Pneumatic Lifting of Pine Seeds from a Horizontal Surface

by

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ABSTRACT

Pneumatic Lifting of Pine Seeds from
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Information was obtained to aid the development of a pneumatic pine seed harvester. Methods from related research were used to determine the characteristics of slash pine seeds:

Mass	0.63 g
Frontal area	26.0 mm^2
Terminal velocity	7.9 m/s
Coefficient of drag	0.63

The minimum air stream velocity for conveying the seeds horizontally was calculated as being 5.5 meters per second. A mathematical model was developed to simulate the movement of a seed in air. The model was applied to the movement of a seed through the transition from horizontal to upward movement during lifting. The results of the simulation showed that the seed's elevation in the air stream when entering the transition region is more important to lifting than the air velocity in the transition region and that the air flow leaving the transition region should be kept as near horizontal as possible.

ACKNOWLEDGEMENTS

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The author appreciated the assistance of Dr. J. P. van Buijtenen (Professor of Forest Science) and Ms. Mary K. Meyer in obtaining the pine seeds used in this research.

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LIST OF SYMBOLS

A	Projected frontal area as presented to flow
C	Coefficient of total aerodynamic drag
d	Distance from the ground to center point of fluid particle paths
D	Average of a seed's three major dimensions
D_1	Length of seed
D_2	Width of seed
D_3	Height of seed
F	Total force due to aerodynamic drag
F_y	Vertical force due to drag
g	Acceleration of gravity
H	Thickness of horizontal air stream
m	Mass of a particle or seed
P	Barometric pressure (mmHg)
R	Reynolds number for horizontal air stream
Re	Reynolds number for a seed
$\dot{s}$	Particle velocity
$\ddot{s}$	Particle acceleration
T	Ambient temperature (Kelvin)
u	Air velocity
U	Mean velocity of horizontal air stream
U_o	Friction velocity of a seed
V	Total velocity of a seed
V_r	Velocity of air relative to seed
V_{ry}	Vertical component of V_r
V_t	Terminal velocity of a seed

LIST OF SYMBOLS (continued)

w	Weight of seed
x	Horizontal position of seed
$\dot{x}$	Horizontal velocity of seed
$\ddot{x}$	Horizontal acceleration of seed
y	Vertical position of seed
$\dot{y}$	Vertical velocity of seed
$\ddot{y}$	Vertical acceleration of seed
α	Angle made by radial line and the vertical
θ	Angle between the direction of the instantaneous air velocity and the horizontal
μ	Viscosity of air
ρ	Density of air
ρ_o	Density of seed

LIST OF EQUATIONS

$$\ddot{s} = \frac{CA\rho}{2m}(u-\dot{s})^2 \qquad (1)$$

$$Re = \frac{DV_t\rho}{\mu} \qquad (2)$$

$$\rho = 0.46449(\frac{P}{T}) \qquad (3)$$

$$\mu = 2.414 \times 10^{-7}(T)^{0.76} \qquad (4)$$

$$C = \frac{2mg}{A\rho V_t^2} \qquad (5)$$

$$\frac{V_t}{U_o} = 4.9\left(\frac{DU_o\rho}{\mu}\right)\left(\frac{\mu}{HU_o}\right)^{0.60}\left(\frac{\rho_o - \rho}{\rho}\right)^{0.23} \qquad (6)$$

$$\frac{U}{U_o} = 5 \log R - 3.9 \qquad (7)$$

$$R = \frac{HU\rho}{\mu} \qquad (8)$$

$$F_y - w = m\ddot{y} \qquad (9)$$

$$F_y = \frac{CA\rho V_{ry}^2}{2} \qquad (10)$$

$$V_{ry} = u(\sin(\theta))-\dot{y} \qquad (11)$$

$$w = mg \qquad (12)$$

$$\frac{CA\rho}{2}(u(\sin(\theta))-\dot{y})^2 - mg = m\ddot{y} \qquad (13)$$

$$\ddot{y} = \frac{CA\rho}{2m}(u(\sin(\theta))-\dot{y})^2 - g \qquad (14)$$

$$\ddot{x} = \frac{CA\rho}{2m}(u(\cos(\theta))-\dot{x})^2 \qquad (15)$$

LIST OF EQUATIONS (continued)

$$\alpha = \arctan\left(\frac{x}{d-y}\right) \quad (16)$$

$$\theta = \arctan\left(\frac{x}{d-y}\right) \quad (17)$$

LIST OF FIGURES

INTRODUCTION

Forests and forest products are essential to human life. Trees provide raw material for the manufacture of lumber, paper, and plastics. Wood is a primary energy source in many underdeveloped countries. Trees prevent erosion, supply oxygen, and help prevent the accumulation of carbon dioxide in the atmosphere.

The natural regrowth of forests cannot keep pace with losses due to havesting and fire. Seeds must be obtained to support the massive reforestation efforts which are under way. The problem of harvesting seeds was the motivation for this project.

The forest products industry needs an efficient, cost-effective means of harvesting pine seeds. The seeds are grown in orchards which are cultivated strictly for seed production. The large quantities of seeds produced make the laborious harvesting methods of the past unacceptable. Harvesting the seeds by vacuuming them off the ground would be an effective solution to the problem, but efforts to design pneumatic harvesting equipment have been only marginally successful. The machines which have been developed to date leave too many seeds on the ground.

The purpose of this project was to obtain information that would aid the development of effective equipment for harvesting pine seeds pneumatically.

Citations and documentation in this thesis follow the style of the <u>TRANSACTIONS of the ASAE</u>.

OBJECTIVES

The project's objectives were as follows:

1) Identify the critical parameters for pneumatically lifting pine seeds from a horizontal surface.

2) Analytically evaluate the pneumatic lifting of pine seeds from a horizontal surface.

3) Develop an experimental apparatus based on the analytical evaluation.

4) Correlate the performance of the experimental apparatus with the results of the analytical evaluation.

REVIEW OF LITERATURE

Properties of Pine Seeds

The analysis of lifting pine seeds with air required data for the physical and aerodynamic characteristics of the seeds. Their dimensions, mass, frontal area, and coefficient of drag were essential to the analysis, but this data was not found in the literature.

Due to the extensive use of pneumatic conveying in agricultural processing, research has been conducted to determine the characteristics of various kinds of grain. The methods used with grain can also be used with pine seeds.

Hawk et al. (1966) used a wind tunnel to determine the terminal velocity of wheat, soybeans, and corn by suspending the seeds in a vertical air stream. Bilanski et al. (1962) and Keck and Goss (1965) dropped alfalfa and rose clover seeds in still air, measured the time required by the seeds to fall through known distances, and calculated terminal velocity. In addition to determining the terminal velocity of the seeds, Bilanski et al. (1962) and Hawk et al. (1966) calculated the coefficient of drag.

It is up to the researcher to decide how to estimate the frontal area of an irregularly shaped seed. The seed may be assumed to have the same frontal area as a sphere of equal volume (Hawk et al., 1966). Some seeds have three major dimensions which may be used to obtain a typical length for estimating frontal area. Hawk et al. (1966) took the square of the longest dimension to be the frontal area of corn kernals. The cross-sectional areas of wheat seeds and soybeans have been calculated by assuming that the area was equal to that of an ellipse with major axis equal to the longest dimension of the kernal and minor axis equal to the average of the two smaller dimensions (Hawk et al., 1966). Bilanski et al. (1962) calculated frontal area as if it was equal to the area of an ellipse whose axes were equal to the two longest dimensions of the seed.

Minimum Fluid Velocity

Thomas (1962) developed a relation for predicting the minimum fluid velocity required for horizontal conveying. This relation was shown to be the most accurate by Jones and Leung (1978). It is applicable when the particle is too large to be covered by the laminar sublayer in the conveying fluid (Thomas, 1962).

Analysis of Particle Movement

Chand and Ghosh (1968) and Stannard (1961) developed equations describing the movement of particles being conveyed pneumatically. They began their analyses with the same equation of a particle's movement in an air stream.

$$\ddot{s} = \frac{C\,A\,\rho}{2m}(u - \dot{s})^2 \qquad (1)$$

West (1972) used two equations which are similar to Eq. (1) for predicting the horizontal and vertical movement of particles moving through an air stream.

METHODS

Measurement of Physical Properties

Slash pine seeds were used in this project. Each seed was measured with a vernier caliper in the three roughly perpendicular dimensions shown in Figure 1. The mass of each seed was measured with an analytical balance.

Determination of Aerodynamic Charactertistics

Frontal Area. The frontal area of a pine seed was taken to be the area of a circle whose diameter is equal to the average of the three major dimensions of the seed.

Terminal velocity. A vertical wind tunnel that had been constructed for other research was used to determine terminal veocity. The experimental apparatus, shown in Figure 2, consisted of a non-overloading fan, an entrance nozzle, a plenum chamber, a plexiglass test section, an adjustable damper, a seed retrieval spout, and a manometer. The fan generated the air flow, discharging into the plenum chamber. Along with straightening vanes and window screen at the entrance to the test section, the plenum chamber reduced disturbances in the flow in the test section. The test section was a plexiglass tube with an inside diameter of 16.5 centimeters and a length of 1.2 meters. The damper was adjusted to restrict the flow and control the velocity of the air in the test section. Seeds which were conveyed out of the test section were retrieved during the course of the experiment at the seed retrieval spout. The nozzle on the fan inlet was fitted with a pressure tap. The

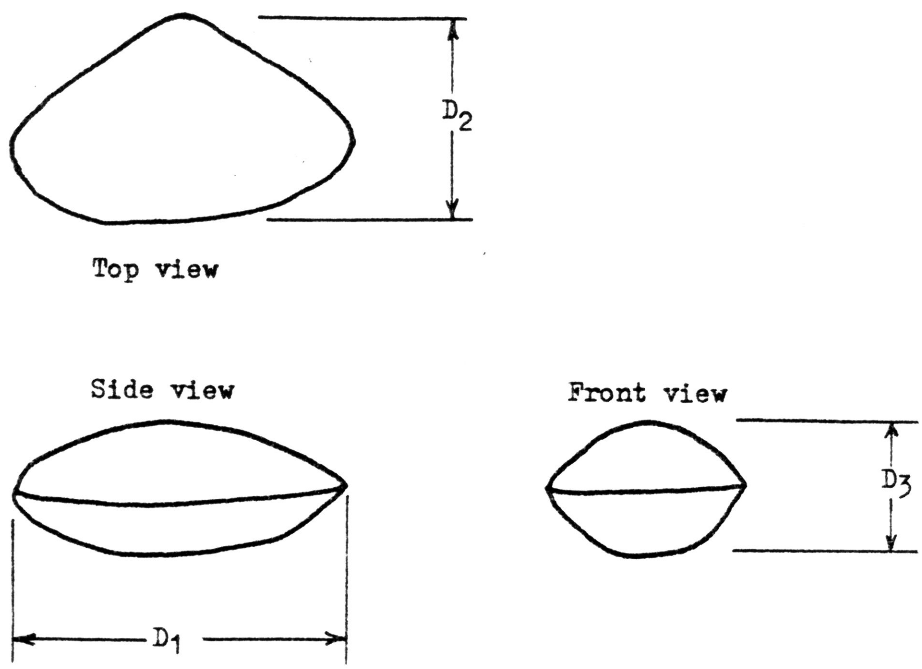


Figure 1. Major dimensions of pine seeds

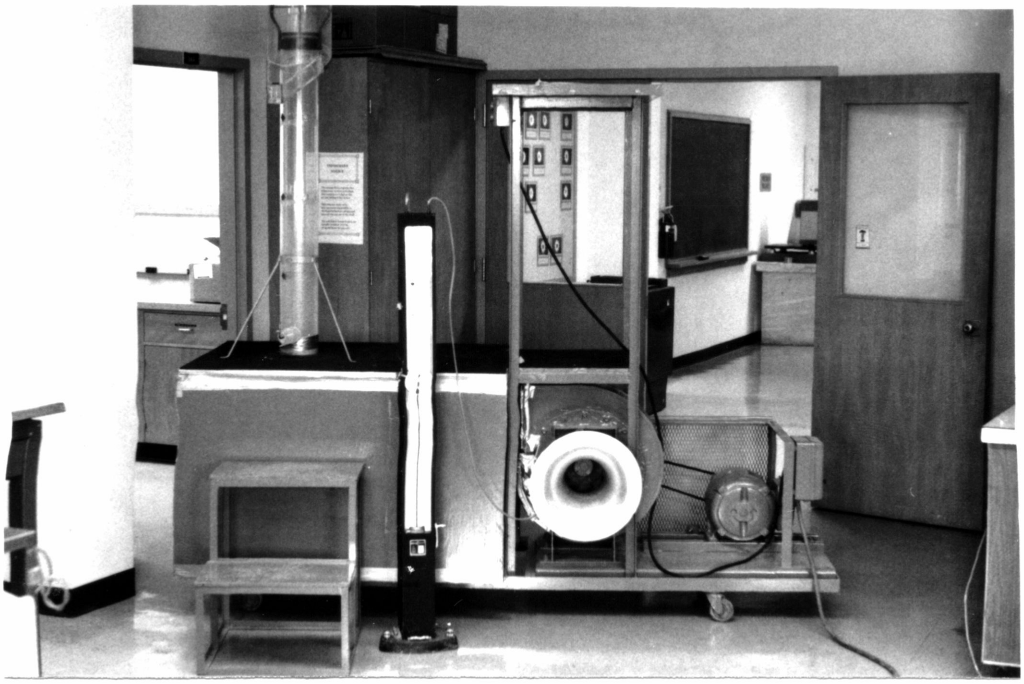


Figure 2. Apparatus for determining terminal velocity

nozzle had been calibrated during a previous project to allow readings of pressure drop at the nozzle to be converted directly to the air velocity in the test section.

The process of measuring the terminal velocity of a seed began with the air velocity in the test section set at 5.4 meters per second. The ambient air temperature and barometric pressure was recorded. Twenty-five seeds were then placed in the test section through an air-tight port. Preliminary trials had shown that when the air velocity in the test section neared the terminal velocity of a seed, the seed would repeatedly be suspended momentarily and then fall back to the bottom of the test section. A small increase in the air velocity would then cause the seed to be conveyed through the test section, out the top, and into the retrieval spout.

During the experiments, the air velocity was increased in small increments and allowed to remain constant for two minutes. The incremental velocity increase was obtained by advancing the manometer setting by 0.005 inches of water and adjusting the air velocity to bring the meniscus of the fluid in the manometer back to zero. This process produced changes in air velocity of approximately 0.2 meters per second, the smallest change that could be measured reliably. As the seeds were conveyed out of the test section, they were placed in numbered coin envelopes for later weighing and measuring. The air velocity at which a seed left the test section was considered its terminal velocity. Since terminal velocity was measured under varying atmospheric conditions, the measured values were adjusted to standard atmospheric conditions by solving Eq. (5) for V_t using the properties of the seeds and the density of standard air at fifteen degrees centigrade.

Reynolds number. The Reynolds number for a seed was calculated using the average of the seed's three major dimensions as the representative length and the terminal velocity as previously defined.

$$Re = \frac{DV_t \rho}{\mu} \qquad (2)$$

Using relations from Hoerner (1965), the density and viscosity of the air were calculated as follows.

$$\rho = 0.46449 \left(\frac{P}{T}\right) \qquad (3)$$

$$\mu = 2.414 \times 10^{-7} (T)^{0.76} \qquad (4)$$

Coefficient of drag. The coefficient of total drag of a seed at its terminal velocity was taken to be

$$C = \frac{2mg}{A \rho V_t^2} \qquad (5)$$

Description of Flow Pattern

A simplified flow pattern for a pneumatic harvester was developed to aid analysis. The flow pattern is shown schematically in Figure 3. It was assumed that a seed would be entrained by a horizontal air stream ten centimeters thick. Once entrained, the seed must remain suspended in the air stream if it is to be lifted. In lifting the seed, the air flow would pass through a transition region where the direction of flow would change from horizontal to some angle above horizontal. The

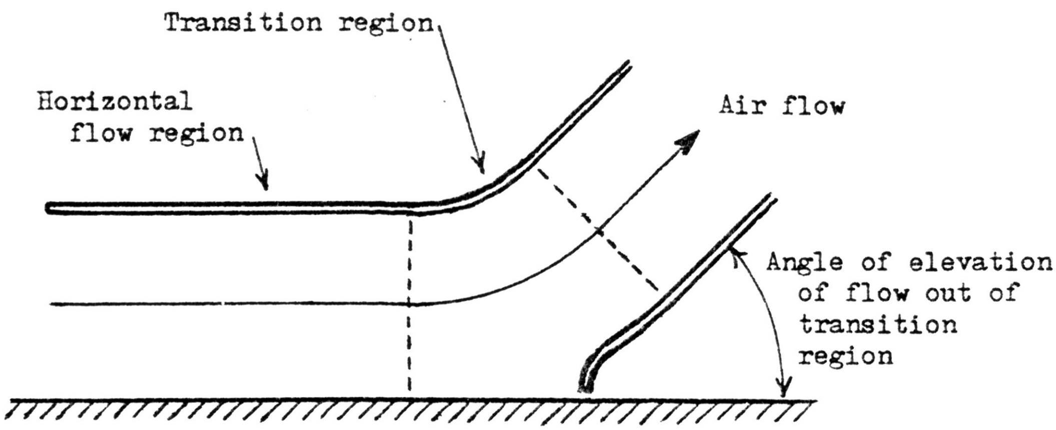


Figure 3. Schematic diagram of air flow generated by harvester

magnitude of the angle would be determined by the configuration of the harvester.

The analysis of the movement of a seed in the harvester air stream was divided into two parts: 1) determine the mean stream velocity required to convey the seed horizontally, 2) simulate the seed's movement in the transition region. The analysis was limited to two dimensions: horizontal and vertical.

Analysis of Entrainment

The relations developed by Thomas (1962) were used to estimate the mean stream velocity required to entrain a seed in the horizontal air flow. The effects of obstructions that would be present under actual harvesting conditions were neglected. It was assumed that the volume fraction of solids in the air flow would be very small, that the laminar sublayer would be thin compared to a seed, and that the horizontal portion of the harvester air flow was equivalent in two dimensions to ordinary horizontal pneumatic conveying in a pipe.

Three equations from Thomas (1962) were used.

$$\frac{V_t}{U_o} = 4.9 \left(\frac{DU_o\rho}{\mu}\right) \left(\frac{\mu}{HU_o\rho}\right)^{0.6} \left(\frac{\rho_o-\rho}{\rho}\right)^{0.23} \qquad (6)$$

$$\frac{U}{U_o} = 5 \log R - 3.9 \qquad (7)$$

where $$R = \frac{HU\rho}{\mu} \qquad (8)$$

Eq. (7) was solved to obtain U_o. This value, the properties of standard air, and a stream thickness of ten centimeters were used with the physical properties of pine seeds to solve Eq. (8) and (9) by trial and error to obtain the minimum transport velocity. Since the density of the seeds was not measured, it was assumed to be the same as the density of water. Observation of seeds submerged in water supported this assumption.

Analysis of Movement in Transition Region

Mathematical model. A mathematical model was developed to describe the motion of a seed in the transition region. The effects of particle rotation were neglected, the seed's coefficient of drag was assumed to be constant, and buoyant forces were ignored. The development of the matematical model is presented below.

Consider a seed moving in an air stream as shown in Figure 4. For the vertical direction, the force and velocity diagrams can be put into mathematical terms as follows.

$$F_y - w = m\ddot{y} \tag{9}$$

where $$F_y = \frac{CA\rho V_{ry}^2}{2} \tag{10}$$

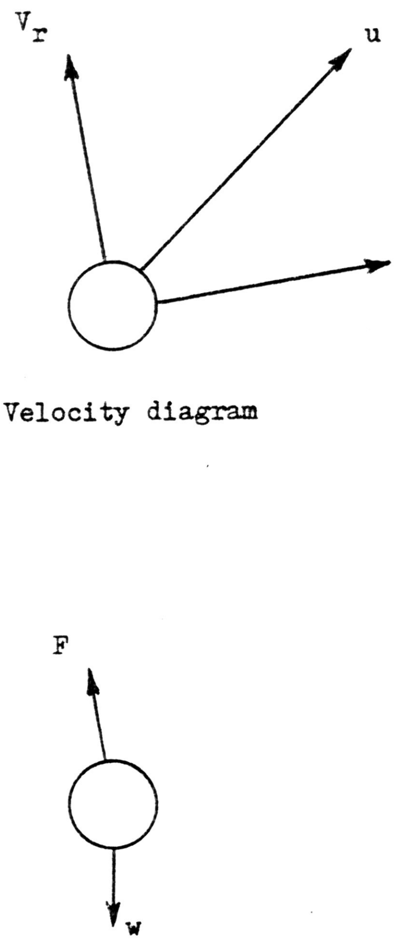
$$V_{ry} = u(\sin(\theta)) - \dot{y} \tag{11}$$

$$w = mg \tag{12}$$

Substituting Eq. (10), (11), and (12) into (9),

$$\frac{CA\rho}{2}(u(\sin(\theta))-\dot{y})^2 - mg = m\ddot{y} \tag{13}$$

Rearranging, an equation is obtained which describes the vertical movement of the seed.



(a) Velocity diagram

(b) Force diagram

Figure 4. Force and velocity diagrams for a seed moving in an air stream

$$\ddot{y} = \frac{CA\rho}{2m} (u(\sin(\theta))-\dot{y})^2 - g \tag{14}$$

Similar analysis yields

$$\ddot{x} = \frac{CA\rho}{2m} (u(\cos(\theta))-\dot{x})^2 \tag{15}$$

for horizontal movement.

The transition region is shown in Figure 5. The dotted lines labeled "A", "B", "C", "D", and "E" prepresent the paths followed by fluid particles through the transition region. The paths were considered segments of circles centered at point C. Each fluid particle passing through the transition region was assumed to follow a circular path. A line was drawn from C through the transition region as shown in Figure 5. The instantaneous velocity of each fluid particle on that line was assumed to have the same magnitude and the same direction. The direction of each particle's velocity is perpendicular to the radial line.

Figure 6 shows the geometric relationship of the fluid velocity at a point to its location. The x-axis was taken to be at ground level under the transition region. The y-axis was taken to be at the beginning of the transition region. In Figure 6,

$$\alpha = \arctan\left(\frac{x}{d-y}\right) \tag{16}$$

Inspection of Figure 6 reveals that $\alpha = \theta$.

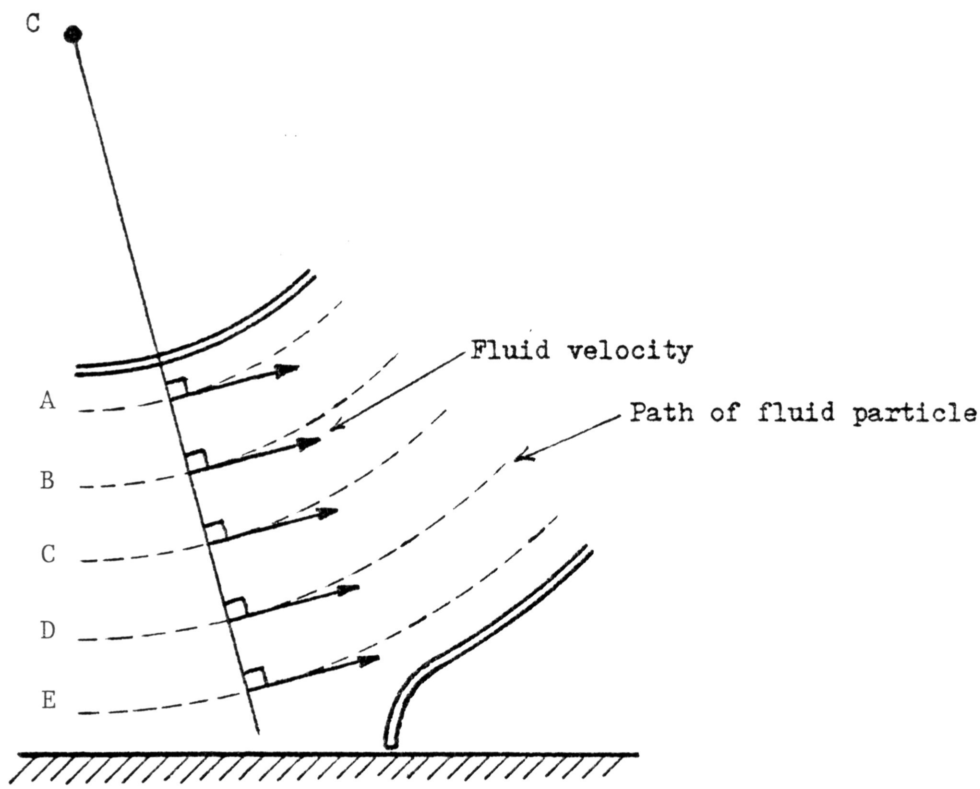


Figure 5. Schematic diagram of paths and instantaneous velocity of fluid particles in transition region

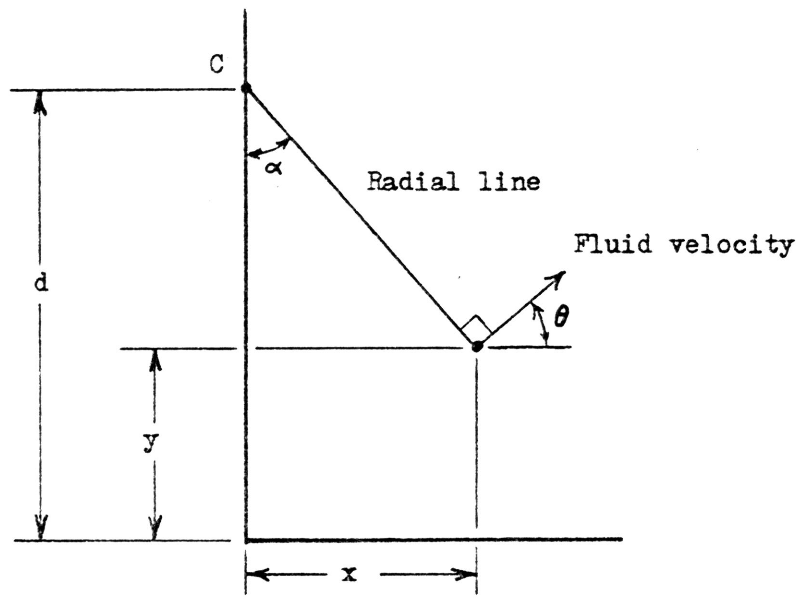


Figure 6. Diagram used in the development of an expression for θ

Thus,

$$\theta = \text{arc } \tan\left(\frac{x}{d-y}\right) \qquad (17)$$

Eq. (14), (15), and (17) make up a system of equations that describes the seed's movement in the transition region. It should be noted that Eq. (14) and (15) hold only when the following conditions are true.

for Eq. (14), $u(\sin(\theta)) > \dot{y}$

for Eq. (15), $u(\cos(\theta)) > \dot{x}$

Simulation. The mathematical model was used to simulate the movement of a seed in the transition region for a range of air velocities. A computer program was written using the classical fourth-order Runge-Kutta method to integrate Eq. (14) and (15) numerically. The flow chart for the program is shown in Figure 7.

For the simulation, the flow transition region was considered to be bounded by two lines as shown in Figure 8. The line marked "A" was considered the beginning of the transition region. The seed's vertical acceleration, vertical velocity, and horizontal acceleration were assumed to be zero at A. The horizontal velocity of the seed at A was assumed to be the minimum transport velocity. The vertical position at A was assumed to be four centimeters above the ground. These assumptions provided the initial conditions required for solution of the differential equations. The air stream was assumed to have a sharp boundary along the line marked "B" at a distance from point C equal to

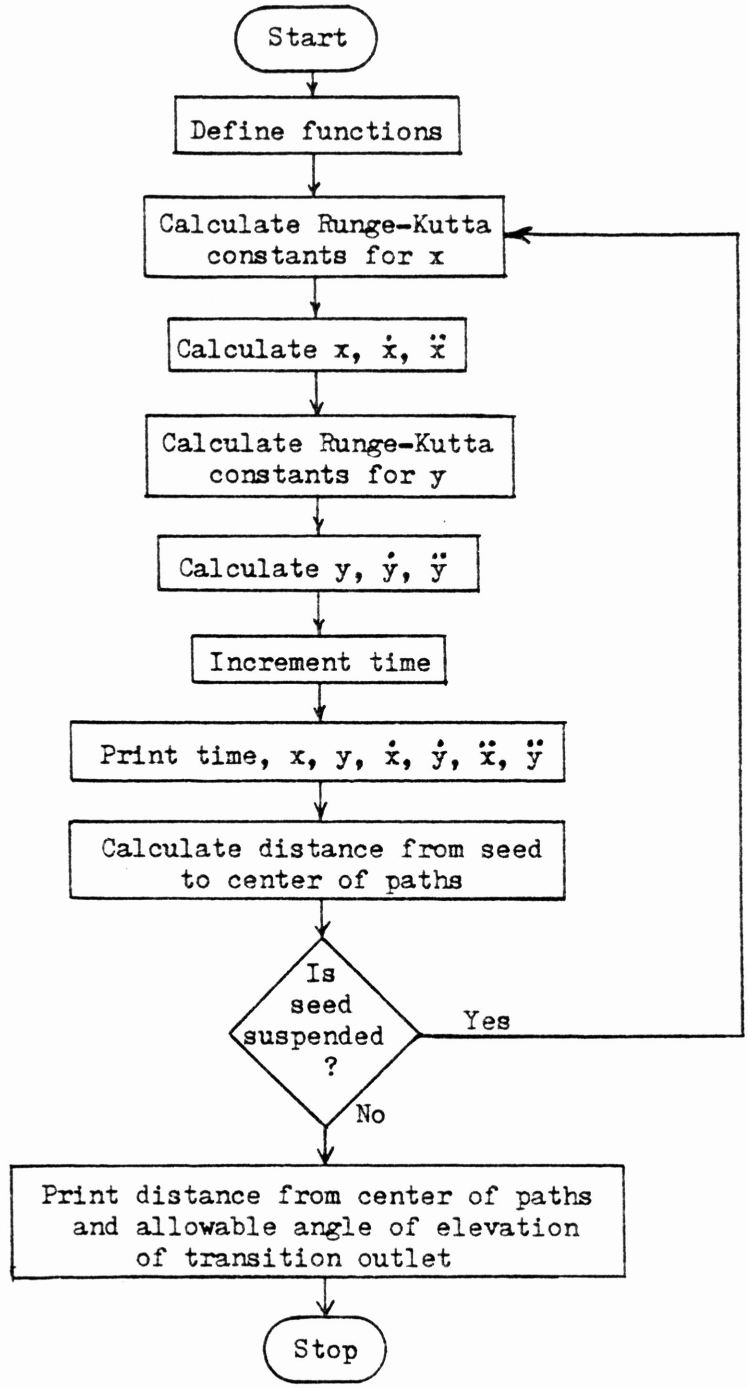


Figure 7. Flow-chart for the simulation program

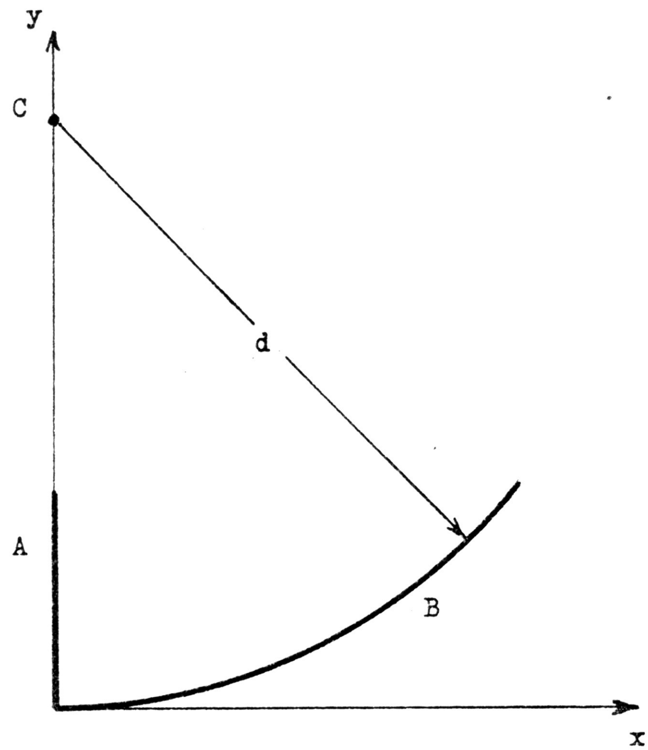


Figure 8. Transition region boundaries used in the simulation

the elevation, forty centimeters, of point C. When the seed reached line B during the simulation, it was considered to have fallen out of the air stream. Thus, the simulation was stopped when the seed reached line B. The angle "θ" shown in Figure 6 was calculated from the coordinates of the seed's position at the time it crossed line B in Figure 8. As used here, the angle corresponds to the maximum angle of elevation of the transition that the seed could be conveyed through without dropping out of the air stream.

RESULTS

A summary of the physical characteristics of pine seeds is presented in Table 1. Data for each seed can be found in Appendices A and B. It should be noted that the coefficient of drag is not independent of the frontal area of the seeds. Thus, the coefficient of drag and frontal area should be used together: use of the coefficient of drag reported here with another estimate of frontal area would produce unreliable results. The methods and apparatus for measuring terminal velocity were checked using plastic spheres. The results obtained for the spheres agreed reasonably well with published data.

A value of 5.5 meters per second was obtained for the minimum horizontal transport velocity.

The results of the simulation are presented in graphical form in Figure 9. The air velocity in the transition region and the vertical position of the seed at the entrance to the transition region were varied during the simulation. In each graph in Figure 9, the transition region air velocity was plotted horizontally, and the maximum angle of elevation of the transition region outflow was plotted vertically. Thus, the graphs show the effect that an increase in air velocity in the transition region has on the ability of the air stream to lift a seed. Each graph corresponds to a different initial seed elevation, allowing the effects of initial seed elevation to be evaluated. Because of the simplicity of the model and the number of assumptions made, the results of the simulation should be used only as a source of qualitative information.

Table 1. Physical Characteristics of Slash Pine Seeds

Characteristic		Mean*	Standard Deviation*
Mass		0.063 g	0.013 g
Dimensions	D_1	7.99 mm	0.421 mm
	D_2	5.70 mm	0.313 mm
	D_3	3.55 mm	0.192 mm
Frontal area		26.0 square mm	1.85 square mm
Terminal velocity		7.9 m/s	0.821 m/s
Coefficient of drag		0.63	0.065

*Based on two hundred seeds.

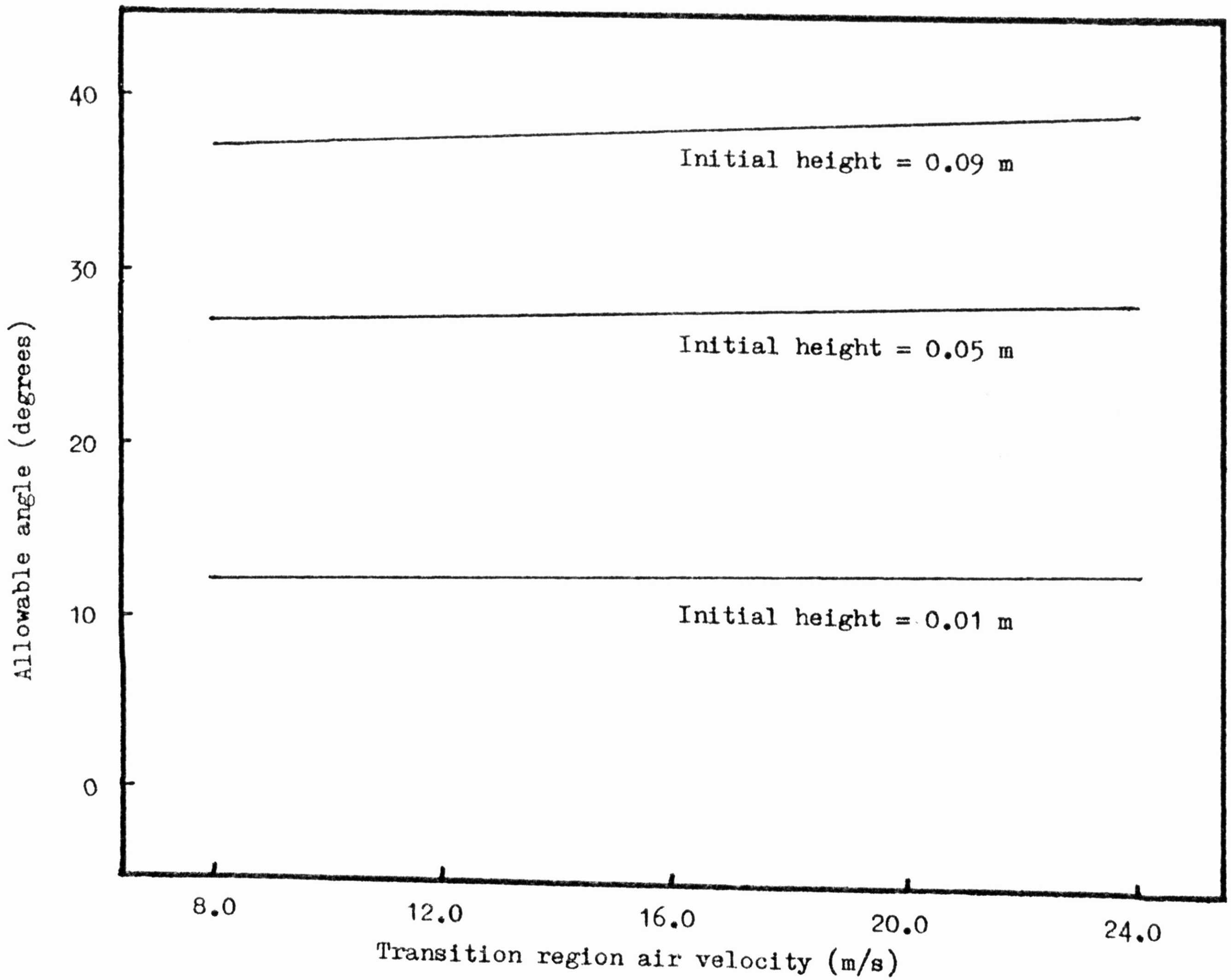


Figure 9. Plots of the allowable angle of elevation of flow out of the transition region vs. the velocity of the air in the transition

CONCLUSIONS

The following conclusions were drawn from the project's results:

(1) The maximum allowable angle of elevation of the transition region depends primarily upon the initial elevation of the seed in the air stream entering the transition region.

(2) Changes in the air velocity in the transition region have relatively little effect on the allowable angle of elevation.

(3) The direction of the transition region outflow in a harvesting machine should be as close to horizontal as possible.

RECOMMENDATIONS FOR FURTHER STUDY

Based on the experience gained in this project, the following recommendations for further study are made.

1) An experimental air intake should be used to further investigate the effects of changes in air velocity and the angle of elevation of the flow out of the transition region.

2) The problem of entrainment should be considered in more detail: the effects of grass and other obstructions on the mean stream air velocity required for entrainment should be investigated.

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APPENDIX A: EXPERIMENTAL DATA

EXPERIMENTAL DATA FOR PINE SEEDS

SEED NO.	DIMENSIONS (MM) D1	D2	D3	MASS (G)	TERMINAL VEL. (M/S)	TEMP. (C)	BAR. PRESS. (MM HG)
1	8.25	5.95	3.50	0.03500	6.4	24.2	737.9
2	7.85	6.10	3.65	0.03525	6.6	24.2	737.9
3	8.60	5.70	3.55	0.03932	6.9	24.2	737.9
4	7.95	5.70	3.25	0.05601	7.5	24.2	737.9
5	8.00	5.85	3.45	0.06804	8.2	24.2	737.9
6	7.70	5.75	3.20	0.05754	8.2	24.2	737.9
7	7.40	5.85	3.65	0.06993	8.4	24.2	737.9
8	7.45	4.85	3.45	0.05733	8.4	24.2	737.9
9	8.50	5.95	3.75	0.07932	8.4	24.2	737.9
10	8.00	4.95	3.40	0.05825	8.4	24.2	737.9
11	7.90	6.00	3.50	0.07350	8.4	24.2	737.9
12	8.60	5.85	3.60	0.07196	8.4	24.2	737.9
13	8.55	5.75	3.55	0.05990	8.4	24.2	737.9
14	8.05	5.70	3.65	0.07149	8.6	24.2	737.9
15	7.75	5.40	3.20	0.07231	8.6	24.2	737.9

EXPERIMENTAL DATA FOR PINE SEEDS (CONTINUED)

SEED NO.	DIMENSIONS (MM) D1	D2	D3	MASS (G)	TERMINAL VEL. (M/S)	TEMP. (C)	BAR. PRESS. (MM HG)
16	7.75	5.60	3.40	0.05863	8.6	24.2	737.9
17	7.55	4.80	3.50	0.05500	8.6	24.2	737.9
18	8.10	5.55	3.60	0.06916	8.6	24.2	737.9
19	8.25	6.45	3.80	0.08866	8.6	24.2	737.9
20	8.10	5.85	3.50	0.07256	8.6	24.2	737.9
21	8.10	5.55	3.55	0.06408	8.6	24.2	737.9
22	7.85	5.25	3.40	0.05950	8.6	24.2	737.9
23	8.00	6.00	3.60	0.07626	9.1	24.2	737.9
24	8.05	5.85	3.70	0.07380	9.3	24.2	737.9
25	7.60	5.75	3.80	0.07226	9.4	24.2	737.9
26	7.80	5.75	3.65	0.03486	6.2	24.4	738.1
27	7.80	5.80	3.70	0.03440	6.2	24.4	738.1
28	7.65	5.70	3.55	0.03262	6.2	24.4	738.1
29	8.65	5.50	3.45	0.04540	6.9	24.4	738.1
30	7.65	5.70	3.10	0.06065	7.5	24.4	738.1

EXPERIMENTAL DATA FOR PINE SEEDS (CONTINUED)

SEED NO.	DIMENSIONS (MM) D1	D2	D3	MASS (G)	TERMINAL VEL. (M/S)	TEMP. (C)	BAR. PRESS. (MM HG)
31	8.15	6.25	3.75	0.07920	7.9	24.4	738.1
32	7.45	5.40	3.20	0.05630	7.9	24.4	738.1
33	8.35	5.85	3.35	0.07149	7.9	24.4	738.1
34	8.05	6.00	3.45	0.07180	8.1	24.4	738.1
35	7.30	6.00	3.50	0.05690	8.1	24.4	738.1
36	7.50	5.80	3.35	0.05609	8.1	24.4	738.1
37	7.25	5.60	3.45	0.06230	8.2	24.4	738.1
38	7.75	5.00	3.60	0.05924	8.2	24.4	738.1
39	8.55	5.70	3.45	0.06875	8.2	24.4	738.1
40	9.00	6.00	3.45	0.07831	8.2	24.4	738.1
41	7.70	6.00	3.55	0.06805	8.4	24.4	738.1
42	7.90	6.25	3.60	0.07561	8.4	24.4	738.1
43	7.95	5.80	3.65	0.06789	8.6	24.4	738.1
44	7.80	6.05	3.65	0.07085	8.8	24.4	738.1
45	8.70	5.85	3.70	0.08000	8.8	24.4	738.1

EXPERIMENTAL DATA FOR PINE SEEDS (CONTINUED)

SEED NO.	DIMENSIONS (MM) D1	D2	D3	MASS (G)	TERMINAL VEL. (M/S)	TEMP. (C)	BAR. PRESS. (MM HG)
46	7.90	5.00	3.65	0.06253	8.8	24.4	738.1
47	7.70	6.15	3.70	0.06999	8.8	24.4	738.1
48	7.80	5.95	3.50	0.07233	8.8	24.4	738.1
49	8.60	5.80	3.40	0.07511	8.8	24.4	738.1
50	8.10	5.25	3.60	0.06522	9.3	24.4	738.1
51	7.80	6.10	3.65	0.03700	6.2	25.0	737.9
52	8.15	5.85	3.15	0.06026	7.3	25.0	737.9
53	7.75	5.90	3.30	0.06237	7.5	25.0	737.9
54	7.85	5.50	3.95	0.06271	8.1	25.0	737.9
55	8.10	5.95	3.55	0.06920	8.1	25.0	737.9
56	8.00	5.65	3.50	0.06490	8.1	25.0	737.9
57	9.00	5.75	3.25	0.07088	8.1	25.0	737.9
58	7.95	6.05	3.60	0.07070	8.2	25.0	737.9
59	7.40	5.60	3.35	0.05854	8.2	25.0	737.9
60	7.90	4.85	3.45	0.05650	8.4	25.0	737.9

EXPERIMENTAL DATA FOR PINE SEEDS (CONTINUED)

SEED NO.	DIMENSIONS (MM) D1	D2	D3	MASS (G)	TERMINAL VEL. (M/S)	TEMP. (C)	BAR. PRESS. (MM HG)
61	7.70	5.75	3.55	0.06637	8.4	25.0	737.9
62	8.30	5.60	3.55	0.06856	8.4	25.0	737.9
63	8.25	5.65	3.20	0.06252	8.4	25.0	737.9
64	7.00	6.10	3.50	0.06687	8.4	25.0	737.9
65	8.40	5.60	3.75	0.06977	8.6	25.0	737.9
66	7.35	5.40	3.10	0.04734	8.6	25.0	737.9
67	8.25	5.80	3.45	0.07331	8.6	25.0	737.9
68	8.60	5.60	3.50	0.07088	8.6	25.0	737.9
69	8.65	5.65	3.85	0.07641	8.8	25.0	737.9
70	7.70	5.75	3.60	0.06750	8.8	25.0	737.9
71	7.95	5.65	3.50	0.06626	8.9	25.0	737.9
72	7.65	4.95	3.75	0.06514	8.9	25.0	737.9
73	8.55	5.95	3.80	0.08230	8.9	25.0	737.9
74	8.30	5.70	3.50	0.06650	9.3	25.0	737.9
75	8.55	6.15	3.55	0.07348	9.4	25.0	737.9

EXPERIMENTAL DATA FOR PINE SEEDS (CONTINUED)

SEED NO.	DIMENSIONS (MM) D1	D2	D3	MASS (G)	TERMINAL VEL. (M/S)	TEMP. (C)	BAR. PRESS. (MM HG)
76	7.95	5.90	3.35	0.06300	7.5	24.4	737.1
77	7.85	5.10	3.25	0.05207	7.9	24.4	737.1
78	8.20	6.00	3.60	0.07304	8.1	24.4	737.1
79	8.10	5.75	3.10	0.06089	8.2	24.4	737.1
80	7.90	5.00	3.55	0.06292	8.2	24.4	737.1
81	8.65	6.20	3.60	0.08029	8.2	24.4	737.1
82	7.95	5.65	3.55	0.06519	8.4	24.4	737.1
83	8.30	5.95	3.55	0.07530	8.4	24.4	737.1
84	8.00	5.60	3.55	0.06794	8.4	24.4	737.1
85	7.50	4.90	3.50	0.05531	8.4	24.4	737.1
86	8.45	6.05	3.35	0.07477	8.4	24.4	737.1
87	8.20	5.90	3.60	0.06844	8.4	24.4	737.1
88	8.10	5.80	3.40	0.06629	8.4	24.4	737.1
89	7.05	5.20	3.45	0.05403	8.4	24.4	737.1
90	8.50	5.90	3.25	0.07311	8.4	24.4	737.1

EXPERIMENTAL DATA FOR PINE SEEDS (CONTINUED)

SEED NO.	DIMENSIONS (MM) D1	D2	D3	MASS (G)	TERMINAL VEL. (M/S)	TEMP. (C)	BAR. PRESS. (MM HG)
91	8.25	6.10	3.85	0.07959	8.4	24.4	737.1
92	7.40	5.60	3.55	0.06117	8.6	24.4	737.1
93	7.90	6.25	3.70	0.07602	8.6	24.4	737.1
94	7.05	5.65	3.80	0.04791	8.6	24.4	737.1
95	7.70	5.55	3.60	0.06469	8.6	24.4	737.1
96	7.40	5.60	3.70	0.07309	8.9	24.4	737.1
97	7.85	5.85	3.75	0.07231	8.9	24.4	737.1
98	8.75	5.70	3.70	0.07518	8.9	24.4	737.1
99	8.75	6.00	3.75	0.08232	9.1	24.4	737.1
100	7.95	5.95	3.60	0.07299	9.6	24.4	737.1
101	8.40	5.80	3.15	0.02443	5.7	24.7	736.9
102	7.40	5.75	3.50	0.03309	6.2	24.7	736.9
103	7.70	6.10	3.60	0.03460	6.4	24.7	736.9
104	7.95	5.60	3.40	0.03740	6.6	24.7	736.9
105	8.20	5.70	3.90	0.06968	7.5	24.7	736.9

EXPERIMENTAL DATA FOR PINE SEEDS (CONTINUED)

SEED NO.	DIMENSIONS (MM) D1	D2	D3	MASS (G)	TERMINAL VEL. (M/S)	TEMP. (C)	BAR. PRESS. (MM HG)
106	8.05	5.60	3.40	0.06307	7.9	24.7	736.9
107	8.35	5.60	3.20	0.06837	8.1	24.7	736.9
108	7.75	5.05	3.35	0.05466	8.1	24.7	736.9
109	7.95	5.70	3.80	0.06658	8.1	24.7	736.9
110	7.95	5.55	3.35	0.06199	8.2	24.7	736.9
111	7.80	5.65	3.70	0.05867	8.4	24.7	736.9
112	8.80	5.70	3.50	0.07798	8.4	24.7	736.9
113	7.75	5.40	3.90	0.05493	8.4	24.7	736.9
114	8.40	6.00	3.90	0.07327	8.4	24.7	736.9
115	8.20	5.65	3.50	0.06666	8.4	24.7	736.9
116	7.50	5.55	3.55	0.06470	8.8	24.7	736.9
117	8.25	5.60	3.60	0.07122	8.8	24.7	736.9
118	8.40	5.75	3.55	0.07291	8.8	24.7	736.9
119	8.15	5.90	3.60	0.07467	8.8	24.7	736.9
120	8.25	5.95	3.45	0.06910	8.9	24.7	736.9

EXPERIMENTAL DATA FOR PINE SEEDS (CONTINUED)

SEED NO.	DIMENSIONS (MM) D1	D2	D3	MASS (G)	TERMINAL VEL. (M/S)	TEMP. (C)	BAR. PRESS. (MM HG)
121	7.40	5.90	4.00	0.07609	8.9	24.7	736.9
122	8.60	5.90	3.40	0.08004	8.9	24.7	736.9
123	8.40	6.00	3.70	0.07943	9.1	24.7	736.9
124	8.25	5.50	3.70	0.07557	9.4	24.7	736.9
125	8.40	5.70	3.80	0.07765	9.4	24.7	736.9
126	8.30	5.70	3.75	0.03337	5.9	26.4	730.5
127	8.05	5.90	3.90	0.03806	5.9	26.4	730.5
128	6.95	6.05	3.40	0.03077	6.2	26.4	730.5
129	7.80	5.65	3.40	0.03794	6.4	26.4	730.5
130	7.95	5.70	3.65	0.03514	6.4	26.4	730.5
131	8.20	5.25	3.80	0.03508	6.6	26.4	730.5
132	9.00	5.70	3.40	0.06044	7.5	26.4	730.5
133	8.50	5.95	3.30	0.07107	7.7	26.4	730.5
134	7.60	5.70	3.40	0.06116	7.7	26.4	730.5
135	7.85	5.50	3.60	0.06253	7.7	26.4	730.5

EXPERIMENTAL DATA FOR PINE SEEDS (CONTINUED)

SEED NO.	DIMENSIONS (MM) D1	D2	D3	MASS (G)	TERMINAL VEL. (M/S)	TEMP. (C)	BAR. PRESS. (MM HG)
136	7.40	5.45	3.55	0.05899	7.9	26.4	730.5
137	7.80	5.30	3.30	0.06133	8.1	26.4	730.5
138	8.55	5.10	3.50	0.06045	8.1	26.4	730.5
139	7.40	5.35	3.25	0.05526	8.1	26.4	730.5
140	8.00	5.80	3.50	0.07000	8.2	26.4	730.5
141	7.60	5.50	3.30	0.06249	8.2	26.4	730.5
142	7.70	5.60	3.75	0.06271	8.2	26.4	730.5
143	7.20	6.00	3.70	0.06773	8.2	26.4	730.5
144	8.90	5.95	3.60	0.07710	8.2	26.4	730.5
145	8.10	5.00	3.60	0.06413	8.4	26.4	730.5
146	8.10	5.55	3.75	0.07252	8.4	26.4	730.5
147	8.20	6.00	3.45	0.07197	8.6	26.4	730.5
148	8.05	5.70	3.70	0.07048	8.8	26.4	730.5
149	7.95	5.95	3.90	0.08195	8.8	26.4	730.5
150	7.45	5.70	3.60	0.06477	8.8	26.4	730.5

EXPERIMENTAL DATA FOR PINE SEEDS (CONTINUED)

SEED NO.	DIMENSIONS (MM) D1	D2	D3	MASS (G)	TERMINAL VEL. (M/S)	TEMP. (C)	BAR. PRESS. (MM HG)
151	7.25	5.65	3.55	0.03083	5.9	26.0	729.0
152	7.25	6.15	3.50	0.03510	5.9	26.0	729.0
153	8.70	5.55	3.80	0.03503	5.9	26.0	729.0
154	8.05	6.40	3.60	0.03938	6.2	26.0	729.0
155	8.05	5.80	4.15	0.04106	6.9	26.0	729.0
156	7.85	5.60	3.80	0.03860	6.9	26.0	729.0
157	7.60	5.80	3.60	0.04424	6.9	26.0	729.0
158	8.35	6.20	3.80	0.08298	7.5	26.0	729.0
159	7.95	5.75	3.35	0.06318	7.7	26.0	729.0
160	7.80	5.65	3.60	0.06299	7.7	26.0	729.0
161	8.35	5.70	3.20	0.06453	7.7	26.0	729.0
162	7.95	4.90	3.60	0.05786	7.9	26.0	729.0
163	8.20	4.80	3.55	0.06178	7.9	26.0	729.0
164	7.50	5.70	3.60	0.05767	8.1	26.0	729.0
165	8.65	5.80	3.55	0.07472	8.1	26.0	729.0

EXPERIMENTAL DATA FOR PINE SEEDS (CONTINUED)

SEED NO.	DIMENSIONS (MM) D1	D2	D3	MASS (G)	TERMINAL VEL. (M/S)	TEMP. (C)	BAR. PRESS. (MM HG)
166	8.10	5.70	3.80	0.06600	8.2	26.0	729.0
167	7.95	5.75	3.40	0.06774	8.6	26.0	729.0
168	8.20	5.75	3.85	0.08016	8.6	26.0	729.0
169	8.20	6.00	3.85	0.07485	8.6	26.0	729.0
170	8.10	5.45	3.60	0.06773	8.6	26.0	729.0
171	8.00	5.00	3.45	0.06157	8.6	26.0	729.0
172	8.20	5.85	3.75	0.07451	8.8	26.0	729.0
173	8.80	5.70	3.30	0.07164	8.8	26.0	729.0
174	7.85	5.80	3.55	0.06858	8.8	26.0	729.0
175	8.50	5.80	3.45	0.07457	9.4	26.0	729.0
176	7.90	5.70	3.45	0.03190	5.4	25.8	729.0
177	7.75	5.60	3.45	0.06008	7.3	25.8	729.0
178	8.05	5.60	3.45	0.05398	7.5	25.8	729.0
179	6.90	5.75	3.40	0.03942	7.5	25.8	729.0
180	7.80	5.60	3.80	0.06550	7.7	25.8	729.0

EXPERIMENTAL DATA FOR PINE SEEDS (CONTINUED)

SEED NO.	DIMENSIONS (MM) D1	D2	D3	MASS (G)	TERMINAL VEL. (M/S)	TEMP. (C)	BAR. PRESS. (MM HG)
181	7.70	5.75	3.35	0.06357	7.9	25.8	729.0
182	7.95	6.00	3.50	0.06786	8.1	25.8	729.0
183	8.30	5.75	3.55	0.06532	8.1	25.8	729.0
184	7.90	6.00	3.60	0.07024	8.1	25.8	729.0
185	7.95	5.85	3.20	0.06227	8.1	25.8	729.0
186	7.85	5.80	3.65	0.07200	8.2	25.8	729.0
187	7.20	5.20	3.75	0.05697	8.2	25.8	729.0
188	8.00	5.70	3.85	0.07099	8.2	25.8	729.0
189	8.00	5.60	3.35	0.06404	8.2	25.8	729.0
190	7.50	6.05	3.40	0.06340	8.4	25.8	729.0
191	8.05	5.45	3.80	0.07047	8.4	25.8	729.0
192	7.95	6.00	3.50	0.07058	8.4	25.8	729.0
193	8.25	5.65	3.70	0.07376	8.4	25.8	729.0
194	8.25	6.10	3.85	0.07799	8.4	25.8	729.0
195	7.85	5.60	3.10	0.05317	8.4	25.8	729.0

EXPERIMENTAL DATA FOR PINE SEEDS (CONTINUED)

SEED NO.	DIMENSIONS (MM) D1	D2	D3	MASS (G)	TERMINAL VEL. (M/S)	TEMP. (C)	BAR. PRESS. (MM HG)
196	8.00	5.65	3.50	0.06739	8.8	25.8	729.0
197	8.00	5.10	3.60	0.06544	8.8	25.8	729.0
198	8.20	5.80	3.40	0.06666	8.8	25.8	729.0
199	7.90	5.75	3.55	0.06883	8.8	25.8	729.0
200	6.80	5.85	3.60	0.05218	9.3	25.8	729.0
	MEAN						
	7.99	5.70	3.55	0.06315			
	STANDARD DEVIATION						
	0.421	0.313	0.192	0.01302			

APPENDIX B: CALCULATED DATA

CALCULATED DATA FOR PINE SEEDS

SEED NO.	FRONTAL AREA (SQ. MM)	STD. AIR TERMINAL VELOCITY (M/S)	REYNOLDS NUMBER	COEFFICIENT OF DRAG
1	27.34	6.2	2379.	0.532
2	27.03	6.4	2450.	0.505
3	27.81	6.7	2571.	0.512
4	24.92	7.3	2661.	0.680
5	26.12	8.0	2995.	0.652
6	24.19	8.0	2883.	0.596
7	24.92	8.2	2991.	0.672
8	21.65	8.2	2788.	0.635
9	28.91	8.2	3221.	0.658
10	23.33	8.2	2894.	0.598
11	26.42	8.2	3080.	0.667
12	28.43	8.2	3195.	0.607
13	27.81	8.2	3159.	0.516
14	26.42	8.3	3141.	0.623
15	23.33	8.3	2951.	0.714

CALCULATED DATA FOR PINE SEEDS (CONTINUED)

SEED NO.	FRONTAL AREA (SQ. MM)	STD. AIR TERMINAL VELOCITY (M/S)	REYNOLDS NUMBER	COEFFICIENT OF DRAG
16	24.48	8.3	3024.	0.552
17	21.92	8.3	2861.	0.578
18	25.97	8.3	3114.	0.614
19	29.87	8.3	3339.	0.684
20	26.57	8.3	3150.	0.629
21	25.82	8.3	3105.	0.572
22	23.76	8.3	2978.	0.577
23	27.03	8.8	3363.	0.580
24	27.03	9.0	3425.	0.541
25	25.67	9.1	3392.	0.540
26	25.82	6.0	2221.	0.607
27	26.12	6.0	2234.	0.592
28	24.92	6.0	2182.	0.588
29	27.03	6.7	2531.	0.608
30	23.61	7.3	2587.	0.778

CALCULATED DATA FOR PINE SEEDS (CONTINUED)

SEED NO.	FRONTAL AREA (SQ. MM)	STD. AIR TERMINAL VELOCITY (M/S)	REYNOLDS NUMBER	COEFFICIENT OF DRAG
31	28.75	7.6	2999.	0.756
32	22.48	7.6	2652.	0.687
33	26.88	7.6	2900.	0.730
34	26.73	7.8	2959.	0.704
35	24.63	7.8	2841.	0.605
36	24.19	7.8	2815.	0.608
37	23.19	8.0	2819.	0.673
38	23.33	8.0	2827.	0.636
39	27.34	8.0	3061.	0.630
40	29.71	8.0	3190.	0.660
41	25.97	8.2	3049.	0.628
42	27.49	8.2	3137.	0.659
43	26.42	8.3	3137.	0.592
44	26.73	8.5	3216.	0.588
45	29.07	8.5	3354.	0.610

CALCULATED DATA FOR PINE SEEDS (CONTINUED)

SEED NO.	FRONTAL AREA (SQ. MM)	STD. AIR TERMINAL VELOCITY (M/S)	REYNOLDS NUMBER	COEFFICIENT OF DRAG
46	23.90	8.5	3042.	0.580
47	26.88	8.5	3226.	0.577
48	25.97	8.5	3170.	0.618
49	27.65	8.5	3271.	0.602
50	25.07	9.0	3294.	0.516
51	26.88	6.0	2258.	0.620
52	25.67	7.1	2611.	0.755
53	25.07	7.3	2656.	0.755
54	26.12	7.8	2915.	0.631
55	27.03	7.8	2965.	0.672
56	25.67	7.8	2889.	0.664
57	28.27	7.8	3033.	0.658
58	27.03	8.0	3032.	0.657
59	23.33	8.0	2817.	0.630
60	22.90	8.2	2853.	0.593

CALCULATED DATA FOR PINE SEEDS (CONTINUED)

SEED NO.	FRONTAL AREA (SQ. MM)	STD. AIR TERMINAL VELOCITY (M/S)	REYNOLDS NUMBER	COEFFICIENT OF DRAG
61	25.22	8.2	2994.	0.632
62	26.57	8.2	3073.	0.620
63	25.52	8.2	3012.	0.589
64	24.05	8.2	2924.	0.668
65	27.49	8.3	3188.	0.586
66	21.92	8.3	2847.	0.499
67	26.73	8.3	3143.	0.634
68	27.34	8.3	3179.	0.599
69	28.75	8.5	3324.	0.591
70	25.37	8.5	3122.	0.591
71	25.52	8.7	3191.	0.556
72	23.33	8.7	3051.	0.598
73	29.22	8.7	3415.	0.603
74	26.73	9.0	3389.	0.495
75	29.07	9.1	3592.	0.486

CALCULATED DATA FOR PINE SEEDS (CONTINUED)

SEED NO.	FRONTAL AREA (SQ. MM)	STD. AIR TERMINAL VELOCITY (M/S)	REYNOLDS NUMBER	COEFFICIENT OF DRAG
76	25.82	7.3	2701.	0.740
77	22.90	7.6	2673.	0.625
78	27.65	7.8	3006.	0.693
79	25.07	8.0	2927.	0.609
80	23.61	8.0	2841.	0.668
81	29.71	8.0	3186.	0.678
82	25.67	8.2	3027.	0.610
83	27.65	8.2	3142.	0.654
84	25.67	8.2	3027.	0.636
85	22.06	8.2	2807.	0.602
86	27.81	8.2	3151.	0.646
87	27.34	8.2	3124.	0.601
88	26.12	8.2	3054.	0.609
89	21.51	8.2	2771.	0.603
90	27.19	8.2	3115.	0.646

CALCULATED DATA FOR PINE SEEDS (CONTINUED)

SEED NO.	FRONTAL AREA (SQ. MM)	STD. AIR TERMINAL VELOCITY (M/S)	REYNOLDS NUMBER	COEFFICIENT OF DRAG
91	28.91	8.2	3213.	0.661
92	23.90	8.3	2979.	0.591
93	27.81	8.3	3213.	0.631
94	23.76	8.3	2970.	0.465
95	24.78	8.3	3033.	0.603
96	24.34	8.7	3124.	0.642
97	26.57	8.7	3264.	0.582
98	28.75	8.7	3395.	0.559
99	29.87	8.8	3525.	0.568
100	26.73	9.3	3508.	0.508
101	26.27	5.5	2051.	0.497
102	24.19	6.0	2143.	0.616
103	26.42	6.2	2328.	0.546
104	25.07	6.4	2349.	0.580
105	27.65	7.3	2790.	0.765

CALCULATED DATA FOR PINE SEEDS (CONTINUED)

SEED NO.	FRONTAL AREA (SQ. MM)	STD. AIR TERMINAL VELOCITY (M/S)	REYNOLDS NUMBER	COEFFICIENT OF DRAG
106	25.37	7.6	2808.	0.684
107	25.67	7.8	2890.	0.700
108	22.76	7.8	2722.	0.631
109	26.57	7.8	2941.	0.658
110	24.78	8.0	2904.	0.628
111	25.67	8.2	3021.	0.550
112	28.27	8.2	3171.	0.663
113	25.37	8.2	3004.	0.521
114	29.22	8.2	3224.	0.603
115	26.27	8.2	3056.	0.610
116	24.05	8.5	3041.	0.598
117	26.57	8.5	3196.	0.596
118	27.34	8.5	3242.	0.593
119	27.19	8.5	3233.	0.611
120	27.19	8.6	3295.	0.544

CALCULATED DATA FOR PINE SEEDS (CONTINUED)

SEED NO.	FRONTAL AREA (SQ. MM)	STD. AIR TERMINAL VELOCITY (M/S)	REYNOLDS NUMBER	COEFFICIENT OF DRAG
121	26.12	8.6	3229.	0.624
122	27.96	8.6	3342.	0.613
123	28.59	8.8	3442.	0.573
124	26.57	9.1	3435.	0.547
125	27.96	9.1	3524.	0.535
126	27.49	5.7	2154.	0.601
127	27.81	5.7	2166.	0.678
128	23.47	5.9	2072.	0.599
129	24.78	6.2	2213.	0.647
130	26.12	6.2	2272.	0.569
131	25.97	6.4	2347.	0.532
132	28.59	7.2	2785.	0.651
133	27.49	7.4	2803.	0.756
134	24.34	7.4	2637.	0.735
135	25.07	7.4	2677.	0.729

CALCULATED DATA FOR PINE SEEDS (CONTINUED)

SEED NO.	FRONTAL AREA (SQ. MM)	STD. AIR TERMINAL VELOCITY (M/S)	REYNOLDS NUMBER	COEFFICIENT OF DRAG
136	23.47	7.6	2652.	0.701
137	23.47	7.8	2713.	0.696
138	25.67	7.8	2837.	0.628
139	22.34	7.8	2647.	0.659
140	26.12	7.9	2927.	0.683
141	23.47	7.9	2775.	0.678
142	25.37	7.9	2885.	0.630
143	24.92	7.9	2859.	0.692
144	29.71	7.9	3121.	0.661
145	24.34	8.1	2888.	0.643
146	26.42	8.1	3009.	0.669
147	27.19	8.3	3113.	0.621
148	26.57	8.4	3138.	0.598
149	27.65	8.4	3201.	0.669
150	24.48	8.4	3012.	0.597

CALCULATED DATA FOR PINE SEEDS (CONTINUED)

SEED NO.	FRONTAL AREA (SQ. MM)	STD. AIR TERMINAL VELOCITY (M/S)	REYNOLDS NUMBER	COEFFICIENT OF DRAG
151	23.61	5.7	1996.	0.647
152	24.92	5.7	2051.	0.698
153	28.43	5.7	2191.	0.611
154	28.43	5.9	2281.	0.633
155	28.27	6.6	2534.	0.535
156	25.97	6.6	2428.	0.548
157	25.22	6.6	2393.	0.647
158	29.38	7.2	2824.	0.871
159	25.37	7.4	2693.	0.729
160	25.37	7.4	2693.	0.727
161	25.97	7.4	2725.	0.727
162	23.61	7.6	2660.	0.684
163	23.90	7.6	2676.	0.722
164	24.63	7.7	2780.	0.624
165	28.27	7.7	2978.	0.705

CALCULATED DATA FOR PINE SEEDS (CONTINUED)

SEED NO.	FRONTAL AREA (SQ. MM)	STD. AIR TERMINAL VELOCITY (M/S)	REYNOLDS NUMBER	COEFFICIENT OF DRAG
166	27.03	7.9	2978.	0.623
167	25.52	8.3	3017.	0.623
168	27.65	8.3	3140.	0.680
169	28.43	8.3	3184.	0.618
170	25.67	8.3	3026.	0.619
171	23.61	8.3	2902.	0.612
172	27.65	8.4	3201.	0.608
173	27.65	8.4	3201.	0.585
174	25.82	8.4	3094.	0.600
175	27.49	9.1	3431.	0.530
176	25.37	5.2	1884.	0.753
177	24.63	7.0	2514.	0.796
178	25.52	7.2	2634.	0.652
179	22.43	7.2	2472.	0.540
180	25.82	7.4	2720.	0.742

CALCULATED DATA FOR PINE SEEDS (CONTINUED)

SEED NO.	FRONTAL AREA (SQ. MM)	STD. AIR TERMINAL VELOCITY (M/S)	REYNOLDS NUMBER	COEFFICIENT OF DRAG
181	24.63	7.6	2719.	0.720
182	26.57	7.8	2890.	0.681
183	27.03	7.8	2915.	0.644
184	26.73	7.8	2899.	0.701
185	25.22	7.8	2816.	0.658
186	26.12	7.9	2930.	0.703
187	22.76	7.9	2736.	0.638
188	26.88	7.9	2973.	0.673
189	25.07	7.9	2871.	0.651
190	25.07	8.1	2935.	0.617
191	26.12	8.1	2995.	0.658
192	26.57	8.1	3021.	0.648
193	27.03	8.1	3047.	0.666
194	28.91	8.1	3151.	0.658
195	23.90	8.1	2866.	0.543

CALCULATED DATA FOR PINE SEEDS (CONTINUED)

SEED NO.	FRONTAL AREA (SQ. MM)	STD. AIR TERMINAL VELOCITY (M/S)	REYNOLDS NUMBER	COEFFICIENT OF DRAG
196	25.67	8.4	3088.	0.592
197	24.34	8.4	3007.	0.607
198	26.42	8.4	3133.	0.569
199	25.82	8.4	3097.	0.601
200	23.04	8.9	3093.	0.457
	-------------- MEAN --------------			
	25.98	7.9	2914.	0.627
	------- STANDARD DEVIATION -------			
	1.853	0.821	334.6	0.065

APPENDIX C: SAMPLE OF DATA FROM SIMULATION

SIMULATION DATA: AIR VELOCITY= 24.0 M/S

TIME (S)	POSITION (M)		VELOCITY (M/S)		ACCELERATION (M/S/S)	
	HOR.	VERT.	HOR.	VERT.	HOR.	VERT.
0.0010	0.00553	0.07000	5.5539	-0.0098	53.697	-9.810
0.0020	0.01111	0.06998	5.6074	-0.0196	53.326	-9.782
0.0030	0.01674	0.06996	5.6605	-0.0293	52.919	-9.700
0.0040	0.02243	0.06992	5.7132	-0.0389	52.474	-9.562
0.0050	0.02817	0.06988	5.7654	-0.0482	51.992	-9.367
0.0060	0.03396	0.06983	5.8172	-0.0573	51.473	-9.116
0.0070	0.03980	0.06976	5.8684	-0.0662	50.917	-8.807
0.0080	0.04570	0.06969	5.9190	-0.0746	50.326	-8.440
0.0090	0.05164	0.06961	5.9690	-0.0826	49.699	-8.016
0.0100	0.05763	0.06953	6.0184	-0.0902	49.038	-7.536
0.0110	0.06368	0.06943	6.0671	-0.0972	48.344	-7.000
0.0120	0.06977	0.06933	6.1151	-0.1036	47.618	-6.408
0.0130	0.07591	0.06923	6.1623	-0.1093	46.863	-5.764
0.0140	0.08209	0.06912	6.2088	-0.1144	46.079	-5.068
0.0150	0.08832	0.06900	6.2545	-0.1187	45.268	-4.322

SIMULATION DATA: AIR VELOCITY= 24.0 M/S (CONTINUED)

TIME (S)	POSITION (M)		VELOCITY (M/S)		ACCELERATION (M/S/S)	
	HOR.	VERT.	HOR.	VERT.	HOR.	VERT.
0.0160	0.09460	0.06888	6.2993	-0.1223	44.433	-3.529
0.0170	0.10092	0.06876	6.3433	-0.1250	43.576	-2.690
0.0180	0.10729	0.06863	6.3865	-0.1268	42.698	-1.809
0.0190	0.11369	0.06850	6.4287	-0.1277	41.801	-0.888
0.0200	0.12014	0.06837	6.4701	-0.1276	40.889	0.070
0.0210	0.12663	0.06825	6.5105	-0.1265	39.963	1.062
0.0220	0.13316	0.06812	6.5500	-0.1244	39.026	2.085
0.0230	0.13973	0.06800	6.5885	-0.1213	38.079	3.136
0.0240	0.14634	0.06788	6.6261	-0.1171	37.125	4.212
0.0250	0.15299	0.06777	6.6628	-0.1117	36.166	5.309
0.0260	0.15967	0.06766	6.6985	-0.1053	35.204	6.425
0.0270	0.16638	0.06756	6.7332	-0.0977	34.242	7.556
0.0280	0.17313	0.06746	6.7670	-0.0890	33.281	8.699
0.0290	0.17992	0.06738	6.7998	-0.0791	32.322	9.852
0.0300	0.18673	0.06730	6.8316	-0.0681	31.368	11.012

SIMULATION DATA: AIR VELOCITY= 24.0 M/S (CONTINUED)

TIME (S)	POSITION (M)		VELOCITY (M/S)		ACCELERATION (M/S/S)	
	HOR.	VERT.	HOR.	VERT.	HOR.	VERT.
0.0310	0.19358	0.06724	6.8625	-0.0559	30.421	12.175
0.0320	0.20046	0.06719	6.8925	-0.0425	29.481	13.339
0.0330	0.20736	0.06716	6.9215	-0.0280	28.551	14.503
0.0340	0.21430	0.06714	6.9496	-0.0123	27.631	15.663
0.0350	0.22126	0.06713	6.9767	0.0046	26.722	16.817
0.0360	0.22825	0.06715	7.0030	0.0226	25.827	17.963

R=0.4036 ANGLE IS 34.4 DEGREES

APPENDIX D: COMPUTER PROGRAMS

DATA ANALYSIS PROGRAM (FORTRAN)

```
      DIMENSION DATA(13,202)
      REAL M
      READ,N,NO
      READ,((DATA(I,J),I=1,N),J=1,NO)
      G=9.81
      DO 1 J=1,NO
      D1=DATA(1,J)
      D2=DATA(2,J)
      D3=DATA(3,J)
      TF=DATA(6,J)
      PBARMM=DATA(7,J)*25.4
      V=DATA(5,J)
      M=DATA(4,J)/1000.0
      D=(D1+D2+D3)/3.0
      AM=0.7854*(D/1000.0)**2
      AMM=0.7854*D**2
      TC=(TF-32.0)/1.8
      TK=TC+273.15
      DNSA=.46449*PBARMM/TK
      VMS=V*0.3048
      CD=2.*M*G/(DNSA*AM*VMS**2)
      VIS=0.0000002414*TK**0.76
      RE=D*VMS*DNSA/VIS/1000.0
      VST=(2.*M*G/(CD*AM*1.225))**0.5
      DATA(5,J)=VMS
      DATA(8,J)=TC
      DATA(9,J)=PBARMM
      DATA(10,J)=AMM
      DATA(11,J)=VST
      DATA(12,J)=RE
      DATA(13,J)=CD
    1 CONTINUE
```

DATA ANALYSIS PROGRAM (continued)

```
      NOP=NO+1
      NOPP=NO+2
C     MEAN
C     SELECT THE DESIRED COLUMNS IN THE ARRAY
      K=0
      I=0
    6 SUM=0.0
      I=I+1
      IF(I.GT.4)GOTO 2
      GO TO 3
    7 I=9
    5 SUM=0.0
      I=I+1
      IF(I.GT.13)GOTO 2
C     CALCULATE MEAN OF COLUMN I
    3 DO 4 J=1,NO
      SUM=SUM+DATA(I,J)
    4 CONTINUE
      DATA(I,NOP)=SUM/FLOAT(NO)
      IF(K.EQ.1)GOTO 5
      GO TO 6
    2 IF(K.EQ.1)GOTO 27
C     STANDARD DEVIATION
C     SELECT THE DESIRED COLUMNS IN THE ARRAY
      I=0
   26 SUM=0.0
      I=I+1
      IF(I.GT.4)GOTO 22
      GO TO 23
   27 I=9
   25 SUM=0.0
      I=I+1
      IF(I.GT.13)GOTO 28
```

DATA ANALYSIS PROGRAM (continued)

```
C     CALCULATE STANDARD DEVIATION OF COLUMN I
   23 DO 24 J=1,NO
      SUM=SUM+(DATA(I,J)-DATA(I,NOP))**2
   24 CONTINUE
      DATA(I,NOPP)=(SUM/(FLOAT(NO)-1.0))**0.5
      IF(K.EQ.1)GOTO 25
      GO TO 26
   22 K=1
      GO TO 7
   28 J=0
C     NEW PAGE
   30 IK=0
      PRINT 121
      PRINT 120
      IF(J.EQ.0)GOTO 34
      PRINT 109
      GO TO 35
C     PRINT HEADINGS FOR EXP. DATA
   34 PRINT 101
   35 PRINT 102
      PRINT 103
      IF(J.EQ.NO)GOTO 33
   36 J=J+1
C     PRINT EXP. DATA
      PRINT 104,J,DATA(1,J),DATA(2,J),DATA(3,J),DATA(4,J),DATA(5,J),
     +DATA(8,J),DATA(9,J)
      IF(J.EQ.NO)GOTO 33
      IK=IK+1
      IF((IK/15)*IK.EQ.IK) GO TO 30
      GO TO 36
C     PRINT MEAN AND STD. DEV. OF EXP. DATA
   33 PRINT 105
      PRINT 106,DATA(1,NOP),DATA(2,NOP),DATA(3,NOP),DATA(4,NOP)
```

DATA ANALYSIS PROGRAM (continued)

```
      PRINT 107
      PRINT 108,DATA(1,NOPP),DATA(2,NOPP),DATA(3,NOPP),DATA(4,NOPP)
      J=0
C   NEW PAGE
   40 IK=0
      PRINT 121
      PRINT 120
      IF(J.EQ.0)GOTO 44
      PRINT 118
      GO TO 45
C   PRINT HEADINGS FOR CALC. DATA
   44 PRINT 110
   45 PRINT 111
      PRINT 112
      IF(J.EQ.NO)GOTO 43
   46 J=J+1
C   PRINT CALC. DATA
      PRINT 113,J,DATA(10,J),DATA(11,J),DATA(12,J),DATA(13,J)
      IF(J.EQ.NO)GOTO 43
      IK=IK+1
      IF((IK/15)*IK.EQ.IK) GO TO 40
      GO TO 46
C   PRINT MEAN AND STD. DEV. OF CALC. DATA
   43 PRINT 114
      PRINT 115,DATA(10,NOP),DATA(11,NOP),DATA(12,NOP),DATA(13,NOP)
      PRINT 116
      PRINT 117,DATA(10,NOPP),DATA(11,NOPP),DATA(12,NOPP),DATA(13,NOPP)
      PRINT 121
  101 FORMAT('0',32X,'EXPERIMENTAL DATA FOR PINE SEEDS')
  102 FORMAT('-',6X,'SEED NO.',5X,'DIMENSIONS (MM)',6X,'MASS (G)',
     +6X,'TERMINAL',5X,'TEMP. (C)',4X,'BAR. PRESS.')
  103 FORMAT(' ',18X,'D1',5X,'D2',6X,'D3',18X,'VEL. (M/S)',19X,
     +'(MM HG)')
```

DATA ANALYSIS PROGRAM (continued)

```
104 FORMAT('0',7X,I3,7X,F4.2,3X,F4.2,4X,F4.2,5X,F7.5,8X,F4.1,10X,
   +F4.1,9X,F5.1)
105 FORMAT('0',16X,'--------------- MEAN ---------------')
106 FORMAT('0',17X,F4.2,3X,F4.2,4X,F4.2,5X,F7.5)
107 FORMAT('0',16X,'------- STANDARD DEVIATION -------')
108 FORMAT('0',16X,F5.3,3X,F5.3,3X,F5.3,4X,F7.5)
109 FORMAT('0',26X,'EXPERIMENTAL DATA FOR PINE SEEDS (CONTINUED)')
110 FORMAT('0',33X,'CALCULATED DATA FOR PINE SEEDS')
111 FORMAT('-',6X,'SEED NO.',4X,'FRONTAL AREA',6X,'STD. AIR TERMINAL',
   +6X,'REYNOLDS NUMBER',6X,'COEFFICIENT')
112 FORMAT(' ',20X,'(SQ. MM)',10X,'VELOCITY (M/S)',30X,'OF DRAG')
113 FORMAT('0',7X,I3,12X,F5.2,15X,F4.1,17X,F6.0,14X,F5.3)
114 FORMAT('0',37X,'--------------- MEAN ---------------')
115 FORMAT('0',22X,F5.2,15X,F4.1,17X,F6.0,14X,F5.3)
116 FORMAT('0',37X,'------- STANDARD DEVIATION -------')
117 FORMAT('0',22X,F5.3,15X,F5.3,16X,F6.1,14X,F5.3)
118 FORMAT('0',27X,'CALCULATED DATA FOR PINE SEEDS (CONTINUED)')
120 FORMAT('-')
121 FORMAT('1')
    STOP
    END
```

SIMULATION PROGRAM (FORTRAN)

```
      REAL K
      FX(X,XD)=K*(VA*COS(ATAN(X/(D-Y)))-XD)**2
      FY(Y,YD)=K*(VA*SIN(ATAN(XX/(D-Y)))-YD)**2-G
      H=0.001
      G=9.81
      CD=0.627
      RM=.0000632
      AREA=25.98/1000.**2
      RHO=1.225
      K=CD*AREA*RHO*0.5/RM
      VA=7.0
      D=0.4
      DO 2 I=1,17
      X=0.0
      XD=5.5
      XDD=0.0
      Y=0.07
      YD=0.0
      YDD=0.0
      T=0.0
      L=0
      J=0
      VA=VA+1.0
    1 XX=X
      AK1=H*FX(X,XD)
      AK2=H*FX(X+H/2.*XD,XD+AK1/2.)
      AK3=H*FX(X+H/2.*(XD+AK1/2.),XD+AK2/2.)
      AK4=H*FX(X+H*(XD+AK2/2.),XD+AK3)
      X=X+H*(XD+(AK1+AK2+AK3)/6.)
      XD=XD+(AK1+2.*AK2+2.*AK3+AK4)/6.
      XDD=FX(X,XD)
      BK1=H*FY(Y,YD)
      BK2=H*FY(Y+H/2.*YD,YD+BK1/2.)
      BK3=H*FY(Y+H/2.*(YD+BK1/2.),YD+BK2/2.)
```

SIMULATION PROGRAM (continued)

```
      BK4=H*FY(Y+H*(YD+BK2/2.),YD+BK3)
      Y=Y+H*(YD+(BK1+BK2+BK3)/6.)
      YD=YD+(BK1+2.*BK2+2.*BK3+BK4)/6.
      YDD=FY(Y,YD)
      T=T+H
      IF(L.EQ.1) GO TO 36
      PRINT 110
      PRINT 109
      IF(J.EQ.1) GO TO 34
      PRINT 101,VA
      GO TO 35
   34 J=0
      PRINT 103,VA
   35 PRINT 105
      PRINT 106
   36 PRINT 107,T,X,Y,XD,YD,XDD,YDD
      L=1
      J=J+1
      IF(J.EQ.15)L=0
      IF(J.EQ.15)J=1
      R=((D-Y)**2+X**2)**0.5
      IF(R.GT.D)GOTO 3
      GO TO 1
    3 CONTINUE
      TNGT=ATAN(X/(D-Y))*57.296
      PRINT 111,R,TNGT
    2 CONTINUE
      PRINT 110
  101 FORMAT('0',27X,'SIMULATION DATA:  AIR VELOCITY= ',F4.1,' M/S')
  103 FORMAT('0',21X,'SIMULATION DATA:  AIR VELOCITY= ',F4.1,' M/S',
     +' (CONTINUED)')
```

SIMULATION PROGRAM (continued)

```
105 FORMAT('-',6X,'TIME (S)',7X,'POSITION (M)',12X,'VELOCITY (M/S)',
   +11X,'ACCELERATION (M/S/S)')
106 FORMAT(' ',20X,'HOR.',8X,'VERT.',9X,'HOR.',8X,'VERT.',8X,'HOR.',
   +8X,'VERT.')
107 FORMAT('0',7X,F6.4,6X,F7.5,5X,F7.5,6X,F7.4,5X,F7.4,6X,F7.3,
   +5X,F7.3)
109 FORMAT('-')
110 FORMAT('1')
111 FORMAT('-',10X,'R=',F6.4,15X,'ANGLE IS ',F4.1,' DEGREES')
    STOP
    END
```