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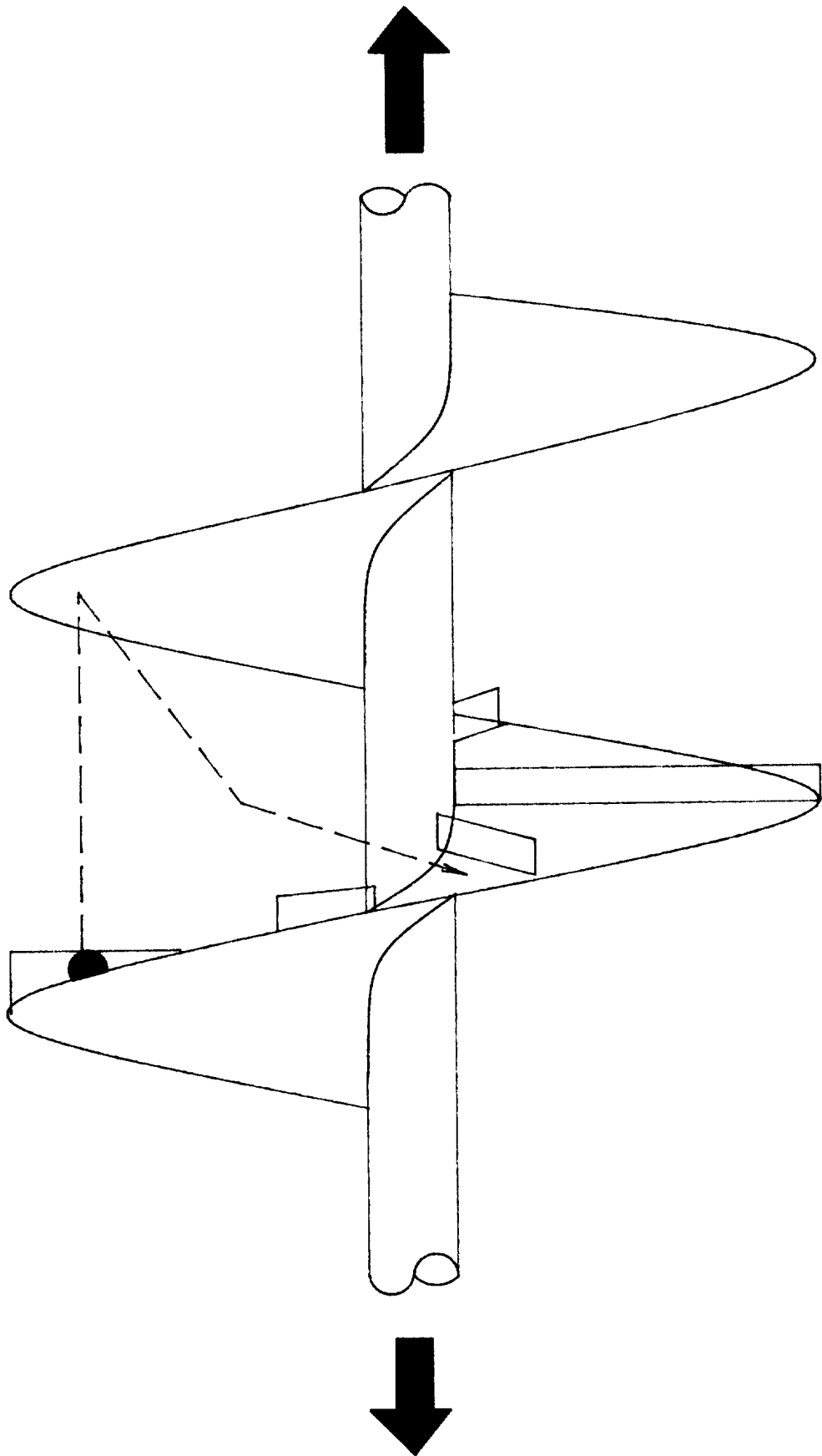
**ME 4182
MECHANICAL DESIGN ENGINEERING**

ADVANCED NASA / UNIVERSITY DESIGN PROGRAM

VERTICALLY RECIPROCATING AUGER

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ABSTRACT

This document summarizes the mathematical model and test results developed for the Vertically Reciprocating Auger (VRA). The VRA is a device capable of transporting cuttings that result from below surface drilling. It was developed chiefly for the lunar surface, where conventional fluid flushing while drilling would not be practical.

The VRA used only reciprocating motion and transports material through reflections with the surface above. Particles are reflected forward and land ahead of radially placed fences, which prevent the particles from rolling back down the auger. Three input wave forms are considered to drive the auger. A modified sawtooth wave form was chosen for testing, over a modified square wave or sine wave, due to its simplicity and effectiveness.

The three dimensional mathematical model predicted a sand throughput rate of 0.2667 pounds/stroke, while the actual test setup transported 0.075 pounds/stroke. Based on this result, a correction factor of 0.281 is suggested for a modified sawtooth input.

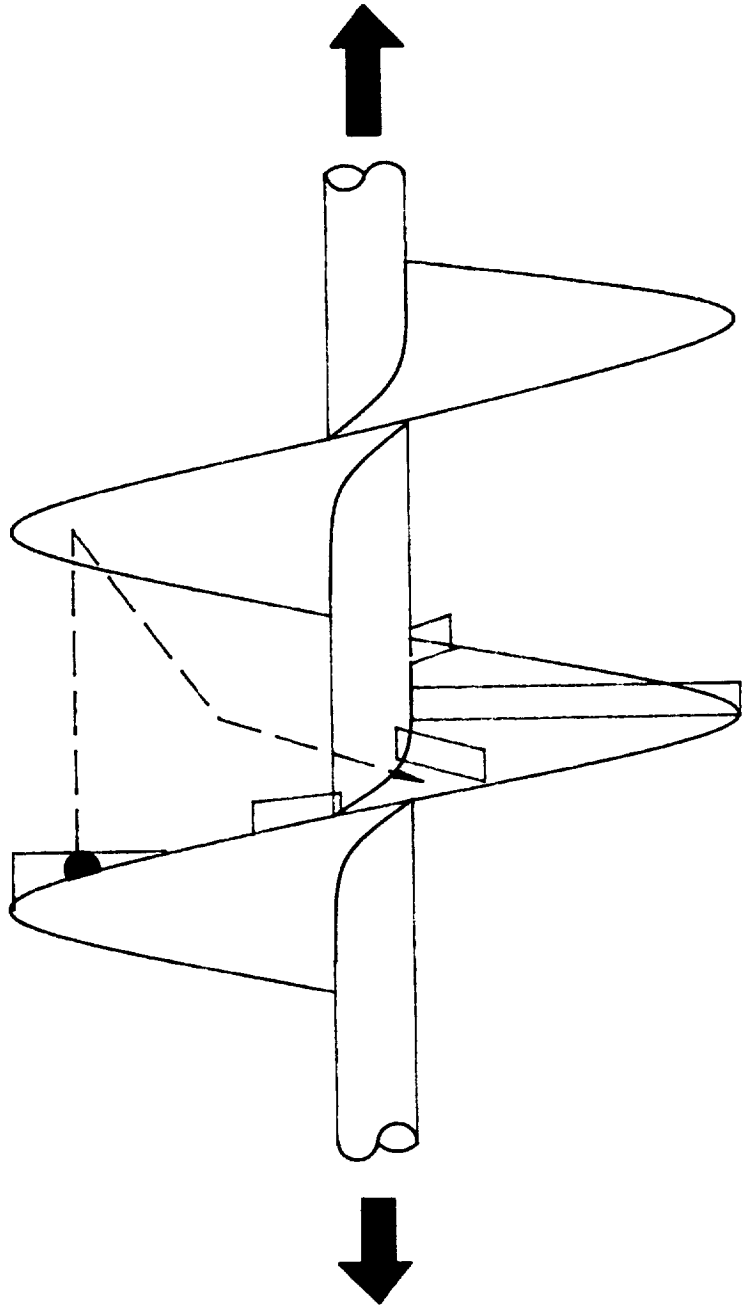


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PROBLEM STATEMENT

The objective of this project is to develop a mathematical model for a mechanism capable of transporting drill cuttings up a vertical shaft using only linear reciprocating motion.

Background

It is anticipated that there will be a need to drill into the lunar surface. It is also anticipated that conventional methods of cutting removal (fluid flushing) will not be practical. Therefore a method of cutting removal that relies on mechanical dynamics is needed. To accomplish this task, an accurate math model and prototype must be developed and tested.

Performance Objectives

The objective of the math model is to accurately predict the amount of material the auger is capable of transporting. The math model must be constructed to allow for variations of parameters such as pitch, fence height, fence separation, gravity and auger velocities.

The prototype must be capable of transporting material and providing information that can be used to improve the math model.

Constraints

The mechanism is allowed to move linearly along its center-line axis.

MATHEMATICAL MODEL

Introduction

The vertical reciprocating auger (VRA) is able to transport material by virtue of its geometry and motion. The auger studied is a common helical screw type with one pitch per turn and pitch equal to outside diameter. However, the relations that follow are generalized to predict particle dynamics of any screw type auger, through a choice of the appropriate geometric parameters. In this study, the auger reciprocates in the vertical axial direction only, coincident with a gravitational force, and is not subjected to a torque about its axis. The VRA differs from normal screw type augers by having an outside fixed sleeve and radially located vertical fences attached to the upper side of the helix. The fences prevent particles from rolling down the auger during transport.

To derive the mathematical model of particle dynamics, the motion of a single particle is studied throughout a single cycle of input motion to the auger. Three different reciprocating inputs are proposed; namely sinusoidal, a modified square wave and a modified sawtooth. Next, through multiple cycles of a reciprocating input, a transport rate of this particle up the auger will be predicted. The analysis will then be extended to include many particles, with a correction factor suggested from actual empirical results. This single particle analysis is reasonable, as the math model will show that particles at different radial locations along the auger will trace different paths in 3-space.

The particle motion is first analyzed by "unwrapping" a turn of the auger for a linear, or 2-dimensional representation (Fig 1). The "floor" and "ceiling" of a single auger turn make an angle, with the horizontal, of:

$$\theta = \tan^{-1} (P / 2\pi R_i) \quad (1)$$

where : P = Auger Pitch
 R_i = Any radius, i , from the central axis.

A particle is able to advance to higher fences through reflection off the ceiling. A particle begins at rest ahead of the first radial fence, and is accelerated upward with the auger. As the auger reaches a steady speed and begins to decelerate, the particle separates from the surface and moves upward. With sufficient kinetic energy, the particle impacts the ceiling at an incident angle θ_i to the ceiling normal and is reflected at an equal angle, θ_r , to the normal. The total angle of reflection from the incident path is $\beta = 2\theta$. The particle now has a horizontal component of $V \sin \beta$, which will allow it to clear the next fence up the auger. This process is repeated and material is transported vertically up the auger.

Inputs

A. Sinusoidal

The first reciprocating input studied was the sine function (Fig 2), in which the particle will reflect once per cycle. Figure (3) shows the particle position at t_n time increments as follows:

- t_0 : Auger and particle are at bottom of motion, velocity = 0.
- t_1 : Auger and particle now at half of amplitude. Auger begins to decelerate. Particle separates, travels upward at velocity v_{1p} , which is the maximum velocity of the auger, occurring at $y=0$.
- t_2 : Auger reaches top of amplitude, begins to accelerate downward, while particle continues upward at approximately v_{1p} .
- t_3 : At the ideal critical frequency of this system, the particle traveling upward at v_{1p} impacts the auger, traveling at $(-v_{1p})$ at time t_3 . The particle now reflects off of the ceiling at $2v_{1p}$.
- t_4 : As auger is decelerating in its downward motion particle impacts bottom, loses energy and settles above the next fence.
- t_5 : Auger and particle are at the bottom of travel - same as t_0 .

The sine input is advantageous since a simplistic driving mechanism could be constructed from a rotary driver. However, this input was not chosen since "tuning" the mechanism to a critical frequency would very difficult.

B. Modified Square Wave

The next input, that was considered, modeled a double-acting pneumatic or hydraulic actuator. This system input takes the form of a modified square wave (Fig.4), and involves an upward and a downward throw. With this input, the particle can complete two reflections per cycle (Fig 5) as the following time increments describe:

- t_0 : Auger and particle are at bottom of motion, velocity = 0.
- t_1 : Auger is nearing top of motion, and beginning to decelerate -- particle separates.
- t_2 : Auger has been brought to stop -- moving particle strikes ceiling of auger level at v_1 and is reflected off at approximately v_1 .
- t_3 : Particle impacts floor of auger, losing energy, just above the next fence and settles. Auger still at rest at its uppermost position. $t_3 \rightarrow t_4$ can be any length of time.
- t_4 : Auger is rapidly thrust downward, leaving particle suspended. Throw must be slightly greater than pitch to account for small drop of particle.
- t_5 : Ceiling of auger strikes particle and particle is reflected ahead of the next fence.
- t_6 : Auger is at rest at bottom and particle impacts, loses energy, and settles.
- t_7 : Cycle is completed--same as t_0 .

This square wave input has several advantages over a sinusoidal input. First, hydraulic and pneumatic actuators are simple, reliable, and easy to control. Also, the motion is no longer frequency dependent; in fact, any length of time can occur between t_3 and t_4 or t_6 and t_7 . Finally, two jumps are now obtained for every cycle of actuation.

The main disadvantage of this input is the length of stroke, which must be slightly greater than the pitch to impact the suspended particle. If the stroke is too small, so that the suspended particle does not strike the ceiling, it may bounce back over the fence and defeat the entire stroke.

C. Modified Sawtooth

The final input studied, and used for the actual test, is the modified sawtooth wave (Fig 6). This wave describes the output of a single acting pneumatic or hydraulic actuator. This sawtooth wave works similarly to the square wave for the upward throw, but decays with the exhaust of the actuator, rather than a downward thrust. The particle will now complete one reflection per cycle (Fig 7), as the following time increments describe:

- t_0 : The instant of time, just before the auger is accelerated upward, when the particle and auger are still at rest.
- t_1 : Auger is nearing top of motion, and beginning to decelerate--particle separates.
- t_2 : Auger has been brought to stop--moving particle strikes ceiling of auger level at v_1 and is reflected off at approximately v_1 .
- t_3 : Particle impacts floor of auger, which is moving downward, and loses energy. Between t_3 and t_4 the particle settles ahead of next gate.
- t_4 : Particle and auger come to stop at bottom of motion.
- t_5 : Cycle is completed--same as t_0 .

Although this input only moves the particle one jump per cycle, the sawtooth wave was chosen for testing due to its effectiveness and simplicity. Like the square wave, the sawtooth wave is not frequency dependent, and the efficiency of mass transport per cycle is not affected by frequency. The sawtooth wave can use a shorter stroke, since it only needs to transfer enough kinetic energy to particles to cause a reflection. At the lower limit, an infinitesimally small stroke can be used with a high

impulse of energy to the auger. In actuality, the stroke length varies with the force and acceleration of the actuator.

Two Dimensional Dynamic Analysis

With the auger "unwrapped" at a particular radius R_i , a dynamic analysis can be performed on a single particle to predict its motion. A force balance is first done on the auger/particle system for the vertical throw at the actuator, from rest at the bottom to point of separation.

$$m_{sys} \ddot{x}_{sys} = F_{act} - m_{sys}g - \text{drag} \quad (2)$$

where m_{sys} includes the mass of the particles and auger, and F_{act} is the actuator force. Drag on the particle is assumed negligible. Rearranging,

$$\ddot{x}_{sys} = \frac{F_{act}}{m_{sys}} - g \quad (3)$$

where \ddot{x}_{sys} is constant throughout the throw.

Assuming that the particle does not separate until the actuator throw, x , is completed, the relationship for x is :

$$x = x_0 + v_0 t + .5 \ddot{x}_{sys} t^2 \quad (4)$$

where x_0 = position at bottom = 0, and v_0 = velocity at bottom = 0.

Actuator throw time, t , is :

$$t = \sqrt{2x / \ddot{x}_{sys}} \quad (5)$$

and separation velocity, v_L , is:

$$v_L = \ddot{x} t \quad (6)$$

The particle now separates and is undergoing freefall in a vacuum with an initial velocity, v_L . The distance to impact the ceiling is the pitch, P , where :

$$P = v_L t - .5gt^2$$

or,

$$.5gt^2 - v_L t + P = 0 \quad (7)$$

solving for the time of impact, t , with the ceiling :

$$t = \frac{v_L \pm \sqrt{(v_L)^2 - 2gP}}{g} \quad (8)$$

and the impact velocity, v_1 , with the ceiling is :

$$v_1 = \sqrt{(v_L)^2 - 2gP} \quad (9)$$

The particle is assumed to impact perfectly elastically, and recover the entire v_1 velocity, now at an angle $\beta = 2\theta$ in a direction defined as N_1 (Fig 8). A direction N_2 is defined orthogonal to N_1 , to form a rotated set of coordinate axes. The true y--axis is defined positive in a direction opposite to gravity, and the x--axis is defined horizontally.

The N_1 and N_2 differential equations of motion are:

$$\ddot{N}_1 = g(\cos\beta) \quad (10)$$

$$\ddot{N}_2 = -g(\sin\beta) \quad (11)$$

with initial conditions

$$\begin{aligned} N_1(t_0) &= 0 \\ \dot{N}_1(t_0) &= v_1 \\ N_2(t_0) &= 0 \\ \dot{N}_2(t_0) &= 0 \end{aligned} \quad (12)$$

with t_0 being the time immediately after impact.

Solving the N_1 and N_2 differential equations of motion subject to the initial conditions :

$$N_1 = \frac{g(\cos\beta)t^2}{2} + v_{1,t} \quad (13)$$

$$N_2 = \frac{-g(\sin\beta)t^2}{2} \quad (14)$$

Now converting N_1 and N_2 positions to x-y coordinates at the at the ceiling impact point yields :

$$x = N_1(\cos\gamma) + N_2(\cos\beta) \quad (15)$$

$$y = N_1(\sin\gamma) + N_2(\sin\beta) \quad (16)$$

where $\gamma = 90 - \beta$

A computer program of x-y position was plotted (Appendix) for expected values of actuating force. The velocity is high enough, and the corresponding travel time is short enough, that gravity has a negligible effect on the particle path. The path appeared to be in the N_1 direction, or in other words, a straight, as opposed to a parabolic, path seemed to be traced.

An assumption can now be made that the reflected paths can be approximated by straight lines for the the 3--dimensional analysis that follows, when the auger is "rewrapped".

3-Dimensional Position Analysis

Since the actual path of a particle does not lie in a single plane, a 3-dimensional analysis is required. Figure 9 shows a top view of an auger segment with a path projection of the particle, starting at radius R_i , at the i(th) position along a fence.

Before the particle can impact the floor of the auger after a ceiling reflection, it impacts the outside sleeve. Viewed from this same top figure, the particle reflects about the surface normal at an angle of $2(\alpha)$. Alpha varies from zero degrees to ninety degrees as the starting point, R_i , varies from zero to R_0 . Orientations of planes A:A and B:B are shown on the top view, normal to the incident path and sleeve reflection path, respectively.

View A:A is shown on figure 10 and is identical to the 2-dimensional model view, except that the sleeve impact point, I, is shown, along with a projection of reflected path (dashed line).

From the top view,

$$D_1 = \sqrt{(R_0)^2 + (R_i)^2} \quad (17)$$

and from A:A :

$$F_1 = D_1 / \sin\beta$$

$$P_1 = F_1 \cos\beta = \frac{\sqrt{(R_0)^2 + (R_i)^2}}{\tan\beta} \quad (18)$$

but,

$$\tan\alpha = R_i / \sqrt{(R_0)^2 + (R_i)^2}$$

and,

$$P_1 = R_i / \tan\alpha \cdot \tan\beta \quad (19)$$

View B:B is also shown on Figure 10 , and is taken normal to the path between I and floor impact. The Z direction remains the same, and P_1 is repeated. It is noted that the same β angle between the vertical climb and ceiling reflection is also between the Z axis and the sleeve reflection path. C_1 is defined as :

$$\begin{aligned} C_1 &= P - P_1 \\ &= m_1 + r_r \end{aligned} \quad (20)$$

where r_r = ramp rise from lift-off

Define $Z_p = r_r$. Z_p can be solved from the intersection of two relationships, as shown in figure 11 . The straight line in this figure represents the particle path from view B:B. The parabolic curve represents the climb in the Z - direction of the auger for position along Y_{bb} . For the first relationship,

$$Z_p = C_1 + mY_\phi \quad (21)$$

where $m = \text{slope}$

$Y_\phi = \text{a distance along } Y_{bb} \text{ as } \phi \text{ is varied}$

but since,

$$\theta = .5\beta = \tan^{-1}(P / 2\pi R;) \quad (22)$$

and,

$$\frac{\Delta Y_\phi}{\Delta z_{bb}} = \tan\beta = \tan(2\tan^{-1}(P / 2\pi R;)) = -1 / m \quad (23)$$

so that,

$$Z_p = \frac{-Y_\phi}{\tan(2\tan^{-1}(P / 2\pi R;))} + P - R; / \tan\alpha \cdot \tan\beta \quad (24)$$

The second relationship can be derived with the aid of figure 12 . This figure is a top view of the auger with the horizontal axis going in the Y_{bb} direction, starting at the sleeve impact point, I. Φ is a variable representing the angle between the fence reference line and any other radial line. By varying ϕ from $(90 - \alpha)$, which is at the sleeve impact normal, to 2π , a relationship between Y_{bb} and ϕ can be found. τ is defined such that :

$$\tau = \Phi + \alpha - 90^\circ$$

and from the figure's geometry :

$$y_{\phi} = R_o \cos \alpha - R_i / \tan(\tau) \quad (25)$$

and since $\alpha = \sin^{-1}(R_i / R_o)$

then

$$y_{\phi} = R_o \cos(\sin^{-1}(R_i / R_o)) - \frac{R_i}{\tan(\phi + 2(\sin^{-1} R_i / R_o) - 90^\circ)} \quad (26)$$

However, for a constant R_i , the rise of the auger, Z_r , varies linearly with angle of twist, ϕ :

$$Z_r = P\phi / 360^\circ \quad (27)$$

or by rearranging,

$$\phi = 360^\circ Z_r / P \quad (28)$$

which can be substituted into eqn. (26) to yield :

$$y_{\phi} = R_o \cos(\sin^{-1}(R_i / R_o)) - \frac{R_i}{\tan(360^\circ Z_r / P + 2(\sin^{-1}(R_i / R_o)) - 90^\circ)} \quad (29)$$

Now solving for Z_r in terms of Y_{ϕ} :

$$Z_r = \frac{P}{360^\circ} \left[\tan^{-1} \left[\frac{R_i}{-y_{\phi} + R_o \cos(\sin^{-1}(R_i / R_o))} \right] + 90^\circ - 2\sin^{-1}(R_i / R_o) \right] \quad (30)$$

Now eqn. (24) and (30) can be solved simultaneously for Y_ϕ . This value of Y_ϕ is given the name S_1 , which is the distance from the sleeve impact point along Y_{bb} .

The particle landing position at S_1 along Y_{bb} can then be referenced to the center of the auger by matrix transformation.

Finally, R_i can be varied from R_{tube} to R_0 to plot a landing path.

Throughput Prediction

From landing position after / cycle, an estimate can be made for throughput rate, based upon single particle analysis. Using equations (24) and (30), a computer program was written (see Appendix) to calculate s_1 in the Y_{bb} direction, starting from wall impact. A 12 fence per turn auger was overlaid on a plot landing of position (Fig. 16) from computer generated data points, which account for the rise of the floor (Fig 17). The computer program was only used to generate data from $R_i = 1.75$ " to 2.50 " since multiple wall reflections were involved, and the math model only accounted for one. For 10 particles from figure 16, the following data was taken :

# of particles	# of fences jumped	%
2	2	20
4	3	40
4	4	40

Figure 15 shows the distribution comparison with experimental results. The average number of fences jumped per stroke may then be determined by :

$$(.2) (2) + (.4) (3) + (.4) (4) = 3.2 \text{ fences / stoke}$$

Assuming the distribution of sand in the auger is approximately 1 pound per turn, and a fence spacing of 12 fences per turn, the distribution of sand may be expressed as :

$$1 / 12 = .08333333 \text{ pounds / fence}$$

The predicted mass throughput may then be expressed as :

$$(3.2 \text{ fences / stroke}) (.08333333 \text{ pounds / fence}) = .26667 \text{ # / stroke}$$

This, then represents the mass throughput predicted by the math model. At the ideal conditions assumed for the derivation, the mass throughput is .26667 pounds / stroke.

Lunar Application

The application of lunar constraints to the performance characteristics of the auger was accomplished by varying the gravitational constant in the path profile program (see Appendix). The initial, Earth based model called for a separation velocity of 20.5 ft / sec in order to achieve a particle path that was virtually linear.

When the lunar gravity constant was substituted into the program, the required separation velocity was found to be around 4 ft / sec. Atmospheric drag forces were considered negligible for the Earth model and none existent for the lunar model.

PROTOTYPE and TEST RESULTS

The motivation for building a prototype is to determine if the concept on paper is feasible on a practical, real world level. If some degree of practicality can be demonstrated, then tests can be run and the results compared with the predictions of the math model.

The setup used for prototype testing of the Vertically Reciprocating Auger (VRA) is described by Figure 13. Specifically, the setup consists of the following elements :

- 1) Auger--The auger supplied to this group is a three foot section of a steel auger used on earth to drill post holes. It is five inches in diameter, with a pitch of five inches (Fig 14). To prepare the auger for duty as a VRA, it was sandblasted and fitted with a total of twelve "fences" per revolution. These fences are simply constructed of thin wooden strips, one inch high, attached to the auger service with glue and extending from the auger's centerline to its outer edge. Finally, the auger is wrapped in a transparent plexiglass sleeve to contain the particles as they ascend while allowing observation of particle movement.
- 2) Test Frame--The purpose of this component is to support the VRA and its driving mechanism during testing. A length of pipe fastened vertically above the auger runs through its hollow center, serving as a guide rod to constrain the augers motion to a purely vertical reciprocation.
- 3) Driving Mechanism--An air actuator is used to provide the force needed to drive the auger vertically. An air actuator was chosen because it is much cheaper than an electrical or hydraulic actuator, and simpler than a purely mechanical drive of the "Geneva Mechanism" variety. Since mass transfer using the sawtooth wave form model is not expected to be frequency dependent, control of the air actuator is accomplished using a simple hand valve. The actuator has a bore of approximately four inches, and the force produced at any given line pressure can be calculated for use in the math model.

Testing consisted of two separate stages, the first in which the single particle math model was tested using ordinary steel "BB's", and the second in which the mass transport of sand through the VRA was observed. Data from these tests is given in Tables 1--4 on the following pages.

The single particle BB test consisted of two parts, the first in which ten BB's were lined up along one arbitrary fence within the auger. The auger was then displaced once and allowed to sink back in a manner consistent with the sawtooth model. The distribution of the ten BB's within the auger was then recorded as the number of fences jumped by each particle. Approximately 40% of the BB's ended up at or below their starting fence; they jumped backwards and made either negative or zero progress up the auger. However, the 60% that made positive progress up the auger made a greater relative progress. In other words, the positive progress BB's jumped more positive fences than the negative progress BB's jumped negative fences. This provides a net positive flow of BB particles up the auger. From the overall data, it is determined that the average number of fences jumped by the BB particles per stroke of the VRA is 0.71, confirming the theory behind the VRA--that particles will indeed ascend the auger on a net basis.

The second part of the BB particle test consisted of placing a single BB at the bottom fence, then counting the number of strokes necessary to pass this BB through a total of 24 fences, or two revolutions up the auger. If the value of 0.71 fences jumped per stroke, found in the first part of the BB test, is correct, then the total number of strokes required to move the BB up 24 fences is $24 / 0.71 = 33.8$ or 34 strokes. The data taken on this second part agrees with this prediction, showing an average of 31.2 or 31 strokes required to move the BB 24 fences. From the close agreement of the data taken in both parts of the single particle model BB test, it is concluded that the tests were uniformly performed, with little error introduced by the operators.

The second stage of testing involved a determination of the approximate mass flow rate of sand through the auger. Ordinary construction sand, used in the manufacture of concrete, was utilized. It was dried thoroughly and purged of any particles larger than 3/4 inch in diameter. The bottom of the VRA was filled with this sand, and kept full while a number of strokes were applied to distribute sand throughout the auger. The depth of sand was brought to a level that was at least covering over the top of all fences. A series of tests were then run in which a total of twenty strokes were applied while the sand exiting the top of the VRA was collected. The data from this test shows that an average

of 1.5 pounds of sand passes through the VRA in twenty strokes, which is equivalent to a mass transfer rate of 0.075 pounds per stroke.

The tendency for the particles to jump backwards, which was observed in the BB test, was not nearly so prevalent in the sand test. Since the sand particles are much smaller than the BB's, it is nearly impossible to test a small group of them and get an exact distribution as was the case with the BB's. However, observation of the sand as it ascends the VRA indicates that backwards jumping of fences is much less of a factor in the overall mass transport of the sand than it is in the transport of the BB's.

This difference in behavior can be attributed to the damping characteristics of the two different transport mediums. The BB particles are quite elastic in their motion, bouncing wildly around inside the VRA on pathlengths spanning up to seven fences. When a BB strikes the floor of the auger close behind a fence, it has a tendency to bounce up against and back off of the rear of that fence, sending it in a backwards direction which causes it to become part of the 40% which end up below their starting fence. The collisions that the BB makes with the auger surface are metal--metal collisions, which incur very little damping. In contrast, the sand particles exhibit a great deal of damping. As they proceed along their respective pathlengths, each particle comes into contact with hundreds of other sand particles. These midair collisions damp out some of the energy of the particles, causing them to settle more quickly after their initial collision with the ceiling above. In addition, the sand particles tend to "coat" the surfaces within the VRA, so that collisions with the floor or sleeve are likely to be damped by collisions with other particles already on those surfaces. Thus the energy of the system, which was initially provided by the thrust of the VRA stroke, is quickly lost through damping, and the sand particles settle down without bouncing backward down the auger.

This explanation is affirmed by observation of a test with many BB particles. If the bottom of the VRA is filled with, say, 500 BB's, then the motion of the BB's through the VRA becomes much more like that of the sand, that is to say, the BB particles tend to move as a group up the auger with much less of a tendency to bounce backwards. Only when a "straggler" BB gets caught below the group, without damping from its

neighbors, does is tend to exhibit a great deal of negative movement through the VRA. When this happens, its motion becomes like that of the BB particles in the first BB experiment in which the distribution of ten BB's for one stroke was studied.

It should be noted that the line pressure used for the BB test was 35 psi, while the pressure used for the sand test was 50 psi. An increase in pressure was needed to accomodate the weight of the auger full of sand.

CONCLUSIONS and RECOMMENDATIONS

The VRA device as tested held approximately one pound of sand per turn. At the distribution of particles given by the math model, an average jump of 3.2 fences/stroke, the mass throughput was predicted to be .2667 pounds/stroke. This is a factor of 3.56 times greater than the actual throughput, which was found to be .075 pounds/stroke. For the test set of twenty strokes, the math model predicts a total throughput of 5.333 pounds, compared to the actual throughput of 1.5 pounds.

The reasons for this discrepancy are numerous. For example, the approximate mass of sand per turn, which was assumed to be one pound, is in fact constantly changing and varies greatly. Additionally, the math model does not take into account the fact that there is a certain amount of zero and negative progress of sand (though there is certainly less with sand than there is with the BB particles). Damping effects, which lower the energy of the particles and cause them to settle quickly, are not considered in the math model. In short, the math model represents the idealized case; it is not surprising that "real world" performance of the VRA is somewhat below predicted levels. Still, the basic theory behind the VRA--that there will be a net positive flow of particles up the auger--is confirmed.

The goal of this investigation was twofold: first, to prove the theory behind the VRA; second, to propose a mathematical model which can predict throughput to some reasonable degree of accuracy. Both goals have been met, with the mathematical model differing from the real world case by a factor of only 3.56. Based on our experimental results, then, a

correction factor of $1/3.56 = .281$ for the math model prediction is suggested.

The actuator method of VRA drive, used in conjunction with the modified sawtooth math model presented in this report, turned out to be a simple and effective combination, in terms of both analysis and implementation. The setup has, apart from the control valves, only one moving part. It is not frequency dependent, and thus requires neither tuning nor precise control. Finally, it is compact and, due to its paucity of moving parts, quite efficient (nearly as efficient as the air compressor used to supply the air actuator). A system similar to this one, then, would be a good choice for a lunar application.

The following recommendations are made concerning the math model and auger design :

- Modify the given math model to predict throughput rate for a sine wave input, and predict an optimal resonant frequency.
- Predict throughput for and test a square wave input that allows two particle jumps each cycle. This will require auger throws to be greater than the pitch, depending upon auger design.
- Consider the use of reflectors above the fences that effectively increase the pitch of the ceiling.
- Consider the use of a multiple helix auger that allows both steep pitch and low ceiling heights.
- Explore the possibilities of optimizing such parameters as fence height, actuator throw, actuator pressure, sand particle size, feed rate and fence spacing.

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June 1972

Operational Mathematics

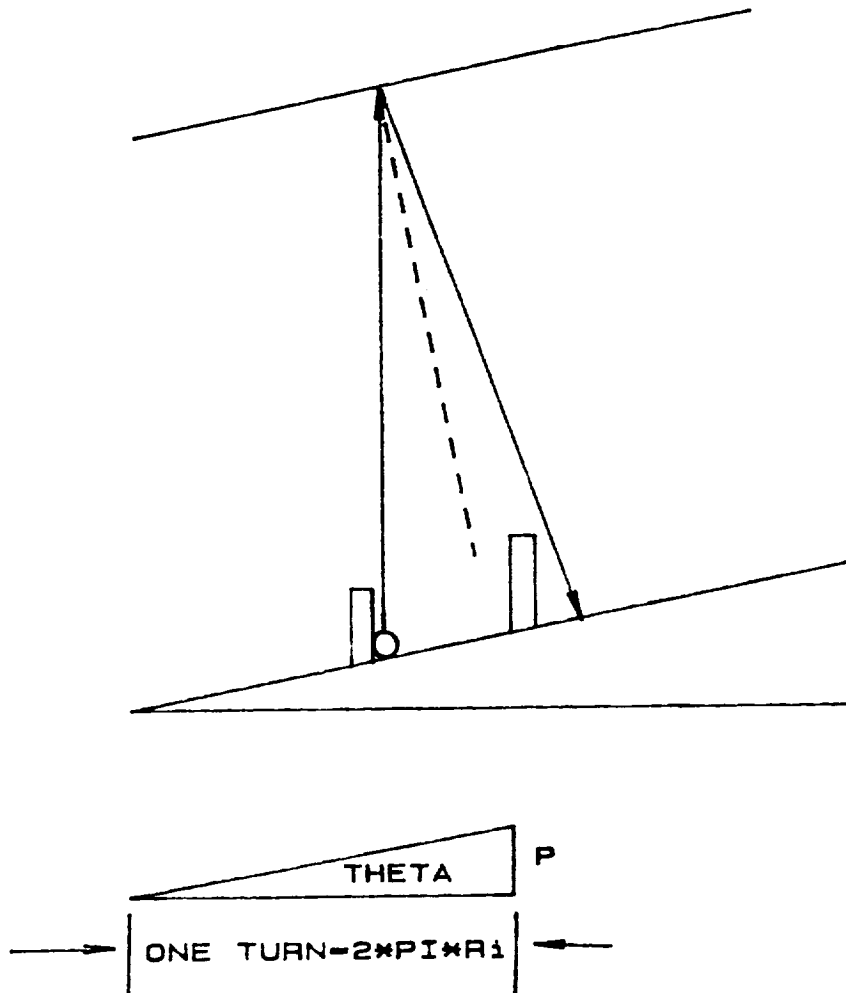
Churchwell

McGraw Hill

FIGURES

Figure 1

"UNWRAPPED" AUGER
AT A
RADIUS R_i



SINE INPUT
AUGER POSITION PLOT

Figure 2

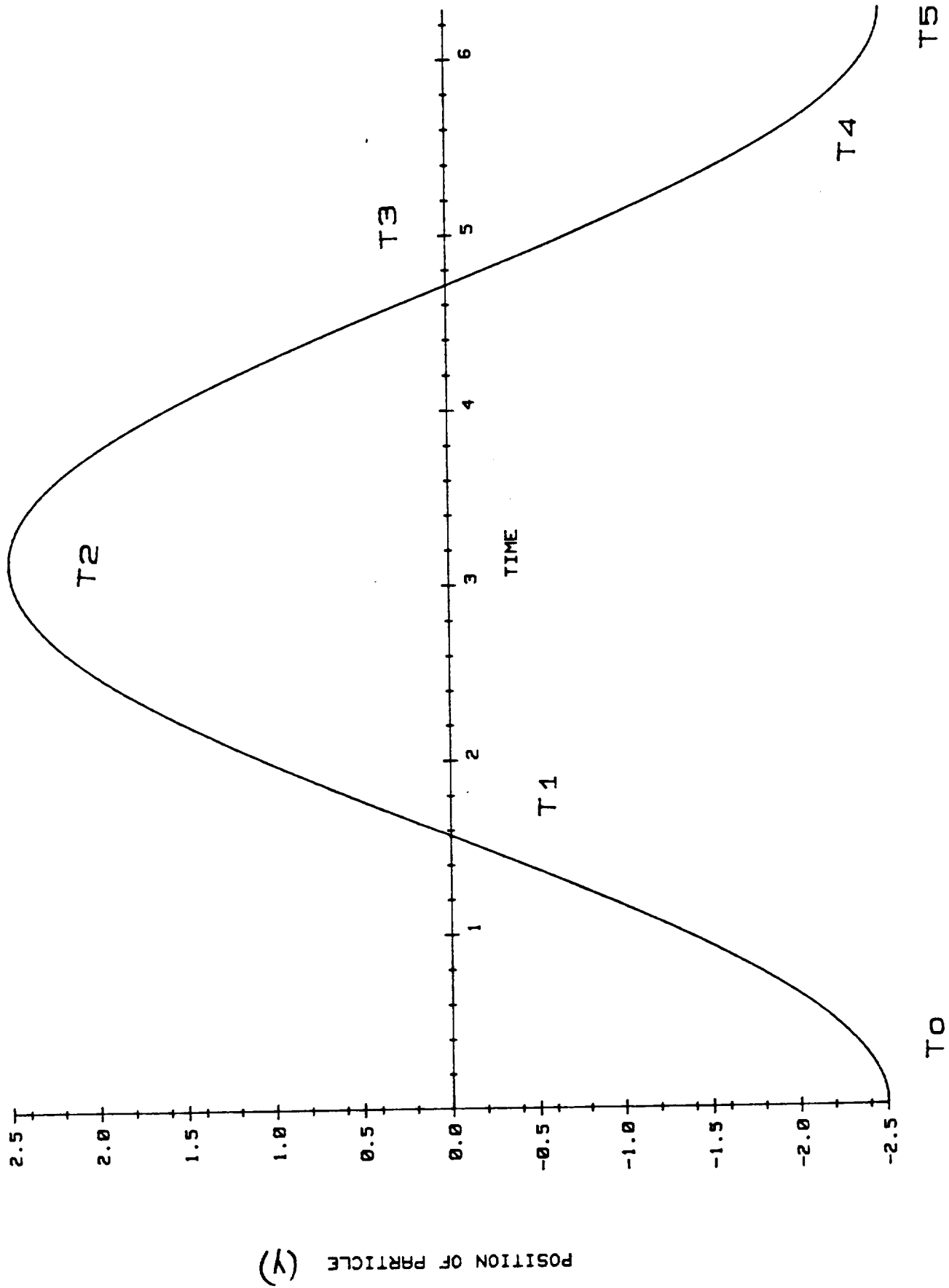


Figure 3

SINE INPUT PARTICLE POSITION, VELOCITY PLOT

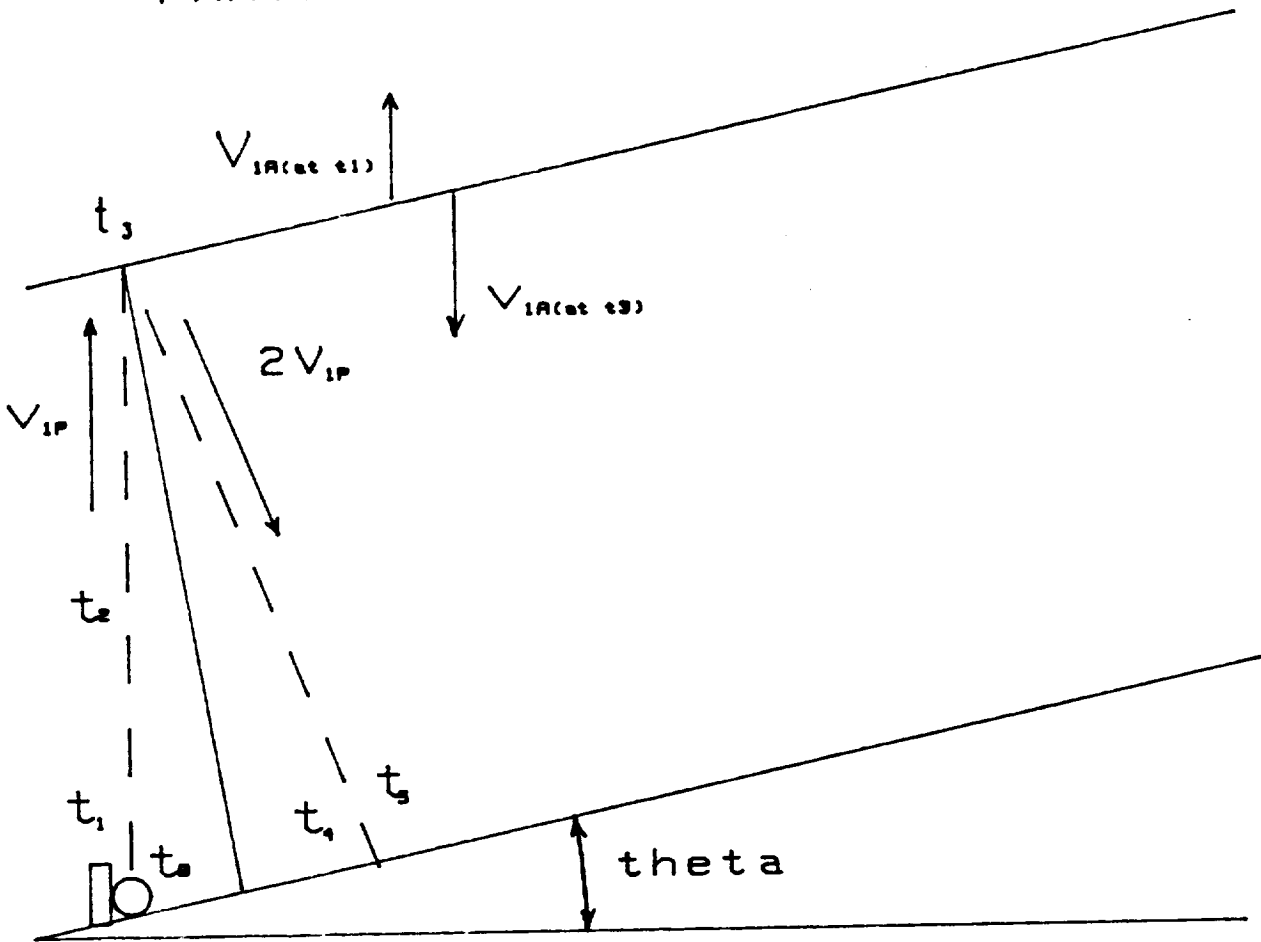


Figure 4

Modified Square Wave
DOUBLE ACTUATING
AUGER POSITION PLOT

$$t_1 \gg t_0, t_2$$

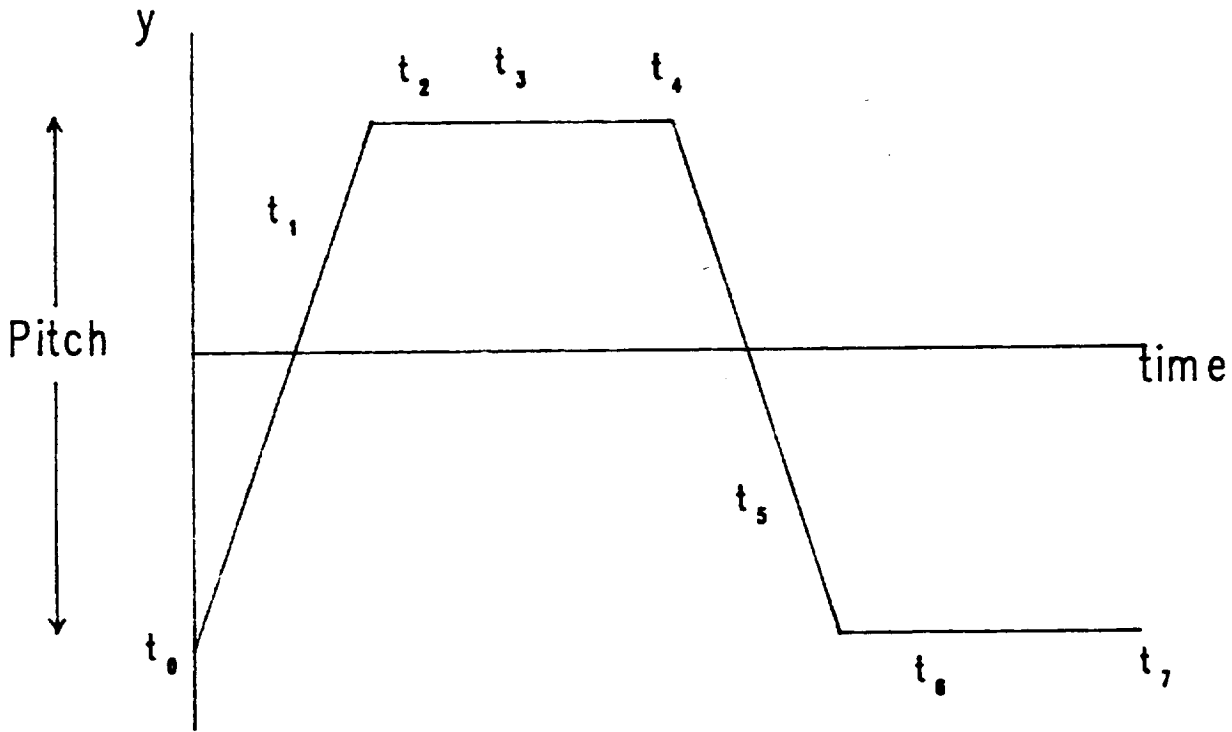


Figure 6

Modified Sawtooth

Single Actuation
Auger Position Plot

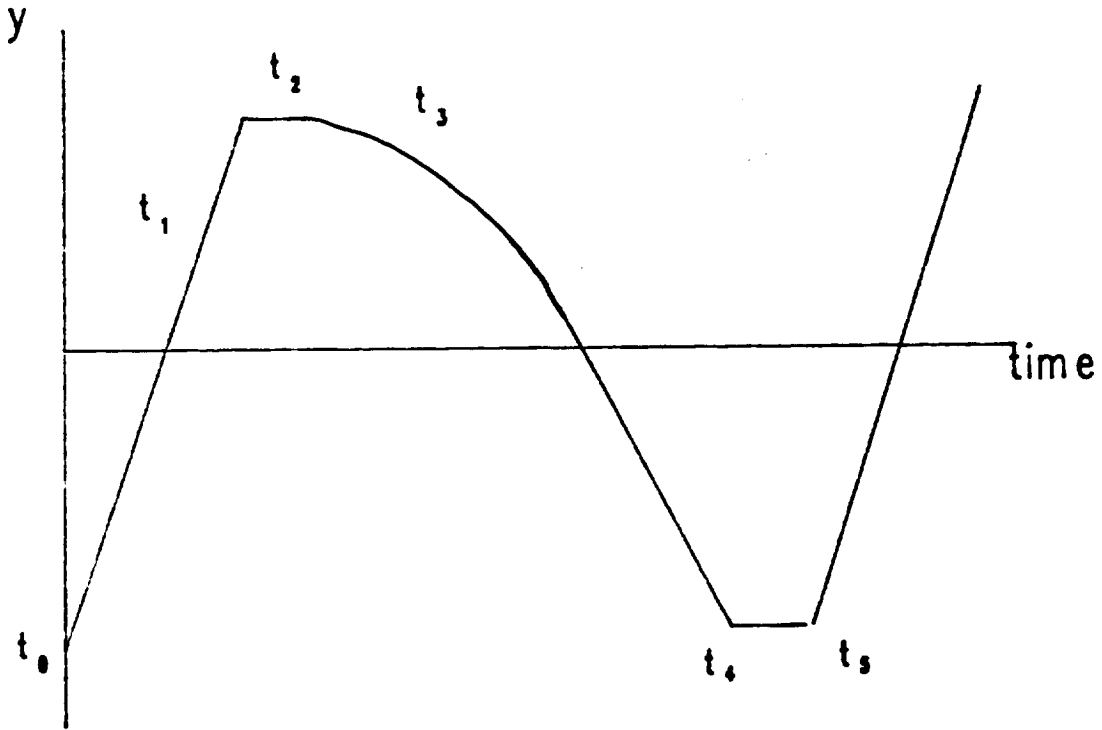


Figure 8

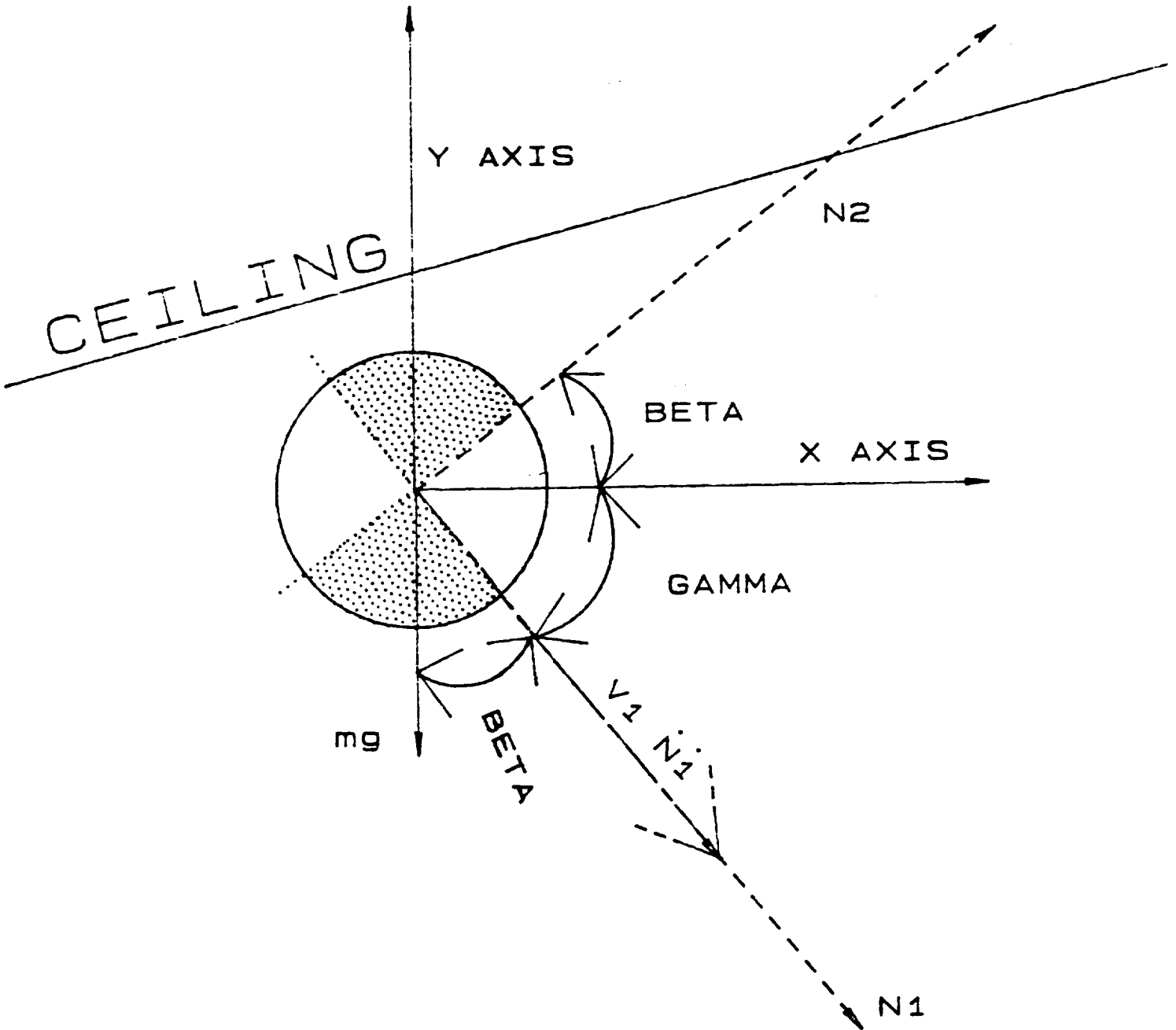


Figure 9

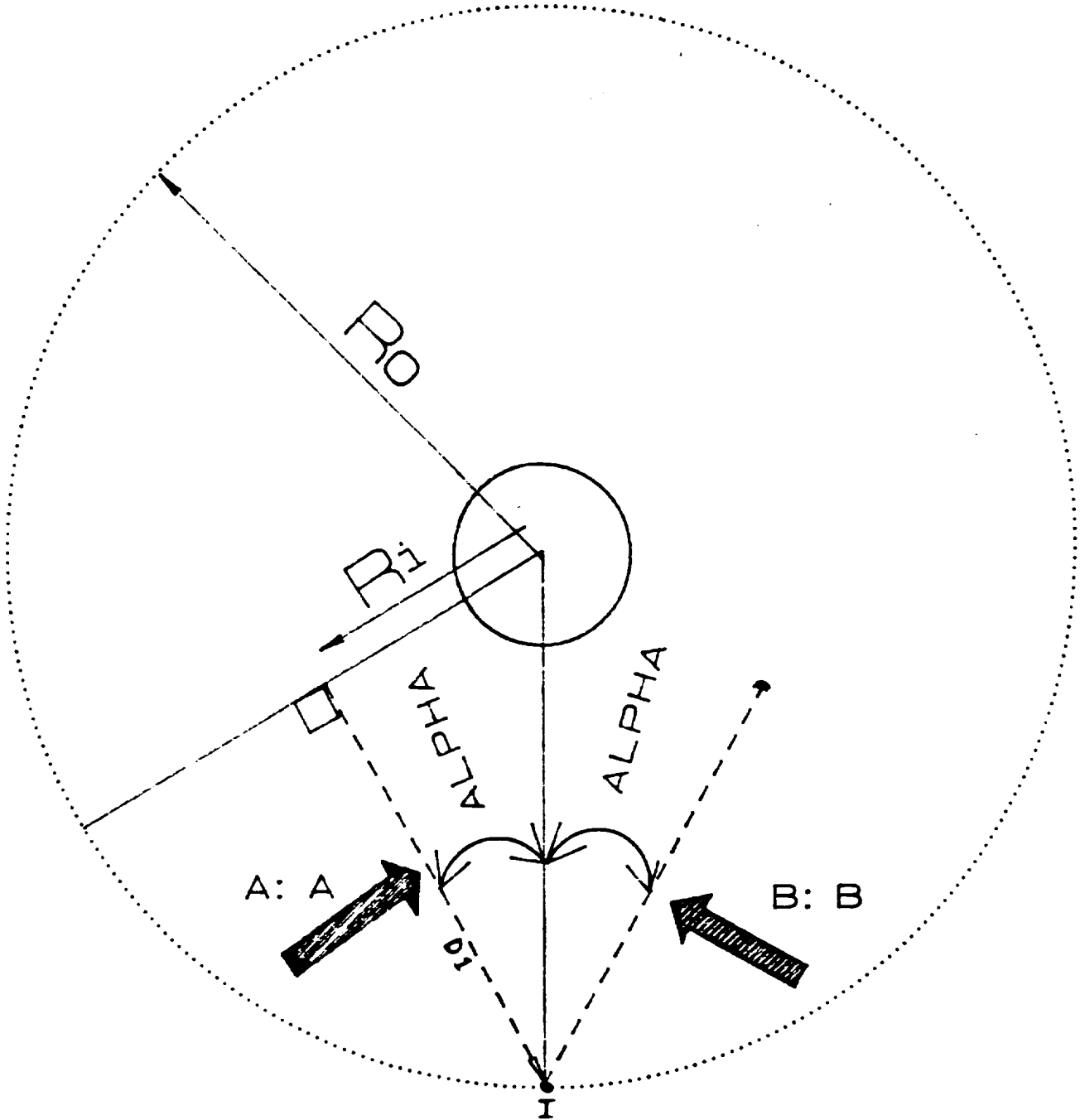


Figure 10

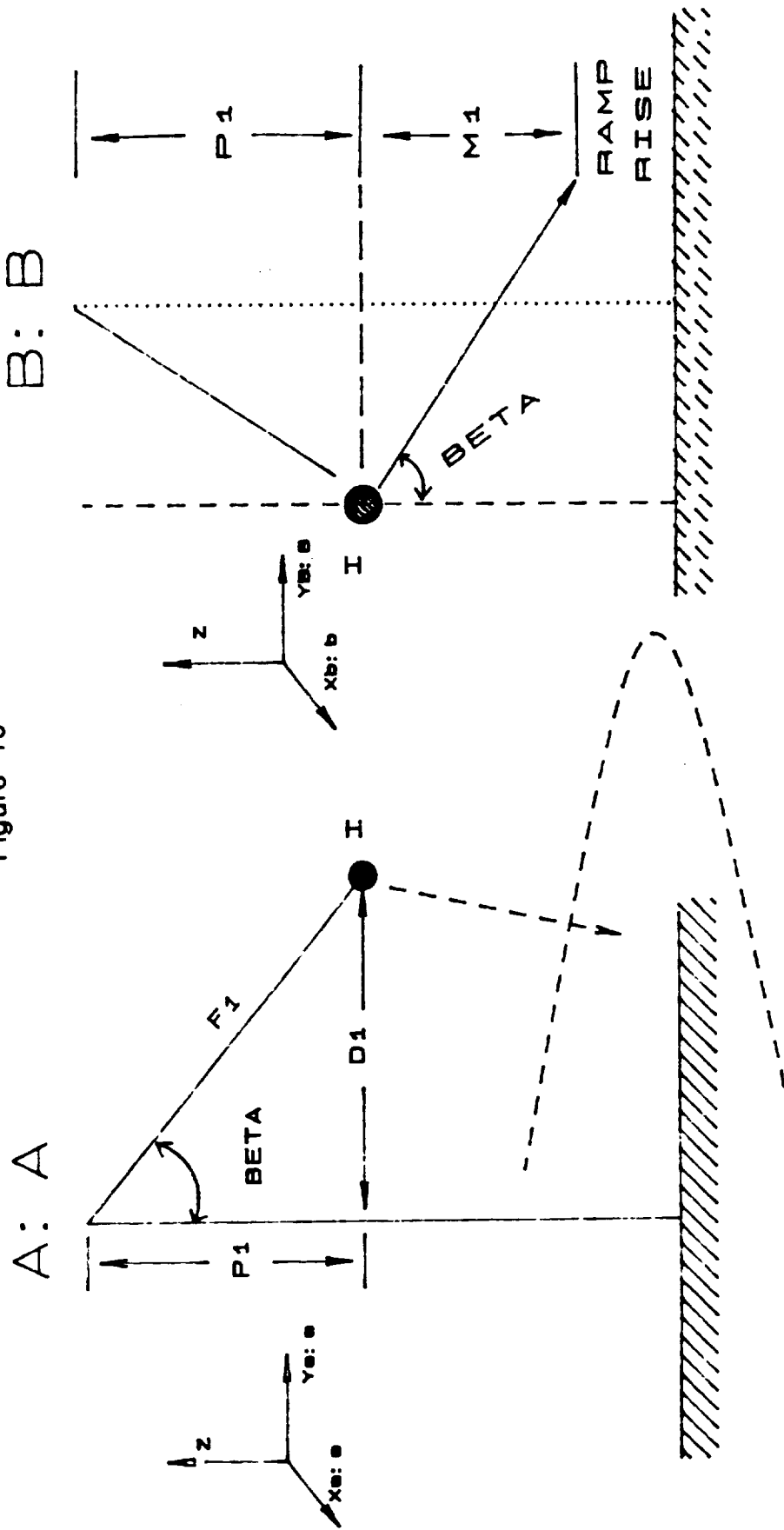


Figure 11

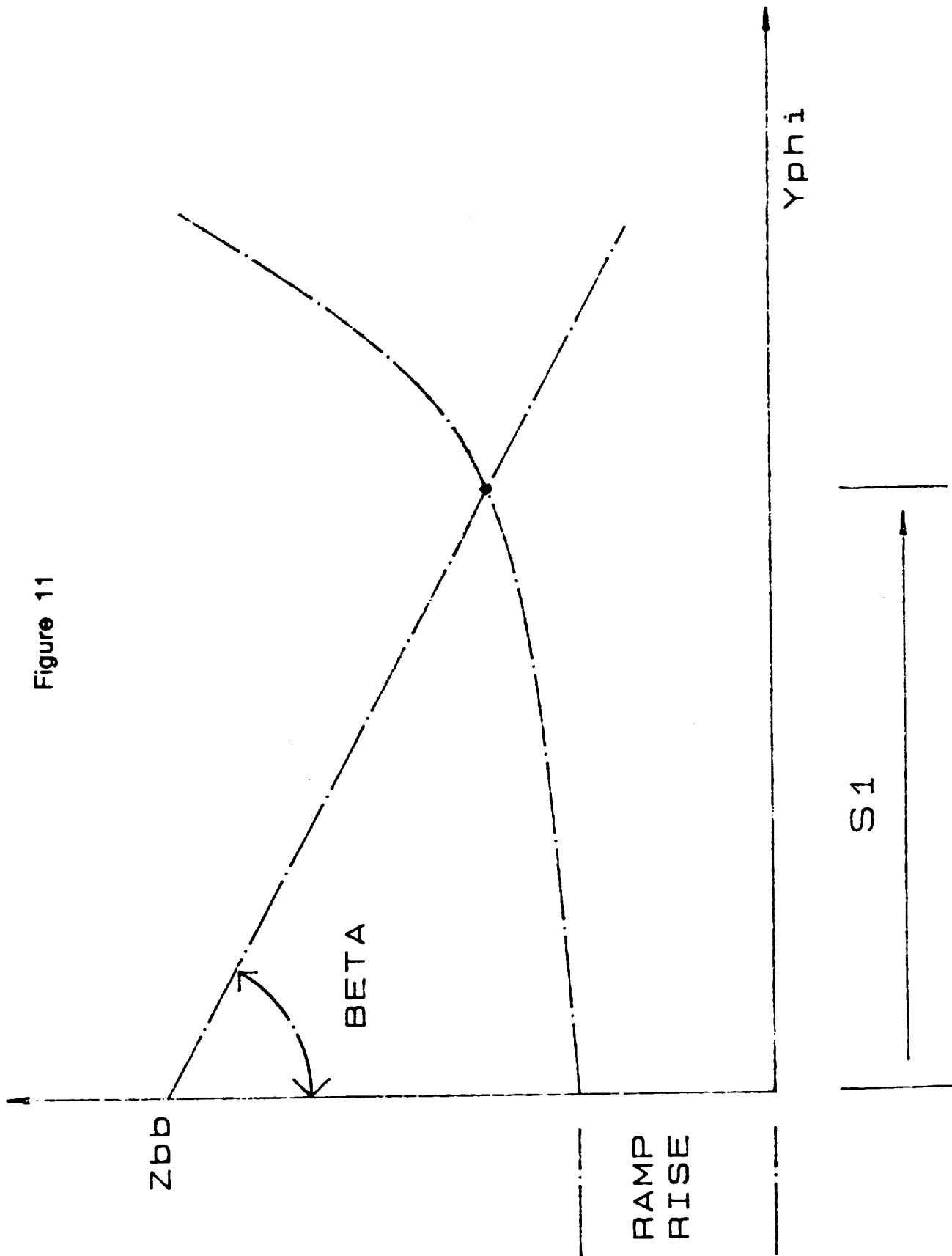


Figure 12

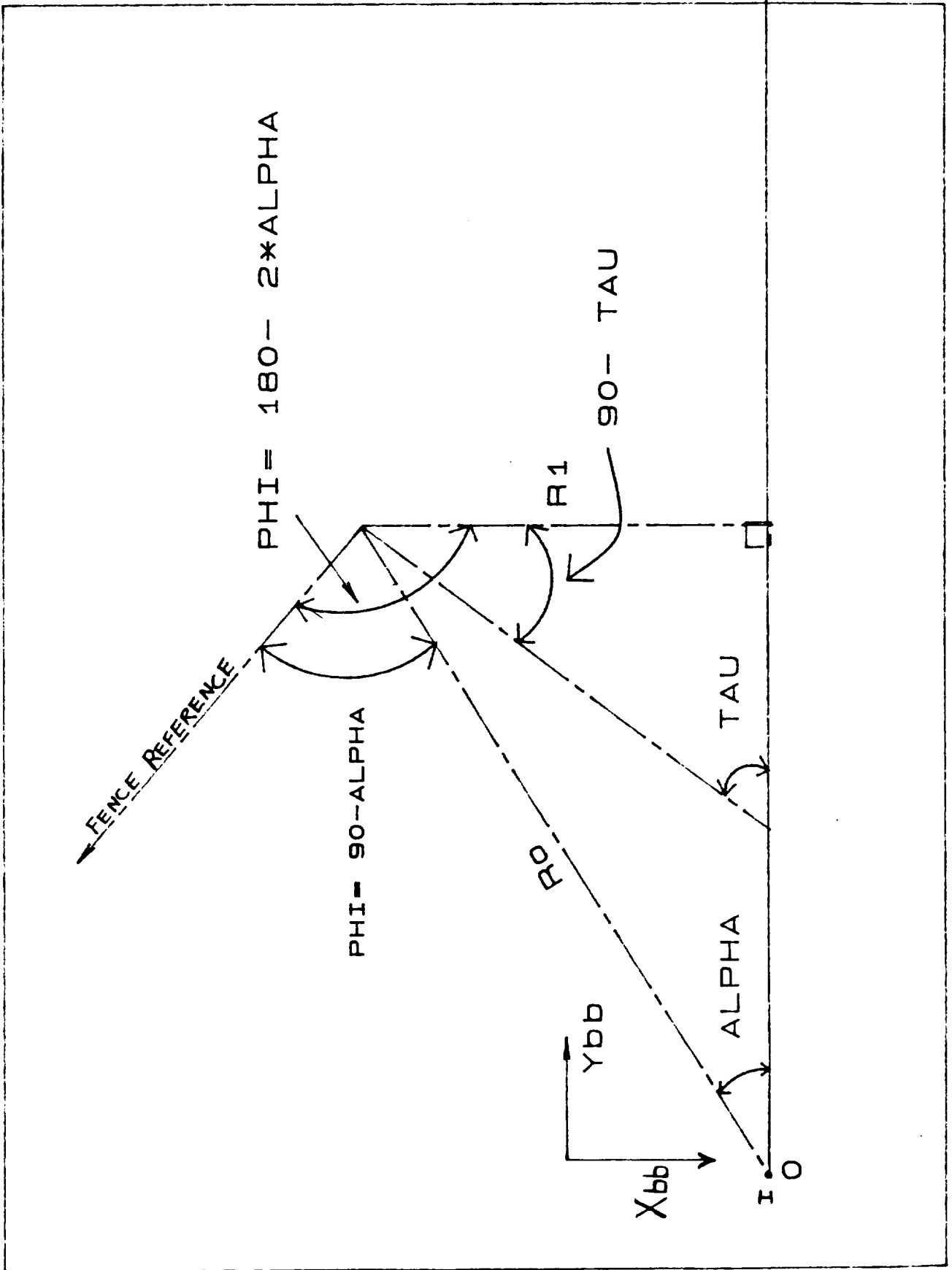


Figure 13

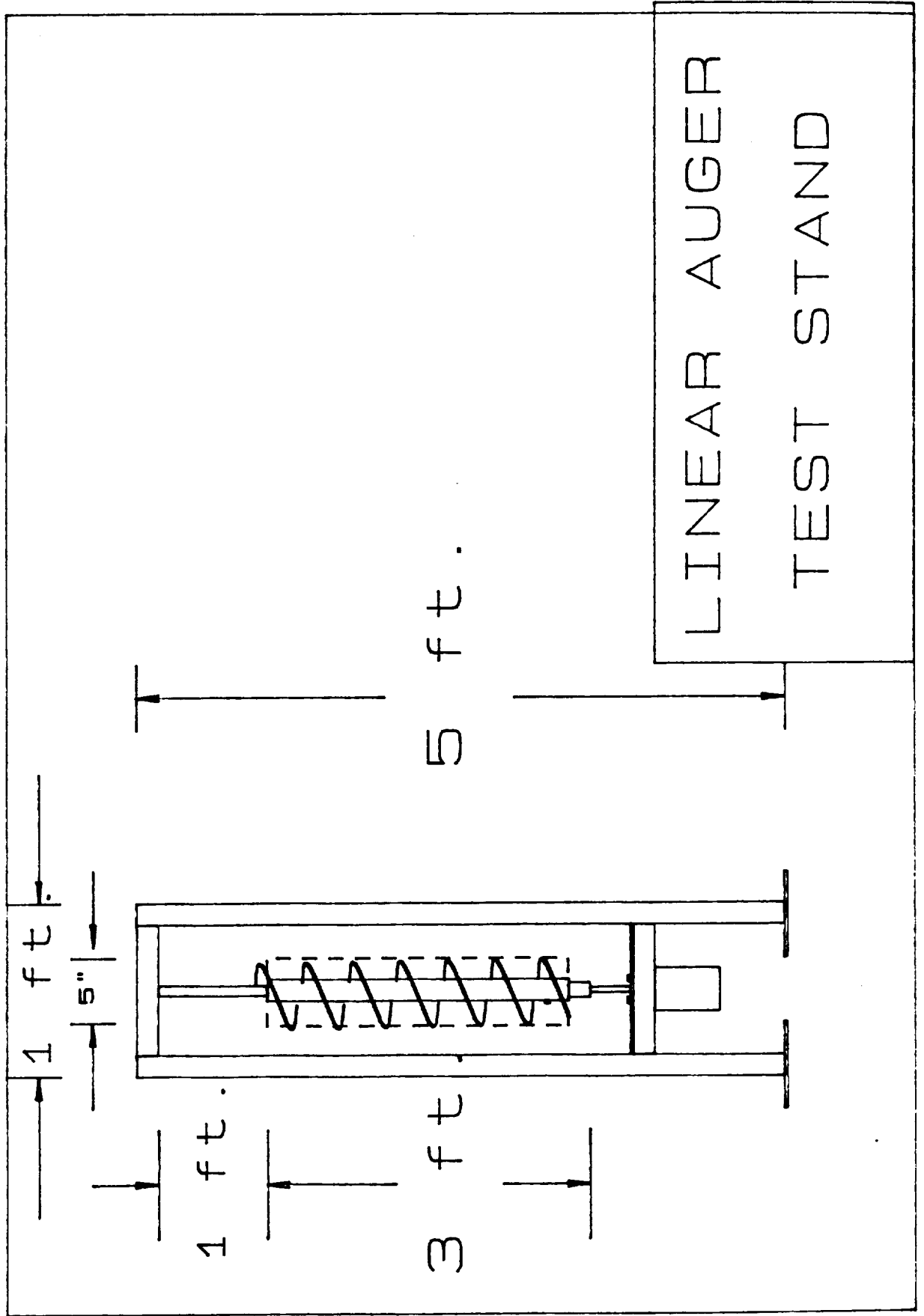
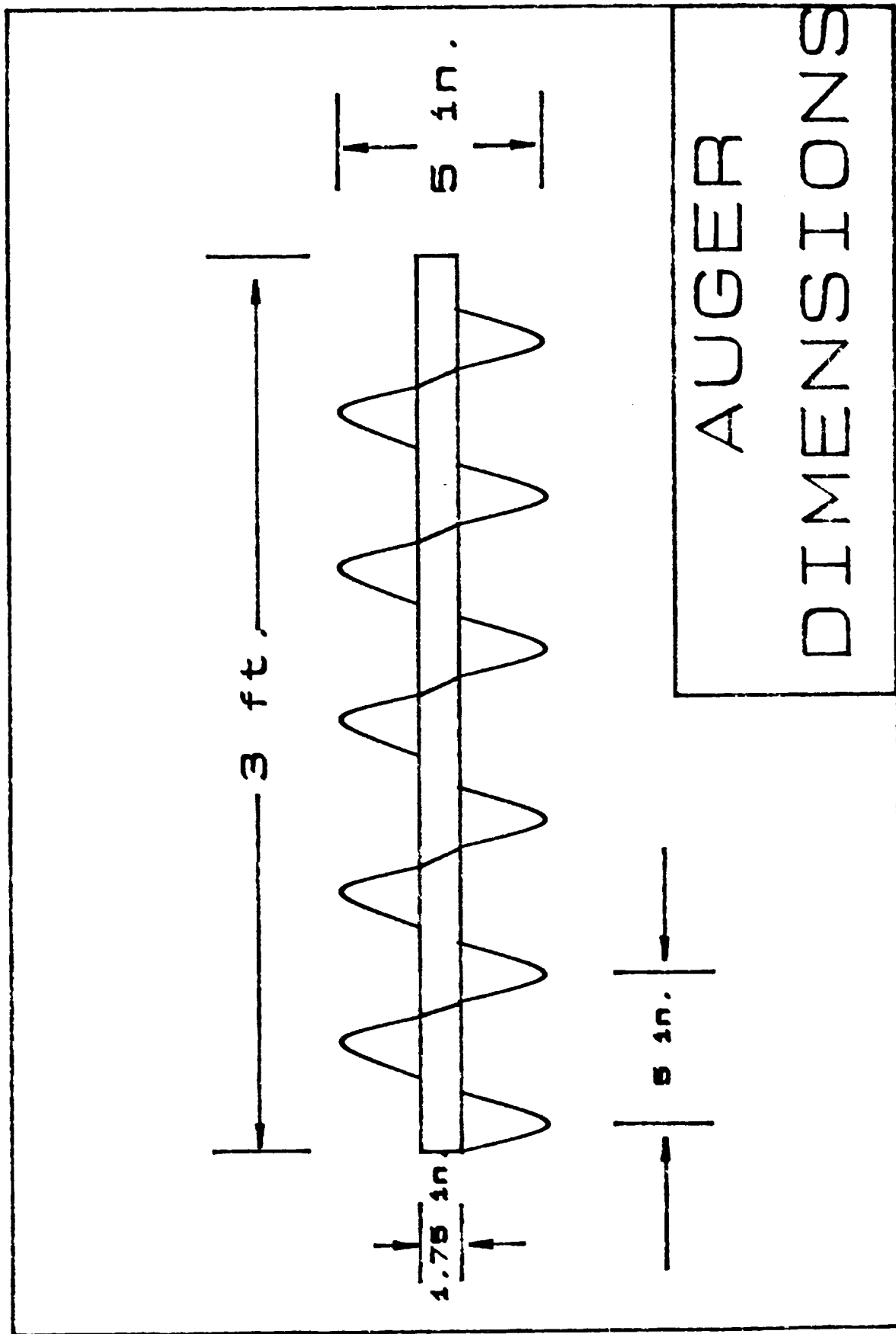


Figure 14



NUMBER OF FENCES JUMPED VS. NUMBER OF PARTICLES

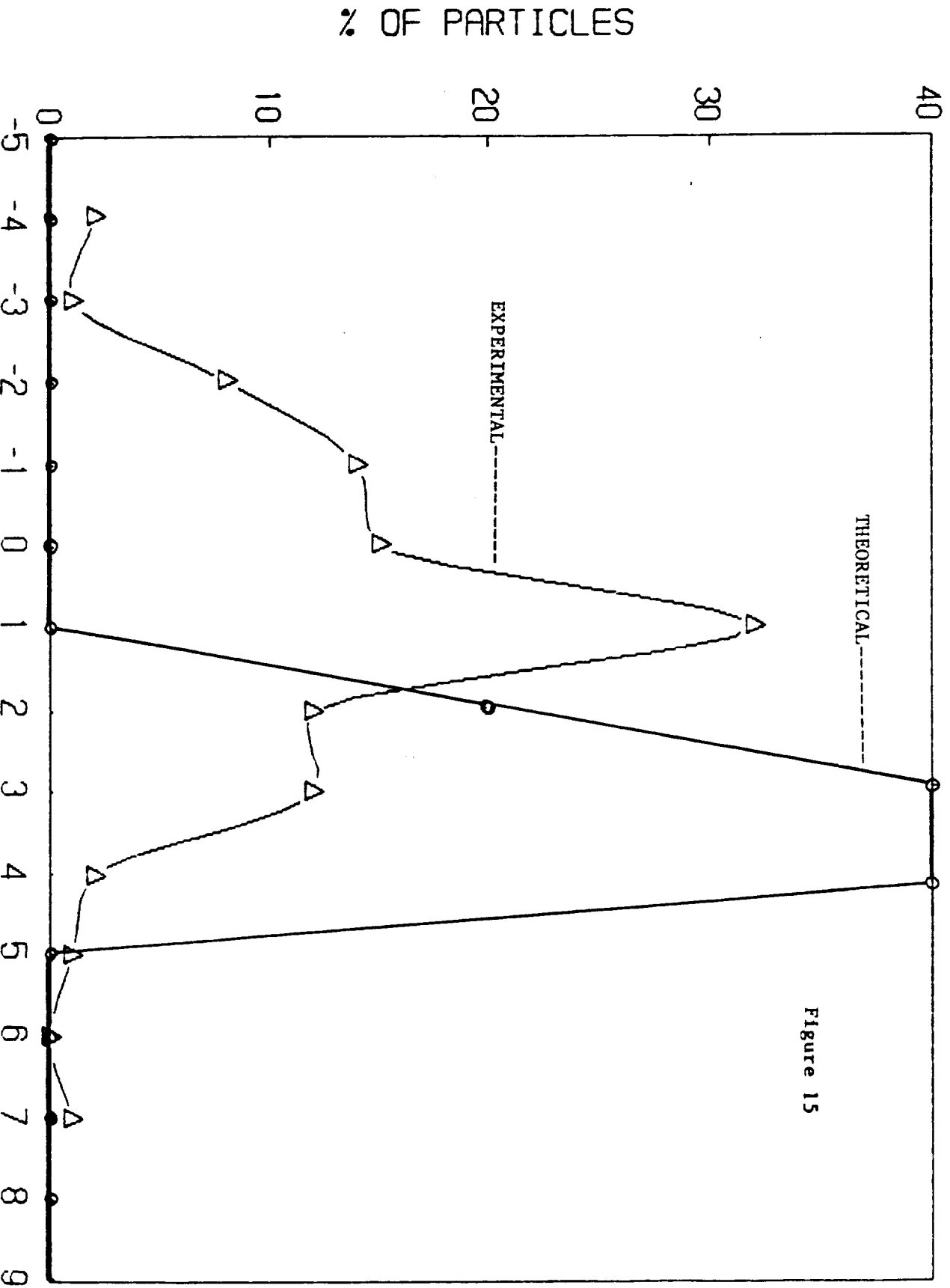
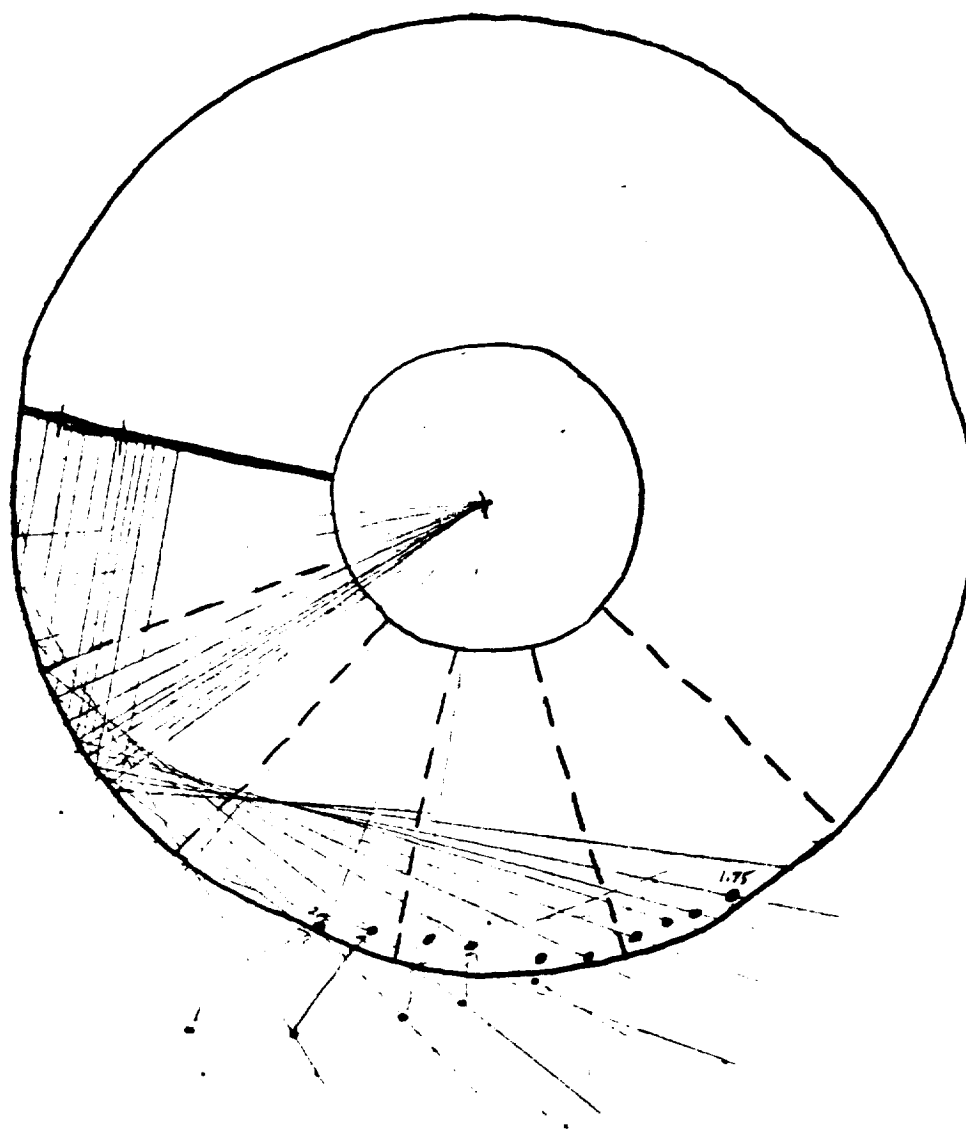


Figure 15

Figure 16

LANDING POSITION PREDICTION
FROM MATH MODEL
(HAND PLOT OF RAW DATA)



TABLES

TABLE 1

DATA FOR PART 1 OF BB PARTICLE TEST, GIVING DISTRIBUTION OF FENCES JUMPED FOR SINGLE STROKES OF THE VRA, USING TEN BB PARTICLES

TRIAL #	FENCES JUMPED											
	-4	-3	-2	-1	0	1	2	3	4	5	6	7
1	0	0	0	3	1	3	1	1	0	1	0	0
2	0	0	0	0	2	5	2	0	0	0	0	1
3	1	0	3	0	1	2	0	1	2	0	0	0
4	1	0	1	1	1	3	1	2	0	0	0	0
5	0	0	1	0	2	4	2	1	0	0	0	0
6	0	0	1	1	1	5	0	2	0	0	0	0
7	0	0	0	3	1	0	3	3	0	0	0	0
8	0	0	0	1	3	4	1	1	0	0	0	0
9	0	0	1	2	2	4	0	1	0	0	0	0
10	0	1	1	3	1	2	2	0	0	0	0	0
TOTAL # PARTICLES JUMPING EACH FENCE FOR TEN STROKES	2	1	8	14	15	32	12	12	2	1	0	1

TABLE 2

PERCENTAGE OF BB PARTICLES JUMPING EACH PARTICULAR
FENCE (PERCENTAGE DISTRIBUTION OF PARTICLES)

$$\left[\begin{array}{l} \text{PERCENTAGE OF PARTICLES} \\ \text{JUMPING EACH PARTICULAR} \\ \text{FENCE} \end{array} \right] = \left[\frac{\text{TOTAL \# PARTICLES JUMPING} \\ \text{EACH FENCE FOR 10 STROKES}}{\text{TOTAL OF 10 BB PARTICLES}} \right] \times 100$$

	FENCES JUMPED												
	-4	-3	-2	-1	0	1	2	3	4	5	6	7	
PERCENTAGE OF PARTICLES JUMPING EACH PARTICULAR FENCE (%)	2	1	8	14	15	32	12	12	2	1	0	1	

$$\Sigma \left[\begin{array}{c} \text{PERCENTAGE OF PARTICLES} \\ \text{JUMPING EACH PARTICULAR} \\ \text{FENCE} \end{array} \right] \times \left[\begin{array}{c} \text{FENCES JUMPED} \end{array} \right] = \left[\begin{array}{c} \text{FENCES} \\ \text{STROKE} \end{array} \right]$$

$$\left[\begin{array}{c} \text{NUMBER OF STROKES} \end{array} \right]$$

$$= \frac{\left[\begin{array}{l} (.02)(-4) + (.01)(-3) + (.08)(-2) + (.14)(-1) + \\ (.15)(0) + (.32)(1) + (.12)(2) + (.12)(3) + \\ (.02)(4) + (.01)(5) + (0)(6) + (.01)(7) \end{array} \right]}{\left[\begin{array}{c} 10 \end{array} \right]}$$

$$= 0.71 \left[\begin{array}{c} \text{FENCES} \\ \text{STROKE} \end{array} \right]$$

THUS THE AVERAGE NUMBER OF FENCES JUMPED BY THE BB PARTICLES PER STROKE OF THE VRA IS EXPERIMENTALLY FOUND TO BE 0.71. THIS NUMBER IS LESS THAN ONE, INDICATING THAT TO GAIN A NET FLOW OF BB PARTICLES UP THE RAMP, AT LEAST TWO STROKES MUST BE APPLIED. THIS NUMBER IS LOW DUE TO THE FACT THAT APPROXIMATELY 40% OF THE BB PARTICLES JUMP BACKWARDS, HAVING A NEGATIVE EFFECT ON THE OVERALL NET MASS FLOW OF BB'S. THIS BACKWARDS JUMPING IS MUCH LESS IMPORTANT IN THE MASS FLOW OF SAND, DUE TO DAMPING EFFECTS WHICH QUICKLY LOWER THE ENERGY LEVEL OF THE SAND PARTICLES AND PREVENT EXCESSIVE BOUNCING.

TABLE 3

DATA GATHERED FOR NUMBER OF STROKES NECESSARY TO
MOVE A SINGLE BB PARTICLE UP A TOTAL OF 24 FENCES

TRIAL #	# OF STROKES NEEDED TO JUMP A SINGLE BB PARTICLE A TOTAL OF 24 FENCES
1	29
2	27
3	38
4	32
5	30

THE AVERAGE NUMBER OF STROKES NEEDED TO MOVE A SINGLE BB PARTICLE UP A TOTAL OF 24 FENCES IS GIVEN BY:

$$\frac{29 + 27 + 38 + 32 + 30}{5} = 31.2 \text{ STROKES}$$

THIS COMPARES NICELY WITH THE NUMBER OF STROKES WHICH WOULD BE PREDICTED BY THE EXPERIMENTAL VALUE OF 0.71 FENCES PER STROKE, FOUND FROM TABLE 2:

$$\frac{24 \text{ FENCES}}{0.71 \text{ FENCES PER STROKE}} = 33.8 \text{ STROKES}$$

FROM THE CLOSE CORRELATION OF THE DATA, IT IS DETERMINED THAT THERE IS LITTLE ERROR INTRODUCED BY THE EXPERIMENTORS IN THE FORM OF NONUNIFORM CONTROL OF THE TEST APPARATUS, OR NONUNIFORM MEASUREMENT OF RESULTS.

TABLE 4

DATA FOR THROUGHPUT OF SAND, GATHERED FOR SEVERAL SETS OF 20 STROKES EACH APPLIED TO THE VRA AFTER FIRST DISTRIBUTING SAND UNIFORMLY THROUGHOUT AUGER

TRIAL #	# STROKES	WEIGHT OF SAND THROUGHPUT (POUNDS)
1	20	1.55
2	20	1.45
3	20	1.60
4	20	1.85
5	20	1.05

$$\begin{aligned}
 \left[\begin{array}{l} \text{AVERAGE SAND} \\ \text{THROUGHPUT} \end{array} \right] &= \frac{\left[\begin{array}{l} \text{WEIGHT OF SAND THROUGHPUT} \\ \text{AT EACH TRIAL} \end{array} \right]}{\left[\begin{array}{l} \text{NUMBER OF TRIALS} \end{array} \right]} \\
 &= \frac{\left[1.55 + 1.45 + 1.6 + 1.85 + 1.05 \right]}{\left[5 \right]} \\
 &= 1.5 \text{ POUNDS PER 20 STROKES} \\
 &= .075 \text{ POUNDS PER STROKE}
 \end{aligned}$$

THE MASS THROUGHPUT OF SAND IS APPROXIMATELY 1.5 POUNDS FOR TWENTY STROKES, WHICH COMES TO .075 POUNDS PER STROKE OF SAND TRANSPORTED THROUGH THE VRA.

LANDING POSITION DATA
FROM 3-D COMPUTER MODEL

Ri	S1
1.75	3.4
1.8	3.3
1.85	3.2
1.9	3.11
1.95	3.04
2	3.0
2.05	2.9
3.1	2.84
2.15	2.80
2.2	2.77
2.25	2.75
2.3	2.74
2.35	2.73
2.4	2.75
2.45	2.78
2.5	3.0

APPENDIX

PROGRAM SPACE (INPUT,OUTPUT)

2-D PARTICLE PATH

REAL N1(500)
REAL N2(500)
REAL X(500)
REAL Y(500)
REAL DISX(500)

REAL X2,T1,T2,T3,V1
INTEGER I,W

PARAMETER (G=32.2,P=.4166667,M=1.0,B=35.32*.0174533)
PARAMETER (D=-54.68*.0174533,F=375.0,THETA=17.66*.0174533)

C THIS PART OF THE PROGRAM CALCULATES THE RISE
C OF THE PARTICLE'S PATH

X2=(F/M)-G
T1=((2*P)/X2)**.5
V1=X2*T1
PRINT*, 'V1 IS ',V1
PRINT*, 'T1 IS ',T1
PRINT*, 'X2 IS ',X2

C THIS PART OF THE PROGRAM CALCULATES THE FALL IN
C PARTICLE

I=0
DO 10 T2= 0.0,1.0,.0005
I=I+1
N1(I) = ((G*COS(B)*T2**2)/2)+V1*T2
N2(I) = (-G*SIN(B)*T2**2)/2
IF (N1(I) .GE. P) GO TO 20
10 CONTINUE
20 W=0
DO 30 W= 1,1,1
X(W) =N1(W)*COS(D) + N2(W)*COS(B)
Y(W) =N1(W)*SIN(D) + N2(W)*SIN(B)
PRINT*, 'X= ',X(W)*12
PRINT*, 'Y= ',Y(W)*12
DISX(W) = X(W)/COS(THETA)
PRINT*, 'DISX= ',DISX(W)*12
30 CONTINUE
PRINT*,X(I-1)
PRINT*,Y(I-1)
STOP
END

3-D LANDING POSITION PROGRAM

```
OPTION BASE 1
DIM A(2,50)
REAL R1,Ro,P
REAL Asp,Beta
INTEGER I
I=0
Ro=2.5
P=5.0
FOR R1=.9 TO 2.5 STEP .05
I=I+1
Asp=ASN(R1/Ro)
Beta=2*ATN(P/(PI*R1))
FOR Z=.02 TO 5 STEP .01
Yr=Ro*COS(Asp)-(R1/(TAN(2*PI*Z/P-PI/2+2*Asp)))
Yp=(Z-P+R1/(TAN(Asp)*(TAN(Beta))))*(TAN(2*ATN(P/(2*PI*R1))))*(-1)
IF (Yp-Yr)>.05 THEN GOTO 200
A(2,I)=Yp
A(1,I)=R1
PRINT R1,Yp
GOTO 210
NEXT Z
NEXT R1
END
```

Progress Report - Week 1

Linear Auger Group

This week we familiarized ourselves with the project itself, which is a reciprocating auger used in drilling and removal of debris at lunar excavating sites.

1. Etheridge, Mark - Reviewed previous reports.
 2. Fair, Robert - Organized meetings and became familiar with the Apollo system.
 3. Morgan, Scott - Became familiar with VersaCad system and looked through Lunar Bases book for references.
 4. Pearson, Brent - Contacted suppliers for a plastic sleeve.
 5. Weldi, Kevin - Reviewed previous reports and became familiar with the Apollo system.
 6. Woodrough, Steve - Reviewed previous reports.
- ☞ Due to inclement weather, the group met Tuesday at 3 pm to discuss the project and scheduling.

MEMORANDUM

TO: Dr. Brazell

FROM: Linear Auger Group (C)

DATE: 1-21-87

SUBJECT: Week #3 Progress Report

On Thursday 1-14-88 at 8:00 PM the group met with Dr. Brazell and discussed the different parameters, constraints and objective concerning the auger design.

On Wednesday 1-20-88 at 12:00 PM the group met again to begin work on the mathematical models and discuss variation of fences and possible reflectors. Discussed methods of welding and attaching fences/reflectors.

Individually:

Robert Fain: Worked on Versacad.

Scott Morgan: Worked on Versacad.

Kevin Weldi: Researched Project more

Steve Woodrough: Worked on dynamics and math model

Brent Pearson: Learned word processor use (PC write) and how to get laser print.

Mark Etheridge: Worked on math model

MEMORANDUM

TO: Dr. Brazell

FROM: Linear Auger Group (C)

DATE: 1-28-87

SUBJECT: Week #4 Progress Report

On Thursday 1-21-88 at 8:30 the group met in the Design Lab for 2.5 hours for discussion of problem statement, math model, actuating device and division of responsibilities.

Arranged to have auger surfaces polished and edges ground.

Group met 1-27-88 at 12:00 PM to discuss integration of system elements. The group was then divided into four sections.

Individually:

Robert Fain: Worked on Versacad.

Scott Morgan: Math model and frequency determination.

Kevin Weldi: Power Requirements.

Steve Woodrough: Spoke with Vendors, GTRI, and met with Brent.

Brent Pearson: Worked on drive mechanism.

Mark Etheridge: Math model and frequency determination.

MEMORANDUM

TO: Dr. Brazell

FROM: Linear Auger Group (C)

DATE: 2-04-87

SUBJECT: Week #5 Progress Report

Group C met in the lounge of the Coon Building at 12:00, Wednesday Feb. 13. The math model, as well as the relationship between math model and test setup, were considered.

The decision has been made to design the test setup using an air actuator, if possible. This device would provide an input more closely approximated by a square rather than the sine wave which had originally been anticipated. The math model therefore, has been reviewed and found in need of modification. A new math model is being developed at this time.

Individually:

Robert Fain: Worked on Versacad.

Scott Morgan: Math model and frequency determination.

Kevin Weldi: Worked with Data-Grapher and Graphics Editor.

Steve Woodrough: Spoke with Vendors, GTRI, and met with Brent.

Brent Pearson: Drew plans for test-setup, determined materials needed.

Mark Etheridge: Math model and frequency determination.

MEMORANDUM

TO: Dr. Brazell

FROM: Linear Auger Group (C)

DATE: 2-11-87

SUBJECT: Week #6 Progress Report

Progress this week centered around preparation for the mid-term presentation. Scott Morgan was chosen to give the presentation. The various sketches, drawings, and graphs were compiled and put on transparencies for class viewing. Of the several possible math models, one was chosen for use in testing procedures, mainly due to the simplicity of its implementation. Vendors have been contacted and plans made for fabrication to begin this weekend.

Individually:

Robert Fain: Worked on Computer programs and Versacad drawings.

Scott Morgan: Prepared for and gave presentation.

Kevin Weldi: Worked on Datagrapher and Versacad drawing.

Steve Woodrough: Helped with Math model and contacted vendors.

Brent Pearson: Worked on Versacad and communicated with vendors.

Mark Etheridge: Continued work on Math model and Computer program.

MEMORANDUM

TO: Dr. Brazell

FROM: Linear Auger Group (C)

DATE: 2-18-87

SUBJECT: Week #7 Progress Report

This weeks focus was on the construction of the test stand and methods of coupling the auger and actuator to allow two degrees of freedom to prevent binding and reduce vibration.

The group also discussed the final report setup and reviewed the patent forms.

The drawings used in the oral presentation are being translated to computer for further analysis.

Considering computer controlled solenoid valve for testing of a the math model.

Individually:

Robert Fain: Working on Computer controlled actuator design.

Scott Morgan: Worked on Math model.

Kevin Weldi: Revising drawings.

Steve Woodrough: Beginning work on written report.

Brent Pearson: Built test stand.

Mark Etheridge: Continued work on Math model and Computer program.

MEMORANDUM

TO: Dr. Brazell

FROM: Linear Auger Group (C)

DATE: 2-25-88

SUBJECT: Week #8 Progress Report

This week we found the fabrication of the test setup slowed due to problems with the air actuator. Line losses have caused the speed with which the actuator throws to be too slow. A less restrictive air delivery system, of an actuator requiring a smaller volume of air, must be investigated. The "fences" for the auger have been purchased and will be applied immediately. Final fabrication is planned to be completed this weekend, so that testing of the model can begin.

Work continued on the math model, with problems arising in the manipulation of 3-D vectors. An Alternative to the purely mathematical vector method of tracing the path of a particle as it proceeds up the auger, suggested by Mr. Brazell, is to use wire of thread to physically trace the path on the auger.

Individually:

Steve Woodrough: Continued design on the test setup and contacted vendors.

Scott Morgan: Continued work on the math model and physical representation using stiff wire.

Mark Etheridge: Worked on math model with Scott.

Robert Fain: Continued work on drawings, computer program and test setup.

Kevin Weldi: Overhauled and tested actuator and worked on design setup.

Brent Pearson: Continued design and fabrication of test setup, purchased materials.

Record of Invention No. _____
UTC No. (if applicable) _____

GEORGIA INSTITUTE OF TECHNOLOGY

APPROVAL SHEET (Attach to DISCLOSURE OF INVENTION)

The following questions should be answered by the laboratory or school director, as applicable. The questions are designed to verify the ownership of the invention. This approval should be included when the Invention Disclosure form is submitted to the Office of Technology Transfer.

1. Title of Invention: Vertical Laser projection laser

2. List of Inventor(s):

<u>Mark S. Erwin</u>	<u>Mark S. Erwin</u>
<u>Steve ...</u>	<u>Steve ...</u>
<u>Steve ...</u>	<u>Steve ...</u>

3. Ownership:

In my opinion this invention:

- A. Is owned by the Institute in accordance with the Patent Policy.
- B. Was developed by the inventor(s) without use of Institute time, facilities or materials, and is not related to the inventor's area of technical responsibility to the Institute and hence belongs to the inventor(s).

4. Research project advisor approval for student submissions (if applicable):

Sept B. Woolley Mark 7/88
Advisor Date

Reviewed for Institute ownership by laboratory or school director.

George P. Burdell Mark 7
Name Date
Director ME Dept
Title/Unit

GEORGIA INSTITUTE OF TECHNOLOGY
DISCLOSURE OF INVENTION

Submit this disclosure to the Office of Technology Transfer (OTT) or contact that office for assistance. Disclosure must contain the following items: (1) title of invention, (2) a complete statement of invention and suggested scope, (3) results demonstrating that the concept is valid, (4) variations and alternate forms of the invention, (5) a statement of the novel features of the invention and how these features distinguish your invention from the state of the art as known to you, (6) applications of the technology, and (7) supporting information.

1. Title

Technical Title: Verticality in Computer Architecture

Layman's Title (34 characters maximum, including spaces): _____

Verticality in Computer Architecture

Inventor(s): (Correspondence, patent questions, etc. will be directed to the first named inventor)

A. Signature Scott Morgan Revenue Share% 16.6 Date 1/7/87

Printed Name _____ Morgan Citizenship US

Home Address 3630 Fortingale Rd.

City Chamblee County DeKalb State GA Zip Code 30341

Campus Unit/Mail Address P.O. Box 35754 Atlanta ³⁰³³² Campus Phone 457-8343

B. Signature Mark E. ... Revenue Share% ... Date ...

Printed Name Mark E. ... Citizenship ...

Home Address 515 Navarro Drive

City Warner Robins County Houston State Ga Zip Code 31088

Campus Unit/Mail Address Po 32061 Campus Phone 728-0093

C. Signature Robert Fair Revenue Share% 5.6 Date 1/7/87

Printed Name Robert Fair Citizenship US

Home Address RTE 2 Box 182

City Edison County Clay State GA Zip Code 31746

Campus Unit/Mail Address Box 35646 Campus Phone 676-0174

DISCLOSURE OF INVENTION

2. Statement of Invention:

Give a complete description of the invention. If necessary, use additional pages, drawings, diagrams, etc. Description may be by reference to a separate document (copy of a report, a preprint, grant application, or the like) attached hereto. If so, identify the document positively. The description should include the best mode that you presently contemplate for making (the apparatus or material invented) or for carrying out the process invented.

[Faint handwritten text, likely bleed-through from the reverse side of the page. The text is illegible due to fading.]

Inventor(s) _____ Date 7

_____ Date _____

_____ Date _____

Witness* George Budell Date 3/7/88

Martha Kaye Date 3/7/88

*The witness should be technically competent and understand the invention.

DISCLOSURE OF INVENTION

5. Novel Features:

a. Specify the novel features of your invention. How does the invention differ from present technology?

The invention is a...

b. What deficiencies or limitations in the present technology does your invention overcome?

...

c. Have you or an associate searched the scientific literature with respect to this invention? Yes _____ No _____. Have you done a patent search? Yes _____ No _____. If yes in either case, or both, indicate what pertinent information you found and enclose copies if available. Also indicate any other art you are aware of (whatever the source of your information) that is pertinent to your invention. Enclose copies of descriptions if available. (Note: An inventor is under duty by law to disclose to the U.S. Patent and Trademark Office any prior art known to him or her.)

NS

Inventor(s) Mark Ellbridge Scott Meyer Date 3/7/88
Johanna Pearson Robert Fein Date 3/7/88
Kevin Wald Steve Winkler Date 7/7/88

Witness George P. Burdell Date 3/7/88
(printed name)
Martha Ruge Date 3/7/88
(printed name)

DISCLOSURE OF INVENTION

6. Application of the Technology:

List all products you envision resulting from this invention. For each, indicate whether the product could be developed in the near term (less than 2 years) or would require long-term development (more than 2 years).

The products most likely to result from this invention are concerned with granular mass transport. It is conceivable that the technology developed here could be combined with some other idea presently known or yet conceived. ~~Because of the simple nature of the device~~ Because the nature of the device is so simple it should be possible to develop most of the new products in the near term.

Inventor(s) Mark Etheridge Scott Meyer Date _____

Jonathan Pearson Robert Park Date _____

Kevin Uldi Steve Wenzel Date 3/7/88

Witness: George P. Burdell Date _____
(printed name)

Martha Key Date _____
(printed name)

DISCLOSURE OF INVENTION
SUPPORTING INFORMATION

1. Are there publications such as theses, reports, preprints, reprints, etc. pertaining to the invention? Please list with publication dates. Include manuscripts (submitted or not), news releases, feature articles and items from internal publications. Supply copies if possible.

The only report that is known to exist is the one submitted to the Georgia Institute of Technology on 10/10/87. It is a technical report and is not available for public release.

2. On what date was the invention first conceived? _____ Is this date documented? _____ Where? _____ Are laboratory records and data available? Give reference numbers and physical location, but do not enclose.

Invention conceived by Mr. Bruse N

3. Give date, place, and circumstances of any disclosure. If disclosed to specific individuals, give names and dates.

See 2

4. Was the work that led to the invention sponsored by an entity external to Georgia Institute of Technology? Yes _____ No _____

a) If yes, has sponsor been notified? Yes _____ No _____

b) Sponsor Names: _____ GIT Project Nos. _____

Georgia Tech

5. What firms do you think may be interested, in the invention and why. Name specific persons within the companies if possible.

Any company doing any type of military work.

DISCLOSURE OF INVENTION
SUPPORTING INFORMATION

6. Setting aside your personal interest, what do you see as the greatest obstacles to the adoption of your invention?

Finding appropriate materials. VLSI is the

7. Alternate Technology and Competition:

a. Describe alternate technologies of which you are aware that accomplish the purpose of the invention.

None

b. List the companies and their products currently on the market which make use of these alternate technologies.

None

c. List any research groups currently engaged in research and development in this area.

None

8. Future Research Plans:

a. What additional research is needed to complete development and testing of the invention? What time frame and estimated budget is needed for the completion of each step?

Approximately 6 months to complete development and testing of the invention. Estimated budget is \$100,000. This project is currently being undertaken by the inventor.

b. Is this additional research presently being undertaken? Yes ___ No ___

c. If yes, under whose sponsorship? *AT&T by contract*

d. If no, should corporate sponsorship be pursued? Yes ___ No

Suggested corporation(s) _____

9. Attach, sign and date additional sheets if necessary. Enclose sketches, drawings, photographs and other materials that help illustrate the description. (Rough artwork, flow sheets, Polaroid photographs and penciled graphs are satisfactory as long as they tell a clear and understandable story.)

