozzle tips used in the field tests. However, this data also indicates that the difference between the assumed 120 miles per hour and the possible 165 miles per hour slipstreams across the nozzle bodies could potentially introduce an error of 16 percent in input droplet size.

(6) The initial velocity vector of the released droplet is unknown. It has been assumed that the effect of the boom on the aerodynamic model is insignificant. This may not be the case. The literature indicates that this information is not available. Considerable theoretical conflict exists in attempting to mathematically predict the interaction between a wing airfoil and a boom with nozzle bodies suspended behind and below the main wing surface.

If the boom were being shielded by the larger wing, it would actually be possible for the boom to exhibit a negative drag coefficient (theoretically possible up to a separation distance of more than 2 effective diameters). In the case of two struts operating one behind the other, the drag on the rear strut increases due to the flow separation from the rear of the second strut because of the momentum deficiency within the wake from the first strut. Two struts operating side by side will result in a positive pressure gradient along the rear surface associated with an increase in velocity and would be responsible for a considerable increase in the drag coefficient (21). Each of these approaches assumes that the bodies in question are of the same or similar size. Such is not the case with a spray boom and an aircraft wing. However, it has been noted in previous flight tests that a Rockwell S2R-R600 Thrush flew at an average of 115 miles per hour indicated airspeed with booms mounted and at 122 miles per hour indicated airspeed without booms at the same engine performance settings. The thrust for these conditions can be estimated by (20):

$$T = n P / V \tag{17}$$

where T is the aircraft estimated thrust, n is the propeller efficiency (0.85), P is the engine power, and V is the velocity. (Utilizing equation 17 and assuming that the engine was producing 450 shaft horsepower with a propeller efficiency of 0.85 and that in steady state flight, the thrust equals the drag, the estimated drag coefficients for the aircraft were .097 with the boom and .082 without the boom.) The approximately 19 percent increase in drag coefficient with the boom would definitely rule out any shielding effects from the presence of a large wing. This indicates that the boom and nozzles must be located in a turbulent mixing zone between the large wake from the wing above and a smaller but significant wake from the boom and nozzles. This wake interaction is not accounted for in the algorithm.

(7) Compressibility of the fluid can generally be ignored within the range of speeds used in agricultural operations. However, this is not true in the area of the propeller blade tips and an error source may result.

(8) It was noted that the downwind deposition pattern of the experimental data had more lateral spread than the upwind pattern. This may be caused by increased turbulence experienced by the downwind particles due to scrubbing over the ground of the downwind vortex. This viscous interaction is not accounted for in the simple wake model used in the aircraft to ground method.

The characteristics of the prediction error was examined by comparing the differences between the predicted and observed centroid locations with the corresponding nozzle locations. However, the relationship between the error and the nozzle location is not well defined as indicated by a 4th order polynomial R-Square of only .109. A statistical "lack of fit" test which divides the total error sum of squares into lack of fit and pure error was performed. The lack of fit portion was significantly different from the pure error which indicates that there is variation in the model not accounted for by random error.

In view of the above mentioned factors, it may be concluded that the existing algorithm does not provide an adequate prediction of the final deposition centroid. The large variation in the prediction data may indicate that the algorithm is 1) extremely sensitive to small input errors, 2) does not address some critical factors in the wake interactions following an agricultural aircraft, 3) that the particle transport phenomena may not be clearly understood, or 4) a combination of all of these.

The magnitude and significance of these errors are illustrated in Figure 14 which shows the field deposition and the predicted deposition from the same nozzle locations. The magnitude of error between the two plots is clearly defined enough to make this method unacceptable for widespread field use in the form used in this study.

Ground to Aircraft Algorithm

A plot of the predicted centroid location versus the observed centroid location for both aircraft resulting from the Ground to Aircraft algorithm is shown in Figure 15.

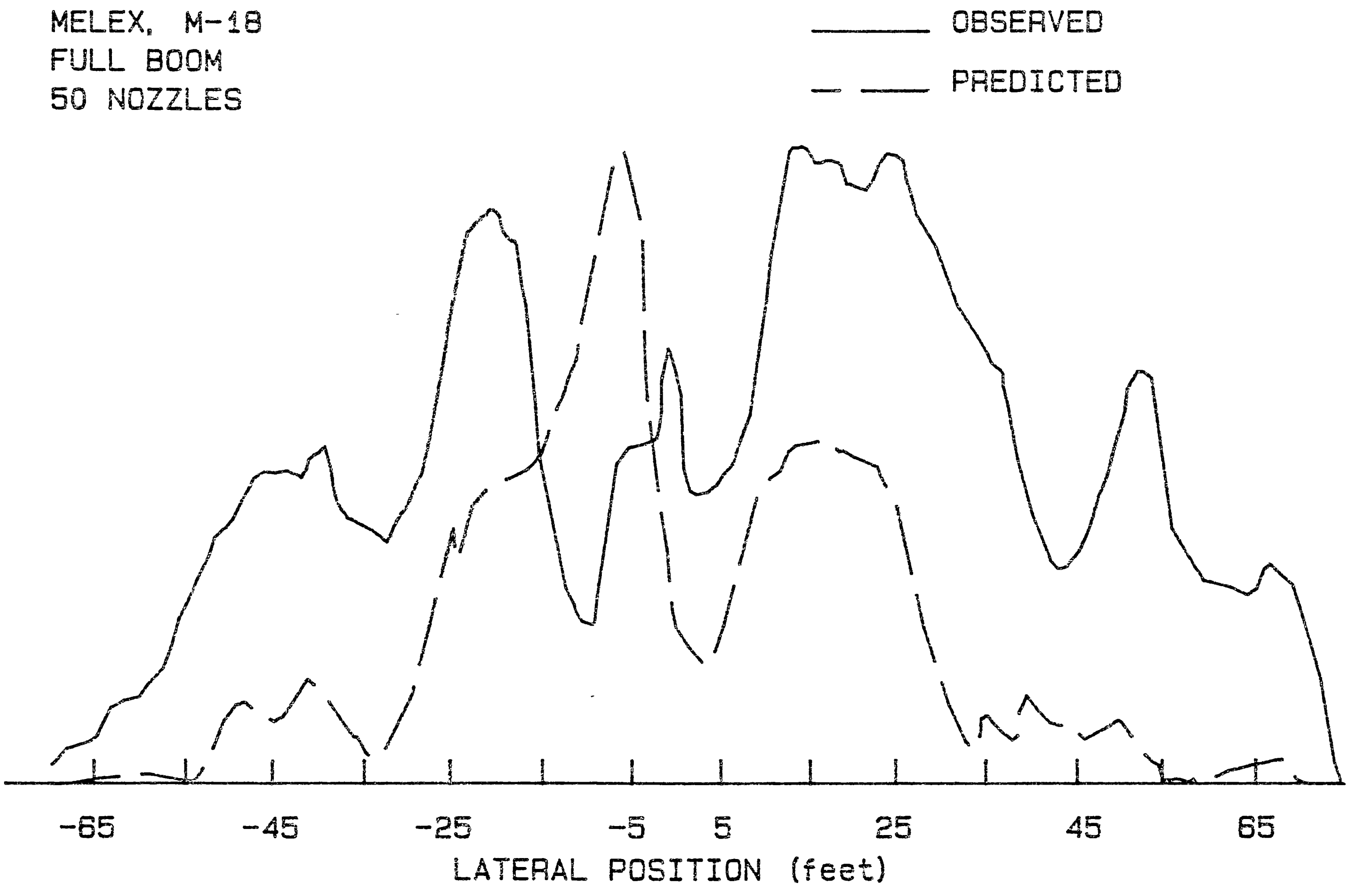


Figure 14. Predicted and Observed Deposition from Air to Ground Algorithm

The plot exhibits a fairly strong statistical relationship described by the relationship:

$$\text{Predicted Value} = .9564\ (\text{Observed Value}) + .1684 \qquad (18)$$

A perfect relationship would appear as a straight line on a 45 degree angle. This relationship exhibited a R-Square of .966 and a Standard Error of 8.5. The relatively high standard error is of concern. Analysis of the predicted/observed error versus nozzle location revealed three significant areas of error; one at each wingtip and one in the area of the propeller. Close examination of the wingtip errors revealed that the high prediction errors occurred on those nozzle locations that were less than 25 percent or greater than 75 percent of the total wingspan. These nozzle locations are not used in the nozzle selection portion of the algorithm due to the high probability of spray released from these locations becoming producers of large quantities of driftable fines. The relationship between prediction error and nozzle location in the propeller influence area is shown in Figure 16. The correction factor evolving from this data is described by:

$$CF = -4.4 - 2.0(X) + .38(X^2) + .15(X^3) - .0075(X^4) - .0024(X^5) - .0000033(X^6) \qquad (19)$$

where CF is the correction factor and X is the nozzle location. This correction factor is applied to any nozzle location in the center 30 percent of the wingspan (15 percent from centerline) in the ground to aircraft algorithm. The addition of the propwash correction term reduced the standard error of the predicted versus the observed centroid locations comparison to 5.3 feet with an R-Square of .96.

Simulations using the algorithm with the propeller correction term produced outputs very similar to those measured in field situations. Figure 17 is an illustration of the predicted and actual field deposition patterns resulting from operation and simulation with the same nozzle locations and conditions. The two curves contain the same characteristic shapes. Deposition patterns from several nozzle configurations from both the Melex and AgCat data have consistently exhibited practically identical characteristic curves. In view of these factors, it was concluded that the ground to aircraft algorithm exhibited sufficient correlations to warrant continued investigation.

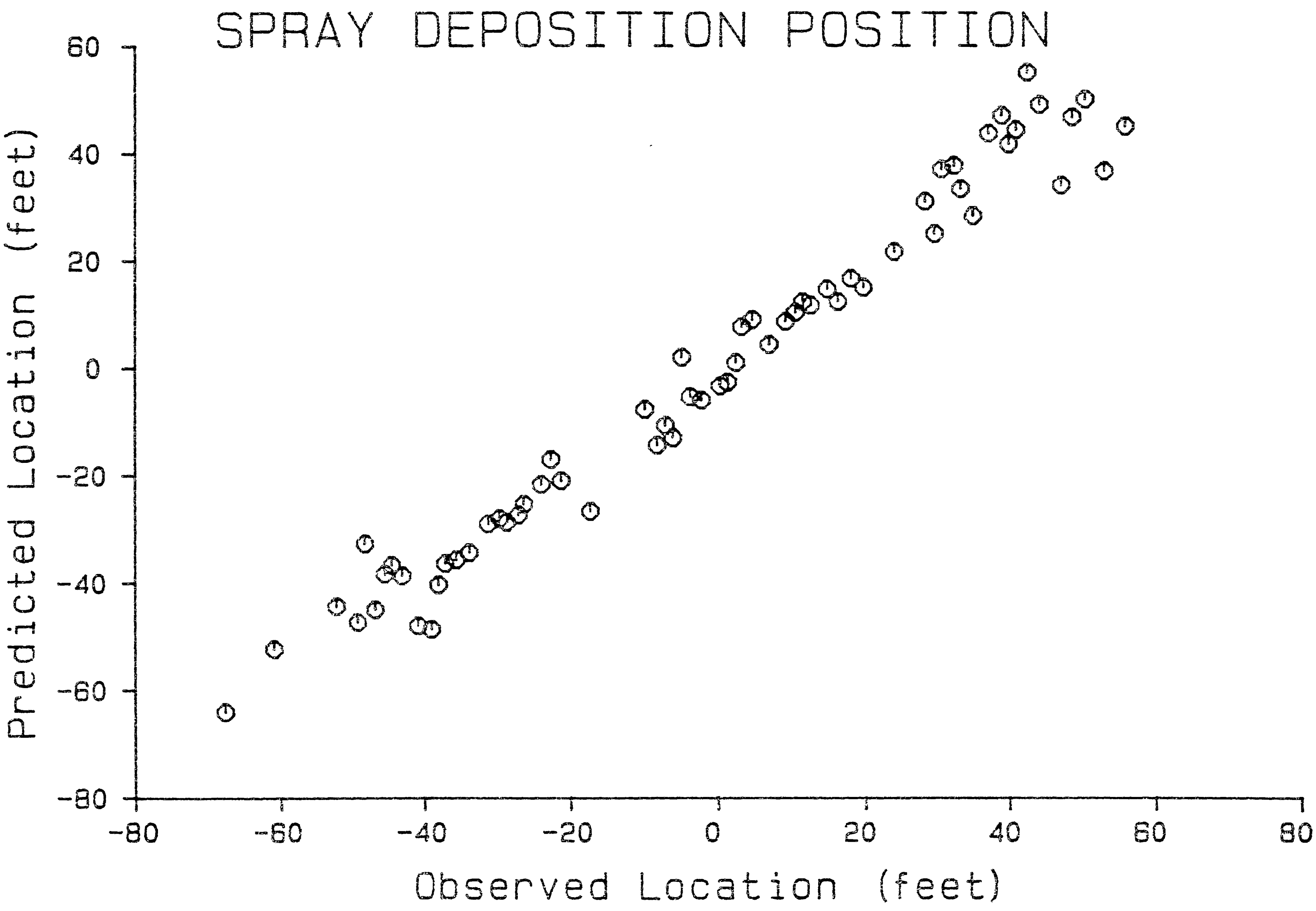


Figure 15. Ground to Aircraft Algorithm Accuracy

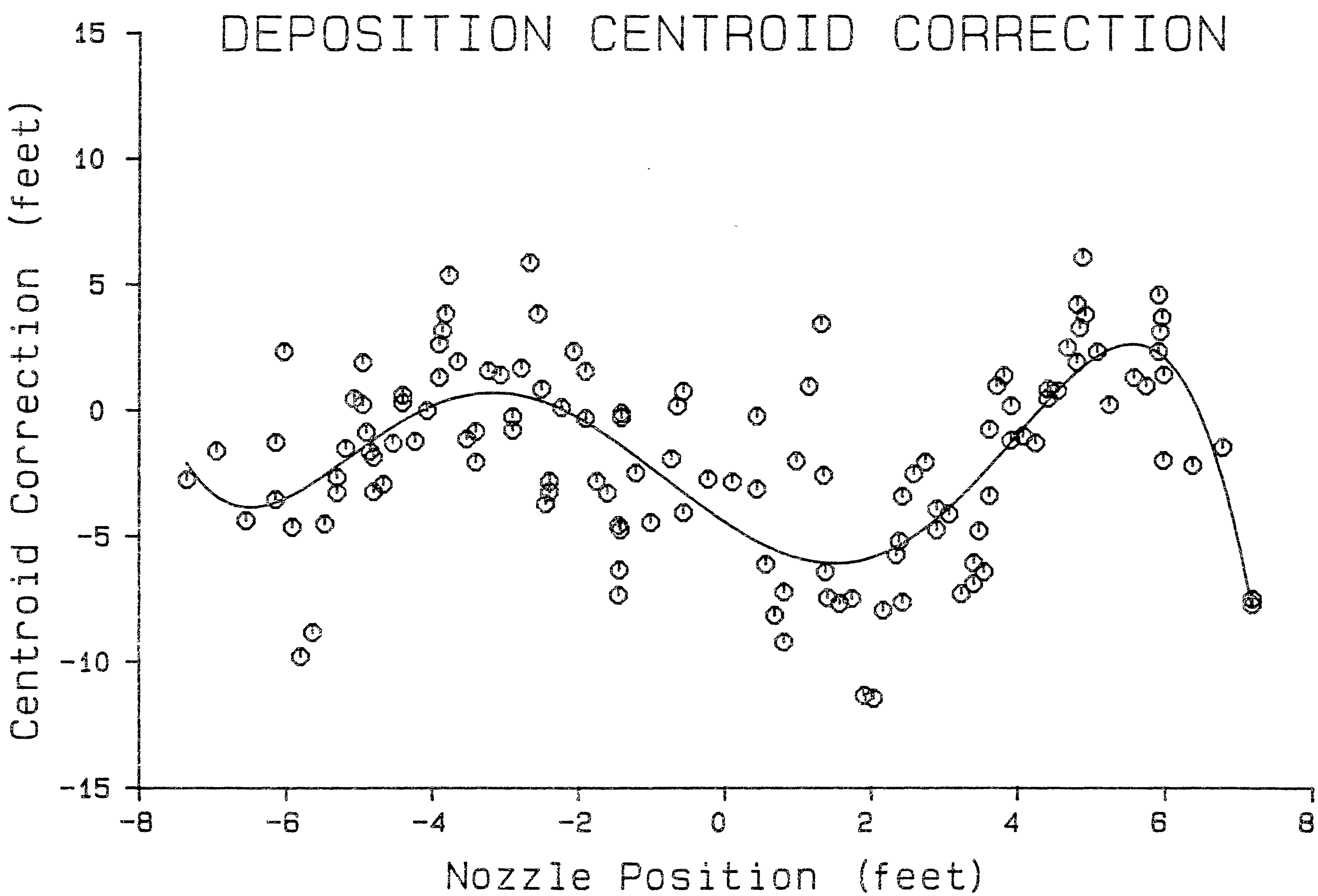


Figure 16. Propeller Induced Error

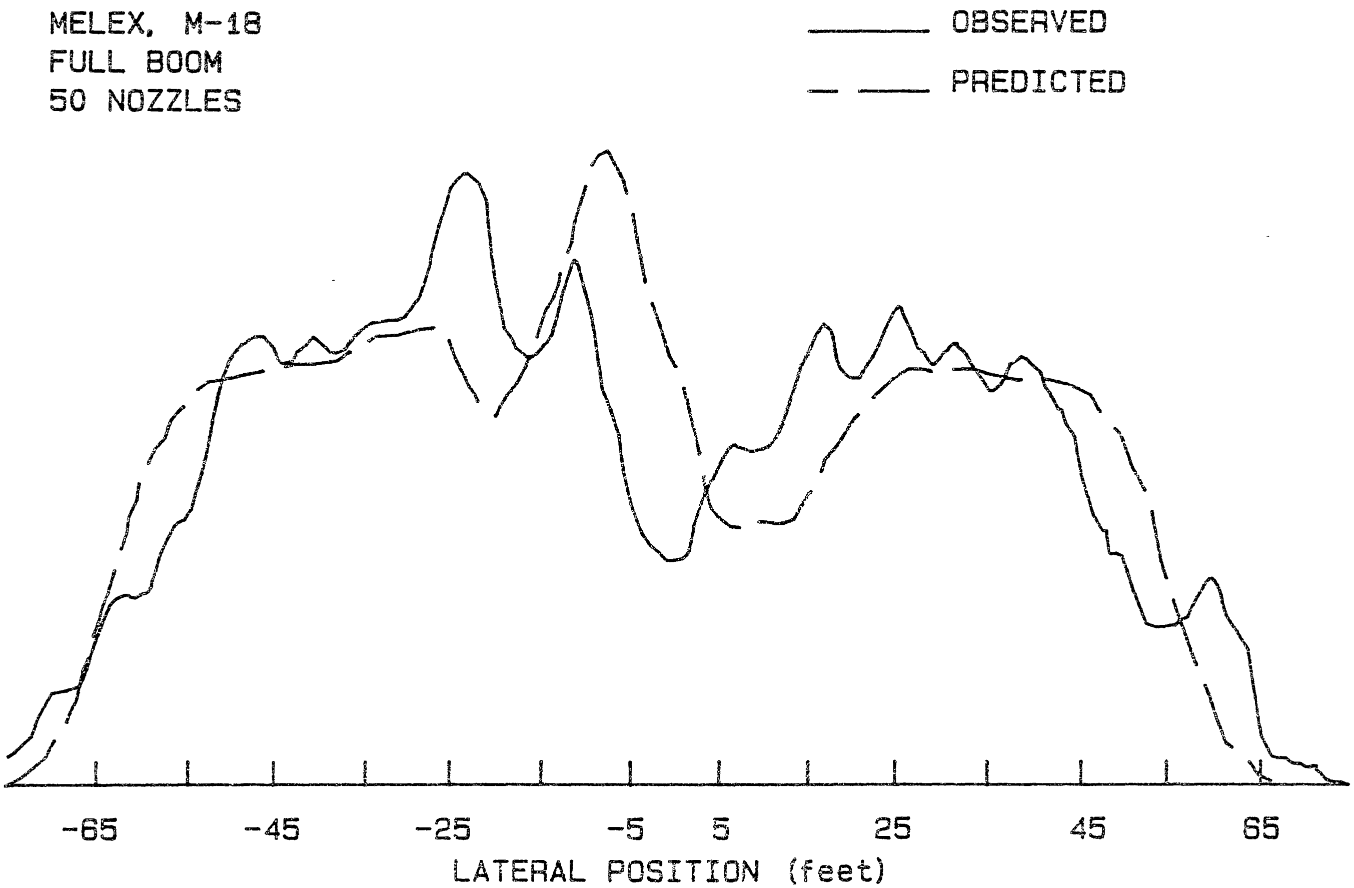


Figure 17. Predicted and Observed Deposition from Ground to Air Algorithm

CHAPTER V

MODEL VERIFICATION

To be an acceptable method of determining nozzle placement, any of the algorithms must have the flexibility of being applied to aircraft in field situations where no data base exists. Both algorithms in this study were developed and tested using two specific types of aircraft; the Melex, M-18 and the AgCat, 164B+.

A field situation developed which allowed the direct application and testing of the algorithms. The objective was to properly place nozzles on an airfoil type boom mounted three inches behind and twelve inches below the wing trailing edge of a Cessna Ag-Truck aircraft. It was desired to use 24 nozzles, use short booms with the outermost possible nozzle position being 11.5 feet (semispan of approximately 21 feet), and maintain an effective swath width of at least 50 feet. The short boom was desired to limit potential drift from field applications. Numerous simulations were run using both algorithms.

The predicted deposition patterns which would result from the recommended nozzle placements from both algorithms were compared. Due to the fact that the field situation involved an active agricultural aircraft with all operational and equipment costs furnished by the aircraft operator, there was no opportunity to test both of the recommended nozzle placements from which a scientific basis for acceptance or rejection could be formed. Based on the analysis of Chapter IV, the output of the Ground to Aircraft algorithm was selected for field verification.

The Ground to Air algorithm produced a recommended nozzle placement as indicated in Table IV. Nozzles were mounted on the aircraft boom at these locations and deposition measured. Figure 18 illustrates the predicted and the observed deposition resulting from spray application with this nozzle placement. The predicted deposition contained an area of underapplication in the center portion of the distribution. The observed deposition contained a slight tendency toward the center gap, but was not nearly as severe as predicted. The field deposition was acceptable and produced an effective swath width of 51 feet compared to the predicted effective swath width of 53 feet.

The differences between the predicted and observed deposition may come from many sources. These algorithms were developed and tested using data from aircraft having large radial engines. These engine mountings are aerodynamically inefficient as compared to the Cessna fully cowled engine mounting. There is also a large difference in the propeller characteristics on the two aircraft with

TABLE IV

NOZZLE PLACEMENT RECOMMENDATIONS, CESSNA

NOZZLE LOCATION (feet)	BEGIN DEPOSITION (feet)	END DEPOSITION (feet)	CENTROID LOCATION (feet)
-11.5	-41.4	-16.4	-29.1
-11.0	-40.3	-15.3	-27.9
-10.5	-39.3	-14.3	-26.8
-10.0	-38.2	-13.2	-25.8
-9.5	-37.2	-12.2	-24.7
-8.5	-35.1	-10.1	-22.6
-7.5	-33.0	-8.0	-20.5
-6.5	-30.9	-5.9	-18.4
-5.5	-30.5	-5.5	-18.1
-4.5	-26.7	-1.7	-14.3
-3.5	-23.6	-1.4	-11.2
2.0	-18.9	6.1	-6.4
3.0	-15.0	10.0	-2.6
3.5	-12.6	12.4	0.1
4.5	-7.3	17.7	5.1
5.5	-3.6	21.3	8.8
6.5	-3.6	21.4	8.9
7.5	-1.5	23.5	11.0
8.5	0.6	25.6	13.1
9.5	2.7	27.7	15.2
10.0	3.8	28.8	16.2
10.5	4.8	29.8	17.3
11.0	5.9	30.9	18.3
11.5	6.9	31.9	19.4

All Distances Relative Aircraft Centerline

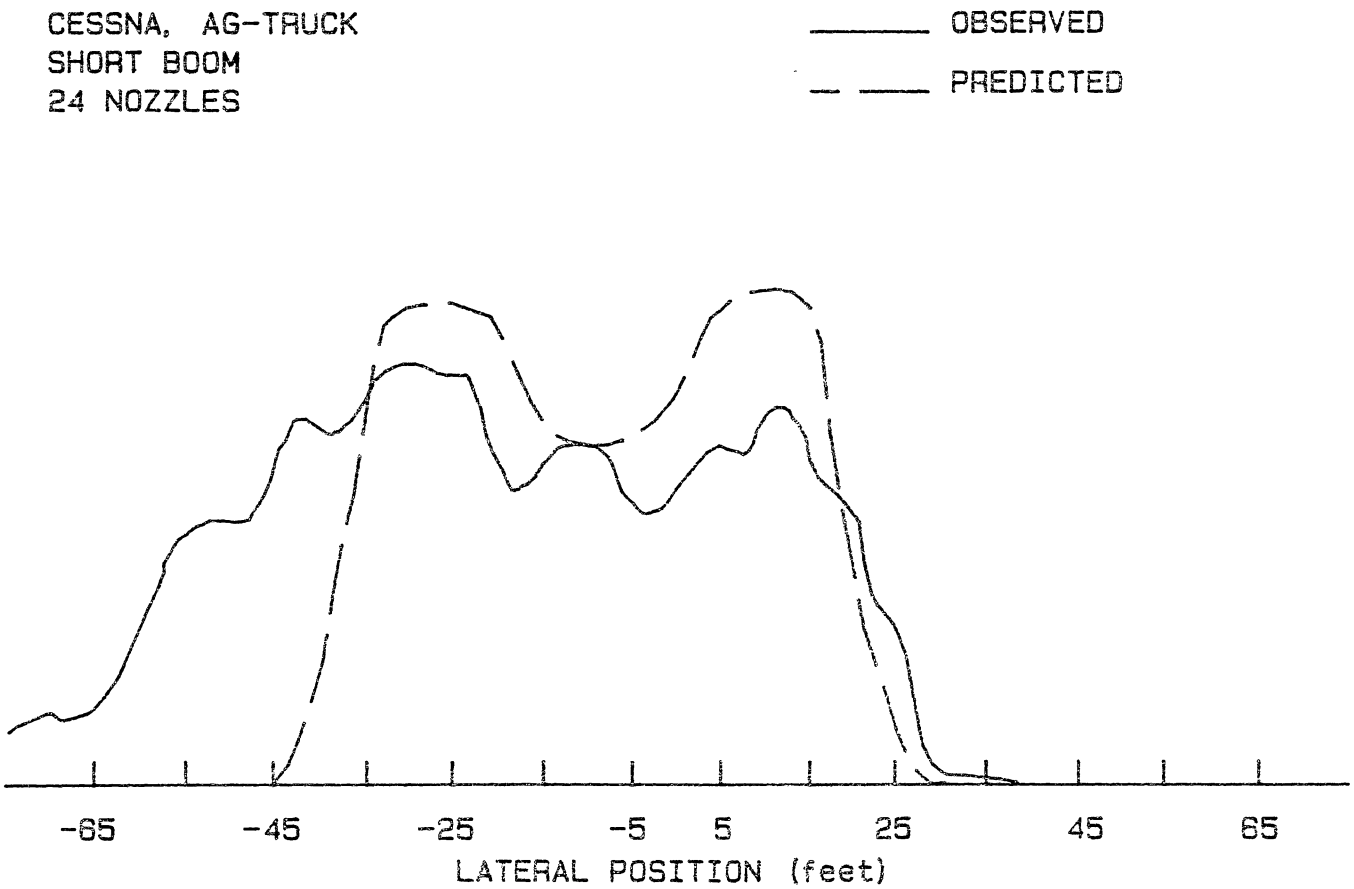


Figure 18. Predicted and Observed Deposition
Cessna Ag-Truck, Final Trial

different propeller tip angular velocities. The predicted deposition with the gap in the center that was not observed in field tests suggests that there may be a lack of predictive accuracy in the propeller helix area. In addition, wing/fuselage juncture vortex flows are not accurately modeled and can affect the particle trajectories in this region. However, the usefulness and general predictive capabilities have been demonstrated. The nozzle placement described above was used in the 1985 application of 1200 acres of fall applied herbicides with no observed loss of efficacy due field streaks or skips.

CHAPTER VI

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

The objectives of this study were to 1) Predict the trajectory of spray particles released from agricultural aircraft, 2) Predict the final deposition positions of released spray particles, and 3) Incorporate the information from 1) and 2) above into a procedure to determine the correct nozzle placement on an aircraft boom to ensure a uniform deposition.

Two mathematical simulation algorithms were developed to meet these objectives. The first algorithm, based on the NASA developed Agdisp code and referred to in this thesis as the "Aircraft to Ground" method, attempted to predict the spray particle trajectory and final deposition position by releasing a particle into the wake following an agricultural aircraft and tracking it to the ground. A Lagrangian approach was used to develop equations of motion of discrete particles released from an aircraft, and a predictor-corrector solution scheme used to solve the resulting set of ordinary differential equations. This code computed the averaged mean motion of the material and the dispersion about this mean motion resulting from turbulent fluid fluctuation. These fluctuations result from turbulence generated by the aircraft itself or present normally in the atmosphere. By repeating this procedure for droplet sizes representing the V.1, V.5, and V.9 positions on a curve of cumulative drop size distribution by volume, a predicted deposition distribution was obtained for each nozzle position, and a deposition matrix formed from which final recommended nozzle placements and predicted depositions were obtained. These predictions were then compared to field data obtained from single nozzle spray tests, for a Melex, M-18 and an AgCat, 164B+, to determine the predicted centroid position accuracy and to evaluate the potential for prediction depostions as a result of full boom spray release.

From the single nozzle test data on the Melex and AgCat aircraft, a second predictive algorithm, referred to as the "Ground to Aircraft" method, was developed by exploring the statistical relationships between the measured variables. Dependent variables included spray span, spray peak amplitude, and spray deposition centroid position while the independent variables included nozzle location, aircraft gross weight, crosswind conditions, aircraft ground speed, spray altitude, relative humidity, and aircraft lateral displacement (aircraft pilot positioning error during tests). Examination of the statistical relationships revealed a linear response as the most favorable. It was determined that a correction factor was needed for nozzles located in the area of the propeller helix influence. This correction term was added to the code and applied to all nozzles located in the center 30 percent of the wingspan (+ 15 percent from centerline). The output from this relationship was used to form a deposition matrix, predict deposition patterns and to select nozzle placements.

Both simulation algorithms were applied to a field case, involving a Cessna Ag-Truck aircraft on which no database existed, with the objective of determining the optimum placement of 24 nozzles on an airfoil type boom to obtain the widest effective swath width while maintaining a uniform deposition.

Conclusions

(1) The Aircraft to Ground algorithm is useful for the comparison of "what-if" situations on a relative basis.

(2) The Aircraft to Ground algorithm exhibited significant lack of correlation when compared with the single nozzle deposition test data for the two aircraft; Melex, M-18 and AgCat, 164B+. This suggests that the algorithm is extremely sensitive to small input errors, that the vortex core locations, strengths or the viscous wake turbulence may not be accurately defined in the input parameters, that the particle transport phenomena may not be clearly understood, or a combination of all these.

(3) The Aircraft to Ground algorithm appears to be accurate when the actual wake profile is known. However,

the actual wake profile is seldom known in field situations. Therefore, errors in the predicted/observed centroid positions may be caused by the unavailability of specifications or the inability to precisely measure required input parameters. These errors tend to magnify greatly in a numerical solution scheme.

(4) The Ground to Aircraft algorithm with the propeller correction terms produced acceptable agreement between the predicted and observed centroid locations.

(5) No strong statistical relationship could be found for deposition span or deposition peak amplitude with the measured independent variables. Statistical tests indicated that the variation in the data was more due to random error than to the measured independent variables.

(6) The application of the Ground to Aircraft algorithm to a field situation did prove the concept of computer simulation for nozzle placement recommendations by predicting an acceptable deposition pattern for recommended nozzle placements on a previously untested aircraft. While the results were encouraging, additional fine tuning may be required for widespread applications.

Recommendations for Improvement

Both algorithms need additional refinement before the widespread use in field applications. The addition of correction routines should be added to correct for the distortions caused by the various components protruding into the slipstream of the aircraft. These could be developed for each section of the wingspan where distortions are known to occur. The outputs of the algorithms should be compared to many types and gross weights of aircraft to obtain a more precise analysis of the applicability of each single algorithm to a wide variety of aircraft, operation, and environmental factors. Data from additional aircraft might also allow the mathematical descriptions of evaporation as a function of nozzle location, temperature, and relative humidity.

Suggestions for Further Study

(1) Determine a more precise estimation of the initial droplet size spectrum by measuring the slipstream velocity vectors over the boom/nozzle configurations in actual flight conditions.

(2) Determine the amount and character of the wake interaction due the wing and trailing boom/nozzle configuration.

(3) Develop a method of determining the height and magnitude of the background turbulence macroscale.

(4) Develop a procedure for determining the aircraft drag coefficient and propeller efficiency for inputs into the algorithms.

(5) Expand the verification/development of the deposition algorithms to include rotary wing aircraft.

(6) Develop a fuselage interaction (wing/fuselage

juncture vortices) relationship for inclusion in the prediction process.

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APPENDIXES

APPENDIX A

SIMULATION CODE FOR AIRCRAFT TO GROUND ALGORITHM

Module One

```
10  REM  NASA DATA PREPERATION PROGRAM
20  REM  THIS PROGRAM WILL PREPARE THE
30  REM  INPUT DATA IN THE CORRECT FORM
40  REM  FOR SUBMISSION TO THE
50  REM  DEC PDP11/34A COMPUTER AT THE
60  REM  KSU DEPT AG. ENGINEERING
70  REM  CARD 0000
80  REM  COMMENT CARDS
90  PRINT "INPUT IDENTIFIER TITLE"
100  PRINT " FOR COMPUTER SIMULATION"
110  PRINT
120  INPUT C$
130 C$ = "0000 " + C$
140  REM   CARD 0010
150  REM  PROGRAM CARD
160  PRINT "INPUT THE MAXIMUM TIME FOR SIMULATION": PRINT
"TIME SHOULD BE IN FORMAT 5.0"
170  INPUT TM$
180  PRINT : PRINT
190  PRINT "THE FULL-PLANE SOLUTION": PRINT "SHOULD BE USED
ONLY IF": PRINT "A CROSSWIND OR A": PRINT "PROPELLER
EXISTS.  SINGLE"
200  PRINT "PARTICLE RELEASE WITHOUT AN": PRINT "AIRCRAFT
SHOULD USE A FULL": PRINT "PLANE SIMULATION": PRINT
210  INPUT "HALF OR FULL-PLANE SIMULATION? ";A$
220  IF A$ = "H" THEN  GOTO 250
230  IF A$ = "F" THEN  GOTO 270
240  GOTO 210
250 A$ = "1"
260  GOTO 280
270 A$ = "2"
280 PP$ = "0010 " + TM$ + " " + A$
290 AA$ = A$
300  REM   CARD 0020
310  REM  AIRCRAFT CHARACTERISTICS
320  HOME : PRINT : PRINT
```

```
330  PRINT : PRINT "THE AIRCRAFT CHARACTERISTICS": PRINT
"WILL NOW BE DESCRIBED": PRINT : PRINT
340  PRINT "WHICH OF THE FOLLOWING TYPES IS DESIRED?"
350  PRINT "   3 = HELICOPTER ENTRY"
360  PRINT "   2 = RECTANGULARLY LOADED"
370  PRINT "       FULLY ROLLED UP TIP VORTEX"
380  PRINT "   1 = TRIANGULARLY LOADED"
390  PRINT "       FULLY ROLLED UP TIP VORTEX"
400  PRINT "   0 = BETZ ROLL UP FROM A GIVEN"
410  PRINT "       CIRCULATION PATTERN"
420  PRINT "  -1 = WAKE PLOT FILE ENTRY"
430  PRINT "        (CARD 0050-REFER TO 81-14)"
440  PRINT "  -2 = NONAIRCRAFT RUN (SINGLE"
450  PRINT "          PARTICLE RELEASE)": PRINT : PRINT
460  INPUT A
470  IF A > 3 OR A <  - 2 THEN  GOTO 340
480 VF$ =  STR$ (A)
490  PRINT
500  INPUT "CROSSWIND DESIRED (Y/N)? ";A$
510  IF A$ = "Y" THEN  GOTO 540
520  IF A$ = "N" THEN  GOTO 560
530  GOTO 500
540 CF$ = "1"
550  GOTO 570
560 CF$ = "0"
570  PRINT : PRINT "THE NEXT ENTRY IS THE WINGSPAN OF THE"
580  PRINT "AIRCRAFT IN FEET": PRINT : PRINT "(ROTOR
DIAMETER FOR A HELICOPTER, "
590  PRINT "THE INITIAL Y COORDINATE OF A": PRINT
"RECTANGULARLY LOADED, FULLY ROLLED-UP"
600  PRINT "TIP VORTEX CENTERLINE": PRINT "AND TWICE THE
INITIAL Y COORDINATE"
610  PRINT "OF A TRIANGULARLY LOADED, FULLY": PRINT "ROLLED
UP TIP VORTEX CENTERLINE)"
620  PRINT : PRINT
630  PRINT "FORMAT 36.6"
640  PRINT : PRINT
650  INPUT A:A = A / 2 * .3048
660 A =  INT (A * 100) / 100
670 SS$ =  STR$ (A)
680  PRINT : PRINT "INPUT THE HEIGHT OF THE AIRCRAFT WING":
PRINT "ABOVE THE SURFACE IN FEET": PRINT
690  PRINT "(RELEASE HEIGHT FOR SINGLE PARTICLES)": PRINT
"THIS HEIGHT IS THE INITIAL Z COORDINATE": PRINT "FOR FULLY
ROLLED-UP TIP VORTICES"
700  PRINT "AND THE Z COORDINATE FOR THE BETZ": PRINT
"ROLL-UP VORTEX SHEET": PRINT
710  INPUT A
720 A =  INT ((A * .3048 * 10) + .5) / 10
730 WH$ =  STR$ (A)
740  PRINT : PRINT "INPUT THE FLIGHT SPEED OF THE": PRINT
"AIRCRAFT IN MPH"
750  INPUT A
760 A =  INT (A * .44704 * 10) / 10
```

```
770 FS$ =  STR$ (A)
780  PRINT : PRINT "IS THE AIRCRAFT A BIPLANE OR": PRINT "A
SINGLE WING? (B/S) "
790  INPUT A$
800  IF A$ = "B" THEN  GOTO 830
810  IF A$ = "S" THEN  GOTO 850
820  GOTO 780
830 BF$ = "1"
840  GOTO 860
850 BF$ = "0"
860 AC$ = "0020 " + VF$ + " " + CF$ + " " + SS$ + " " + WH$
+ " " + FS$ + " " + BF$
870  REM   CARD 0021
880  REM  BIPLANE CONFIGURATION
890  HOME
900  IF BF$ = "0" THEN  GOTO 1020
910  PRINT : PRINT "INPUT THE VERTICLE DISTANCE (FEET)":
PRINT "FROM THE MAIN WING SPECIFIED EARLIER": PRINT "TO THE
BIPLANE WING"
920  INPUT A:A =  INT (A * .3048 * 10) / 10
930 WD$ =  STR$ (A)
940  PRINT : PRINT "INPUT THE SEMISPAN OF THE BIPLANE
WING": PRINT "AS A FRACTION OF THE SEMISPAN OF THE LOWER":
PRINT "WING (IF WINGS ARE OF EQUAL LENGTH,": PRINT "ENTER
1.0)": PRINT
950  INPUT A
960 SB$ =  STR$ (A)
970  PRINT : PRINT "INPUT THE VORTEX STRENGTH OF THE":
PRINT "BIPLANE WING AS A FRACTION OF THE": PRINT "MAIN
VORTEX STRENGTH (1.0 IF THEY": PRINT "ARE EQUAL"
980  INPUT A
990 SV$ =  STR$ (A)
1000 BC$ = "0021 " + WD$ + " " + SB$ + " " + SV$
1010  REM   CARD 0022
1020  REM  CIRCULATION VALUE
1030  HOME
1040 A =  VAL (VF$)
1050  IF A < 1 OR A > 2 GOTO 1150
1060  PRINT "INPUT THE SIMULATED WEIGHT OF THE"
1070  INPUT "AIRCRAFT (LBS) ";L
1080 L = L * 4.448
1090 S =  VAL (SS$)
1100 V =  VAL (FS$)
1110 CV = L / (2 * S * V * 1.2266)
1120 CV =  INT (CV * 110) / 100
1130 CV$ = "0022 " +  STR$ (CV)
1140  REM   CARD 0025
1150  REM  BETZ WING LOAD DISTRIBUTION
1160  HOME
1170  IF  VAL (VF$) <  > 0 THEN  GOTO 1370
1180  PRINT : PRINT "INPUT THE REQUIRED INFORMATION": PRINT
"TO DESCRIBE THE BETZ LOADING": PRINT "A MAXIMUM OF 100
ENTRIES MAY BE USED": PRINT : PRINT "USE A NEGATIVE
IDENTIFIER TO TERMINATE": PRINT "THIS INPUT SECTION"
```

```
1190 CT = 0:S$ = " "
1200  FOR I = 1 TO 100
1210 CT = CT + 1
1220  PRINT
1230  INPUT "INPUT IDENTIFIER NUMBER ";A
1240  IF A < 0 THEN S$ = " -"
1250  PRINT
1260  PRINT "INPUT THE POSITION (FEET) MEASURED FROM":
PRINT "THE WING ROOT TOWARDS THE TIP": PRINT "FOR POSITION
";CT
1270  INPUT PO:PO = PO * .3048
1280 PO =  INT (PO * 10) / 10
1290  PRINT : PRINT "INPUT THE CIRCULATION VALUE FOR"
1300  PRINT "POSITION ";CT;" IN FT/SEC^2"
1310  INPUT CV
1320 CV =  INT (CV * .3048 * 110) / 100
1330 BZ$(CT) = "0025" + S$ +  STR$ (CT) + " " +  STR$ (PO)
+ " " +  STR$ (CV)
1340  IF S$ = " -" THEN  GOTO 1370
1350  NEXT I
1360  REM   CARD 0028
1370  REM  CROSSWIND CARD
1380  HOME
1390  IF  VAL (CF$) = 0 THEN  GOTO 1510
1400  PRINT : PRINT "INPUT THE REQUESTED CROSSWIND VALUES":
PRINT "TO DESCRIBE THE NEUTRAL": PRINT "CROSSWIND VELOCITY
PROFILE SHAPE"
1410  PRINT
1420  PRINT "INPUT THE MEAN WIND VELOCITY ": INPUT "IN MPH
";V
1430  PRINT
1440  PRINT "INPUT THE HEIGHT OF MEAN VELOCITY": INPUT "(
OR MEASUREMENT HEIGHT-FEET) ";H
1450  PRINT
1460  PRINT "INPUT THE SURFACE HEIGHT ROUGHNESS (FEET)":
INPUT Z
1470 V = V * .4470:H = H * .3048:Z = Z * .3048
1480 V =  INT (V * 10) / 10:H =  INT (H * 10) / 10:Z =  INT
(Z * 100) / 100
1490 CW$ = "0028 " +  STR$ (V) + " " +  STR$ (H) + " " +
STR$ (Z)
1500  REM   CARD 0030
1510  REM  HELICOPTER CARD
1520  HOME
1530  IF  VAL (VF$) <  > 3 THEN  GOTO 1610
1540  PRINT : PRINT "INPUT THE TWO VALUES AS REQUESTED TO":
PRINT "DESCRIBE THE HELICOPTER FLOW FIELD": PRINT
1550  INPUT "INPUT THE WEIGHT OF THE HELICOPTER (LBS) ";W
1560 W = W * 4.448: PRINT
1570 W =  INT (W * 10) / 10
1580  INPUT "INPUT THE FORWARD ADVANCE RATIO (> ZERO) ";A
1590 HC$ = "0030 " +  STR$ (W) + " " +  STR$ (A)
1600  REM   CARD 0040
1610  REM  PROPELLER DATA CARD
```

```
1620  HOME
1630  PRINT
1640  PRINT "WILL THIS SIMULATION INCLUDE A PROPELLER"
1650  INPUT "(Y/N)? ";A$
1660  IF A$ = "N" THEN  GOTO 1810
1670  PRINT : PRINT "INPUT THE REQUESTED VALUES TO
DESCRIBE": PRINT "THE PROPELLER INTERACTION": PRINT
1680  PRINT "INPUT THE DRAG COEFFICIENT OF"
1690  INPUT "THE AIRCRAFT ";DC
1700  PRINT : PRINT "INPUT THE PLANFORM AREA OF THE"
1710  INPUT "AIRCRAFT (FEET**2) ";PA
1720  PRINT : INPUT "INPUT THE PROPELLER EFFICIENCY ";PE
1730  PRINT : INPUT "INPUT THE SHAFT RPM ";RPM
1740  PRINT : INPUT "INPUT THE BLADE RADIUS (FEET) ";BR
1750  PRINT : PRINT "INPUT THE INCREMENTAL DISTANCE
(FEET)": PRINT "OF THE SHAFT CENTERLINE ABOVE": PRINT "OR
BELOW THE NOMINAL RELEASE": PRINT "HEIGHT GIVEN EARLIER"
1760  INPUT ID:ID = ID * .3048
1770 BR = BR * .3048:PA = PA * .0929
1780 ID =  INT (ID * 100) / 100:BR =  INT ((BR * 10) + .5)
/ 10:PA =  INT (PA * 10) / 10
1790 PC$ = "0040 " +  STR$ (DC) + " " +  STR$ (PA) + " " +
STR$ (PE) + " " +  STR$ (RPM) + " " +  STR$ (BR) + " " +
STR$ (ID)
1800  REM   CARD 0050
1810  REM  TURBULENCE CARD
1820  HOME
1830  PRINT : PRINT "SELECT THE DESIRED TURBULENCE BASE":
PRINT
1840  PRINT "-1 = SUPEREQUILIBRIUM"
1850  PRINT " 0 = ASSUMES FIXED VALUE"
1860  PRINT
1870  PRINT " 1   SPECIFIES THE TURBULENT COMPONENTS"
1880  PRINT " 2 = IN THE ATTACHED WAKE PLOT FILE"
1890  PRINT " 3   INVOKED WITH EARLIER ENTRY"
1900  PRINT : PRINT "A -1 OR 0 IS USUALLY USED IN THE"
1910  PRINT "ABSENCE OF A WAKE PLOT FILE": PRINT
1920  INPUT "INPUT TURBULENCE BASE ";TB
1930  PRINT : IF TB <  - 1 OR TB > 3 THEN  GOTO 1810
1940  PRINT "INPUT THE VALUE OF THE MAXIMUM VALUE"
1950  PRINT "(IN FT**2/SEC**2)"
1960  INPUT "OF THE BACKGROUND TURBULENCE ";MT
1970  PRINT : PRINT "INPUT THE MAXIMUM VALUE OF THE
BACKGROUND"
1980  PRINT "TURBULENT MACROSCALE": INPUT "(FEET) ";MH
1990 MT = MT * .0929:MH = MH * .3048
2000 MT =  INT (MT * 10) / 10:MH =  INT (MH * 10) / 10
2010 TC$ = "0050 " +  STR$ (TB) + " " +  STR$ (MT) + " " +
STR$ (MH)
2020  REM  CANOPY PLANT PROFILE
2030  HOME : PRINT : PRINT "THE PLANT CANOPY PROFILE CAN ":
PRINT "NOW BE DESCRIBED"
2040  PRINT "WILL A PLANT PROFILE BE USED IN": INPUT "THE
SIMULATION (Y/N) ";A$
```

```
2050  IF A$ = "Y" THEN  GOTO 2080
2060  IF A$ = "N" THEN  GOTO 2220
2070  GOTO 2040
2080  PRINT : PRINT "INPUT A NEGATIVE ENTRY NUMBER": PRINT
"TO TERMINATE INPUT": PRINT
2090 CP = 0:S$ = " "
2100  PRINT : PRINT "INPUT THE Z POSITION AND": PRINT "THE
PLANT AREA DENSITY": PRINT "(FT^2/FT^3) CORRESPONDING TO
THE Z": PRINT "POSITION";" STARTING AT THE SURFACE AND":
PRINT "INCREASING ""MONOTONICALLY TO THE TOP": PRINT
2110  PRINT "INPUT A NEGATIVE ENTRY NUMBER TO END INPUT"
2120  FOR I = 1 TO 100
2130 CP = CP + 1
2140  INPUT "INPUT THE ENTRY NUMBER";A
2150  IF A < 0 THEN S$ = " -"
2160  INPUT "INPUT POSITION AND DENSITY ";PP,PA
2170 PP = PP * .3048
2180 CP$(CP) = "0055" + S$ +  STR$ (CP) + " " +  STR$ (PP)
+ " " +  STR$ (PA)
2190  IF S$ = " -" THEN  GOTO 2220
2200  NEXT I
2210  REM   CARD 0060
2220  REM  PARTICLE DATA CARD
2230  HOME
2240  PRINT : PRINT "INPUT THE TOTAL NUMBER OF PARTICLES":
PRINT "TO BE RELEASED (NOT COUNTING THE CENTER)"
2250  PRINT "IN THE HALF-PLANE CONFIGURATION"
2255  PRINT : PRINT "****  MUST BE INTEGER VALUE  ****"
2260  INPUT TN
2270  PRINT : PRINT "DO YOU WANT A PARTICLE RELEASED AT"
2280  INPUT "THE CENTER OF THE AIRCRAFT ";A$
2290  IF A$ = "Y" THEN  GOTO 2320
2300  IF A$ = "N" THEN  GOTO 2340
2310  GOTO 2270
2320 CN$ = "1"
2330  GOTO 2350
2340 CN$ = "0"
2350 T = TN: IF  VAL (AA$) = 1 THEN  GOTO 2370
2360 T = T * 2
2370  PRINT : PRINT "DO YOU DESIRE SPECIFIC NOZZLE": PRINT
"POSITIONING OR AUTOMATIC UNIFORM"
2380  INPUT "SPACING? ENTER S OR A ";A$
2390  IF A$ = "A" THEN  GOTO 2430
2400 CN$ = "-" + CN$
2410 T = T +  VAL (CN$)
2420 TN =  - TN
2430  PRINT : PRINT "INPUT THE VERTICLE POSITION
OFFSETING": PRINT "THE PARTICLE RELEASE POINT FROM": PRINT
"THE HEIGHT OF THE WING GIVEN EARLIER"
2440  PRINT "(IN FEET)"
2450  INPUT PO
2460 PO = PO * .3048
2470 PO =  INT ((PO * 10) + .5) / 10
2480 DD$ = "0060 " +  STR$ (TN) + " " + CN$ + " " +  STR$
```

```
(PO)
2490  PRINT : INPUT "INPUT THE MICRON SIZE OF THE INITIAL
PARTICLE";PS
2500 DD$ = DD$ + " " +  STR$ (PS)
2510  PRINT : PRINT "INPUT THE SPECIFIC GRAVITY OF THE":
INPUT "RELEASED PARTICLE ";SG
2520 DD$ = DD$ + " " +  STR$ (SG)
2530  PRINT : PRINT "DO YOU DESIRE EVAPORATION TO BE
CONSIDERED": INPUT "IN THE SIMULATION? (Y/N) ";A$
2540  IF A$ = "N" THEN EF = 0
2550  IF A$ = "Y" THEN EF = 1
2560 DD$ = DD$ + " " +  STR$ (EF)
2570  REM   CARD 0061
2580  REM  DISCRETE PARTICLE LOCATION CARDS
2590  IF TN >  = 0 THEN  GOTO 2790
2600  HOME
2610  PRINT : PRINT "YOU MUST ENTER ";T;" PARTICLE LOCATION
CARDS": PRINT
2620  PRINT : PRINT : PRINT "A PARTICLE RELEASED AT THE":
PRINT "CENTERLINE SHOULD BE ENTERED LAST"
2630  PRINT : PRINT : PRINT
2640  PRINT "INPUT THE Y POSITION ALONG THE WING": PRINT
"(ZERO IS AT THE CENTERLINE)": PRINT "AND THE VERTICLE
OFF-SET OF THE PARTICLE": PRINT "FROM THE WING IN FEET FOR
EACH": PRINT "PARTICLE POSITION"
2650  PRINT : PRINT : PRINT
2660  FOR I = 1 TO T
2670  PRINT "INPUT THE Y POSITION FOR LOCATION ";I
2680  INPUT Y
2690 Y = Y * .3048
2700 Y =  INT ((Y * 10) + .5) / 10
2710  PRINT "INPUT THE Z POSITION (VERTICLE OFF-SET": PRINT
" OF THE ";I;"TH POSITION"
2720 HV =  INT (HV * 10) / 10
2730  INPUT Z
2740 Z = Z * .3048
2750 Z =  INT ((Z * 10) + .5) / 10
2760 PL$(I) = "0061 " +  STR$ (I) + " " +  STR$ (Y) + " " +
STR$ (Z)
2770  NEXT I
2780  REM   CARD 0062
2790  REM  PARTICLE INITIAL CONDITION CARDS
2800  HOME : PRINT : PRINT "WOULD YOU LIKE TO DEFINE A
PARTICLE": PRINT "INITIAL CONDITION? (Y/N) "
2810  INPUT " IF NO, ALL CONDITIONS WILL BE SET TO ZERO
";A$
2815  IF A$ = "Y" THEN  GOTO 2830
2820  IF A$ = "N" THEN  GOTO 2960
2825  GOTO 2800
2830  PRINT "INPUT THE INITIAL HORIZONTAL VELOCITY": INPUT
" IN FEET/SEC ";HV
2840 HV = HV * .3048
2850  PRINT : PRINT "INPUT THE INITIAL VERTICAL VELOCITY":
INPUT "IN FEET/SEC ";VV
```

```
2860 VV = VV * .3048
2870 VV =  INT (VV * 10) / 10
2880  PRINT : PRINT "INPUT THE INITIAL SPATIAL VARIANCE":
INPUT " OF THE PARTICLE PATH IN FEET**2 ";SV
2890 SV = SV * .09290304
2900 SV =  INT (SV * 10) / 10
2910  PRINT : PRINT "INPUT THE INITIAL VELOCITY VARIANCE OF
THE": INPUT "PARTICLE IN FEET^2/SEC^2 ";IV
2920 IV = IV * .09290304
2930 IV =  INT (IV * 10) / 10
2940 IC$ = "0062 " +  STR$ (HV) + " " +  STR$ (VV) + " " +
STR$ (SV) + " " +  STR$ (IV)
2950  REM   CARD 0065
2960  REM  EVAPORATION DATA CARD
2970  HOME
2980  IF EF = 0 THEN  GOTO 3060
2990  HOME : PRINT : PRINT "ENTER THE TEST DRY BULB
TEMPERATURE": INPUT "IN DEGREES F ";DB
3000  PRINT : PRINT "ENTER THE TEST WET BULB TEMPERATURE":
INPUT "IN DEGREES F ";WB
3010 DB = (5 / 9) * (DB - 32)
3020 WB = (5 / 9) * (WB - 32)
3030 DB =  INT (DB * 10) / 10
3035 WB =  INT (WB * 10) / 10
3040  PRINT : PRINT "INPUT THE SIZE OF THE DROPLET
(MICRONS)": INPUT "AT WHICH EVAPORATION HAS OCCURRED ";MS
3050 EC$ = "0065 " +  STR$ (DB - WB) + " " +  STR$ (MS)
3060  REM  END OF INPUTS
3070  HOME : PRINT "END OF INPUT SECTION": PRINT : PRINT
3075  PRINT : PRINT : PRINT "** INSERT DATA DISK INTO DRIVE
2 **"
3080  PRINT "INPUT THE DESIRED NAME OF": INPUT "THE DATA
SET ";A$
3100 D$ = ""
3110  PRINT D$;"OPEN ";A$;",D2"
3120  PRINT D$;"WRITE ";A$
3130  IF C$ = "" THEN  GOTO 3160
3140  PRINT C$
3150  IF PP$ = "" THEN  GOTO 3170
3160  PRINT PP$
3170  IF AC$ = "" THEN  GOTO 3190
3180  PRINT AC$
3190  IF BC$ = "" THEN  GOTO 3210
3200  PRINT BC$
3210  IF CV$ = "" THEN  GOTO 3230
3220  PRINT CV$
3230  IF CT = 0 THEN  GOTO 3270
3240  FOR I = 1 TO CT
3250  PRINT BZ$(I)
3260  NEXT I
3270  IF CW$ = "" THEN  GOTO 3290
3280  PRINT CW$
3290  IF HC$ = "" THEN  GOTO 3310
3300  PRINT HC$
```

```
3310  IF PC$ = "" THEN  GOTO 3330
3320  PRINT PC$
3330  IF TC$ = "" THEN  GOTO 3350
3340  PRINT TC$
3350  IF CP$ = "" THEN  GOTO 3370
3360  PRINT CP$
3370  IF CP = 0 THEN  GOTO 3390
3380  FOR I = 1 TO CP: PRINT CP$(I): NEXT I
3390  IF DD$ = "" THEN  GOTO 3410
3400  PRINT DD$
3410  IF T = 0 THEN  GOTO 3430
3420  FOR I = 1 TO T: PRINT PL$(I): NEXT I
3430  IF IC$ = "" THEN  GOTO 3450
3440  PRINT IC$
3450  IF EC$ = "" THEN  GOTO 3470
3460  PRINT EC$
3470  PRINT D$;"CLOSE ";A$
3480  PRINT D$;"CATALOG"
3485  PRINT : PRINT
3490  PRINT "THE DATA FILE HAS BEEN ESTABLISHED": PRINT
3500  PRINT "EXECUTE THE MODEL BY TRANSFERING": PRINT "THE
DATA FILE TO THE DEC PDP11/34A": PRINT "AND EXECUTING MOD1
OR MOD2"
```

Module Two

```
C  AERIAL APPLICATION SIMULATION BASED ON THE
C  NASA-LANGLEY COMPUTATIONAL WAKE INTERACTIONS ANALYSIS
C  BY CONTINUUM DYNAMICS, INC., MOD 2.0
C
      DIMENSION CV(19),ICV(400),XOV(10,60),XV(2)
        CHARACTER*4 P2V,P3V
      DIMENSION LV(11),P2V(2),P3V(3,5),LCV(11)
C
      COMMON /AREA/ NPAD,ZV(100),AV(100)
      COMMON /BETZ/ NGAM,YV(100),GV(100),DGV(100),PGBP,PSBP
      COMMON /EVAP/
LEVAP,DTEMP,DIAM,DCUT,DENF,DMCV(60),TMCV(60)
      COMMON /HELI/ WHEL,HHEL,RHEL,YHEL,ZHEL
      COMMON /MEAN/
LMVEL,LMCRS,NVOR,RLIM,ZO,USK,HTPAD,ZOPAD,UO,XO
      COMMON /MEAN/ YBAR(8),ZBAR(8),YBAL(8),ZBAL(8),G2PI(8)
      COMMON /MEAN/
FACR(8),FACL(8),SRV(8),DSYM(8),DSYP(8),GSAV(8)
      COMMON /NORM/ DTAU,TMAX,DT,EDOV(60),EDNV(60)
      COMMON /OUTP/ NOUT,NPLT,NPRT,NSAV,NVAR
      COMMON /PROP/
LPRP,YPRP,ZPRP,RPRP,VPRP,QQPRP,CPQ,CPR,XPR
      COMMON /TERR/ CTA,STA
      COMMON /TURB/ LQQSE,QQMX,SLMX
      common /mdata/
cv,tem,ninc,lhfpl,lzero,s,dist,dzbp,time,n,
```

```
     $  ndat,cc,xov,ta
C
      EQUIVALENCE (XV(1),XOV(1,1))
      EQUIVALENCE
(LV(1),L10),(LV(2),L20),(LV(3),L21),(LV(4),L22)
      EQUIVALENCE (LV(5),L25),(LV(6),L28),(LV(7),L30)
      EQUIVALENCE
(LV(8),L50),(LV(9),L60),(LV(10),L61),(LV(11),L65)
C
      DATA TPI/6.2831853/
      DATA P2V/4HHALF,4HFULL/
      DATA P3V/6*'    ',' QQ ',2*'    ',' QQ ','SL  ','
',
     $          ' QQ ','SL V','V WW'/
      DATA LCV/10,20,21,22,25,28,30,
     $          50,60,61,65/
C
1000  FORMAT(I4,19A4)
1010  FORMAT(47H *** AGDISP CODE DOES NOT SUPPORT CARD
NUMBER: ,I4)
1020  FORMAT(20A4)
1030  FORMAT(36H *** INSUFFICIENT DATA BEFORE CARD: ,I4)
1040  FORMAT(35H *** INCORRECT NUMBER OF PARTICLES:,2I3)
1050  FORMAT(37H *** ERROR IN CIRCULATION DATA INPUT:,2I3)
1060  FORMAT(47H *** INPUT DOES NOT FULLY INITIALIZE AGDISP
RUN/
     $        5X,19HMISSING DATA CARDS:,11(2X,I4))
1070  FORMAT(39H *** ERROR IN PLANT AREA DENSITY
INPUT:,2I3)
1080  FORMAT(45H *** CARD ORDER INCONSISTENT AT CARD
NUMBER: ,I4)
1090  FORMAT(/38H NASA AGDISP (MOD 2.0) PROGRAM RESULTS/)
1100  FORMAT(38H1NASA AGDISP (MOD 2.0) PROGRAM RESULTS//
     $        17H INPUT DATA DECK:/)
1110  FORMAT(I4,2H: ,20A4)
1120  FORMAT(/34H NASA AGDISP (MOD 2.0) PROGRAM END)
1130  FORMAT(/28H DEPOSITION DIAMETER
RATIOS:/5X,1H#,6X,2HDR,
     $        9X,4HTIME,9X,1HY,11X,2HYY)
1140  FORMAT(I6,4E12.4)
1150  FORMAT(23X,3HSEC,10X,1HM,10X,4HM**2//
     $        21H DEPOSITION FRACTION:,E12.4)
2010  FORMAT(19H INITIAL TIME STEP:,E13.5,4H SEC/
     $        14H MAXIMUM TIME:,E13.5,4H SEC/)
2020  FORMAT(21H TERRAIN SLOPE ANGLE:,E13.5,4H DEG)
2030  FORMAT(1X,A4,18H-PLANE CALCULATION)
2040  FORMAT(32H AIRCRAFT SEMI-SPAN/DISK RADIUS:,E13.5,2H
M/
     $        18X,14H FLIGHT SPEED:,E13.5,6H M/SEC)
2050  FORMAT(24H NOMINAL RELEASE HEIGHT:,E13.5,2H M)
2060  FORMAT(38H RECTANGULARLY LOADED WING WITH GAMMA:,
     $        E13.5,9H M**2/SEC)
2070  FORMAT(37H TRIANGULARLY LOADED WING WITH GAMMA:,
     $        E13.5,9H M**2/SEC)
```

```
2080  FORMAT(22H PROPELLER HUB HEIGHT:,E13.5,2H M/
     $         15X,7HRADIUS:,E13.5,2H M/
     $         7X,15HSWIRL VELOCITY:,E13.5,6H M/SEC/
     $         11X,11HTURBULENCE:,E13.5,11H (M/SEC)**2)
2090  FORMAT(28H HELICOPTER FORWARD ADVANCE:,E13.5/
     $         10X,18HDOWNWASH VELOCITY:,E13.5,6H M/SEC/
     $         12X,16HEFFECTIVE GAMMA:,E13.5,9H M**2/SEC)
2100  FORMAT(21H CROSS-WIND VELOCITY:,E13.5,6H M/SEC/
     $         18X,3H Z:,E13.5,2H M/17X,4H Z0:,E13.5,2H M)
2110  FORMAT(28H BIPLANE INCREMENTAL HEIGHT:,E13.5,2H M/
     $         14X,14HSPAN FRACTION:,E13.5/
     $         13X,15HGAMMA FRACTION:,E13.5)
2210  FORMAT(35H VARIABLES FROM WAKE PLOT FILE: V W,3A4)
2220  FORMAT(24H TURBULENCE FIXED VALUE:,E13.5,11H
(M/SEC)**2)
2230  FORMAT(33H TURBULENCE FROM SUPEREQUILIBRIUM)
2250  FORMAT(28H SCALE LENGTH MAXIMUM VALUE:,E13.5,2H M)
2300  FORMAT(27H TOTAL NUMBER OF PARTICLES:,I3/
     $         17X,10H DIAMETER:,E13.5,8H MICRONS/
     $         9X,18H SPECIFIC GRAVITY:,E13.5)
2310  FORMAT(25H EVAPORATION TEMPERATURE:,E13.5,6H DEG C/
     $         8X,17H CUTOFF DIAMETER:,E13.5,8H MICRONS)
3090  FORMAT(/21H INTEGRATION COMPLETE)
4000  FORMAT(36H $$$ WARNING: SMALL PARTICLE INVOKED)
4010  FORMAT(49H $$$ WARNING: SUPEREQUILIBRIUM TURBULENCE
INVOKED)
4020  FORMAT(33H $$$ WARNING: EVAPORATION INVOKED)
4030  FORMAT(36H $$$ WARNING: MANY PARTICLES INVOKED)
4040  FORMAT(42H $$$ WARNING: LONG SIMULATION TIME INVOKED)
4050  FORMAT(36H $$$ WARNING: WAKE PLOT FILE INVOKED)
C
      NDAT=4
      NOUT=6
      NPRT=9
C
C  SET ALL NECESSARY DEFAULT FLAGS
C
      NPAD=0
      HTPAD=0.0
      LOCA=0
      NGAM=0
      LOCB=0
      NVOR=0
      LPRP=-1
      DZBP=0.0
      PSBP=0.0
      TA=0.0
      CTA=1.0
      STA=0.0
      WRITE (NPRT,1100)
      WRITE (NOUT,1090)
C
C  PROCESS INPUT DATA CARDS
C
```

```
      ICARD=0
20    READ (NDAT,1000,END=40) INUM,CV
      ICARD=ICARD+1
      ICV(ICARD)=INUM
      GO TO 20
40    REWIND NDAT
      ICMX=ICARD
      ICARD=0
42    READ (NDAT,1020,END=44) CC,CV
      ICARD=ICARD+1
      WRITE (NPRT,1110) ICARD,CC,CV
      WRITE (NOUT,1110) ICARD,CC,CV
      GO TO 42
44    WRITE (NPRT,1110)
      WRITE (NOUT,1110)
      REWIND NDAT
      DO 45 I=1,11
      LV(I)=0
45    CONTINUE
      L10=-1
      ICARD=0
50    ICARD=ICARD+1
      IF (ICARD.GT.ICMX) GO TO 400
      IF (ICV(ICARD).EQ.0) GO TO 100
      IF (ICV(ICARD).EQ.10) GO TO 120
      IF (ICV(ICARD).EQ.15) GO TO 125
      IF (ICV(ICARD).EQ.20) GO TO 130
      IF (ICV(ICARD).EQ.21) GO TO 135
      IF (ICV(ICARD).EQ.22) GO TO 140
      IF (ICV(ICARD).EQ.25) GO TO 150
      IF (ICV(ICARD).EQ.28) GO TO 160
      IF (ICV(ICARD).EQ.30) GO TO 180
      IF (ICV(ICARD).EQ.40) GO TO 190
      IF (ICV(ICARD).EQ.50) GO TO 200
      IF (ICV(ICARD).EQ.55) GO TO 210
      IF (ICV(ICARD).EQ.60) GO TO 220
      IF (ICV(ICARD).EQ.61) GO TO 230
      IF (ICV(ICARD).EQ.62) GO TO 240
      IF (ICV(ICARD).EQ.65) GO TO 250
      WRITE (NOUT,1010) ICV(ICARD)
      STOP
C
C  0000  COMMENT CARD
C
100   READ (NDAT,1000,END=300) I,CV
      IF (I.NE.ICV(ICARD)) GO TO 300
      GO TO 50
C
C  0010  TIME AND SPACE PROGRAM CARD
C
120   READ (NDAT,*,END=300) I,TMAX,LHFPL
      IF (I.NE.ICV(ICARD)) GO TO 300
      L10=0
      L20=-1
```

```
      WRITE (NOUT,2030) P2V(LHFPL)
      GO TO 50
C
C   0015  TERRAIN SLOPE CARD
C
125   READ (NDAT,*,END=300) I,TA
      IF (I.NE.ICV(ICARD)) GO TO 300
      IF (L20.EQ.0) GO TO 370
      WRITE (NOUT,2020) TA
      TA=TA*TPI/360.0
      CTA=COS(TA)
      STA=SIN(TA)
      GO TO 50
C
C   0020  AIRCRAFT CHARACTERISTICS CARD
C
130   READ (NDAT,*,END=300) I,LMVEL,LMCRS,S,DIST,UO,LBP
      IF (I.NE.ICV(ICARD)) GO TO 300
      IF (L20.EQ.0) GO TO 370
      L20=0
      LPRP=0
      L50=-1
      IF (LMVEL.EQ.3) L30=-1
      IF (LMVEL.EQ.1.OR.LMVEL.EQ.2) L22=-1
      IF (LMVEL.EQ.0) L25=-3
      IF (LMCRS.EQ.1.AND.LMVEL.NE.(-1)) L28=-1
      IF (S.NE.0.0) WRITE (NOUT,2040) S,UO
      WRITE (NOUT,2050) DIST
      IF (LBP.NE.0) L21=-1
      GO TO 50
C
C   0021  BIPLANE CHARACTERISTICS CARD
C
135   READ (NDAT,*,END=300) I,DZBP,PSBP,PGBP
      IF (I.NE.ICV(ICARD)) GO TO 300
      IF (L21.EQ.0) GO TO 370
      L21=0
      WRITE (NOUT,2110) DZBP,PSBP,PGBP
      GO TO 50
C
C   0022  TRIANGULAR/RECTANGULAR LOADING CARD
C
140   READ (NDAT,*,END=300) I,GAMMA
      IF (I.NE.ICV(ICARD)) GO TO 300
      IF (L21.NE.0) GO TO 370
      IF (L22.EQ.0) GO TO 370
      L22=0
      NVOR=1
      G2PI(1)=GAMMA/TPI
      Y=0.5*S*FLOAT(LMVEL)
      Z=DIST
      YBAR(1)=Z*STA+Y*CTA
      ZBAR(1)=Z*CTA-Y*STA
      YBAL(1)=Z*STA-Y*CTA
```

```
      ZBAL(1)=Z*CTA+Y*STA
      FACR(1)=1.0
      FACL(1)=1.0
      GSAV(1)=0.0
      SRV(1)=S
      IF (LMVEL.EQ.1) SRV(1)=0.5*S
      IF (LBP.EQ.0) GO TO 145
      NVOR=2
      G2PI(2)=PGBP*G2PI(1)
      Y=PSBP*Y
      Z=Z+DZBP
      YBAR(2)=Z*STA+Y*CTA
      ZBAR(2)=Z*CTA-Y*STA
      YBAL(2)=Z*STA-Y*CTA
      ZBAL(2)=Z*CTA+Y*STA
      FACR(2)=1.0
      FACL(2)=1.0
      GSAV(2)=0.0
      SRV(2)=PSBP*SRV(1)
145   RLIM=0.0
      IF (LMVEL.EQ.1) RLIM=0.5*S
      IF (LMVEL.EQ.2) WRITE (NOUT,2060) GAMMA
      IF (LMVEL.EQ.1) WRITE (NOUT,2070) GAMMA
      GO TO 50
C
C  0025  BETZ DATA CARDS AND INITIALIZATION
C
150   READ (NDAT,*,END=300) I,YY,GG
      IF (I.NE.ICV(ICARD)) GO TO 300
      IF (L21.NE.0) GO TO 370
      IF (L25.EQ.0.AND.LOCB.EQ.0) GO TO 370
      IF (LOCB.LT.0) GO TO 330
      LOCB=LOCB+1
      IF (YY.LT.0.0) LOCB=-LOCB
      L25=MIN0(L25+1,0)
      NGAM=NGAM+1
      IF (NGAM.GT.100) GO TO 330
      YV(NGAM)=ABS(YY)
      GV(NGAM)=GG
      IF (LOCB.LT.0) CALL AGBZG(DIST,DZBP)
      GO TO 50
C
C  0028  CROSS WIND CARD
C
160   READ (NDAT,*,END=300) I,U,Z,ZO
      IF (I.NE.ICV(ICARD)) GO TO 300
      IF (L28.EQ.0) GO TO 370
      L28=0
      USK=U/ALOG((Z+ZO)/ZO)
      WRITE (NOUT,2100) U,Z,ZO
      GO TO 50
C
C  0030  HELICOPTER INPUT CARD
C
```

```
180    READ (NDAT,*,END=300) I,WT,XMU
       IF (I.NE.ICV(ICARD)) GO TO 300
       IF (L30.EQ.0) GO TO 370
       L30=0
       RHEL=S
       HHEL=DIST
       NVOR=1
       GAMMA=XMU*WT/RHEL/UO/2.4532
       G2PI(1)=GAMMA/TPI
       YBAR(1)=HHEL*STA+RHEL*CTA
       ZBAR(1)=HHEL*CTA-RHEL*STA
       YBAL(1)=HHEL*STA-RHEL*CTA
       ZBAL(1)=HHEL*CTA+RHEL*STA
       FACR(1)=1.0
       FACL(1)=1.0
       GSAV(1)=0.0
       RLIM=0.0
       SRV(1)=RHEL
       WHEL=SQRT((1.0-XMU)*WT/TPI/1.2266)/RHEL
       YHEL=HHEL*STA
       ZHEL=HHEL*CTA
       WRITE (NOUT,2090) XMU,WHEL,GAMMA
       DZBP=-DIST
       GO TO 50
C
C  0040  PROPELLER INPUT CARD
C
190    READ (NDAT,*,END=300) I,CD,AS,ETA,TDOT,RPRP,DZ
       IF (I.NE.ICV(ICARD)) GO TO 300
       IF (LPRP.EQ.(-1).OR.LMVEL.EQ.(-1)) GO TO 370
       LPRP=1
       APRP=0.5*TPI*RPRP**2
       UI=0.5*UO*(-1.0+SQRT(1.0+CD*AS/APRP))
       QQPRP=0.72*UI*UI

VPRP=60.0*CD*AS*UO**3/(TPI*ETA*TDOT*APRP*RPRP*(UO+UI))
       XPR=0.857*RPRP*UO/SQRT(QQPRP)
       CPQ=0.857*SQRT(QQPRP)*UO*RPRP*XPR**0.18
       CPR=1.167/UO
       Z=DIST+DZ
       YPRP=Z*STA
       ZPRP=Z*CTA
       WRITE (NOUT,2080) DZ,RPRP,VPRP,QQPRP
       GO TO 50
C
C  0050  TURBULENCE DATA CARD
C
200    READ (NDAT,*,END=300) I,LQQSE,QQMX,SLMX
       IF (I.NE.ICV(ICARD)) GO TO 300
       IF (L50.EQ.0) GO TO 370
       IF (LQQSE.GT.0.AND.LMVEL.NE.(-1)) GO TO 370
       L50=0
       L60=-1
       IF (LQQSE.EQ.0.AND.LMCRS.EQ.1) QQMX=QQMX+0.845*USK**2
```

```
      IF (LMVEL.EQ.(-1)) WRITE (NOUT,2210)
(P3V(I,LQQSE+2),I=1,3)
      IF (LQQSE.EQ.0) WRITE (NOUT,2220) QQMX
      IF (LQQSE.EQ.(-1)) WRITE (NOUT,2230)
      IF (LMVEL.NE.(-1).OR.LQQSE.LE.1) WRITE (NOUT,2250)
SLMX
C
C  WAKE PLOT FILE INITIALIZATION
C
      IF (LMVEL.EQ.(-1)) CALL AGWKS(LQQSE)
      GO TO 50
C
C  0055  CANOPY INPUT CARDS AND INITIALIZATION
C
210   READ (NDAT,*,END=300) I,ZZ,AA
      IF (I.NE.ICV(ICARD)) GO TO 300
      IF (LMVEL.EQ.(-1)) GO TO 370
      IF (LOCA.LT.0) GO TO 360
      LOCA=LOCA+1
      IF (ZZ.LT.0.0) LOCA=-LOCA
      NPAD=NPAD+1
      IF (NPAD.GT.100) GO TO 360
      ZV(NPAD)=ABS(ZZ)
      AV(NPAD)=AA
      IF (LOCA.LT.0) CALL AGPAD(HTPAD,ZOPAD)
      GO TO 50
C
C  0060  PARTICLE DATA CARD
C
220   READ (NDAT,*,END=300)
I,LPART,LZERO,DZ,DIAM,DENF,LEVAP
      IF (I.NE.ICV(ICARD)) GO TO 300
      IF (L60.EQ.0) GO TO 370
      L60=0
      IF (LPART.LT.0) L61=LHFPL*LPART+LZERO
      IF (LEVAP.EQ.1) L65=-1
      IF (IABS(LPART+LZERO).GT.30) GO TO 310
      DO 222 I=1,600
      XV(I)=0.0
222   CONTINUE
      DO 223 I=1,60
      DMCV(I)=0.0
      EDOV(I)=DIAM
223   CONTINUE
      NVAR=0
      IF (LPART.LT.0) GO TO 228
      Z=DIST+DZ
      IF (LPART.GT.0) GO TO 224
      NVAR=1
      XOV(1,1)=Z*STA
      XOV(6,1)=Z*CTA
      WRITE (NOUT,2300) NVAR,DIAM,DENF
      GO TO 50
224   DS=S/FLOAT(LPART+1)
```

```
      DO 226 N=1,LPART
      Y=DS*FLOAT(N)
      XOV(1,N)=Z*STA+Y*CTA
      IF (LHFPL.EQ.2) XOV(1,N+LPART)=Z*STA-Y*CTA
      XOV(6,N)=Z*CTA-Y*STA
      IF (LHFPL.EQ.2) XOV(6,N+LPART)=Z*CTA+Y*STA
226   CONTINUE
      NVAR=LPART
      IF (LHFPL.EQ.2) NVAR=2*LPART
      IF (LZERO.EQ.0) GO TO 228
      NVAR=NVAR+1
      XOV(1,NVAR)=Z*STA
      XOV(6,NVAR)=Z*CTA
228   N=IABS(LPART)
      IF (LHFPL.EQ.2) N=2*N
      IF (LZERO.NE.0) N=N+1
      WRITE (NOUT,2300) N,DIAM,DENF
      GO TO 50
C
C  0061  PARTICLE LOCATION DATA CARDS
C
230   READ (NDAT,*,END=300) I,IIII,YY,DZ
      IF (I.NE.ICV(ICARD)) GO TO 300
      IF (L61.EQ.0) GO TO 370
      L61=L61+1
      NVAR=NVAR+1
      IF (NVAR.GT.(-LHFPL*LPART-LZERO)) GO TO 320
      Z=DIST+DZ
      XOV(1,NVAR)=Z*STA+YY*CTA
      XOV(6,NVAR)=Z*CTA-YY*STA
      GO TO 50
C
C  0062  PARTICLE INITIAL CONDITION DATA CARD
C
240   READ (NDAT,*,END=300) I,V,W,XS,VS
      IF (I.NE.ICV(ICARD)) GO TO 300
      DO 242 N=1,NVAR
      XOV(2,N)=W*STA+V*CTA
      XOV(3,N)=XS
      XOV(5,N)=VS
      XOV(7,N)=W*CTA-V*STA
      XOV(8,N)=XS
      XOV(10,N)=VS
242   CONTINUE
      GO TO 50
C
C  0065  EVAPORATION DATA CARD
C
250   READ (NDAT,*,END=300) I,DTEMP,DCUT
      IF (I.NE.ICV(ICARD)) GO TO 300
      IF (L65.EQ.0) GO TO 370
      L65=0
      WRITE (NOUT,2310) DTEMP,DCUT
      GO TO 50
```

```
C
C  ERROR/WARNING MESSAGES
C
300    WRITE (NOUT,1030) ICARD
       STOP
310    WRITE (NOUT,1040) LPART
       STOP
320    WRITE (NOUT,1040) LOC,NVAR
       STOP
330    WRITE (NOUT,1050) LOCB,NGAM
       STOP
340    I=0
       DO 350 L=1,11
       IF (LV(L).EQ.0) GO TO 350
       I=I+1
       LV(I)=LCV(L)
350    CONTINUE
       WRITE (NOUT,1060) (LV(L),L=1,I)
       STOP
360    WRITE (NOUT,1070) LOCA,NPAD
       STOP
370    WRITE (NOUT,1080) I
       STOP
400    IF (LOCA.GT.0) GO TO 360
       IF (LOCB.GT.0) GO TO 330
       LTOT=L10+L20+L21+L22+L25+L28+L30+L50+L60+L61+L65
       IF (LTOT.NE.0) GO TO 340
       IF (DIAM*DENF**2.LT.50.0) WRITE (NOUT,4000)
       IF (LQQSE.EQ.(-1)) WRITE (NOUT,4010)
       IF (LMVEL.EQ.(-1)) WRITE (NOUT,4050)
       IF (LEVAP.EQ.1) WRITE (NOUT,4020)
       IF (NVAR.GT.10) WRITE (NOUT,4030)
       IF (TMAX/DIAM/DENF**2.GT.0.1) WRITE (NOUT,4040)

         call dump

         stop
         end


         subroutine dump
       DIMENSION CV(19),ICV(400),XOV(10,60),XV(2)
         CHARACTER*4 P2V,P3V
       DIMENSION LV(11),P2V(2),P3V(3,5),LCV(11)
C
       COMMON /AREA/ NPAD,ZV(100),AV(100)
       COMMON /BETZ/ NGAM,YV(100),GV(100),DGV(100),PGBP,PSBP
       COMMON /EVAP/
LEVAP,DTEMP,DIAM,DCUT,DENF,DMCV(60),TMCV(60)
       COMMON /HELI/ WHEL,HHEL,RHEL,YHEL,ZHEL
       COMMON /MEAN/
LMVEL,LMCRS,NVOR,RLIM,ZO,USK,HTPAD,ZOPAD,UO,XO
       COMMON /MEAN/ YBAR(8),ZBAR(8),YBAL(8),ZBAL(8),G2PI(8)
       COMMON /MEAN/
```

```
FACR(8),FACL(8),SRV(8),DSYM(8),DSYP(8),GSAV(8)
      COMMON /NORM/ DTAU,TMAX,DT,EDOV(60),EDNV(60)
      COMMON /OUTP/ NOUT,NPLT,NPRT,NSAV,NVAR
      COMMON /PROP/
LPRP,YPRP,ZPRP,RPRP,VPRP,QQPRP,CPQ,CPR,XPR
      COMMON /TERR/ CTA,STA
      COMMON /TURB/ LQQSE,QQMX,SLMX

      common /mdata/
cv,tem,ninc,lhfpl,lzero,s,dist,dzbp,time,n,
     $  ndat,cc,xov,ta
        integer tmpfil

        tmpfil = 19

        call setfil(19, 'agdisp.int ')


      write (tmpfil)  npad,zv,av
      write (tmpfil)  ngam,yv,gv,dgv,pgbp,psbp
      write (tmpfil)  levap,dtemp,diam,dcut,denf,dmcv,tmcv
      write (tmpfil)  whel,hhel,rhel,yhel,zhel
      write (tmpfil)
lmvel,lmcrs,nvor,rlim,zo,usk,htpad,zopad,uo,xo
      write (tmpfil)  ybar,zbar,ybal,zbal,g2pi
      write (tmpfil)  facr,facl,srv,dsym,dsyp,gsav
      write (tmpfil)  dtau,tmax,dt,edov,ednv
      write (tmpfil)  nout,nplt,nprt,nsav,nvar
      write (tmpfil)
lprp,yprp,zprp,rprp,vprp,qqprp,cpq,cpr,xpr
      write (tmpfil)  cta,sta
      write (tmpfil)  lqqse,qqmx,slmx
      write (tmpfil)
cv,tem,ninc,lhfpl,lzero,s,dist,dzbp,time,n,
     $  ndat,cc,xov,ta
        return
        end
C  SECTION TWO PDP11/34A VERSION
C
      DIMENSION CV(19),ICV(400),XOV(10,60),XV(2)
C
      COMMON /AREA/ NPAD,ZV(100),AV(100)
      COMMON /BETZ/ NGAM,YV(100),GV(100),DGV(100),PGBP,PSBP
      COMMON /EVAP/
LEVAP,DTEMP,DIAM,DCUT,DENF,DMCV(60),TMCV(60)
      COMMON /HELI/ WHEL,HHEL,RHEL,YHEL,ZHEL
      COMMON /MEAN/
LMVEL,LMCRS,NVOR,RLIM,ZO,USK,HTPAD,ZOPAD,UO,XO
      COMMON /MEAN/ YBAR(8),ZBAR(8),YBAL(8),ZBAL(8),G2PI(8)
      COMMON /MEAN/
FACR(8),FACL(8),SRV(8),DSYM(8),DSYP(8),GSAV(8)
      COMMON /NORM/ DTAU,TMAX,DT,EDOV(60),EDNV(60)
      COMMON /OUTP/ NOUT,NPLT,NPRT,NSAV,NVAR
      COMMON /PROP/
```

```
LPRP,YPRP,ZPRP,RPRP,VPRP,QQPRP,CPQ,CPR,XPR
      COMMON /TERR/ CTA,STA
      COMMON /TURB/ LQQSE,QQMX,SLMX
      common /mdata/
cv,tem,ninc,lhfpl,lzero,s,dist,dzbp,time,n,
     $  ndat,cc,xov,ta
C
      EQUIVALENCE (XV(1),XOV(1,1))
C
1020  FORMAT(20A4)
1120  FORMAT(/34H NASA AGDISP (MOD 2.0) PROGRAM END)
1130  FORMAT(/28H DEPOSITION DIAMETER
RATIOS:/5X,1H#,6X,2HDR,
     $          9X,4HTIME,9X,1HY,11X,2HYY)
1140  FORMAT(I6,4E12.4)
1150  FORMAT(23X,3HSEC,10X,1HM,10X,4HM**2//
     $          21H DEPOSITION FRACTION:,E12.4)
2010  FORMAT(19H INITIAL TIME STEP:,E13.5,4H SEC/
     $          14H MAXIMUM TIME:,E13.5,4H SEC/)
3090  FORMAT(/21H INTEGRATION COMPLETE)
C

        call restor

C
C  ESTABLISH STEP SIZE MAXIMUM
C
      DT=0.0
      CALL AGDEC(0.0,0.0,TEM,1)
      DT=0.5*AMIN1(DTAU,0.2)
      NINC=MAXO(10,IFIX(1.0/DT))
      NSAV=NINC/10
      WRITE (NOUT,2010) DT,TMAX
C
C  INTEGRATE THE EQUATIONS TO MAXIMUM TIME
C
      CALL AGINT(XOV)
      WRITE (NPRT,3090)
      WRITE (NOUT,3090)
      TIME=-1.0
      WRITE (NPRT,1130)
      DO 410 N=1,NVAR
      IF (DMCV(N).EQ.0.0) WRITE (NPRT,1140) N,DMCV(N)
      IF (DMCV(N).GT.0.0) WRITE (NPRT,1140)
N,DMCV(N),TMCV(N),
     $
XOV(1,N),XOV(3,N)
410   CONTINUE
      TEM=0.0
      DO 450 N=1,NVAR
      TEM=TEM+DMCV(N)
      IF (LHFPL.EQ.2) GO TO 450
      IF (N.EQ.NVAR.AND.LZERO.NE.0) GO TO 450
      TEM=TEM+DMCV(N)
```

```
450   CONTINUE
      N=NVAR
      IF (LHFPL.EQ.1) N=2*NVAR-IABS(LZERO)
      TEM=TEM/FLOAT(N)
      WRITE (NPRT,1150) TEM
      WRITE (NPRT,1120)
      WRITE (NOUT,1120)
480   STOP
      END

        subroutine restor
      DIMENSION CV(19),ICV(400),XOV(10,60),XV(2)
C
      COMMON /AREA/ NPAD,ZV(100),AV(100)
      COMMON /BETZ/ NGAM,YV(100),GV(100),DGV(100),PGBP,PSBP
      COMMON /EVAP/
LEVAP,DTEMP,DIAM,DCUT,DENF,DMCV(60),TMCV(60)
      COMMON /HELI/ WHEL,HHEL,RHEL,YHEL,ZHEL
      COMMON /MEAN/
LMVEL,LMCRS,NVOR,RLIM,ZO,USK,HTPAD,ZOPAD,UO,XO
      COMMON /MEAN/ YBAR(8),ZBAR(8),YBAL(8),ZBAL(8),G2PI(8)
      COMMON /MEAN/
FACR(8),FACL(8),SRV(8),DSYM(8),DSYP(8),GSAV(8)
      COMMON /NORM/ DTAU,TMAX,DT,EDOV(60),EDNV(60)
      COMMON /OUTP/ NOUT,NPLT,NPRT,NSAV,NVAR
      COMMON /PROP/
LPRP,YPRP,ZPRP,RPRP,VPRP,QQPRP,CPQ,CPR,XPR
      COMMON /TERR/ CTA,STA
      COMMON /TURB/ LQQSE,QQMX,SLMX

      common /mdata/
cv,tem,ninc,lhfpl,lzero,s,dist,dzbp,time,n,
     $  ndat,cc,xov,ta
        integer tmpfil

        tmpfil = 19

        call setfil(19, 'agdisp.int ')


      read (tmpfil)  npad,zv,av
      read (tmpfil)  ngam,yv,gv,dgv,pgbp,psbp
      read (tmpfil)  levap,dtemp,diam,dcut,denf,dmcv,tmcv
      read (tmpfil)  whel,hhel,rhel,yhel,zhel
      read (tmpfil)
lmvel,lmcrs,nvor,rlim,zo,usk,htpad,zopad,uo,xo
      read (tmpfil)  ybar,zbar,ybal,zbal,g2pi
      read (tmpfil)  facr,facl,srv,dsym,dsyp,gsav
      read (tmpfil)  dtau,tmax,dt,edov,ednv
      read (tmpfil)  nout,nplt,nprt,nsav,nvar
      read (tmpfil)
lprp,yprp,zprp,rprp,vprp,qqprp,cpq,cpr,xpr
      read (tmpfil)  cta,sta
      read (tmpfil)  lqqse,qqmx,slmx
```

```
      read (tmpfil)
cv,tem,ninc,lhfpl,lzero,s,dist,dzbp,time,n,
     $  ndat,cc,xov,ta

        close(tmpfil)

        return
        end
      SUBROUTINE AGBZD(XV,DV,MS,MX,ME,MT)
C
C  EVALUATE DERIVATIVES FOR BETZ ROLL UP
C
      DIMENSION XV(2),DV(2)
      COMMON /BETZ/ NGAM,YV(100),GV(100),DGV(100),PGBP,PSBP
      DATA TPI/6.2831853/
      IF (XV(1).EQ.0.0)
     $
DV(1)=2.0*ABS(AGBZT(MT,YV(MS),DGV(MS),YV(MX)))/TPI
      IF (XV(1).GT.0.0) DV(1)=ABS(XV(2))/XV(1)/TPI
      Y1=YV(MX)-XV(1)
      D1=0.0
      IF (Y1.GT.YV(MS)) D1=AGBZT(MT,YV(MS),DGV(MS),Y1)
      Y2=YV(MX)+XV(1)
      D2=0.0
      IF (Y2.LT.YV(ME)) D2=AGBZT(MT,YV(MS),DGV(MS),Y2)
      DV(2)=-DV(1)*(D1+D2)
      RETURN
      END
C
      SUBROUTINE AGBZG(DIST,DZ)
C  ANALYZE INPUT DISTRIBUTION AND INITIALIZE BETZ ROLL UP
PROCEDURE
      DIMENSION AGV(102),LGV(100)
      COMMON /BETZ/ NGAM,YV(100),GV(100),DGV(100),PGBP,PSBP
      COMMON /MEAN/
LMVEL,LMCRS,NVOR,RLIM,ZO,USK,HTPAD,ZOPAD,UO,XO
      COMMON /MEAN/ YBAR(8),ZBAR(8),YBAL(8),ZBAL(8),G2PI(8)
      COMMON /MEAN/
FACR(8),FACL(8),SRV(8),DSYM(8),DSYP(8),GSAV(8)
      COMMON /OUTP/ NOUT,NPLT,NPRT,NSAV,NVAR
      COMMON /TERR/ CTA,STA
      COMMON /VORT/ MSV(4),MXV(4),MEV(4),DTV(4),NBTZ
      COMMON /VORT/ XOV(2,4),DOV(2,4),YOV(4),ZOV(4)
      DATA TPI/6.2831853/
      DATA LB,LM,LX/2H  ,2HMN,2HMX/
1000  FORMAT(/29H BETZ ROLL UP INITIALIZATION:/
     $       4X,1HN,9X,1HY,12X,5HGAMMA,10X,5HDERIV)
1010  FORMAT(I5,3E15.6,3X,A2)
1020  FORMAT(/22H BETZ ROLL UP SUMMARY:/
     $
4X,6HVORTEX,5X,5HSTART,3X,7HMAXIMUM,7X,3HEND,13X,2HYB,
     $       12X,5HGAMMA,15X,3HDY-,12X,3HDY+,11X,5HAVE G)
1030  FORMAT(4I10,5X,2E15.6,4X,3E15.6)
1040  FORMAT(5H *** ,I2,37H NONDISCRETE DISTRIBUTION
```

```
LOCATION(S))
1050  FORMAT(43H *** BETZ WILL ROLL UP MORE THAN 4
VORTICES)
1060  FORMAT(39H BETZ ROLL UP INVOKED, MAXIMUM ENTRIES:,I4)
C  COMPUTE SLOPES
      NGAMM=NGAM-1
      AGV(1)=0.0
      DGV(1)=(GV(2)-GV(1))/(YV(2)-YV(1))
      AGV(2)=ABS(DGV(1))
      DGV(NGAM)=(GV(NGAM)-GV(NGAM-1))/(YV(NGAM)-YV(NGAM-1))
      AGV(NGAM+1)=ABS(DGV(NGAM))
      AGV(NGAM+2)=0.0
      DGMM=0.0
      DO 10 N=2,NGAMM
      DYM=YV(N)-YV(N-1)
      DYP=YV(N+1)-YV(N)
      DYT=DYM+DYP
      FYM=-DYP/DYM/DYT
      FYP=DYM/DYP/DYT
      FY=-FYM-FYP
      DGV(N)=FYM*GV(N-1)+FY*GV(N)+FYP*GV(N+1)
      AGV(N+1)=ABS(DGV(N))
      DGMM=AMAX1(DGMM,AGV(N+1))
10    CONTINUE
      DGMM=0.005*DGMM
C  DETERMINE LOCATION OF MINIMA/MAXIMA
      LERF=0
      DO 20 N=1,NGAM
      DGM=AGV(N+1)-AGV(N)
      DGP=AGV(N+2)-AGV(N+1)
      LGV(N)=LB
      IF (DGM.GE.DGMM.AND.DGP.LE.DGMM) LGV(N)=LX
      IF (DGM.LT.DGMM.AND.DGP.GT.DGMM) LGV(N)=LM
      IF (N.EQ.1) GO TO 20
      IF (LGV(N).EQ.LX.AND.LGV(N-1).EQ.LM) LERF=LERF+1
      IF (LGV(N).EQ.LM.AND.LGV(N-1).EQ.LX) LERF=LERF+1
20    CONTINUE
      WRITE (NOUT,1060) NGAM
      WRITE (NPRT,1000)
      WRITE (NPRT,1010)
(N,YV(N),GV(N),DGV(N),LGV(N),N=1,NGAM)
      IF (LERF.EQ.0) GO TO 30
      WRITE (NOUT,1040) LERF
      STOP
30    NVOR=1
      N=1
40    MSV(NVOR)=N
      IF (LGV(N).EQ.LX) MXV(NVOR)=N
      N=N+1
50    IF (LGV(N).EQ.LX) MXV(NVOR)=N
      IF (LGV(N).EQ.LM) GO TO 60
      N=N+1
      IF (N.LE.NGAM) GO TO 50
      N=NGAM
```

```
60     MEV(NVOR)=N
       IF (N.EQ.NGAM) GO TO 70
       NVOR=NVOR+1
       IF (NVOR.LE.4) GO TO 40
       WRITE (NOUT,1050)
       STOP
C  BETZ INTEGRATION INITIALIZATION
70     WRITE (NPRT,1020)
       RLIM=0.0
       DO 80 N=1,NVOR
       XOV(1,N)=0.0
       XOV(2,N)=0.0
       MS=MSV(N)
       MX=MXV(N)
       ME=MEV(N)
       MT=ME-MS+1
       CALL AGBZD(XOV(1,N),DOV(1,N),MS,MX,ME,MT)
       YOV(N)=YV(MX)
       ZOV(N)=0.0
       YBAR(N)=DIST*STA+YV(MX)*CTA
       ZBAR(N)=DIST*CTA-YV(MX)*STA
       YBAL(N)=DIST*STA-YV(MX)*CTA
       ZBAL(N)=DIST*CTA+YV(MX)*STA
       G2PI(N)=0.0
       FACR(N)=1.0
       FACL(N)=1.0
       SRV(N)=0.0
       DSYM(N)=YV(MX)-YV(MS)
       DSYP(N)=YV(ME)-YV(MX)

GSAV(N)=AGBZQ(MT,YV(MS),GV(MS),YV(MS),YV(ME),0)/(YV(ME)-YV(
MS))**2
       DG=GV(MS)-GV(ME)
       DY=AMAX1(YV(MX)-YV(MS),YV(ME)-YV(MX))
       DTV(N)=0.01*TPI*DY**2/ABS(DG)
       WRITE (NPRT,1030)
N,MS,MX,ME,YV(MX),DG,DSYM(N),DSYP(N),GSAV(N)
80     CONTINUE
       WRITE (NPRT,1030)
       NBTZ=NVOR
       IF (DZ.EQ.0.0) RETURN
       DO 90 N=1,NBTZ
       MX=MXV(N)
       Y=PSBP*YV(MX)
       Z=DIST+DZ
       NN=NBTZ+N
       YBAR(NN)=Z*STA+Y*CTA
       ZBAR(NN)=Z*CTA-Y*STA
       YBAL(NN)=Z*STA-Y*CTA
       ZBAL(NN)=Z*CTA+Y*STA
       G2PI(NN)=0.0
       FACR(NN)=1.0
       FACL(NN)=1.0
       SRV(NN)=0.0
```

```
      DSYM(NN)=PSBP*DSYM(N)
      DSYP(NN)=PSBP*DSYP(N)
      GSAV(NN)=PGBP*GSAV(N)
90    CONTINUE
      NVOR=2*NBTZ
      RETURN
      END
      SUBROUTINE AGBZI(TIME,DELT)
C   TIME DEPENDENT BETZ ROLL UP STEP INTEGRATION
      DIMENSION XNV(2),DNV(2)
      COMMON /BETZ/ NGAM,YV(100),GV(100),DGV(100),PGBP,PSBP
      COMMON /MEAN/
LMVEL,LMCRS,NVOR,RLIM,ZO,USK,HTPAD,ZOPAD,UO,XO
      COMMON /MEAN/ YBAR(8),ZBAR(8),YBAL(8),ZBAL(8),G2PI(8)
      COMMON /MEAN/
FACR(8),FACL(8),SRV(8),DSYM(8),DSYP(8),GSAV(8)
      COMMON /OUTP/ NOUT,NPLT,NPRT,NSAV,NVAR
      COMMON /TERR/ CTA,STA
      COMMON /VORT/ MSV(4),MXV(4),MEV(4),DTV(4),NBTZ
      COMMON /VORT/ XOV(2,4),DOV(2,4),YOV(4),ZOV(4)
      DATA TPI/6.2831853/
1000  FORMAT(14H BETZ VORTEX #,I2,15H ROLLS UP AT T:,E12.4,
     $        14H SEC   WITH R:,E12.4,2H M)
C   DETERMINE BETZ TIME STEP
      DT=DELT
      K=0
      DO 10 N=1,NBTZ
      IF (GSAV(N).EQ.0.0) GO TO 10
      DT=AMIN1(DT,DTV(N))
      K=K+1
10    CONTINUE
      IF (K.EQ.0) RETURN
      NSTP=IFIX(DELT/DT)+1
      DT=DELT/FLOAT(NSTP)
      HDT=0.5*DT
      DO 80 NS=1,NSTP
      T=TIME+DT*FLOAT(NS)
C   LOOP ON VORTICES SOLVED
      DO 70 N=1,NBTZ
      IF (GSAV(N).EQ.0.0) GO TO 70
      MS=MSV(N)
      MX=MXV(N)
      ME=MEV(N)
      MT=ME-MS+1
C   PREDICTOR
      DO 15 I=1,2
      XNV(I)=XOV(I,N)+DT*DOV(I,N)
15    CONTINUE
C   CORRECTOR
      DO 30 K=1,2
      CALL AGBZD(XNV,DNV,MS,MX,ME,MT)
      DO 20 I=1,2
      XNV(I)=XOV(I,N)+HDT*(DOV(I,N)+DNV(I))
20    CONTINUE
```

```
30    CONTINUE
      DO 40 I=1,2
      XOV(I,N)=XNV(I)
      DOV(I,N)=DNV(I)
40    CONTINUE
C  CENTROID CALCULATION
      Y1=YV(MX)-XNV(1)
      YS=AMAX1(Y1,YV(MS))
      G1=GV(MS)
      X1=0.0
      IF (Y1.LT.YV(MS)) GO TO 50
      G1=AGBZT(MT,YV(MS),GV(MS),Y1)
      X1=AGBZQ(MT,YV(MS),DGV(MS),YV(MS),Y1,1)
50    Y2=YV(MX)+XNV(1)
      YE=AMIN1(Y2,YV(ME))
      G2=GV(ME)
      X2=0.0
      IF (Y2.GT.YV(ME)) GO TO 60
      G2=AGBZT(MT,YV(MS),GV(MS),Y2)
      X2=AGBZQ(MT,YV(MS),DGV(MS),Y2,YV(ME),1)
60    DG=GV(ME)-GV(MS)

TEM=G2*YE**2-G1*YS**2-2.0*AGBZQ(MT,YV(MS),GV(MS),YS,YE,1)
      YNV=SQRT(ABS(TEM/(G1-G2)))
      ZNV=0.0
C  UPDATE VORTEX PARAMETERS FOR THIS INCREMENTAL STEP SIZE
      DY=YNV-YOV(N)
      DZ=ZNV-ZOV(N)
      YBAR(N)=YBAR(N)+DZ*STA+DY*CTA
      ZBAR(N)=ZBAR(N)+DZ*CTA-DY*STA
      YBAL(N)=YBAL(N)+DZ*STA-DY*CTA
      ZBAL(N)=ZBAL(N)+DZ*CTA+DY*STA
      G2PI(N)=(G1-G2)/TPI
      IF (NBTZ.EQ.NVOR) GO TO 65
      NN=NBTZ+N
      DY=PSBP*DY
      DZ=PSBP*DZ
      YBAR(NN)=YBAR(NN)+DZ*STA+DY*CTA
      ZBAR(NN)=ZBAR(NN)+DZ*CTA-DY*STA
      YBAL(NN)=YBAL(NN)+DZ*STA-DY*CTA
      ZBAL(NN)=ZBAL(NN)+DZ*CTA+DY*STA
      G2PI(NN)=PGBP*G2PI(N)
65    YOV(N)=YNV
      ZOV(N)=ZNV
      IF (Y1.GT.YV(MS)) GO TO 70
      IF (Y2.LT.YV(ME)) GO TO 70
      DSYM(N)=0.0
      DSYP(N)=0.0
      GSAV(N)=0.0
      SRV(N)=AMAX1(YV(ME)-YV(MX),YV(MX)-YV(MS))
      WRITE (NPRT,1000) N,T,SRV(N)
      IF (NBTZ.EQ.NVOR) GO TO 70
      NN=NBTZ+N
      DSYM(NN)=0.0
```

```
      DSYP(NN)=0.0
      GSAV(NN)=0.0
      SRV(NN)=PSBP*SRV(N)
70    CONTINUE
80    CONTINUE
C  UPDATE VORTEX PARAMETERS FOR THIS COMPLETE STEP
      DO 90 N=1,NBTZ
      IF (GSAV(N).EQ.0.0) GO TO 90
      SRV(N)=XOV(1,N)
      MS=MSV(N)
      MX=MXV(N)
      ME=MEV(N)
      MT=ME-MS+1
      DSYM(N)=AMAX1(0.0,YV(MX)-YV(MS)-SRV(N))
      DSYP(N)=AMAX1(0.0,YV(ME)-YV(MX)-SRV(N))
      IF (NBTZ.EQ.NVOR) GO TO 90
      NN=NBTZ+N
      SRV(NN)=PSBP*SRV(N)
      DSYM(NN)=PSBP*DSYM(N)
      DSYP(NN)=PSBP*DSYP(N)
90    CONTINUE
      RETURN
      END
      FUNCTION AGBZQ(N,YV,ZV,YS,YE,M)
C  GAUSS-LEGENDRE QUADRATURE INTEGRATION FOR BETZ ROLL UP
      DIMENSION ZT(8),WT(8),YV(2),ZV(2)
      DATA ZT/0.0
,0.201194094,0.394151347,0.570972173,
     $
0.724417731,0.848206583,0.937273392,0.987992518/
      DATA
WT/0.202578242,0.198431485,0.186161000,0.166269206,
     $
0.139570678,0.107159221,0.070366047,0.030753242/
      XS=(YE-YS)/2.0
      XA=(YE+YS)/2.0
      IF (M.EQ.0) X=WT(1)*AGBZT(N,YV,ZV,XA)
      IF (M.EQ.1) X=WT(1)*XA*AGBZT(N,YV,ZV,XA)
      DO 10 J=2,8
      XP=XA+XS*ZT(J)
      XM=XA-XS*ZT(J)
      IF (M.EQ.0)
X=X+WT(J)*(AGBZT(N,YV,ZV,XM)+AGBZT(N,YV,ZV,XP))
      IF (M.EQ.1)
X=X+WT(J)*(XM*AGBZT(N,YV,ZV,XM)+XP*AGBZT(N,YV,ZV,XP))
10    CONTINUE
      AGBZQ=X*XS
      RETURN
      END
      FUNCTION AGBZT(N,YV,ZV,Y)
C  TABLE INTERPOLATION FOR BETZ ROLL UP
      DIMENSION YV(2),ZV(2)
      IF (Y.GT.YV(1)) GO TO 10
      AGBZT=ZV(1)
```

```
      RETURN
10    DO 20 I=2,N
      IF (Y.LE.YV(I)) GO TO 30
20    CONTINUE
      AGBZT=ZV(N)
      RETURN
30
AGBZT=(ZV(I-1)*(YV(I)-Y)+ZV(I)*(Y-YV(I-1)))/(YV(I)-YV(I-1))
      RETURN
      END
      SUBROUTINE AGCOR(T,DTAU,WTAU,UX,UV)
C  ANALYTIC TURBULENT CORRELATIONS
      C=T/WTAU
      EXPC=EXP(-C)
      EXPT=EXP(-T/DTAU)
      B=(DTAU/WTAU)**2
      IF (ABS(B-1.0).LE.0.01) GO TO 10
      SUM1=0.5*(3.0-B)/(B-1.0)**2
      SUM2=0.5/(B-1.0)
      XK1=-SUM1*DTAU/WTAU+SUM1+SUM2
      XK2=-SUM1*EXPT*DTAU/WTAU+SUM1*EXPC+SUM2*EXPC*(1.0+C)
      XK3=-SUM1*EXPT+SUM1*EXPC+SUM2*C*EXPC
      GO TO 20
10    XK1=0.375
      XK2=(3.0+3.0*C-C*C)*EXPC/8.0
      XK3=(5.0-C)*C*EXPC/8.0
20    XK4=0.5+EXPC

UX=XK4*WTAU-XK1*DTAU-XK3*EXPT*DTAU*DTAU/WTAU+XK2*EXPT*DTAU
      UV=XK1-XK2*EXPT-XK3*EXPT
      RETURN
      END
      SUBROUTINE AGDEC(T,DU,EPS,I)
C  TIME DECAY EVALUATION
      COMMON /EVAP/
LEVAP,DTEMP,DIAM,DCUT,DENF,DMCV(60),TMCV(60)
      COMMON /NORM/ DTAU,TMAX,DT,EDOV(60),EDNV(60)
      D=EDOV(I)
      DTAU=3.12E-06*D*D*DENF
      IF (DU.EQ.0.0) GO TO 10
      REYNO=0.0688*D*DU
      DTAU=DTAU/(1.0+0.197*REYNO**0.63+0.00026*REYNO**1.38)
10    EPS=1.0/DTAU
      IF (LEVAP.EQ.0) RETURN
      IF (D.LE.DCUT) RETURN
      ETAU=D*D/DTEMP/84.76
      IF (DU.EQ.0.0) GO TO 20
      ETAU=ETAU/(1.0+0.27*SQRT(REYNO))
20    EDNV(I)=D*SQRT(1.0-DT/ETAU)
      EPS=EPS-1.5/(ETAU-T)
      RETURN
      END
      SUBROUTINE AGDIF(XV,DV,T,DTMN)
C  DIFFERENTIAL EVALUATION
```

```
      DIMENSION XV(10,2),DV(10,2)
      COMMON /NORM/ DTAU,TMAX,DT,EDOV(60),EDNV(60)
      COMMON /OUTP/ NOUT,NPLT,NPRT,NSAV,NVAR
      COMMON /TERR/ CTA,STA
      DATA UX,UV/2*0.0/
C  LOOP FOR ALL PARTICLES
      DTMN=TMAX
      DO 20 N=1,NVAR
C  DETERMINE MEAN VELOCITY AT THE PARTICLE POSITION
      CALL AGVEL(XV(1,N),XV(6,N),V,W)
C  DETERMINE DECAY CONSTANT
      CALL
AGDEC(T,SQRT((XV(2,N)-V)**2+(XV(7,N)-W)**2),DECAY,N)
      DTMN=AMIN1(DTMN,DTAU)
C  DETERMINE TURBULENCE AND SCALE AT THE PARTICLE POSITION
      CALL AGTUR(XV(1,N),XV(6,N),QQ,SL,VV,WW)
      IF (QQ.EQ.0.0) GO TO 10
C  DETERMINE ANALYTIC TURBULENT CORRELATIONS WITH THE
PARTICLE

WTAU=SL/(SQRT((XV(2,N)-V)**2+(XV(7,N)-W)**2)+0.375*SQRT(QQ)
)
      CALL AGCOR(T,DTAU,WTAU,UX,UV)
      QQ=QQ/3.0
C  EVALUATE DERIVATIVES
C  1:Y  2:V  3:YY  4:YV  5:VV  6:Z  7:W  8:ZZ  9:ZW  10:WW
10    DV(1,N)=XV(2,N)
      DV(2,N)=(V-XV(2,N))*DECAY-9.8*STA
      DV(3,N)=2.0*XV(4,N)
      DV(4,N)=XV(5,N)+(UX*QQ-XV(4,N))*DECAY
      DV(5,N)=2.0*(UV*QQ-XV(5,N))*DECAY
      DV(6,N)=XV(7,N)
      DV(7,N)=(W-XV(7,N))*DECAY-9.8*CTA
      DV(8,N)=2.0*XV(9,N)
      DV(9,N)=XV(10,N)+(UX*QQ-XV(9,N))*DECAY
      DV(10,N)=2.0*(UV*QQ-XV(10,N))*DECAY
20    CONTINUE
      RETURN
      END
      SUBROUTINE AGINT(XOV)
C  INTEGRATE THE EQUATIONS
      DIMENSION
XOV(10,60),XNV(10,60),DOV(10,60),DNV(10,60),LV(4)
      COMMON /EVAP/
LEVAP,DTEMP,DIAM,DCUT,DENF,DMCV(60),TMCV(60)
      COMMON /HELI/ WHEL,HHEL,RHEL,YHEL,ZHEL
      COMMON /MEAN/
LMVEL,LMCRS,NVOR,RLIM,ZO,USK,HTPAD,ZOPAD,UO,XO
      COMMON /MEAN/ YBAR(8),ZBAR(8),YBAL(8),ZBAL(8),G2PI(8)
      COMMON /MEAN/
FACR(8),FACL(8),SRV(8),DSYM(8),DSYP(8),GSAV(8)
      COMMON /NORM/ DTAU,TMAX,DT,EDOV(60),EDNV(60)
      COMMON /OUTP/ NOUT,NPLT,NPRT,NSAV,NVAR
      COMMON /PROP/
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```
LPRP,YPRP,ZPRP,RPRP,VPRP,QQPRP,CPQ,CPR,XPR
      COMMON /SAVE/ ISWC,ISW(60),IOUT
      COMMON /TERR/ CTA,STA
      DATA LV/3,5,8,10/
C   SAVE INITIAL POSITIONS
      ISWC=NVAR
      DO 10 I=1,NVAR
      ISW(I)=1
10    CONTINUE
      IOUT=0
      CALL AGSAV(XOV,0.0)
C   INITIALIZE INTEGRATION
      XO=0.0
      CALL AGDIF(XOV,DOV,0.0,DTMN)
      T=0.0
C   INTEGRATE TO TMAX
      N=0
20    N=N+1
      DT=0.5*AMIN1(DTMN,0.2)
      HDT=0.5*DT
      T=T+DT
      XO=UO*T
      IF (LMVEL.EQ.(-1)) CALL AGWKR(T)
      IF (LMVEL.EQ.0) CALL AGBZI(T-DT,DT)
      IF (HTPAD.GT.0.0) CALL AGPAC(DT)
      IF (LPRP.NE.0) CALL AGPRP(XO)
      IF (LMVEL.NE.3) GO TO 25
      ZN=HHEL*CTA*EXP(-WHEL*T/HHEL)
      YHEL=YHEL+(ZN-ZHEL)*STA/CTA
      ZHEL=ZN
C   PREDICTOR
25    DO 40 I=1,NVAR
      IF (ISW(I).EQ.0) GO TO 40
      DO 30 J=1,10
      XNV(J,I)=XOV(J,I)+DT*DOV(J,I)
30    CONTINUE
      DO 35 L=1,4
      J=LV(L)
      XNV(J,I)=AMAX1(0.0,XNV(J,I))
35    CONTINUE
40    CONTINUE
C   CORRECTOR
      DO 70 K=1,2
      CALL AGDIF(XNV,DNV,T,DTMN)
      DO 65 I=1,NVAR
      IF (ISW(I).EQ.0) GO TO 65
      DO 50 J=1,10
      XNV(J,I)=XOV(J,I)+HDT*(DOV(J,I)+DNV(J,I))
50    CONTINUE
      DO 55 L=1,4
      J=LV(L)
      XNV(J,I)=AMAX1(0.0,XNV(J,I))
55    CONTINUE
      IF (XNV(6,I).GE.0.0) GO TO 65
```

```
      RATE=XOV(6,I)/(XOV(6,I)-XNV(6,I))
      DO 60 J=1,10
      XNV(J,I)=XOV(J,I)+RATE*(XNV(J,I)-XOV(J,I))
60    CONTINUE
      XNV(6,I)=0.0
65    CONTINUE
70    CONTINUE
C  DETERMINE NEW POSITIONS OF ROLLED UP VORTICES
      IF (LMVEL.GE.0) CALL AGVCH(DT)
C  CHECK SOLUTION AND CONTINUE
      ISWC=0
      DO 90 I=1,NVAR
      IF (XNV(6,I).EQ.0.0) ISW(I)=0
      ISWC=ISWC+ISW(I)
      DO 80 J=1,10
      XOV(J,I)=XNV(J,I)
      DOV(J,I)=DNV(J,I)
80    CONTINUE
      IF (LEVAP.EQ.1) EDOV(I)=AMAX1(EDNV(I),DCUT)
      IF (ISW(I).NE.0) GO TO 90
      IF (DMCV(I).NE.0.0) GO TO 90
      DMCV(I)=(EDOV(I)/DIAM)**3
      TMCV(I)=T
90    CONTINUE
      I=0
      IF (MOD(N,NSAV).EQ.0) I=1
      IOUT=0
      IF (MOD(N,10*NSAV).EQ.0) IOUT=1
      IF (T.GE.TMAX) ISWC=0
      IF (ISWC.EQ.0) I=1
      IF (I.EQ.1) CALL AGSAV(XNV,T)
      IF (ISWC.NE.0) GO TO 20
      RETURN
      END
      SUBROUTINE AGLQD(A,XLU,IPVT,EQUIL,IER)
C  LINEAR DECOMPOSITION FOR SUPEREQUILIBRIUM
      DIMENSION A(6,2),XLU(6,2),IPVT(2),EQUIL(2)
      DATA
ZERO,ONE,FOUR,SIXTN,SIXTH/0.0,1.0,4.0,16.0,0.0625/
      IER=0
      WREL=ZERO
      D1=ONE
      D2=ZERO
      BIGA=ZERO
      DO 20 I=1,6
      BIG=ZERO
      DO 10 J=1,6
      P=A(I,J)
      XLU(I,J)=P
      P=ABS(P)
      IF (P.GT.BIG) BIG=P
10    CONTINUE
      IF (BIG.GT.BIGA) BIGA=BIG
      IF (BIG.EQ.ZERO) GO TO 110
```

```
      EQUIL(I)=ONE/BIG
20    CONTINUE
      DO 105 J=1,6
      JM1=J-1
      IF (JM1.LT.1) GO TO 40
      DO 35 I=1,JM1
      SUM=XLU(I,J)
      IM1=I-1
      IF (IM1.LT.1) GO TO 35
      DO 30 K=1,IM1
      SUM=SUM-XLU(I,K)*XLU(K,J)
30    CONTINUE
      XLU(I,J)=SUM
35    CONTINUE
40    P=ZERO
      DO 70 I=J,6
      SUM=XLU(I,J)
      IF (JM1.LT.1) GO TO 65
      DO 60 K=1,JM1
      SUM=SUM-XLU(I,K)*XLU(K,J)
60    CONTINUE
      XLU(I,J)=SUM
65    Q=EQUIL(I)*ABS(SUM)
      IF (P.GE.Q) GO TO 70
      P=Q
      IMAX=I
70    CONTINUE
      IF (P.EQ.ZERO) GO TO 110
      IF (J.EQ.IMAX) GO TO 80
      D1=-D1
      DO 75 K=1,6
      P=XLU(IMAX,K)
      XLU(IMAX,K)=XLU(J,K)
      XLU(J,K)=P
75    CONTINUE
      EQUIL(IMAX)=EQUIL(J)
80    IPVT(J)=IMAX
      D1=D1*XLU(J,J)
85    IF (ABS(D1).LE.ONE) GO TO 90
      D1=D1*SIXTH
      D2=D2+FOUR
      GO TO 85
90    IF (ABS(D1).GE.SIXTH) GO TO 95
      D1=D1*SIXTN
      D2=D2-FOUR
      GO TO 90
95    JP1=J+1
      IF (JP1.GT.6) GO TO 105
      P=XLU(J,J)
      DO 100 I=JP1,6
      XLU(I,J)=XLU(I,J)/P
100   CONTINUE
105   CONTINUE
      RETURN
```

```
110   IER=1
      RETURN
      END
      SUBROUTINE AGLQS(A,B,IPVT,X)
C  LINEAR SUBSTITUTION FOR SUPEREQUILIBRIUM
      DIMENSION A(6,2),B(2),IPVT(2),X(2)
      DO 10 I=1,6
      X(I)=B(I)
10    CONTINUE
      IW=0
      DO 22 I=1,6
      IP=IPVT(I)
      SUM=X(IP)
      X(IP)=X(I)
      IF (IW.EQ.0) GO TO 15
      IM1=I-1
      DO 12 J=IW,IM1
      SUM=SUM-A(I,J)*X(J)
12    CONTINUE
      GO TO 20
15    IF (SUM.NE.0.0) IW=I
20    X(I)=SUM
22    CONTINUE
      DO 32 IB=1,6
      I=7-IB
      IP1=I+1
      SUM=X(I)
      IF (IP1.GT.6) GO TO 30
      DO 25 J=IP1,6
      SUM=SUM-A(I,J)*X(J)
25    CONTINUE
30    X(I)=SUM/A(I,I)
32    CONTINUE
      RETURN
      END
      FUNCTION AGMAT(Q)
C  SUPEREQUILIBRIUM MATRIX FOR  UIUJ
      DIMENSION AV(6,6),WK(6)
      COMMON /OUTP/ NOUT,NPLT,NPRT,NSAV,NVAR
      COMMON /SUPR/ UY,UZ,VY,VZ,WY,WZ,DV(6)
      DATA B/0.125/
1000  FORMAT(44H *** LINEAR SOLVER ERROR IN
SUPEREQUILIBRIUM)
      DO 20 J=1,6
      DO 10 I=1,6
      AV(I,J)=0.0
10    CONTINUE
      DV(J)=0.0
20    CONTINUE
      QL1=Q
      QL2=(1.0-2.0*B)*Q**3/3.0
      AV(1,1)=QL1
      AV(1,4)=2.0*UY
      AV(1,5)=2.0*UZ
```

```
      DV(1)=QL2
      AV(2,2)=QL1+2.0*VY
      AV(2,6)=2.0*VZ
      DV(2)=QL2
      AV(3,3)=QL1+2.0*WZ
      AV(3,6)=2.0*WY
      DV(3)=QL2
      AV(4,2)=UY
      AV(4,4)=QL1+VY
      AV(4,5)=VZ
      AV(4,6)=UZ
      AV(5,3)=UZ
      AV(5,4)=WY
      AV(5,5)=QL1+WZ
      AV(5,6)=UY
      AV(6,2)=WY
      AV(6,3)=VZ
      AV(6,6)=QL1
      CALL AGLQD(AV,AV,WK,WK,IER)
      IF (IER.EQ.0) CALL AGLQS(AV,DV,WK,DV)
      IF (IER.NE.0) WRITE (NOUT,1000)
      AGMAT=Q*Q-DV(1)-DV(2)-DV(3)
      RETURN
      END
      SUBROUTINE AGPAC(DELT)
C  COMPUTE PLANT AREA DENSITY CIRCULATION CORRECTION
      DIMENSION ASV(100)
      COMMON /AREA/ NPAD,ZV(100),AV(100)
      COMMON /INTG/ FR(8),FL(8),IFR(8),IFL(8)
      COMMON /MEAN/
LMVEL,LMCRS,NVOR,RLIM,ZO,USK,HTPAD,ZOPAD,UO,XO
      COMMON /MEAN/ YBAR(8),ZBAR(8),YBAL(8),ZBAL(8),G2PI(8)
      COMMON /MEAN/
FACR(8),FACL(8),SRV(8),DSYM(8),DSYP(8),GSAV(8)
      COMMON /OUTP/ NOUT,NPLT,NPRT,NSAV,NVAR
      DATA CD/0.16/,TPI/6.2831853/
1000  FORMAT(15H RIGHT VORTEX #,I2,14H LEAVES CANOPY)
1010  FORMAT(15H RIGHT VORTEX #,I2,14H ENTERS CANOPY)
1020  FORMAT(15H  LEFT VORTEX #,I2,14H LEAVES CANOPY)
1030  FORMAT(15H  LEFT VORTEX #,I2,14H ENTERS CANOPY)
      IF (NVOR.EQ.0) RETURN
      DO 60 N=1,NVOR
C  RIGHT VORTEX
      IF (ZBAR(N)-SRV(N).LT.HTPAD) GO TO 10
      IF (IFR(N).EQ.1) WRITE (NPRT,1000) N
      IFR(N)=0
      GO TO 30
10    IF (IFR(N).EQ.0) WRITE (NPRT,1010) N
      IFR(N)=1
      DO 20 J=1,NPAD
      SQ=SRV(N)**2-(ZV(J)-ZBAR(N))**2
      IF (SQ.LE.0.0) ASV(J)=0.0
      IF (SQ.GT.0.0) ASV(J)=AV(J)*SQRT(SQ)
20    CONTINUE
```

```
CDA=4.0*CD*AGBZQ(NPAD,ZV,ASV,ZV(1),ZV(NPAD),0)/TPI/SRV(N)**
2
      FR(N)=FR(N)+DELT*CDA
      FACR(N)=1.0/(1.0+FR(N)*ABS(G2PI(N))/SRV(N))
C  LEFT VORTEX
30    IF (ZBAL(N)-SRV(N).LT.HTPAD) GO TO 40
      IF (IFL(N).EQ.1) WRITE (NPRT,1020) N
      IFL(N)=0
      GO TO 60
40    IF (IFL(N).EQ.0) WRITE (NPRT,1030) N
      IFL(N)=1
      DO 50 J=1,NPAD
      SQ=SRV(N)**2-(ZV(J)-ZBAL(N))**2
      IF (SQ.LE.0.0) ASV(J)=0.0
      IF (SQ.GT.0.0) ASV(J)=AV(J)*SQRT(SQ)
50    CONTINUE

CDA=4.0*CD*AGBZQ(NPAD,ZV,ASV,ZV(1),ZV(NPAD),0)/TPI/SRV(N)**
2
      FL(N)=FL(N)+DELT*CDA
      FACL(N)=1.0/(1.0+FL(N)*ABS(G2PI(N))/SRV(N))
60    CONTINUE
      RETURN
      END
      SUBROUTINE AGPAD(HT,ZO)
C  COMPUTE PLANT AREA DENSITY DISPLACEMENT THICKNESS
      COMMON /AREA/ NPAD,ZV(100),AV(100)
      COMMON /INTG/ FR(8),FL(8),IFR(8),IFL(8)
      COMMON /OUTP/ NOUT,NPLT,NPRT,NSAV,NVAR
1000  FORMAT(33H CANOPY INVOKED, MAXIMUM ENTRIES:,I4)
1010  FORMAT(27H PLANT AREA DENSITY HEIGHT:,E13.5,2H M/
     $        3X,24H DISPLACEMENT THICKNESS:,E13.5,2H M)
      HT=ZV(NPAD)
      ZO=AGBZQ(NPAD,ZV,AV,ZV(1),ZV(NPAD),1)/
     $   AGBZQ(NPAD,ZV,AV,ZV(1),ZV(NPAD),0)
      DO 10 I=1,8
      FR(I)=0.0
      FL(I)=0.0
      IFR(I)=0
      IFL(I)=0
10    CONTINUE
      WRITE (NOUT,1000) NPAD
      WRITE (NOUT,1010) HT,ZO
      RETURN
      END
      SUBROUTINE AGPRP(X)
C  UPDATE PROPELLER VARIABLES
      COMMON /PROP/
LPRP,YPRP,ZPRP,RPRP,VPRP,QQPRP,CPQ,CPR,XPR
      QQPRP=CPQ/(X+XPR)**1.18
      RN=CPR*SQRT(QQPRP)*(X+XPR)
      VPRP=VPRP*(RPRP/RN)**2
      RPRP=RN
```

```
      RETURN
      END
      SUBROUTINE AGRTF(F,EPS,NSIG,X,ITMAX,IER)
C   ROOT FINDER FOR SUPEREQUILIBRIUM
      DATA TEN,ONE,ZERO,P9,P11,HALF,PP1,F4
     $      /10.0,1.0,0.0,0.9,1.1,0.5,0.1,4.0/
      IER=0
      DIGT=TEN**(-NSIG)
      P=-ONE
      P1=ONE
      P2=ZERO
      H=ZERO
      JK=0
      IF (X.EQ.ZERO) GO TO 10
      P=P9*X
      P1=P11*X
      P2=X
10    RT=P
      GO TO 65
12    IF (JK.NE.1) GO TO 15
      RT=P1
      X0=FPRT
      GO TO 65
15    IF (JK.NE.2) GO TO 20
      RT=P2
      X1=FPRT
      GO TO 65
20    IF (JK.NE.3) GO TO 55
      X2=FPRT
      D=-HALF
      IF (X.EQ.ZERO) GO TO 25
      H=-PP1*X
      GO TO 30
25    H=-ONE
30    DD=ONE+D
      BI=X0*D**2-X1*DD**2+X2*(DD+D)
      DEN=BI**2-F4*X2*D*DD*(X0*D-X1*DD+X2)
      IF (DEN.LE.ZERO) GO TO 35
      DEN=SQRT(DEN)
      GO TO 40
35    DEN=ZERO
40    DN=BI+DEN
      DM=BI-DEN
      IF (ABS(DN).LE.ABS(DM)) GO TO 45
      DEN=DN
      GO TO 50
45    DEN=DM
50    IF (DEN.EQ.ZERO) DEN=ONE
      DI=-DD*(X2+X2)/DEN
      H=DI*H
      RT=RT+H
      IF (ABS(H).LT.ABS(RT)*DIGT) GO TO 90
      GO TO 65
55    IF (ABS(FPRT).GE.ABS(X2*10.0))  GO TO 60
```

```
      X0=X1
      X1=X2
      X2=FPRT
      D=DI
      GO TO 30
60    DI=DI*HALF
      H=H*HALF
      RT=RT-H
65    JK=JK+1
      IF (JK.LT.ITMAX)  GO TO 75
      IER=1
      X=-1.0
      GO TO 95
75    FPRT=F(RT)
      IF (ABS(FPRT).GE.EPS) GO TO 12
90    X=RT
95    ITMAX=JK
      RETURN
      END
      SUBROUTINE AGSAV(XV,T)
C  SAVE THE CURRENT RESULTS FOR PLOTTING
      DIMENSION XV(10,60)
      COMMON /EVAP/
LEVAP,DTEMP,DIAM,DCUT,DENF,DMCV(60),TMCV(60)
      COMMON /MEAN/
LMVEL,LMCRS,NVOR,RLIM,ZO,USK,HTPAD,ZOPAD,UO,XO
      COMMON /MEAN/ YBAR(8),ZBAR(8),YBAL(8),ZBAL(8),G2PI(8)
      COMMON /MEAN/
FACR(8),FACL(8),SRV(8),DSYM(8),DSYP(8),GSAV(8)
      COMMON /NORM/ DTAU,TMAX,DT,EDOV(60),EDNV(60)
      COMMON /OUTP/ NOUT,NPLT,NPRT,NSAV,NVAR
      COMMON /PROP/
LPRP,YPRP,ZPRP,RPRP,VPRP,QQPRP,CPQ,CPR,XPR
      COMMON /SAVE/ ISWC,ISW(60),IOUT
      DATA JVOR/0/
1000  FORMAT(6H TIME:,E12.4,4H SEC)
2000  FORMAT(/6H TIME:,E12.4,4H
SEC/5X,1H#,6X,1HY,11X,1HV,11X,2HYY,10X,
     $
2HYV,10X,2HVV,10X,1HZ,11X,1HW,11X,2HZZ,10X,2HZW,10X,2HWW)
2010  FORMAT(I6,10E12.4)
2020  FORMAT(14H VORTEX (Y,Z):,8E14.5)
2030  FORMAT(19H PROP (Y,Z,R,V,QQ):,5E14.5)
      IF (ISWC.EQ.0) RETURN
      WRITE (NPRT,2000) T
      IF (IOUT.EQ.1) WRITE (NOUT,1000) T
      DO 40 N=1,NVAR
      IF (ISW(N).NE.0) WRITE (NPRT,2010) N,(XV(I,N),I=1,10)
40    CONTINUE
      IF (JVOR.EQ.0) RETURN
      WRITE (NPRT,2020) (YBAR(N),ZBAR(N),N=1,NVOR)
      WRITE (NPRT,2020) (YBAL(N),ZBAL(N),N=1,NVOR)
      IF (LPRP.NE.0) WRITE (NPRT,2030)
YPRP,ZPRP,RPRP,VPRP,QQPRP
```

```
      RETURN
      END
      SUBROUTINE AGSUP(XL,DVDY,DVDZ,DWDY,DWDZ,UU,VV,WW)
C   DETERMINE  QQ  BY SUPEREQUILIBRIUM ITERATION
      COMMON /OUTP/ NOUT,NPLT,NPRT,NSAV,NVAR
      COMMON /SUPR/ UY,UZ,VY,VZ,WY,WZ,DV(6)
      EXTERNAL AGMAT
      DATA EPS/0.1/
1000  FORMAT(42H *** ROOT FINDER ERROR IN SUPEREQUILIBRIUM)
      UY=0.0
      UZ=0.0
      VY=DVDY
      VZ=DVDZ
      WY=DWDY
      WZ=DWDZ

DMAX=AMAX1(ABS(UY),ABS(UZ),ABS(VY),ABS(VZ),ABS(WY),ABS(WZ))
      IF (DMAX.LE.0.0001) GO TO 30
      UY=UY/DMAX
      UZ=UZ/DMAX
      VY=VY/DMAX
      VZ=VZ/DMAX
      WY=WY/DMAX
      WZ=WZ/DMAX
      XM=AMAX1(EPS,2.0*ABS(WZ))
      SM=AGMAT(XM)
      IMAX=0
10    IMAX=IMAX+1
      XP=XM+EPS
      SP=AGMAT(XP)
      IF (SM.LE.0.0.AND.SP.GE.0.0) GO TO 20
      XM=XP
      SM=SP
      IF (IMAX.LT.20) GO TO 10
      GO TO 30
20    IMAX=20
      CALL AGRTF(AGMAT,0.001,4,XM,IMAX,IER)
      IF (IER.NE.0) GO TO 25
      XLD=(XL*DMAX)**2
      UU=DV(1)*XLD
      VV=DV(2)*XLD
      WW=DV(3)*XLD
      RETURN
25    WRITE (NOUT,1000)
30    UU=0.0
      VV=0.0
      WW=0.0
      RETURN
      END
      SUBROUTINE AGSVE(XN,YN,ZN,S,G,V,W)
C   COMPUTE UNROLLED UP SHEET VELOCITY EFFECT
      DATA TPI/6.2831853/
      TEMC=0.01*S
      TEMS=0.1*S
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      X=AMAX1(XN,TEMC)
      IF (ABS(ZN).LE.TEMC) GO TO 10
      Z=ZN
      IF (Z.LT.0.0.AND.Z+TEMS.GT.0.0) Z=-TEMS
      IF (Z.GT.0.0.AND.Z-TEMS.LT.0.0) Z=TEMS
      TEMV=ATAN2(S-YN,Z)+ATAN2(YN,Z)
     $    +ATAN2(X*(S-YN),Z*SQRT(X*X+(S-YN)**2+Z*Z))
     $    +ATAN2(X*YN,Z*SQRT(X*X+YN*YN+Z*Z))
      V=V-TEMV*G*ZN/Z/TPI/2.0
10    IF (YN+TEMC.GE.0.0.AND.YN-S-TEMC.LE.0.0) RETURN
      Y=YN
      IF (Y.LT.0.0.AND.Y+TEMS.GT.0.0) Y=-TEMS
      IF (Y-S.GT.0.0.AND.Y-S-TEMS.LT.0.0) Y=S+TEMS
      RP2=Y*Y+ZN*ZN
      RM2=(S-Y)**2+ZN*ZN
      XF=SQRT((Y-0.5*S)**2+ZN*ZN)
      IF (X.GT.10.0*XF) GO TO 20
      TEMW=ALOG(RP2*(SQRT(RP2+X*X)-X)*(SQRT(RM2+X*X)+X)/
     $           RM2/(SQRT(RP2+X*X)+X)/(SQRT(RM2+X*X)-X))
      GO TO 30
20    TEMW=2.0*ALOG(RP2/RM2)
30    TEMC=YN/Y
      IF (Y.GT.0.0) TEMC=(YN-S)/(Y-S)
      W=W+TEMW*G*TEMC/TPI/4.0
      RETURN
      END
      SUBROUTINE AGTUR(Y,Z,QQ,SL,VV,WW)
C  TURBULENCE AND SCALE EVALUATION
      COMMON /MEAN/
LMVEL,LMCRS,NVOR,RLIM,ZO,USK,HTPAD,ZOPAD,UO,XO
      COMMON /MEAN/ YBAR(8),ZBAR(8),YBAL(8),ZBAL(8),G2PI(8)
      COMMON /MEAN/
FACR(8),FACL(8),SRV(8),DSYM(8),DSYP(8),GSAV(8)
      COMMON /PROP/
LPRP,YPRP,ZPRP,RPRP,VPRP,QQPRP,CPQ,CPR,XPR
      COMMON /TURB/ LQQSE,QQMX,SLMX
      DATA DELTA/0.05/
C  SCALE LENGTH
      IF (LQQSE.EQ.2.OR.LQQSE.EQ.3) GO TO 20
      SL=AMIN1(0.65*Z,SLMX)
      IF (NVOR.EQ.0) GO TO 30
      DO 10 N=1,NVOR
      R=SQRT((Y-YBAR(N))**2+(Z-ZBAR(N))**2)
      SL=AMIN1(SL,0.6*R)
      R=SQRT((Y-YBAL(N))**2+(Z-ZBAL(N))**2)
      SL=AMIN1(SL,0.6*R)
10    CONTINUE
      GO TO 30
20    CALL AGWKI(Y,Z,4,SL)
30    IF (SL.GT.0.0) GO TO 40
      QQ=0.0
      VV=0.0
      WW=0.0
      RETURN
```

```
C  TURBULENCE
40     IF (LQQSE.EQ.(-1)) GO TO 60
       IF (LQQSE.EQ.0) QQ=QQMX
       IF (LQQSE.GE.1) CALL AGWKI(Y,Z,3,QQ)
       IF (LQQSE.EQ.3) GO TO 50
       IF (LPRP.EQ.0) GO TO 45
       R=SQRT((Y-YPRP)**2+(Z-ZPRP)**2)
       IF (R.LE.RPRP) QQ=QQ+QQPRP
45     VV=QQ/3.0
       WW=QQ/3.0
       IF (HTPAD.EQ.0.0) RETURN
       GO TO 70
50     CALL AGWKI(Y,Z,5,VV)
       CALL AGWKI(Y,Z,6,WW)
       RETURN
C  SUPEREQUILIBRIUM
60     CALL AGVEL(Y+DELTA,Z,VPY,WPY)
       CALL AGVEL(Y-DELTA,Z,VMY,WMY)
       CALL AGVEL(Y,Z+DELTA,VPZ,WPZ)
       CALL AGVEL(Y,Z-DELTA,VMZ,WMZ)
       DVDY=(VPY-VMY)/DELTA/2.0
       DVDZ=(VPZ-VMZ)/DELTA/2.0
       DWDY=(WPY-WMY)/DELTA/2.0
       DWDZ=(WPZ-WMZ)/DELTA/2.0
       EPS=0.5*(DVDY+DWDZ)
       DVDY=DVDY-EPS
       DWDZ=DWDZ-EPS
       CALL AGSUP(SL,DVDY,DVDZ,DWDY,DWDZ,UU,VV,WW)
       QQ=UU+VV+WW
       IF (HTPAD.EQ.0.0) RETURN
C  CORRECTION FOR CANOPY
70     IF (Z.GE.HTPAD) RETURN
       QQ=QQ*Z/HTPAD
       VV=VV*Z/HTPAD
       WW=WW*Z/HTPAD
       RETURN
       END
       SUBROUTINE AGVCH(DELT)
C  CORRECTION OF ROLLED UP VORTEX POSITIONS IN TIME
       DIMENSION YNR(8),ZNR(8),YNL(8),ZNL(8)
       COMMON /HELI/ WHEL,HHEL,RHEL,YHEL,ZHEL
       COMMON /MEAN/
LMVEL,LMCRS,NVOR,RLIM,ZO,USK,HTPAD,ZOPAD,UO,XO
       COMMON /MEAN/ YBAR(8),ZBAR(8),YBAL(8),ZBAL(8),G2PI(8)
       COMMON /MEAN/
FACR(8),FACL(8),SRV(8),DSYM(8),DSYP(8),GSAV(8)
       COMMON /PROP/
LPRP,YPRP,ZPRP,RPRP,VPRP,QQPRP,CPQ,CPR,XPR
       IF (NVOR.EQ.0) RETURN
       DO 10 N=1,NVOR
       CALL AGVEL(YBAR(N),ZBAR(N),VBAR,WBAR)
       YNR(N)=YBAR(N)+DELT*VBAR
       ZNR(N)=ZBAR(N)+DELT*WBAR
       CALL AGVEL(YBAL(N),ZBAL(N),VBAL,WBAL)
```

```
      YNL(N)=YBAL(N)+DELT*VBAL
      ZNL(N)=ZBAL(N)+DELT*WBAL
10    CONTINUE
      IF (LPRP.EQ.0) GO TO 15
      CALL AGVEL(YPRP,ZPRP,VBAR,WBAR)
      YPRP=YPRP+DELT*VBAR
      ZPRP=ZPRP+DELT*WBAR
15    DO 20 N=1,NVOR
      YBAR(N)=YNR(N)
      ZBAR(N)=ZNR(N)
      YBAL(N)=YNL(N)
      ZBAL(N)=ZNL(N)
20    CONTINUE
      IF (LMVEL.NE.3) RETURN
      NVOR=0
      CALL AGVEL(YHEL,ZHEL,VBAR,WBAR)
      YHEL=YHEL+DELT*VBAR
      NVOR=1
      RETURN
      END
      SUBROUTINE AGVEL(Y,Z,V,W)
C  MEAN VELOCITY DETERMINATION AT  (Y,Z)  LOCATION
      COMMON /HELI/ WHEL,HHEL,RHEL,YHEL,ZHEL
      COMMON /MEAN/
LMVEL,LMCRS,NVOR,RLIM,ZO,USK,HTPAD,ZOPAD,UO,XO
      COMMON /MEAN/ YBAR(8),ZBAR(8),YBAL(8),ZBAL(8),G2PI(8)
      COMMON /MEAN/
FACR(8),FACL(8),SRV(8),DSYM(8),DSYP(8),GSAV(8)
      COMMON /PROP/
LPRP,YPRP,ZPRP,RPRP,VPRP,QQPRP,CPQ,CPR,XPR
      COMMON /TERR/ CTA,STA
      IF (LMVEL.EQ.(-1)) GO TO 30
      V=0.0
      W=0.0
      IF (Z.LE.0.0) RETURN
      IF (NVOR.EQ.0) GO TO 20
      DO 10 N=1,NVOR
C  QUADRANT 1 VORTEX
      R=AMAX1(0.01,SQRT((Y-YBAR(N))**2+(Z-ZBAR(N))**2))
      B=G2PI(N)*FACR(N)/AMAX1(R,RLIM)/R
      V=V-B*(Z-ZBAR(N))
      W=W+B*(Y-YBAR(N))
C  QUADRANT 2 VORTEX
      R=AMAX1(0.01,SQRT((Y-YBAL(N))**2+(Z-ZBAL(N))**2))
      B=G2PI(N)*FACL(N)/AMAX1(R,RLIM)/R
      V=V+B*(Z-ZBAL(N))
      W=W-B*(Y-YBAL(N))
C  QUADRANT 3 VORTEX
      R=AMAX1(0.01,SQRT((Y-YBAL(N))**2+(Z+ZBAL(N))**2))
      B=G2PI(N)*FACL(N)/AMAX1(R,RLIM)/R
      V=V-B*(Z+ZBAL(N))
      W=W+B*(Y-YBAL(N))
C  QUADRANT 4 VORTEX
      R=AMAX1(0.01,SQRT((Y-YBAR(N))**2+(Z+ZBAR(N))**2))
```

```
      B=G2PI(N)*FACR(N)/AMAX1(R,RLIM)/R
      V=V+B*(Z+ZBAR(N))
      W=W-B*(Y-YBAR(N))
C  UNROLLED UP SHEET EFFECT
      IF (GSAV(N).EQ.0.0) GO TO 10
      VE=0.0
      WE=0.0
      S=DSYM(N)+DSYP(N)
      YE=(Y-YBAR(N))*CTA-(Z-ZBAR(N))*STA
      ZE=(Y-YBAR(N))*STA+(Z-ZBAR(N))*CTA
      CALL AGSVE(XO,YE+DSYM(N),ZE,S,GSAV(N)*FACR(N),VE,WE)
      YE=(Y-YBAL(N))*CTA-(Z-ZBAL(N))*STA
      ZE=(Y-YBAL(N))*STA+(Z-ZBAL(N))*CTA
      CALL AGSVE(XO,YE+DSYP(N),ZE,S,-GSAV(N)*FACL(N),VE,WE)
      YE=(Y-YBAL(N))*CTA-(Z+ZBAL(N))*STA
      ZE=(Y-YBAL(N))*STA+(Z+ZBAL(N))*CTA
      CALL AGSVE(XO,YE+DSYP(N),ZE,S,GSAV(N)*FACL(N),VE,WE)
      YE=(Y-YBAR(N))*CTA-(Z+ZBAR(N))*STA
      ZE=(Y-YBAR(N))*STA+(Z+ZBAR(N))*CTA
      CALL AGSVE(XO,YE+DSYM(N),ZE,S,-GSAV(N)*FACR(N),VE,WE)
      V=V+WE*STA+VE*CTA
      W=W+WE*CTA-VE*STA
10    CONTINUE
C  HELICOPTER ROTOR
      IF (LMVEL.NE.3) GO TO 15
      IF (Z.GT.ZHEL) GO TO 20
      HZ=HHEL*CTA
      B=SQRT(1.0-(Z/HZ)**2)
      YS=RHEL*CTA-HZ*B+HZ*ALOG((1.0+B)*HZ/Z)
      IF (ABS(Y-YHEL).GT.YS) GO TO 20
      V=V+WHEL*CTA*B*(Y-YHEL)/YS-WHEL*STA*Z/HZ
      W=W-WHEL*CTA*Z/HZ
      GO TO 20
C  PROPELLER
15    IF (LPRP.EQ.0) GO TO 20
      R=SQRT((Y-YPRP)**2+(Z-ZPRP)**2)
      IF (R.GT.RPRP) GO TO 20
      V=V+VPRP*(Z-ZPRP)/RPRP
      W=W-VPRP*(Y-YPRP)/RPRP
C  MEAN CROSS WIND
20    IF (LMCRS.EQ.0) RETURN
      IF (HTPAD.GT.0.0) GO TO 25
      V=V+USK*ALOG((Z+ZO)/ZO)
      RETURN
25    B=USK*ALOG((AMAX1(Z,HTPAD)+ZOPAD)/ZOPAD)
      IF (Z.LT.HTPAD) B=B*Z/HTPAD
      V=V+B
      RETURN
C  WAKE PLOT FILE
30    CALL AGWKI(Y,Z,1,V)
      CALL AGWKI(Y,Z,2,W)
      RETURN
      END
      SUBROUTINE AGWKI(Y,Z,N,X)
```

```
C  ARRAY INTERPOLATOR FOR WAKE PLOT FILE
      COMMON /OUTP/ NOUT,NPLT,NPRT,NSAV,NVAR
      COMMON /WAKE/ NEXTF,NY,NZ,YV(16),ZV(16),AV(16,16,6)
1000  FORMAT(48H *** WARNING: 1ST WAKE PLOT FILE
EXTRAPOLATION (,
     $        E12.4,2H ,,E12.4,4H ) M)
C  EXTRAPOLATION CHECK
      IF (Y.LT.YV(1).OR.Y.GT.YV(NY)) NEXTF=NEXTF+1
      IF (Z.LT.ZV(1).OR.Z.GT.ZV(NZ)) NEXTF=NEXTF+1
C  LOCATE RECTANGLE AROUND  (Y,Z)  DATA POINT
      DO 10 IY=2,NY
      IF (Y.LE.YV(IY)) GO TO 20
10    CONTINUE
      IY=NY
20    DO 30 IZ=2,NZ
      IF (Z.LE.ZV(IZ)) GO TO 40
30    CONTINUE
      IZ=NZ
C  INTERPOLATE
40    RATE=(Y-YV(IY-1))/(YV(IY)-YV(IY-1))

XM=AV(IY-1,IZ-1,N)+RATE*(AV(IY,IZ-1,N)-AV(IY-1,IZ-1,N))
      XP=AV(IY-1,IZ,N)+RATE*(AV(IY,IZ,N)-AV(IY-1,IZ,N))
      X=XM+(XP-XM)*(Z-ZV(IZ-1))/(ZV(IZ)-ZV(IZ-1))
      IF (NEXTF.GT.0) GO TO 50
      IF (NEXTF.LT.0) NEXTF=-3
      RETURN
50    WRITE (NPRT,1000) Y,Z
      NEXTF=-3
      RETURN
      END
      SUBROUTINE AGWKR(T)
C  RETRIEVAL FOR WAKE PLOT FILE
      DIMENSION AVS(19)
      COMMON /OUTP/ NOUT,NPLT,NPRT,NSAV,NVAR
      COMMON /WAKE/ NEXTF,NY,NZ,YV(16),ZV(16),AV(16,16,6)
      COMMON /WLOC/ NWPF,NWPV,TR,NENDF
1000  FORMAT(24H WAKE PLOT FILE ACCESS: ,E12.4,4H SEC)
C  CHECK WHETHER NEXT  1/10TH  INTERPOLATE IS NEEDED
      IF (T.LT.TR) RETURN
C  CHECK END-OF-PLOT-FILE
      IF (NENDF.EQ.(-1)) RETURN
C  READ PLOT FILE UNTIL DESIRED TIME IS BRACKETED
      REWIND NWPF
      READ (NWPF) (AVS(I),I=1,19)
      DO 10 K=1,3
      READ (NWPF) N
      READ (NWPF) (AVS(I),I=1,N)
10    CONTINUE
      NF=0
20    READ (NWPF) TFE
      IF (TFE.LT.0.0) GO TO 50
      NF=NF+1
      IF (NENDF.LT.NF) WRITE (NPRT,1000) TFE
```

```
      NENDF=MAX0(NENDF,NF)
      IF (TFE.GT.T) GO TO 60
      DO 40 N=1,NWPV
      DO 30 K=1,NZ
      READ (NWPF) (AV(J,K,N),J=1,NY)
30    CONTINUE
40    CONTINUE
      TFS=TFE
      GO TO 20
C  END-OF-PLOT-FILE REACHED
50    NENDF=-1
      WRITE (NPRT,1000) TFE
      TR=TFS
      RETURN
C  INTERPOLATE BETWEEN TWO PLOT FILE ENTRIES
60    NDLT=IFIX(10.0*(T-TFS)/(TFE-TFS))
      IF (NDLT.EQ.0) GO TO 100
      FCT=0.1*FLOAT(NDLT)
      DO 90 N=1,NWPV
      DO 80 K=1,NZ
      READ (NWPF) (AVS(J),J=1,NY)
      DO 70 J=1,NY
      AV(J,K,N)=AV(J,K,N)+FCT*(AVS(J)-AV(J,K,N))
70    CONTINUE
80    CONTINUE
90    CONTINUE
100   TR=TFS+0.1*FLOAT(NDLT+1)*(TFE-TFS)
      RETURN
      END
      SUBROUTINE AGWKS(LQQ)
C  START RECOVERY OF WAKE PLOT FILE DATA
      DIMENSION CMNT(19),NV(5)
      COMMON /OUTP/ NOUT,NPLT,NPRT,NSAV,NVAR
      COMMON /WAKE/ NEXTF,NY,NZ,YV(16),ZV(16),AV(16,16,6)
      COMMON /WLOC/ NWPF,NWPV,TR,NENDF
      DATA NV/2,2,3,4,6/,NMAX/16/
1000  FORMAT(22H WAKE PLOT FILE TITLE:/2X,19A4)
1010  FORMAT(35H *** WAKE PLOT FILE VARIABLE ERROR:/2X,I4,
     $       38H VARIABLES APPEAR WHEN AGDISP EXPECTS:,I4)
1020  FORMAT(29H WAKE PLOT FILE MESH SIZES: (,I3,2H ,,I3,2H
))
1030  FORMAT(32H *** WAKE PLOT FILE Y MESH SIZE:,I4/
     $       42H OUT OF RANGE -- SHOULD BE BETWEEN:  2
AND,I4)
1040  FORMAT(32H *** WAKE PLOT FILE Z MESH SIZE:,I4/
     $       42H OUT OF RANGE -- SHOULD BE BETWEEN:  2
AND,I4)
1050  FORMAT(5X,6HY (M):,10E12.4)
1060  FORMAT(5X,6HZ (M):,10E12.4)
1070  FORMAT(22H WAKE PLOT FILE TIMES:)
1080  FORMAT(4X,E12.4,4H SEC)
1090  FORMAT(44H *** PREMATURE END OF WAKE PLOT FILE
REACHED)
C  READ PLOT FILE HEADER AND VERIFY DATA
```

```
      NWPF=10
      READ (NWPF) CMNT
      WRITE (NOUT,1000) CMNT
      READ (NWPF) NWPV
      READ (NWPF) (CMNT(N),N=1,NWPV)
      IF (NWPV.EQ.NV(LQQ+2)) GO TO 20
      WRITE (NOUT,1010) NWPV,NV(LQQ+2)
      STOP
C   READ MESH DATA
20    READ (NWPF) NY
      IF (NY.LT.2.OR.NY.GT.NMAX) GO TO 70
      READ (NWPF) (YV(N),N=1,NY)
      READ (NWPF) NZ
      IF (NZ.LT.2.OR.NZ.GT.NMAX) GO TO 80
      READ (NWPF) (ZV(N),N=1,NZ)
      WRITE (NOUT,1020) NY,NZ
      WRITE (NOUT,1050) (YV(N),N=1,NY)
      WRITE (NOUT,1060) (ZV(N),N=1,NZ)
C   CHECK FILE CONTENTS
      WRITE (NOUT,1070)
30    READ (NWPF,END=90) TR
      WRITE (NOUT,1080) TR
      IF (TR.LT.0.0) GO TO 60
      DO 50 N=1,NWPV
      DO 40 K=1,NZ
      READ (NWPF,END=90) (AV(J,K,N),J=1,NY)
40    CONTINUE
50    CONTINUE
      GO TO 30
C   INITIALIZE FOR START OF RUN
60    TR=-1.0
      NENDF=0
      CALL AGWKR(0.0)
      NEXTF=0
      RETURN
C   ERROR EXITS
70    WRITE (NOUT,1030) NY,NMAX
      STOP
80    WRITE (NOUT,1040) NZ,NMAX
      STOP
90    WRITE (NOUT,1090)
      STOP
      END
```

<u>Module Three</u>

```
8   REM   INPUT METRIC VALUES
10  REM   NOZZLE DEPOSITION DATA FILE
20  REM   MAKER ****
21  REM   MAX OF 75 NOZZLE POSITIONS
22  REM   NOZZLE POSITIONS = Y(I,1)
23  REM   D/R V10% = Y(I,2)
```

```
24   REM    D/R V50% = Y(I,3)
25   REM    D/R V90% = Y(I,4)
26   REM     V10% BEGIN POSITION = Y(I,5)
27   REM     V10% MID   POSITION = Y(I,6)
28   REM      V10% END   POSITION = Y(I,7)
29   REM      V50% BEGIN POSITION = Y(I,8)
30   REM      V50% MID   POSITION = Y(I,9)
31   REM      V50% END   POSITION = Y(I,10)
32   REM       V90% BEGIN POSITION = Y(I,11)
33   REM       V90% MID   POSITION = Y(I,12)
34   REM       V90% END   POSITION = Y(I,13)
35   DIM Y(75,13),NZ(75,60),TE(300)
36   INPUT "INPUT AVERAGE DEPOSITION SPREAD (FT) ";ZS:ZS =
ZS / 3.28084
40   PRINT " DO YOU WISH TO READ AN EXISTING": INPUT "RAW
DATA FILE? ";A$
42   IF A$ = "Y" THEN  GOTO 10200
50   IF A$ <  > "N" THEN  GOTO 40
100   INPUT "INPUT THE TYPE AIRCRAFT ";TA$
110   INPUT "INPUT THE FLIGHT SPEED ";FS$
120   INPUT "INPUT THE GROSS WEIGHT ";GW$
130   INPUT "INPUT THE SPRAY HEIGHT ";SH$
140   INPUT "INPUT THE CROSSWIND CONDITIONS ";CW$
150   INPUT "INPUT THE NOZZLE FLOW RATE (GPM) ";GPM
200   INPUT "INPUT THE NUMBER OF TESTED NOZZLES ";TN
220   HOME : PRINT "INPUT THE FOLLOWING RESULTS": PRINT
"FROM THE COMPUTER SIMULATIONS"
225   PRINT "VALUES SHOULD BE METRIC"
230   PRINT
240   FOR I = 1 TO TN
250   PRINT "INPUT THE ";I;" NOZZLE POSITION ": INPUT Y(I,1)
255   PRINT : PRINT : PRINT "** V 10%        DROPLETS **"
260   PRINT "INPUT THE DEPOSITION DR FOR THE": INPUT "V.1
DROPLET SIZE ";Y(I,2)
270   INPUT "INPUT THE SIMULATED DEPOSITION LOCATION
";Y(I,6)
300   PRINT : PRINT : PRINT "** V 50% (VMD) DROPLETS **"
310   PRINT "INPUT THE DEPOSITION DR FOR THE": INPUT "V.5
DROPLET SIZE ";Y(I,3)
320   INPUT "INPUT THE SIMULATED DEPOSITION LOCATION
";Y(I,9)
350   PRINT : PRINT : PRINT "** V 90%        DROPLETS **"
360   PRINT "INPUT THE DEPOSITION DR FOR THE": INPUT "V.9
DROPLET SIZE ";Y(I,4)
370   INPUT "INPUT THE SIMULATED DEPOSITION LOCATION
";Y(I,12)
395   HOME
400   NEXT I
410   REM   CHANGE SECTION
420   HOME : PRINT "***** INPUT VALUES *****"
422   PRINT "TOTAL NUMBER NOZZLES IN DATA = ";TN
425   INPUT "IS RAW DATA CHECKING DESIRED? ";A$
426   IF A$ = "N" THEN  GOTO 1050
427   IF A$ <  > "Y" THEN  GOTO 425
```

```
430  PRINT : PRINT "CHECK FOR CORRECT VALUES"
435  PRINT
440  PRINT "AIRCRAFT TYPE = ";TA$
450  PRINT "FLIGHT SPEED = ";FS$;" MPH"
460  PRINT "GROSS WEIGHT = ";GW$
470  PRINT "CROSSWIND CONDITIONS OF ";CW$
475  PRINT "THE NOZZLE FLOW RATE (GPM) = ";GPM
476  PRINT
480  INPUT "ARE THESE VALUES CORRECT? ";A$
490  IF A$ = "Y" THEN  GOTO 600
495  IF A$ = "N" THEN  GOTO 500
497  GOTO 480
500  PRINT "WHICH OF THE FOLLOWING IS INCORRECT? "
510  PRINT : PRINT "TYPE AIRCRAFT (TA)": PRINT "FLIGHT
SPEED (FS)": PRINT "GROSS WEIGHT (GW)": PRINT "CROSSWIND
CONDITIONS (CW)"
515  PRINT "NOZZLE FLOW RATE (GPM)": PRINT
520  INPUT A$
530  IF A$ <  > "TA" THEN  GOTO 540
535  INPUT "INPUT CORRECT TYPE AIRCRAFT ";TA$
540  IF A$ <  > "FS" THEN  GOTO 550
545  INPUT "INPUT CORRECT FLIGHT SPEED ";FS$
550  IF A$ <  > "GW" THEN  GOTO 560
555  INPUT "INPUT CORRECT GROSS WEIGHT ";GW$
560  IF A$ <  > "CW" THEN  GOTO 567
565  INPUT "INPUT CORRECT CROSSWIND CONDITIONS ";CW$
567  IF A$ <  > "GPM" THEN  GOTO 500
570  INPUT "INPUT CORRECT NOZZLE FLOW RATE ";GPM
580  GOTO 430
600  HOME : PRINT "CHECK EACH NOZZLE POSITION": PRINT "FOR
CORRECT VALUES"
610  FOR I = 1 TO TN
620  PRINT "NOZZLE POSITION ";I;" = ";Y(I,1)
630  INPUT "CORRECT? ";A$
640  IF A$ = "Y" THEN  GOTO 660
645  IF A$ <  > "N" THEN  GOTO 630
650  INPUT "INPUT CORRECT VALUE ";Y(I,1)
655  GOTO 620
660  PRINT "THE DEPOSITION DR FOR THE V.1 DROPLET SIZE =
";Y(I,2)
670  INPUT "CORRECT? ";A$
680  IF A$ = "Y" THEN  GOTO 720
690  IF A$ <  > "N" THEN  GOTO 670
700  INPUT "INPUT CORRECT VALUE ";Y(I,2)
710  GOTO 660
720  PRINT " THE DEPOSITION LOCATION FOR V.1%  = ";Y(I,6)
730  INPUT "CORRECT? ";A$
740  IF A$ = "Y" THEN  GOTO 770
750  IF A$ <  > "N" THEN  GOTO 730
760  INPUT "INPUT CORRECT VALUE ";Y(I,6)
765  GOTO 720
770  PRINT "THE DEPOSITION DR FOR THE V.5 DROPLET SIZE =
";Y(I,3)
780  INPUT "CORRECT? ";A$
```

```
790  IF A$ = "Y" THEN  GOTO 830
800  IF A$ < > "N" THEN  GOTO 780
810  INPUT "INPUT CORRECT VALUE ";Y(I,3)
820  GOTO 770
830  PRINT " THE DEPOSITION LOCATION FOR V.5%  = ";Y(I,9)
840  INPUT "CORRECT? ";A$
850  IF A$ = "Y" THEN  GOTO 900
860  IF A$ < > "N" THEN  GOTO 840
870  INPUT "INPUT CORRECT VALUE ";Y(I,9)
895  GOTO 830
900  PRINT "THE DEPOSITION DR FOR THE V.9 DROPLET SIZE =
";Y(I,4)
910  INPUT "CORRECT? ";A$
920  IF A$ = "Y" THEN  GOTO 960
930  IF A$ < > "N" THEN  GOTO 910
940  INPUT "INPUT CORRECT VALUE ";Y(I,4)
950  GOTO 900
960  PRINT " THE DEPOSITION LOCATION FOR V.9%  = ";Y(I,12)
970  INPUT "CORRECT? ";A$
980  IF A$ = "Y" THEN  GOTO 1040
990  IF A$ < > "N" THEN  GOTO 970
1000  INPUT "INPUT CORRECT VALUE ";Y(I,12)
1030  GOTO 960
1040  NEXT I
1050  INPUT "DO YOU WISH TO SAVE THE RAW DATA FILE? ";A$
1060  IF A$ = "Y" THEN  GOTO 10000
1070  REM   PROCESS RAW DATA
1080  HOME : PRINT "THE DATA IS NOW BEING TRANSFORMED":
PRINT "INTO A DEPOSITION MATRIX"
1090  FOR I = 1 TO TN
1092  PRINT "WORKING ON NOZZLE NUMBER ";I
1095  FOR J = 1 TO 300:TE(J) = 0: NEXT J
1100 A1 = GPM * .10 * Y(I,2)
1110 A2 = GPM * .40 * Y(I,3)
1120 A3 = GPM * .50 * Y(I,4)
1121 SD = (ZS * .90) / 2
1122 Y(I,5) = Y(I,6) - SD:Y(I,7) = Y(I,6) + SD
1123 SD = (ZS * .50) / 2
1124 Y(I,8) = Y(I,9) - SD:Y(I,10) = Y(I,9) + SD
1125 SD = (ZS * .30) / 2
1126 Y(I,11) = Y(I,12) - SD:Y(I,13) = Y(I,12) + SD
1130 B =  INT (Y(I,5) * 3.28084 * 2 + 150.5)
1140 M =  INT (Y(I,6) * 3.28084 * 2 + 150.5)
1150 E =  INT (Y(I,7) * 3.28084 * 2 + 150.5)
1153  IF (E - B) < = 0 THEN  GOTO 1260
1155 A1 = (A1 / (E - B)) * 2
1160  FOR J = B TO M
1162  IF J < 0 THEN  GOTO 1200
1163  IF J > 300 THEN  GOTO 1200
1165  IF (M - B) < = 0 THEN  GOTO 1200
1170 AM = A1 * (J - B) / (M - B)
1180  IF J = B THEN AM = 0
1190 TE(J) = TE(J) + AM
1200  NEXT J
```

```
1210  FOR J = (M + 1) TO E
1212  IF J > 300 THEN  GOTO 1250
1213  IF J < 0 THEN  GOTO 1250
1215  IF (E - M) <  = 0 THEN  GOTO 1250
1220 AM = (A1 * (E - J) / (E - M))
1230  IF J = E THEN AM = 0
1240 TE(J) = TE(J) + AM
1250  NEXT J
1260 B =  INT (Y(I,8) * 3.28084 * 2 + 150.5)
1270 M =  INT (Y(I,9) * 3.28084 * 2 + 150.5)
1280 E =  INT (Y(I,10) * 3.28084 * 2 + 150.5)
1283  IF (E - B) <  = 0 THEN  GOTO 1390
1285 A2 = (A2 / (E - B)) * 2
1290  FOR J = B TO M
1292  IF J < 0 THEN  GOTO 1330
1293  IF J > 300 THEN  GOTO 1330
1295  IF (M - B) <  = 0 THEN  GOTO 1330
1300 AM = A2 * (J - B) / (M - B)
1310  IF J = B THEN AM = 0
1320 TE(J) = TE(J) + AM
1330  NEXT J
1340  FOR J = (M + 1) TO E
1342  IF J > 300 THEN  GOTO 1380
1343  IF J < 0 THEN  GOTO 1380
1345  IF (E - M) <  = 0 THEN  GOTO 1380
1350 AM = (A2 * (E - J) / (E - M))
1360  IF J = E THEN AM = 0
1370 TE(J) = TE(J) + AM
1380  NEXT J
1390 B =  INT (Y(I,11) * 3.28084 * 2 + 150.5)
1400 M =  INT (Y(I,12) * 3.28084 * 2 + 150.5)
1410 E =  INT (Y(I,13) * 3.28084 * 2 + 150.5)
1413  IF (E - B) <  = 0 THEN  GOTO 1520
1415 A3 = (A3 / (E - B)) * 2
1420  FOR J = B TO M
1422  IF J < 0 THEN  GOTO 1460
1423  IF J > 300 THEN  GOTO 1460
1425  IF (M - B) <  = 0 THEN  GOTO 1460
1430 AM = A3 * (J - B) / (M - B)
1440  IF J = B THEN AM = 0
1450 TE(J) = TE(J) + AM
1460  NEXT J
1470  FOR J = (M + 1) TO E
1472  IF J > 300 THEN  GOTO 1510
1473  IF J < 0 THEN  GOTO 1510
1475  IF (E - M) <  = 0 THEN  GOTO 1510
1480 AM = (A3 * (E - J) / (E - M))
1490  IF J = E THEN AM = 0
1500 TE(J) = TE(J) + AM
1510  NEXT J
1520  FOR J = 1 TO 300
1530  IF TE(J) > 0 THEN  GOTO 1550
1540  NEXT J
1550 B = J - 1
```

```
1560  FOR J = 1 TO 300
1565 K = 300 - J + 1
1570  IF TE(K) > 0 THEN  GOTO 1590
1580  NEXT J
1590 E = K + 1
1605  IF (E - B) > 60 THEN  GOSUB 11000
1610 Y(I,2) =  INT (B)
1620 Y(I,3) =  INT (E)
1630 Y(I,4) = (E - B)
1640  FOR J = 1 TO 60
1650 NZ(I,J) = TE(B)
1660  IF B = E GOTO 1690
1670 B = B + 1
1680  NEXT J
1690  NEXT I
1700  REM   WRITE OUT PROCESSED FILE
1702  HOME : PRINT : PRINT : PRINT : PRINT
1704  PRINT "NOW SAVING THE PROCESSED FILE": PRINT : PRINT
"     UNDER THE NAME TEMPFILE"
1710  REM   PROCESSED FILE HAS NAME OF TEMPFILE
1711  REM   Y(I,2) = BEGIN DEPOSIT
1712  REM   Y(I,3) = END   DEPOSIT
1713  REM   Y(I,4) = DEPOSIT SPAN
1720 D$ = ""
1730  PRINT D$;"OPEN TEMPFILE, D2"
1740  PRINT D$;"WRITE TEMPFILE"
1750  PRINT TN
1752  PRINT TA$
1754  PRINT FS$
1756  PRINT GW$
1758  PRINT CW$
1759  PRINT GPM
1760  FOR I = 1 TO TN
1765 Y(I,1) =  INT (Y(I,1) * 3.28084 * 10) / 10
1770  FOR J = 1 TO 4
1780  PRINT Y(I,J)
1790  NEXT J
1800  FOR J = 1 TO 60
1810  PRINT NZ(I,J)
1820  NEXT J
1830  NEXT I
1840  PRINT D$;"CLOSE TEMPFILE"
1845  HOME : PRINT : PRINT : PRINT : PRINT "LOADING NEXT
PROGRAM SEGMENT AND DATA"
1850  REM   END OF THIS SECTION
1860  PRINT D$;"RUN MODEL3,D1"
1870  END
10000  REM   WRITE RAW DATA FILE
10010 D$ = ""
10020  INPUT "INPUT SAVE FILE NAME ";NF$
10030  PRINT D$;"OPEN ";NF$;" RAW,D2"
10040  PRINT D$;"WRITE ";NF$;" RAW"
10041  PRINT TN
10042  PRINT TA$
```

```
10044  PRINT FS$
10046  PRINT GW$
10048  PRINT CW$
10049  PRINT GPM
10050  FOR I = 1 TO TN
10060  FOR J = 1 TO 13
10070  PRINT Y(I,J)
10080  NEXT J
10090  NEXT I
10100  PRINT D$;"CLOSE ";NF$;" RAW"
10110  GOTO 1070
10200  REM    READ RAW DATA FILE
10210 D$ = ""
10212  HOME : PRINT D$;"CATALOG,D2"
10213  PRINT
10220  INPUT "INPUT READ FILE NAME ";NF$
10230  PRINT D$;"OPEN ";NF$;",D2"
10240  PRINT D$;"READ ";NF$
10241  INPUT TN
10242  INPUT TA$
10244  INPUT FS$
10246  INPUT GW$
10248  INPUT CW$
10249  INPUT GPM
10250  FOR I = 1 TO TN
10260  FOR J = 1 TO 13
10270  INPUT Y(I,J)
10280  NEXT J
10290  NEXT I
10300  PRINT D$;"CLOSE ";NF$
10310  GOTO 410
11000  REM    SPAN GREATER THAN 30             FT.
11010  REM   CENTER AND CHOP THE
11020  REM   END MATERIAL
11030 CE =  INT ((E + B) / 2)
11040 B = CE - 30
11045  IF B < 0 THEN B = 0
11050 E = B + 60
11090  RETURN
```

<u>Module Four</u>

```
2  HOME : PRINT : PRINT : PRINT : PRINT "ENTERING MODEL3":
PRINT : PRINT
3 ZC = 50
10  DIM Y(75,5),NZ(75,60),TE(300)
100  REM    READ IN   PROCESSED FILE
110  REM    PROCESSED FILE HAS NAME OF TEMPFILE
120 D$ = ""
130  PRINT D$;"OPEN TEMPFILE, D2"
140  PRINT D$;"READ TEMPFILE"
150  INPUT TN
```

```
152  INPUT TA$
154  INPUT FS$
156  INPUT GW$
158  INPUT CW$
159  INPUT GPM
160  FOR I = 1 TO TN
170  FOR J = 1 TO 4
180  INPUT Y(I,J)
190  NEXT J
200  FOR J = 1 TO 60
210  INPUT NZ(I,J)
220  NEXT J
230  NEXT I
240  PRINT D$;"CLOSE TEMPFILE"
300  HOME : PRINT "WHICH ANALYSIS PROCESS IS DESIRED?"
310  PRINT "1.  INDIVIDUAL CENTROID ANALYSIS"
315 TI = 0
320  PRINT "2.  FULL BOOM NOZZLE PLACEMENT ANALYSIS"
330  PRINT "3.  SPECIFIC BOOM NOZZLE PLACEMENT"
500  INPUT A
510  IF A < 1 OR A > 3 GOTO 300
520  ON A GOTO 1000,2000,2800
1000  REM   INDIVIDUAL CENTROID ANALYSIS
1010  HOME : PRINT "PRINTER MUST BE INSTALLED IN SLOT #1"
1020  PRINT : PRINT : PRINT
1025 SF = 80 / (GPM * .50)
1026  INPUT "PRINT OUT INDIVIDUAL NOZZLE HISTOGRAM? ";A$
1027  INPUT "OUTPUT HARDCOPY? ";ZZ$
1028  IF ZZ$ = "N" THEN  GOTO 1030
1029 D$ = "": PRINT D$;"PR#1"
1030  FOR I = 1 TO TN
1035 T = 0:MO = 0
1036 ARM = Y(I,2)
1040  FOR J = 1 TO 60
1050 T = T + NZ(I,J)
1060 MO = MO + (NZ(I,J) * (ARM + J))
1070  NEXT J
1075  IF T = 0 THEN  GOTO 1090
1080 CENTROID =  INT ((((MO / T) - 150) / 2) * 10) / 10
1090  PRINT "NOZZLE NUMBER = ";I
1100  PRINT "NOZZLE POSITION = ";Y(I,1);" FT"
1110  PRINT "DEPOSITION CENTROID = ";CENTROID;" FT"
1120  PRINT "DEPOSITION SPAN = ";(Y(I,4)) / 2;" FT"
1130  PRINT "% DEPOSITION = ";((T / GPM) * 100);" %"
1131  IF ZZ$ = "Y" THEN  GOTO 1140
1132 SF = 0: IF T = 0 THEN  GOTO 1150
1133  FOR J = 1 TO 60
1134  IF SF < NZ(I,J) THEN SF = NZ(I,J)
1135  NEXT J
1136 SF = 35 / SF
1140  PRINT : PRINT
1141 Z$ = ":": IF A$ = "N" THEN  GOTO 1150
1142  FOR J = 1 TO 60
1144 Z =  INT (NZ(I,J) * SF)
```

```
1146  FOR K = 1 TO Z: IF Z = 0 THEN  GOTO 1148
1147 Z$ = Z$ + "*": NEXT K
1148  PRINT Z$:Z$ = ":"
1149  NEXT J
1150  PRINT "IE": NEXT I
1160  PRINT D$;"PR#0"
1200  GOTO 300
2000  REM   FULL BOOM ANALYSIS
2010  INPUT "INPUT A/C WINGSPAN (FT) ";WS
2020 Z$ = "FULL BOOM ANALYSIS"
2030  PRINT : PRINT "FULL BOOM PATTERN ANALYSIS": PRINT :
PRINT "UNDERWAY---STANDBY": PRINT
2040 LE =  - (WS / 2) * .75
2050 RE =  + (WS / 2) * .75
2060  FOR L = 1 TO TN
2070  IF Y(L,1) > LE GOTO 2090
2080 Y(L,5) = 1
2090  IF Y(L,1) < RE GOTO 2110
2100 Y(L,5) = 1
2110  NEXT L
2120  GOSUB 12000
2130  GOSUB 13000
2140  GOSUB 14000
2150 S1 = SW:A1 = AV:D1 = DV
2160  REM   START NOZZLE ANALYSIS
2170  FOR LL = 1 TO TN
2171 L = TN / 2 + 1 - LL
2172  IF L < 1 THEN  GOTO 2174
2173  GOTO 2176
2174 L = TN / 2 + (LL - TN / 2)
2175  IF L > TN THEN  GOTO 2500
2176  IF Y(L,1) < LE GOTO 2500
2177  IF Y(L,1) > RE GOTO 2500
2180  PRINT : PRINT "WORKING ON NOZZLE ";L: PRINT
2190  IF Y(L,5) = 1 THEN  GOTO 2250
2200  IF Y(L,5) = 0 THEN  GOTO 2220
2210  PRINT "ERROR IN DATA FILE ON NOZZLE ";L: PRINT
2220  REM   TURN NOZZLE OFF
2225 I = L
2230  GOSUB 15000
2240  GOTO 2270
2250  REM   TURN NOZZLE ON
2255 I = L
2260  GOSUB 16000
2270  GOSUB 14000
2272  PRINT SW,S1
2273  PRINT DV,D1
2280  IF SW > S1 THEN  GOTO 2330
2290  IF DV < D1 THEN  GOTO 2330
2295 I = L
2300  IF Y(L,5) = 0 THEN  GOTO 2302
2301  GOTO 2310
2302 I = L
2304  GOSUB 16000
```

```
2310  IF Y(L,5) = 1 THEN  GOTO 2312
2311  GOTO 2320
2312 I = L
2314  GOSUB 15000
2320  GOTO 2500
2330  IF Y(L,5) = 1 THEN  GOTO 2370
2340  IF Y(L,5) = 0 THEN  GOTO 2410
2350  PRINT "ERROR LINE 2320 ON NOZZLE ";L
2360  GOTO 2500
2370 Y(L,5) = 0
2380 I = L
2385  GOSUB 12000
2387 I = L
2390  IF Y(L,5) = 1 THEN  GOTO 2392
2391  GOTO 2400
2392 I = L
2394  GOSUB 15000
2400  GOTO 2420
2410 Y(L,5) = 1
2420  GOSUB 14000
2430 S1 = SW:D1 = DV
2480 L = 1
2490 CT = CT + 1
2500  NEXT LL
2520  GOTO 5000
2530  FOR I = 1 TO 300:TE(I) = 0: NEXT I
2540  GOTO 2130
2800  REM   SPECIFIC NOZZLE LOCATION
2805 Z$ = "SPECIFIC NOZZLE LOCATIONS"
2810  REM   DEPOSITION GENERATOR
2820  HOME : PRINT : PRINT "DEPOSITION PATTERN FROM
SELECTED"
2830  PRINT "NOZZLES WILL NOW BE PREPARED": PRINT
2840  PRINT : PRINT : PRINT "INDICATE WHICH NOZZLES SHOULD
BE TURNED ON"
2850  PRINT : PRINT "THIS IS THE ";TA$;" TEST SERIES":
PRINT
2860  PRINT "A TOTAL OF ";TN;" NOZZLES ARE AVAILABLE IN THE
DATABASE": PRINT
2870  INPUT "WOULD YOU LIKE TO TURN NOZZLES OFF? ";A$
2880  IF A$ = "N" THEN  GOTO 5000
2890  IF A$ <  > "Y" THEN  GOTO 2870
2900  INPUT "INPUT POSITION NUMBER OF NOZZLE TO TURN OFF
";I
2910  PRINT "NOZZLE NUMBER ";I;" NOW TURNED OFF": PRINT :
PRINT
2920 Y(I,5) = 1
2930  INPUT "MORE (Y/N)? ";A$
2940  IF A$ = "N" THEN  GOTO 5000
2950  GOTO 2900
5000  REM   OUTPUT OR MORE ANALYSIS
5005  HOME
5006  INPUT "HARDCOPY OUTPUT? ";A$
5007  IF A$ = "N" THEN  GOTO 5010
```

```
5008  PRINT D$;"PR#1"
5010  PRINT "NOZZLE STATUS": PRINT
5020  PRINT "-----------------------------------------"
5030  PRINT "POSITION  ON/OFF  BEGIN  END  SPAN"
5035  PRINT "  FEET              FT     FT    FT"
5040  PRINT "-----------------------------------------"
5050  FOR I = 1 TO TN
5060 F = Y(I,1):B = (Y(I,2) - 150) / 2:E = (Y(I,3) - 150) /
2:S = Y(I,4) / 2
5070  IF Y(I,5) = 0 THEN ST$ = "ON"
5080  IF Y(I,5) = 1 THEN ST$ = "OFF"
5090  PRINT "  ";F;"    ";ST$;"    ";B;"    ";E;"    ";S
5100  NEXT I
5110  PRINT "-----------------------------------------"
5120  REM   ESTIMATED CALIBRATION
5122  IF S1 = 0 THEN  GOTO 5210
5125 C = 0
5130  FOR I = 1 TO TN
5140  IF Y(I,5) <  > 0 THEN  GOTO 5160
5150 C = C + 1
5160  NEXT I
5170 NU = GPM * C * 43560
5180 DE = S1 * ( VAL (FS$) / 60) * 5280
5190 CAL = NU / DE
5200  PRINT : PRINT "ESTIMATED CALIBRATION = ";CAL
5205  PRINT D$;"PR#0"
5210  REM   MAKE DISTRIBUTION FILE TO SAVE
5215  FOR I = 1 TO 300:TE(I) = 0: NEXT I
5220  FOR I = 1 TO TN
5230  IF Y(I,5) <  > 0 THEN  GOTO 5290
5240 B = Y(I,2)
5250  FOR J = 1 TO 60
5260 TE(B) = TE(B) + NZ(I,J)
5270 B = B + 1
5280  NEXT J
5290  NEXT I
5300  PRINT D$;"OPEN PLOTFILE, D2"
5310  PRINT D$;"WRITE PLOTFILE"
5320  PRINT TN
5330  PRINT TA$
5340  PRINT FS$
5350  PRINT GW$
5360  PRINT CW$
5370  PRINT GPM
5380  FOR I = 1 TO TN
5390  FOR J = 1 TO 5
5400  PRINT Y(I,J)
5410  NEXT J
5420  NEXT I
5430  FOR I = 1 TO 300
5440  PRINT TE(I)
5450  NEXT I
5452  PRINT Z$
5453  FOR I = 1 TO TN
```

```
5454  FOR J = 1 TO 60
5455  PRINT NZ(I,J)
5456  NEXT J
5457  NEXT I
5460  PRINT D$;"CLOSE PLOTFILE"
5470  PRINT D$;"RUN MODEL4,D1"
12000  REM   SUBROUTINE TO TURN OFF NOZZLES
12002  REM   WITH LOW DEPOSITION
12010 T = 0
12030  FOR J = 1 TO 60
12040 T = T + NZ(I,J)
12050  NEXT J
12060  IF ((T / GPM) * 100) > ZC THEN  RETURN
12070 Y(I,5) = 1
12080  RETURN
13000  REM   FORM DEPOSIT MATRIX
13030  FOR I = 1 TO TN
13040  IF Y(I,5) = 1 THEN  GOTO 13100
13050 B = Y(I,2)
13060  FOR J = 1 TO 60
13070 TE(B) = TE(B) + NZ(I,J)
13080 B = B + 1
13090  NEXT J
13100  NEXT I
13110  RETURN
14000  REM   DETERMINE STAT PARAMETERS
14010  FOR I = 1 TO 300
14020  IF TE(I) > TE(I - 1) THEN MAX = TE(I)
14030  NEXT I
14040  FOR I = 1 TO 300
14050  IF TE(I) > MAX / 2 THEN  GOTO 14070
14060  NEXT I
14070 BE = I
14080  FOR K = 1 TO 300
14090 I = 301 - K
14100  IF TE(I) > MAX / 2 THEN  GOTO 14120
14110  NEXT K
14120 EN = I
14130 SW = (EN - BE) / 2
14140  PRINT "SWATH WIDTH = ";SW: PRINT : PRINT
14150 AV = 0:DV = 0
14160  FOR I = BE TO EN
14170 AV = AV + TE(I)
14180  NEXT I
14190 AV = AV / (I - 1)
14200  FOR I = BE TO EN
14210 DV = DV + ((TE(I) - AV) ^ 2)
14220  NEXT I
14230 DV = (DV ^ .5) / AV
14240  RETURN
15000  REM   TURN NOZZLE OFF
15010 C = Y(I,2)
15020  FOR J = 1 TO 60
15030 TE(C) = TE(C) - NZ(I,J)
```

```
15040 C = C + 1
15050  NEXT J
15060  RETURN
16000  REM   TURN NOZZLE ON
16010 C = Y(I,2)
16020  FOR J = 1 TO 60
16030 TE(C) = TE(C) + NZ(I,J)
16040 C = C + 1
16050  NEXT J
16060  RETURN
```

Module Five

```
10  LOMEM: 16384
20  DIM YY(75,5)
40  DIM X(450),Y(450),L(300),A(300)
50  GOSUB 1170
68 T1 = 0:D2 = 0
260  GOSUB 1130
300 TT = 0:C = 0
310  FOR N = 1 TO 300
320 X(N) = L(N)
330 Y(N) = A(N)
335 TT = TT + A(N)
340  NEXT N
342  FOR I = 1 TO TN
344  IF YY(I,5) = 0 THEN C = C + 1
346  NEXT I
348 ED =  INT (((TT / (C * GPM)) * 1000) + .5) / 10
349 S% = 300
350  GOSUB 1770
360  GOSUB 2000
370 SET = 3
380  HCOLOR= SET
390  HPLOT X(1),Y(1)
400  FOR K = 2 TO 300
410  HPLOT  TO X(K),Y(K)
420  NEXT K
430 P% = 150
440 P = P%
450  HCOLOR= 3
460  HPLOT X(P),159 TO X(P),0
470 TM = 0
480  FOR K = 1 TO 14
490 Z = (TM + (K * 10) * 2) / XCV
500  HPLOT Z,0 TO Z,5
510  NEXT K
515  PRINT "ESTIMATED DEPOSITION = ";ED;" %"
520  INPUT "HARDCOPY? (Y/N)";A$
530  IF A$ = "N" THEN  GOTO 610
540 D$ = "": REM   CTRL-D
550 Q$ = "IH": REM    CTRL-IH
```

```
560  PRINT D$;"PR#1"
570  PRINT Z$: PRINT
572  IF ZZ <  > 1 THEN  GOTO 575
573  PRINT "SWATH WIDTH IS NOT UNIFORM AND MAY POSSIBLY
PRODUCE FIELD STREAKS": PRINT : PRINT "SWATH WIDTH = ";PS%
574  GOTO 589
575  IF ZZ <  > 2 THEN  GOTO 579
576  PRINT "PATTERN UNIFORMITY SHOULD BE IMPROVED BEFORE":
PRINT "      SWATH WIDTH DETERMINATION CAN BE MADE"
577  GOTO 589
579  PRINT "SWATH WIDTH = ";PS%
589  PRINT "ESTIMATED DEPOSITION = ";ED;" %": POKE  -
12524,0: REM     INVERSE
590  PRINT Q$
600  PRINT D$;"PR#0"
610  REM   PLOT MULTIPLE PATHS
615  GOSUB 1130
620 SW = PS%
630 P% = 150
640 P = P%
650 SW% = SW * 2
660 OL% = SW%
680 PW% = 300
690 N = 1
700 X(N) = L(N)
710 Y(N) = A(N)
720 N = N + 1
730  IF L(N) >  = OL% THEN  GOTO 750
740  GOTO 700
750 B = 1
760 X(N) = L(N)
770 Y(N) = (A(N) + A(B))
780 B = B + 1
790 N = N + 1
800  IF L(N) >  = PW% THEN  GOTO 820
810  GOTO 760
820 X(N) = (SW% + L(B))
830 Y(N) = A(B)
840 B = B + 1
850 N = N + 1
860  IF (L(B) + SW%) >  = (PW% + SW%) THEN  GOTO 880
870  GOTO 820
880 X(N) = L(B) + SW%
890 Y(N) = A(B)
895 EC = (GPM * C * 5940) / ( VAL (FS$) * PS% * 12)
896 S% = N
900  GOSUB 1770
910  GOSUB 930
920  GOTO 1000
930 SET = 3
940  HCOLOR= SET
950  HPLOT X(1),Y(1)
960  FOR K = 2 TO N
970  HPLOT  TO X(K),Y(K)
```

```
980  NEXT K
990  RETURN
1000  HCOLOR= 3
1010  HPLOT X(P),159 TO X(P),30
1020 C = (L(P) + SW%) / XCV
1030  HPLOT C,159 TO C,30
1035  PRINT "ESTIMATED CALIBRATION = ";EC;" GPA"
1040  INPUT "HARDCOPY ? (Y/N) ";A$
1050  IF A$ = "N" THEN  GOTO 5000
1052 D$ = "": REM     CTRL-D
1054 Q$ = "IH": REM      CTRL-IH
1060  PRINT D$;"PR#1"
1070  PRINT Z$;"  SWATH WIDTH = ";SW
1080  PRINT "ESTIMATED CALIBRATION = ";EC;" GPA": PRINT
1090  POKE - 12524,0: REM   INVERSE
1100  PRINT Q$
1110  PRINT D$;"PR#0"
1120  GOTO 5000
1130  HGR
1140  HCOLOR= 3
1150  HPLOT 0,0 TO 279,0 TO 279,159 TO 0,159 TO 0,0
1160  RETURN
1170 D$ = "": REM   CTRL-D
1190  PRINT D$;"OPEN PLOTFILE, D2"
1200  PRINT D$;"READ PLOTFILE"
1210  INPUT TN
1220  INPUT TA$
1230  INPUT FS$
1240  INPUT GW$
1250  INPUT CW$
1255  INPUT GPM
1256  FOR I = 1 TO TN
1257  FOR J = 1 TO 5
1258  INPUT YY(I,J)
1259  NEXT J
1268  NEXT I
1269  FOR J = 1 TO 300
1270 L(J) = J
1280  INPUT A(J)
1290  NEXT J
1295  INPUT Z$
1300  PRINT D$;"CLOSE PLOTFILE"
1310  RETURN
1770 AMAX = 0:LMAX = 0
1780  FOR I = 1 TO S%
1790  IF AMAX < Y(I) THEN AMAX = Y(I)
1800  IF LMAX < X(I) THEN LMAX = X(I)
1810  NEXT I
1820 XCV = LMAX / 279
1830 YCV = AMAX / 120
1840  FOR I = 1 TO S%
1850 Y(I) = 159 - Y(I) / YCV
1860 X(I) = X(I) / XCV
1870  NEXT I
```

```
1880  RETURN
2000  REM   SWATH WIDTH DETERMINATION
2005 ZZ = 0
2010 LOW = AMAX / 2
2020  FOR I = 1 TO 300
2030  IF A(I) < LOW THEN  NEXT I
2040 P1 = L(I)
2050  FOR J = 1 TO 300
2051 I = 301 - J
2060  IF A(I) < LOW THEN  NEXT J
2070 P2 = L(I)
2080 PS% = (P2 - P1) / 2
2090  IF PS% < 35 THEN  GOTO 2120
2091  FOR I = P1 TO P2
2092  IF A(I) < LOW THEN  GOTO 2095
2093  NEXT I
2094  GOTO 2100
2095  PRINT "DEPOSITION IS NOT UNIFORM AND MAY": PRINT
"PRODUCE POSSIBLE FIELD STREAKS":ZZ = 1
2096  PRINT "SWATH WIDTH = ";PS%;" FEET"
2097  RETURN
2100  PRINT "SWATH WIDTH =  ";PS%;" FEET"
2110  RETURN
2120  PRINT "PATTERN SHOULD BE IMPROVED BEFORE": PRINT
"SWATH WIDTH DETERMINATION CAN BE MADE":ZZ = 2
2130  RETURN
5000  TEXT
5005  HOME : PRINT : PRINT : PRINT "WOULD YOU LIKE TO TRY
ANOTHER NOZZLE"
5010  INPUT "   SET-UP OR STOP (A/S)?";A$
5020  IF A$ = "A" THEN  GOTO 5050
5030  IF A$ <  > "S" THEN  GOTO 5000
5040  PRINT "END SIMULATION": END
5050  HOME : PRINT : PRINT : PRINT : PRINT "     LOADING
MODEL PART THREE"
5060  PRINT  CHR$ (4);"RUN MODEL3,D1"
```

APPENDIX B

SIMULATION CODE FOR GROUND TO AIRCRAFT ALGORITHM

Module One

```
1  REM  REGRESSION MODEL 1
35  DIM Y(75,5),NZ(75,60),TE(300)
36 ZS = 25
40  PRINT " DO YOU WISH TO READ AN EXISTING": INPUT "RAW
DATA FILE? ";A$
42  IF A$ = "Y" THEN  GOTO 10200
50  IF A$ <  > "N" THEN  GOTO 40
100  INPUT "INPUT THE TYPE AIRCRAFT ";TA$
105  INPUT "INPUT AIRCRAFT WINGSPAN (FT) ";WS
110  INPUT "INPUT THE FLIGHT SPEED ";FS$
120  INPUT "INPUT THE GROSS WEIGHT ";GW$
130  INPUT "INPUT THE SPRAY HEIGHT ";SH$
140  INPUT "INPUT THE CROSSWIND CONDITIONS ";CW$
150  INPUT "INPUT THE NOZZLE FLOW RATE (GPM) ";GPM
160  INPUT "INPUT THE NUMBER OF TESTED NOZZLES ";TN
170  INPUT "AUTOMATIC OR MANUAL NOZZLE POSITIONING A/M?
";A$
180  IF A$ = "M" THEN  GOTO 240
185  PRINT : PRINT "BEGIN AT THE LEFTMOST POSITION": PRINT
" (- POSITION)": PRINT
190  INPUT "INPUT INITIAL NOZZLE POSITION ";IP: INPUT
"INPUT NOZZLE SPACING ";NS
200 Y(1,1) = IP
210  FOR I = 2 TO TN
220 Y(I,1) = Y(I - 1,1) + NS
230  NEXT I
235  GOTO 395
240  FOR I = 1 TO TN
250  PRINT "INPUT THE ";I;" NOZZLE POSITION ": INPUT Y(I,1)
260  NEXT I
395  HOME
410  REM   CHANGE SECTION
420  HOME : PRINT "***** INPUT VALUES *****"
422  PRINT "TOTAL NUMBER NOZZLES IN DATA = ";TN
425  INPUT "IS RAW DATA CHECKING DESIRED? ";A$
426  IF A$ = "N" THEN  GOTO 1050
```

```
427  IF A$ < > "Y" THEN GOTO 425
430  PRINT : PRINT "CHECK FOR CORRECT VALUES"
435  PRINT
440  PRINT "AIRCRAFT TYPE = ";TA$
445  PRINT "WINGSPAN = ";WS;" FT."
450  PRINT "FLIGHT SPEED = ";FS$;" MPH"
460  PRINT "GROSS WEIGHT = ";GW$
470  PRINT "CROSSWIND CONDITIONS OF ";CW$
475  PRINT "THE NOZZLE FLOW RATE (GPM) = ";GPM
476  PRINT
480  INPUT "ARE THESE VALUES CORRECT? ";A$
490  IF A$ = "Y" THEN GOTO 600
495  IF A$ = "N" THEN GOTO 500
497  GOTO 480
500  PRINT "WHICH OF THE FOLLOWING IS INCORRECT? "
510  PRINT : PRINT "TYPE AIRCRAFT (TA)": PRINT "AIRCRAFT
WINGSPAN (WS)": PRINT "FLIGHT SPEED (FS)": PRINT "GROSS
WEIGHT (GW)": PRINT "CROSSWIND CONDITIONS (CW)"
515  PRINT "NOZZLE FLOW RATE (GPM)": PRINT
520  INPUT A$
530  IF A$ < > "TA" THEN GOTO 540
535  INPUT "INPUT CORRECT TYPE AIRCRAFT ";TA$
540  IF A$ < > "FS" THEN GOTO 547
545  INPUT "INPUT CORRECT FLIGHT SPEED ";FS$
547  IF A$ < > "WS" THEN GOTO 550
548  INPUT "INPUT CORRECT AIRCRAFT WINGSPAN ";WS
550  IF A$ < > "GW" THEN GOTO 560
555  INPUT "INPUT CORRECT GROSS WEIGHT ";GW$
560  IF A$ < > "CW" THEN GOTO 567
565  INPUT "INPUT CORRECT CROSSWIND CONDITIONS ";CW$
567  IF A$ < > "GPM" THEN GOTO 580
570  INPUT "INPUT CORRECT NOZZLE FLOW RATE ";GPM
580  GOTO 430
600  HOME : PRINT "CHECK EACH NOZZLE POSITION": PRINT :
PRINT "FOR CORRECT VALUES"
610  FOR I = 1 TO TN
620  PRINT "NOZZLE POSITION ";I;" = ";Y(I,1): PRINT
630  PRINT "CORRECT? "
640  GET A$
650  IF A$ = "N" THEN GOTO 670
660  NEXT I
665  GOTO 690
670  INPUT "INPUT THE CORRECT VALUE ";Y(I,1)
680  GOTO 620
690  REM  CONTINUE
1050  INPUT "DO YOU WISH TO SAVE THE RAW DATA FILE? ";A$
1060  IF A$ = "Y" THEN GOTO 10000
1070  REM   PROCESS RAW DATA
1080  HOME : PRINT "THE DATA IS NOW BEING TRANSFORMED":
PRINT "INTO A DEPOSITION MATRIX"
1090  FOR I = 1 TO TN
1092  PRINT "WORKING ON NOZZLE NUMBER ";I
1095  FOR J = 1 TO 300:TE(J) = 0: NEXT J
1110 CY = 20.06 + 2.10 * Y(I,1) + .0017 *  VAL (GW$) + 2.56
```

```
* VAL (CR$) + .297 * VAL (SH$) - .337 * VAL (FS$)
1113 IF Y(I,1) > ((WS * .30) / 2) THEN GOTO 1120
1114 IF Y(I,1) < - ((WS * .30) / 2) THEN GOTO 1120
1115 CZ = - 4.4 - 2.0 * Y(I,1) + .38 * Y(I,1) ^ 2 + .15 *
Y(I,1) ^ 3 - .0075 * Y(I,1) ^ 4 - .0024 * Y(I,1) ^ 5 -
.0000033 * Y(I,1) ^ 6
1116 CY = CY + CZ
1120 Y(I,2) = (CY * 2) + 125
1130 Y(I,3) = Y(I,2) + 50
1140 Y(I,4) = 50
1150 IC = 51 / 27
1155 NZ(I,1) = 0
1160  FOR J = 2 TO 49
1170  IF J = 26 THEN IC = - IC
1180 NZ(I,J) = NZ(I,J - 1) + IC
1185  IF NZ(I,J) < 0 THEN NZ(I,J) = 0
1190  NEXT J
1200 NZ(I,50) = 0
1690  NEXT I
1700  REM  WRITE OUT PROCESSED FILE
1702  HOME : PRINT : PRINT : PRINT : PRINT
1704  PRINT "NOW SAVING THE PROCESSED FILE": PRINT : PRINT
"     UNDER THE NAME TEMPFILE"
1710  REM  PROCESSED FILE HAS NAME OF TEMPFILE
1711  REM  Y(I,2) = BEGIN DEPOSIT
1712  REM  Y(I,3) = END  DEPOSIT
1713  REM  Y(I,4) = DEPOSIT SPAN
1720 D$ = ""
1730  PRINT D$;"OPEN RGTEMP,D2"
1740  PRINT D$;"WRITE RGTEMP"
1750  PRINT TN
1751  PRINT WS
1752  PRINT TA$
1754  PRINT FS$
1756  PRINT GW$
1758  PRINT CW$
1759  PRINT GPM
1760  FOR I = 1 TO TN
1770  FOR J = 1 TO 4
1780  PRINT Y(I,J)
1790  NEXT J
1800  FOR J = 1 TO 50
1810  PRINT NZ(I,J)
1820  NEXT J
1830  NEXT I
1840  PRINT D$;"CLOSE RGTEMP"
1845  HOME : PRINT : PRINT : PRINT : PRINT "LOADING NEXT
PROGRAM SEGMENT AND DATA"
1850  REM  END OF THIS SECTION
1860  PRINT D$;"RUN REGRESS2,D1"
1870  END
10000  REM  WRITE RAW DATA FILE
10010 D$ = ""
10020  INPUT "INPUT SAVE FILE NAME ";NF$
```

```
10030  PRINT D$;"OPEN ";NF$;" RGRAW,D2"
10040  PRINT D$;"WRITE ";NF$;" RGRAW"
10041  PRINT TN
10042  PRINT WS
10043  PRINT TA$
10044  PRINT FS$
10045  PRINT GW$
10050  PRINT CW$
10055  PRINT GPM
10060  FOR I = 1 TO TN
10070  PRINT Y(I,1)
10090  NEXT I
10100  PRINT D$;"CLOSE ";NF$;" RGRAW"
10110  GOTO 1070
10200  REM    READ RAW DATA FILE
10210 D$ = ""
10212  HOME : PRINT D$;"CATALOG,D2"
10213  PRINT
10220  INPUT "INPUT READ FILE NAME ";NF$
10230  PRINT D$;"OPEN ";NF$;",D2"
10240  PRINT D$;"READ ";NF$
10241  INPUT TN
10242  INPUT WS
10243  INPUT TA$
10244  INPUT FS$
10246  INPUT GW$
10248  INPUT CW$
10249  INPUT GPM
10250  FOR I = 1 TO TN
10270  INPUT Y(I,1)
10290  NEXT I
10300  PRINT D$;"CLOSE ";NF$
10310  GOTO 410
```

Module Two

```
1  REM    REGRESS SECTION 2
2  HOME : PRINT : PRINT : PRINT : PRINT "ENTERING SECTION
2": PRINT : PRINT
3 ZC = 50
10  DIM Y(75,5),NZ(75,60),TE(300)
100  REM    READ IN   PROCESSED FILE
110  REM    PROCESSED FILE HAS NAME OF TEMPFILE
120 D$ = ""
130  PRINT D$;"OPEN RGTEMP,D2"
140  PRINT D$;"READ RGTEMP"
150  INPUT TN
151  INPUT WS
152  INPUT TA$
154  INPUT FS$
156  INPUT GW$
158  INPUT CW$
```

```
159  INPUT GPM
160  FOR I = 1 TO TN
170  FOR J = 1 TO 4
180  INPUT Y(I,J)
190  NEXT J
200  FOR J = 1 TO 50
210  INPUT NZ(I,J)
220  NEXT J
230  NEXT I
240  PRINT D$;"CLOSE RGTEMP"
300  HOME : PRINT "WHICH ANALYSIS PROCESS IS DESIRED?"
310  PRINT "1.  INDIVIDUAL CENTROID ANALYSIS"
315 TI = 0
320  PRINT "2.  FULL BOOM NOZZLE PLACEMENT ANALYSIS"
330  PRINT "3.  SPECIFIC BOOM NOZZLE PLACEMENT"
500  INPUT A
510  IF A < 1 OR A > 3 GOTO 300
520  ON A GOTO 1000,2000,2800
1000  REM   INDIVIDUAL CENTROID ANALYSIS
1010  HOME : PRINT "PRINTER MUST BE INSTALLED IN SLOT #1"
1020  PRINT : PRINT : PRINT
1025 SF = 80 / (GPM * .50)
1026  INPUT "PRINT OUT INDIVIDUAL NOZZLE HISTOGRAM? ";A$
1027  INPUT "OUTPUT HARDCOPY? ";ZZ$
1028  IF ZZ$ = "N" THEN  GOTO 1030
1029 D$ = "": PRINT D$;"PR#1"
1030  FOR I = 1 TO TN
1035 T = 0:MO = 0
1036 ARM = Y(I,2)
1040  FOR J = 1 TO 50
1050 T = T + NZ(I,J)
1060 MO = MO + (NZ(I,J) * (ARM + J))
1070  NEXT J
1075  IF T = 0 THEN  GOTO 1090
1080 CENTROID =  INT ((((MO / T) - 150) / 2) * 10) / 10
1090  PRINT "NOZZLE NUMBER = ";I
1100  PRINT "NOZZLE POSITION = ";Y(I,1);" FT"
1110  PRINT "DEPOSITION CENTROID = ";CENTROID;" FT"
1120  PRINT "DEPOSITION SPAN = ";(Y(I,4)) / 2;" FT"
1131  IF ZZ$ = "Y" THEN  GOTO 1140
1132 SF = 0: IF T = 0 THEN  GOTO 1150
1133  FOR J = 1 TO 50
1134  IF SF < NZ(I,J) THEN SF = NZ(I,J)
1135  NEXT J
1136 SF = 35 / SF
1140  PRINT : PRINT
1141 Z$ = ":": IF A$ = "N" THEN  GOTO 1150
1142  FOR J = 1 TO 50
1144 Z =  INT (NZ(I,J) * SF)
1146  FOR K = 1 TO Z: IF Z = 0 THEN  GOTO 1148
1147 Z$ = Z$ + "*": NEXT K
1148  PRINT Z$:Z$ = ":"
1149  NEXT J
1150  PRINT "IE": NEXT I
```

```
1160  PRINT D$;"PR#0"
1200  GOTO 300
2000  REM   FULL BOOM ANALYSIS
2020 Z$ = "FULL BOOM ANALYSIS"
2030  PRINT : PRINT "FULL BOOM PATTERN ANALYSIS": PRINT :
PRINT "UNDERWAY---STANDBY": PRINT
2040 LE =  - (WS / 2) * .75
2050 RE =  + (WS / 2) * .75
2060  FOR L = 1 TO TN
2070  IF Y(L,1) > LE GOTO 2090
2080 Y(L,5) = 1
2090  IF Y(L,1) < RE GOTO 2110
2100 Y(L,5) = 1
2110  NEXT L
2130  GOSUB 13000
2140  GOSUB 14000
2150 S1 = SW:A1 = AV:D1 = DV
2160  REM   START NOZZLE ANALYSIS
2170  FOR LL = 1 TO TN
2171 L =  INT (TN / 2 + 1 - LL)
2172  IF L < 1 THEN  GOTO 2174
2173  GOTO 2176
2174 L = TN / 2 + (LL - TN / 2)
2175  IF L > TN THEN  GOTO 2500
2176  IF Y(L,1) < LE GOTO 2500
2177  IF Y(L,1) > RE GOTO 2500
2180  PRINT : PRINT "WORKING ON NOZZLE ";L: PRINT
2190  IF Y(L,5) = 1 THEN  GOTO 2250
2200  IF Y(L,5) = 0 THEN  GOTO 2220
2210  PRINT "ERROR IN DATA FILE ON NOZZLE ";L: PRINT
2220  REM   TURN NOZZLE OFF
2225 I = L
2230  GOSUB 15000
2240  GOTO 2270
2250  REM   TURN NOZZLE ON
2255 I = L
2260  GOSUB 16000
2270  GOSUB 14000
2272  PRINT SW,S1
2273  PRINT DV,D1
2290  IF DV < D1 THEN  GOTO 2330
2295 I = L
2300  IF Y(L,5) = 0 THEN  GOTO 2302
2301  GOTO 2310
2302 I = L
2304  GOSUB 16000
2310  IF Y(L,5) = 1 THEN  GOTO 2312
2311  GOTO 2320
2312 I = L
2314  GOSUB 15000
2320  GOTO 2500
2330  IF Y(L,5) = 1 THEN  GOTO 2370
2340  IF Y(L,5) = 0 THEN  GOTO 2410
2350  PRINT "ERROR LINE 2320 ON NOZZLE ";L
```

```
2360  GOTO 2500
2370 Y(L,5) = 0
2380 I = L
2387 I = L
2390  IF Y(L,5) = 1 THEN  GOTO 2392
2391  GOTO 2400
2392 I = L
2394  GOSUB 15000
2400  GOTO 2420
2410 Y(L,5) = 1
2420  GOSUB 14000
2430 S1 = SW:D1 = DV
2480 L = 1
2490 CT = CT + 1
2500  NEXT LL
2520  GOTO 5000
2530  FOR I = 1 TO 300:TE(I) = 0: NEXT I
2540  GOTO 2130
2800  REM   SPECIFIC NOZZLE LOCATION
2805 Z$ = "SPECIFIC NOZZLE LOCATIONS"
2810  REM   DEPOSITION GENERATOR
2820  HOME : PRINT : PRINT "DEPOSITION PATTERN FROM
SELECTED"
2830  PRINT "NOZZLES WILL NOW BE PREPARED": PRINT
2840  PRINT : PRINT : PRINT "INDICATE WHICH NOZZLES SHOULD
BE TURNED ON"
2850  PRINT : PRINT "THIS IS THE ";TA$;" TEST SERIES":
PRINT
2860  PRINT "A TOTAL OF ";TN;" NOZZLES ARE AVAILABLE IN THE
DATABASE": PRINT
2870  INPUT "WOULD YOU LIKE TO TURN NOZZLES OFF? ";A$
2880  IF A$ = "N" THEN  GOTO 5000
2890  IF A$ <  > "Y" THEN  GOTO 2870
2900  INPUT "INPUT POSITION NUMBER OF NOZZLE TO TURN OFF
";I
2910  PRINT "NOZZLE NUMBER ";I;" NOW TURNED OFF": PRINT :
PRINT
2920 Y(I,5) = 1
2930  INPUT "MORE (Y/N)? ";A$
2940  IF A$ = "N" THEN  GOTO 5000
2950  GOTO 2900
5000  REM   OUTPUT OR MORE ANALYSIS
5005  HOME
5006  INPUT "HARDCOPY OUTPUT? ";A$
5007  IF A$ = "N" THEN  GOTO 5010
5008  PRINT D$;"PR#1"
5010  PRINT "NOZZLE STATUS": PRINT
5020  PRINT "----------------------------------------"
5030  PRINT "POSITION  ON/OFF  BEGIN  END  SPAN"
5035  PRINT "  FEET              FT     FT    FT"
5040  PRINT "----------------------------------------"
5050  FOR I = 1 TO TN
5060 F = Y(I,1):B = (Y(I,2) - 150) / 2:E = (Y(I,3) - 150) /
2:S = Y(I,4) / 2
```

```
5070  IF Y(I,5) = 0 THEN ST$ = "ON"
5080  IF Y(I,5) = 1 THEN ST$ = "OFF"
5090  PRINT "  ";F;"    ";ST$;"    ";B;"    ";E;"    ";S
5100  NEXT I
5110  PRINT "----------------------------------------"
5120  REM   ESTIMATED CALIBRATION
5122  IF S1 = 0 THEN  GOTO 5210
5125 C = 0
5130  FOR I = 1 TO TN
5140  IF Y(I,5) <  > 0 THEN  GOTO 5160
5150 C = C + 1
5160  NEXT I
5170 NU = GPM * C * 43560
5180 DE = S1 * ( VAL (FS$) / 60) * 5280
5190 CAL = NU / DE
5200  PRINT : PRINT "ESTIMATED CALIBRATION = ";CAL
5205  PRINT D$;"PR#0"
5210  REM   MAKE DISTRIBUTION FILE TO SAVE
5215  FOR I = 1 TO 300:TE(I) = 0: NEXT I
5220  FOR I = 1 TO TN
5230  IF Y(I,5) <  > 0 THEN  GOTO 5290
5240 B = Y(I,2)
5250  FOR J = 1 TO 50
5260 TE(B) = TE(B) + NZ(I,J)
5270 B = B + 1
5280  NEXT J
5290  NEXT I
5300  PRINT D$;"OPEN PLOTFILE, D2"
5310  PRINT D$;"WRITE PLOTFILE"
5320  PRINT TN
5330  PRINT TA$
5340  PRINT FS$
5350  PRINT GW$
5360  PRINT CW$
5370  PRINT GPM
5380  FOR I = 1 TO TN
5390  FOR J = 1 TO 5
5400  PRINT Y(I,J)
5410  NEXT J
5420  NEXT I
5430  FOR I = 1 TO 300
5440  PRINT TE(I)
5450  NEXT I
5452  PRINT Z$
5453  FOR I = 1 TO TN
5454  FOR J = 1 TO 60
5455  PRINT NZ(I,J)
5456  NEXT J
5457  NEXT I
5460  PRINT D$;"CLOSE PLOTFILE"
5470  PRINT D$;"RUN REGRESS3,D1"
13000  REM   FORM DEPOSIT MATRIX
13030  FOR I = 1 TO TN
13040  IF Y(I,5) = 1 THEN  GOTO 13100
```

```
13050 B = Y(I,2)
13060  FOR J = 1 TO 50
13070 TE(B) = TE(B) + NZ(I,J)
13080 B = B + 1
13090  NEXT J
13100  NEXT I
13110  RETURN
14000  REM   DETERMINE STAT PARAMETERS
14010  FOR I = 1 TO 300
14020  IF TE(I) > TE(I - 1) THEN MAX = TE(I)
14030  NEXT I
14040  FOR I = 1 TO 300
14050  IF TE(I) > MAX / 2 THEN  GOTO 14070
14060  NEXT I
14070 BE = I
14080  FOR K = 1 TO 300
14090 I = 301 - K
14100  IF TE(I) > MAX / 2 THEN  GOTO 14120
14110  NEXT K
14120 EN = I
14130 SW = (EN - BE) / 2
14140  PRINT "SWATH WIDTH = ";SW: PRINT : PRINT
14150 AV = 0:DV = 0
14160  FOR I = BE TO EN
14170 AV = AV + TE(I)
14180  NEXT I
14190 AV = AV / (I - 1)
14200  FOR I = BE TO EN
14210 DV = DV + ((TE(I) - AV) ^ 2)
14220  NEXT I
14230 DV = (DV ^ .5) / AV
14240  RETURN
15000  REM   TURN NOZZLE OFF
15010 C = Y(I,2)
15020  FOR J = 1 TO 50
15030 TE(C) = TE(C) - NZ(I,J)
15040 C = C + 1
15050  NEXT J
15060  RETURN
16000  REM   TURN NOZZLE ON
16010 C = Y(I,2)
16020  FOR J = 1 TO 50
16030 TE(C) = TE(C) + NZ(I,J)
16040 C = C + 1
16050  NEXT J
16060  RETURN
```

<u>Module Three</u>

```
1  REM    REGRESS 3
10  LOMEM: 16384
20  DIM YY(75,5)
```

```
40  DIM X(550),Y(550),L(300),A(300)
50  GOSUB 1170
68 T1 = 0:D2 = 0
260  GOSUB 1130
300 TT = 0:C = 0
310  FOR N = 1 TO 300
320 X(N) = L(N)
330 Y(N) = A(N)
340  NEXT N
342  FOR I = 1 TO TN
344  IF YY(I,5) = 0 THEN C = C + 1
346  NEXT I
349 S% = 300
350  GOSUB 1770
360  GOSUB 2000
370 SET = 3
380  HCOLOR= SET
390  HPLOT X(1),Y(1)
400  FOR K = 2 TO 300
410  HPLOT  TO X(K),Y(K)
420  NEXT K
430 P% = 150
440 P = P%
450  HCOLOR= 3
460  HPLOT X(P),159 TO X(P),0
470 TM = 0
480  FOR K = 1 TO 14
490 Z = (TM + (K * 10) * 2) / XCV
500  HPLOT Z,0 TO Z,5
510  NEXT K
520  INPUT "HARDCOPY? (Y/N)";A$
530  IF A$ = "N" THEN  GOTO 610
540 D$ = "": REM   CTRL-D
550 Q$ = "IH": REM    CTRL-IH
560  PRINT D$;"PR#1"
570  PRINT Z$: PRINT
572  IF ZZ <  > 1 THEN  GOTO 575
573  PRINT "SWATH WIDTH IS NOT UNIFORM AND MAY POSSIBLY
PRODUCE FIELD STREAKS": PRINT : PRINT "SWATH WIDTH = ";PS%
574  GOTO 589
575  IF ZZ <  > 2 THEN  GOTO 579
576  PRINT "PATTERN UNIFORMITY SHOULD BE IMPROVED BEFORE":
PRINT "      SWATH WIDTH DETERMINATION CAN BE MADE"
577  GOTO 589
579  PRINT "SWATH WIDTH = ";PS%
589  POKE  - 12524,0: REM      INVERSE
590  PRINT Q$
600  PRINT D$;"PR#0"
610  REM   PLOT MULTIPLE PATHS
615  GOSUB 1130
620 SW = PS%
630 P% = 150
640 P = P%
650 SW% = SW * 2
```

```
660 OL% = SW%
680 PW% = 300
690 N = 1
700 X(N) = L(N)
710 Y(N) = A(N)
720 N = N + 1
730  IF L(N) >  = OL% THEN  GOTO 750
740  GOTO 700
750 B = 1
760 X(N) = L(N)
770 Y(N) = (A(N) + A(B))
780 B = B + 1
790 N = N + 1
800  IF L(N) >  = PW% THEN  GOTO 820
810  GOTO 760
820 X(N) = (SW% + L(B))
830 Y(N) = A(B)
840 B = B + 1
850 N = N + 1
860  IF (L(B) + SW%) >  = (PW% + SW%) THEN  GOTO 880
870  GOTO 820
880 X(N) = L(B) + SW%
890 Y(N) = A(B)
895 EC = (GPM * C * 5940) / ( VAL (FS$) * PS% * 12)
896 S% = N
900  GOSUB 1770
910  GOSUB 930
920  GOTO 1000
930 SET = 3
940  HCOLOR= SET
950  HPLOT X(1),Y(1)
960  FOR K = 2 TO N
970  HPLOT  TO X(K),Y(K)
980  NEXT K
990  RETURN
1000  HCOLOR= 3
1010  HPLOT X(P),159 TO X(P),30
1020 C = (L(P) + SW%) / XCV
1030  HPLOT C,159 TO C,30
1035  PRINT "ESTIMATED CALIBRATION = ";EC;" GPA"
1040  INPUT "HARDCOPY ? (Y/N) ";A$
1050  IF A$ = "N" THEN  GOTO 5000
1052 D$ = "": REM     CTRL-D
1054 Q$ = "IH": REM      CTRL-IH
1060  PRINT D$;"PR#1"
1070  PRINT Z$;"  SWATH WIDTH = ";SW
1080  PRINT "ESTIMATED CALIBRATION = ";EC;" GPA": PRINT
1090  POKE  - 12524,0: REM   INVERSE
1100  PRINT Q$
1110  PRINT D$;"PR#0"
1120  GOTO 5000
1130  HGR
1140  HCOLOR= 3
1150  HPLOT 0,0 TO 279,0 TO 279,159 TO 0,159 TO 0,0
```

```
1160  RETURN
1170 D$ = "": REM   CTRL-D
1190  PRINT D$;"OPEN PLOTFILE, D2"
1200  PRINT D$;"READ PLOTFILE"
1210  INPUT TN
1220  INPUT TA$
1230  INPUT FS$
1240  INPUT GW$
1250  INPUT CW$
1255  INPUT GPM
1256  FOR I = 1 TO TN
1257  FOR J = 1 TO 5
1258  INPUT YY(I,J)
1259  NEXT J
1268  NEXT I
1269  FOR J = 1 TO 300
1270 L(J) = J
1280  INPUT A(J)
1290  NEXT J
1295  INPUT Z$
1300  PRINT D$;"CLOSE PLOTFILE"
1310  RETURN
1770 AMAX = 0:LMAX = 0
1780  FOR I = 1 TO S%
1790  IF AMAX < Y(I) THEN AMAX = Y(I)
1800  IF LMAX < X(I) THEN LMAX = X(I)
1810  NEXT I
1820 XCV = LMAX / 279
1830 YCV = AMAX / 120
1840  FOR I = 1 TO S%
1850 Y(I) = 159 - Y(I) / YCV
1860 X(I) = X(I) / XCV
1870  NEXT I
1880  RETURN
2000  REM   SWATH WIDTH DETERMINATION
2005 ZZ = 0
2010 LOW = AMAX / 2
2020  FOR I = 1 TO 300
2030  IF A(I) < LOW THEN  NEXT I
2040 P1 = L(I)
2050  FOR J = 1 TO 300
2051 I = 301 - J
2060  IF A(I) < LOW THEN  NEXT J
2070 P2 = L(I)
2080 PS% = (P2 - P1) / 2
2090  IF PS% < 35 THEN  GOTO 2120
2091  FOR I = P1 TO P2
2092  IF A(I) < LOW THEN  GOTO 2095
2093  NEXT I
2094  GOTO 2100
2095  PRINT "DEPOSITION IS NOT UNIFORM AND MAY": PRINT
"PRODUCE POSSIBLE FIELD STREAKS":ZZ = 1
2096  PRINT "SWATH WIDTH = ";PS%;" FEET"
2097  RETURN
```

```
2100  PRINT "SWATH WIDTH =  ";PS%;" FEET"
2110  RETURN
2120  PRINT "PATTERN SHOULD BE IMPROVED BEFORE": PRINT
"SWATH WIDTH DETERMINATION CAN BE MADE":ZZ = 2
2130  RETURN
5000  TEXT
5005  HOME : PRINT : PRINT : PRINT "WOULD YOU LIKE TO TRY
ANOTHER NOZZLE"
5010  INPUT "   SET-UP OR STOP (A/S)?";A$
5020  IF A$ = "A" THEN  GOTO 5050
5030  IF A$ <  > "S" THEN  GOTO 5000
5040  PRINT "END SIMULATION": END
5050  HOME : PRINT : PRINT : PRINT : PRINT "     LOADING
MODEL PART THREE"
5060  PRINT  CHR$ (4);"RUN REGRESS2,D1"
```

VITA 2

Dennis K. Kuhlman

Candidate for the Degree of

Doctor of Philosophy

Thesis: UNIFORM AERIAL APPLICATION USING COMPUTER SIMULATION

Major Field: Agricultural Engineering

Biographical:

Personal Data: Born in Garden City, Kansas, November 20, 1948, the son of Erwin R. and Vera A. Kuhlman. Married to Carol A. Singer on July 8, 1972.

Education: Graduated from Lakin Rural High School, Lakin, Kansas, in May 1966; received Associate of Science degree from Garden City Junior College in May, 1968; received Bachelor of Science degree in Agricultural Engineering from Kansas State University in December 1970; received Master of Science degree in Agricultural Engineering from Kansas State University in May 1975; completed the requirements for the Doctor of Philosophy degree at Oklahoma State University in July, 1985.

Professional Experience: Garden City Branch Agricultural Experiment Station, Garden City, Kansas, May, 1967 to August, 1968; Graduate Research Assistant, Department Agricultural Engineering, Kansas State University, January, 1971 to October, 1971 and August 1975, to December, 1975; United States Navy, October, 1971 to August, 1975; Research Assistant, Department Agricultural Engineering, Kansas State University, January, 1976 to September, 1977; Assistant Professor and Associate Professor, Department Agricultural Engineering, Kansas State

University, September, 1977 to present.

Professional Organizations: Member of American Society of Agricultural Engineers; Sigma Xi; Epsilon Sigma Phi; Gamma Sigma Delta; Alpha Epsilon; Kansas Registered Professional Engineer 9033.