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ADVANCED DESIGN PROGRAM

DESIGN OF A ROTARY STEPPED AUGER FOR A LUNAR ENVIRONMENT

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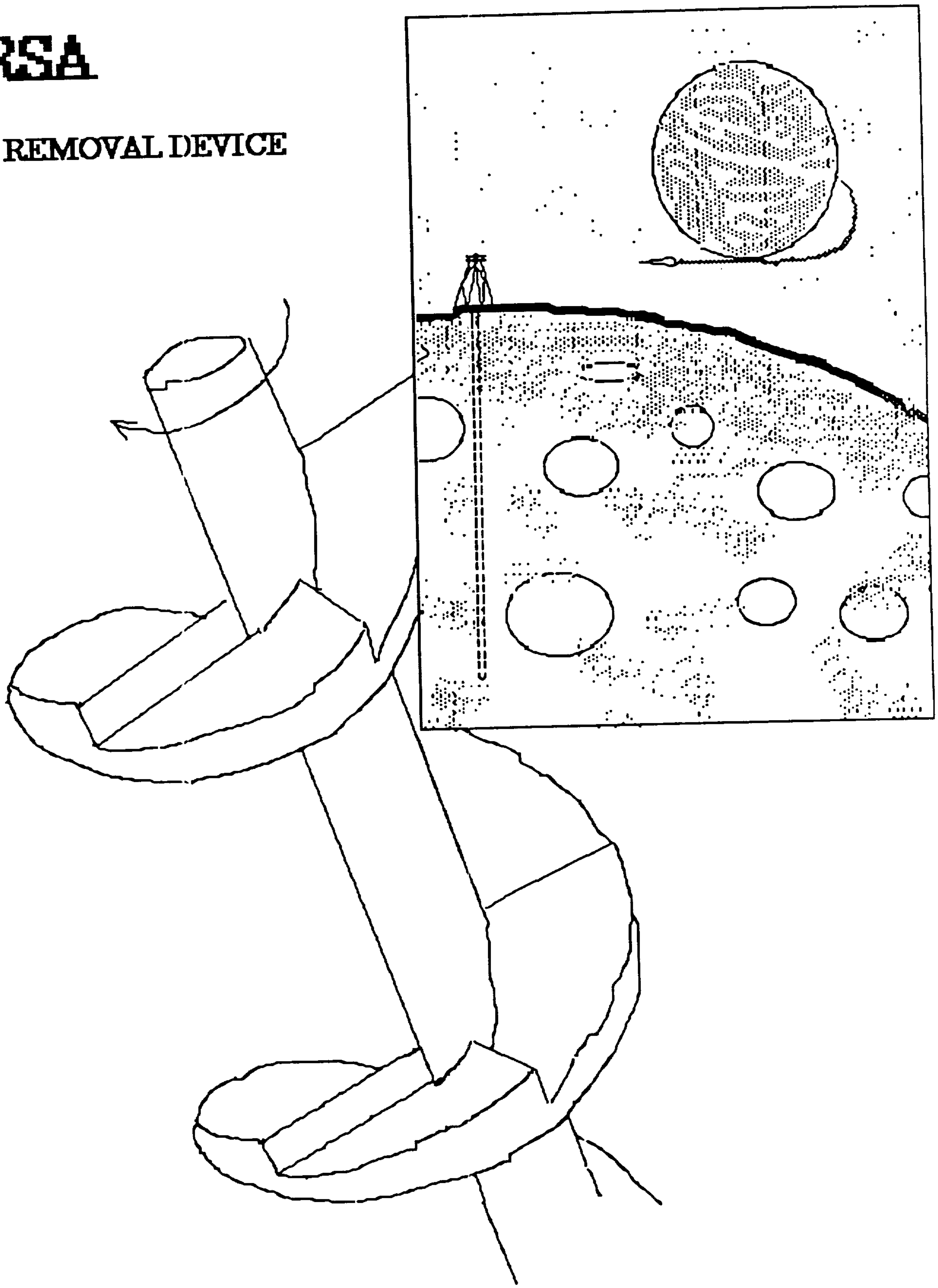
RSA

CHIP REMOVAL DEVICE



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ABSTRACT

A lunar outpost will have need for deep drilling operations for both explorative and practical purposes. As in any drilling operation, the cuttings must be cleared from the hole. The hard vacuum of the lunar environment renders conventional flushing methods of cutting removal unfeasible, and requires a new system of removal. A rotary stepped auger (RSA) is a simple mechanical method of removing dry cuttings from a deep hole, and is ideally suited to the lunar environment.

The RSA consists of a helical auger with "stepped" ramps which allow cuttings to slide up the helix, but will prevent them from sliding back down. The auger is driven in a pulsed manner by applying a periodic function of acceleration to the auger shaft. These pulses will compel the cuttings to slide up the auger's helix while the stepped ramps prevent the cuttings from backsliding while the auger accelerates.

A mathematical model of the RSA was developed and experimentally evaluated. The math model produced a good baseline design, but the experimental model required some tuning to account for the approximations made in the math model.

This design is suited for lunar drilling because it is mechanically simple, integral to the drill string, requires no fluids, is suited to the dry soil, and has relatively low weight and power requirements.

1. PROBLEM STATEMENT

Definition of Problem: The purpose of this project is to develop and test a method for removing cuttings produced by drilling.

Justification: Lunar drilling operations require alternative methods of removing cuttings from the hole.

Constraints:

* The method is a rotary stepped auger (RSA)
* The auger must perform in the lunar environment.
* The weight of the auger should be minimized.
* The auger must optimize throughput.

Objectives:

* Develop a general mathematical model applicable to any rotary stepped auger.
* Develop an experiment to test the math model.

2. BACKGROUND

2.1 LUNAR DRILLING

Any future lunar settlement will be involved in deep drilling for mining, construction, and scientific research operations. There are some serious problems in adapting existing drilling techniques for use in the lunar environment.

Earthbound drilling operations typically bore a hole with a hard bit, and then flush the cuttings from the hole using compressed air or a flushing fluid known as "drilling mud." In order to adapt the flushing concept to a lunar drilling operation, the hole would have to be pressurized and the fluids contained and recycled. Any pressure leak would cause the system's fluids to flash immediately into the vacuum, resulting in a loss of irreplaceable fluids. Even a perfectly sealed hole would be vulnerable to pressure failure due to cavities or fissures inside the hole. These obstacles force us to seek a new method of cutting removal which does not rely on a fluid medium. It must also accommodate the lack of atmosphere, temperature extremes, reduced gravity, and dry soil found on the moon. Appendix D summarizes the lunar environmental constraints. A working system must also be lightweight and work efficiently in order to be practical.

2.2 RSA CONFIGURATION

The Rotary Stepped Auger (RSA) was concieved to meet these demanding requirements. The RSA consists of a series of helical "steps" as pictured in Figure 2.1. These steps allow the material to slide up the helix, but prevents them from sliding back down. By driving the RSA with a periodic, or pulsed, acceleration function, any material on the auger can be compelled to travel up the helix. The motion imparted to the auger can be any periodic function such that the average angular velocity is constant and there are periods of acceleration and deceleration. The magnitude of the accelerations will depend on the specific geometry of the RSA.

This may be visualized by comparing the action to a snow shovel. Just as a snow shovel will compel snow to slide up onto its blade when it is thrust forward on the walk, the RSA will compel cuttings to slide up its helix as it pulses forward in the drill hole.

The RSA has several geometry variables :

* pitch of auger
* inner diameter of auger
* outer diameter of auger
* step height
* number of steps per pitch

The pulsed driving function is also completely variable, with the restriction that the average angular velocity is constant so that the RSA can run continuously. The motion of particles or cuttings on the RSA will depend on all of these variables. Our goal is to quantify the particle motion in terms of all of the geometry and auger motion variables in order to specify a baseline design for lunar cutting removal.

3. MATHEMATICAL MODELS

3.1 THE LINEAR MODEL

In order to simplify the task of creating a mathematical model of the auger, a linear model was first developed which considered an "unwound" helix. This reduced the model to two dimensions, θ and z in cylindrical coordinates so that radial accelerations could be ignored. The model is as shown in Figure 3.1.

The linear model consists of a ramp of infinite width and length with ramp angle ϕ (helix angle). Steps are superimposed upon the ramp with height h, length l, and step angle ψ, which includes the effective helix angle. A particle of mass m, rests upon the auger which has a coefficient of friction μ.

The ramp is given an acceleration, a_a, in the negative θ direction. The free body diagram of the particle is shown in Figure 3.2. The particle has the resultant acceleration, a_p, equal to

$$a_p = a_a\ (\cos\theta - \mu\sin\theta) - g\ (\sin\theta - \mu\cos\theta)$$

With sufficient acceleration of the ramp, the particle acceleration will cause the particle to move up and over its step where it will remain until the acceleration causes it to slide over the next step. Any of the parameters of this model may be varied to optimize the particle motion. This is done with the mathematical rotary model which is described in the next section.

3.2 THE ROTARY MODEL

The addition of the radial dimension introduces an additional component of friction and acceleration. The complete development of the three dimensional math model is given in Appendix B. The radial acceleration tends to throw the particles to the outside of the auger, and some containment scheme is required to keep them from flying off the edge of the helix.

Two containment schemes were considered to keep the dirt in the middle of the step (see Figure 3.2). A great deal of time was devoted to the examination of a helix with a non-flat radial profile which would prevent particles from traveling radially by virtue of its slope. It was determined, however, that the particles would travel radially as well as tangentially as soon as sliding was achieved. In order to operate a system in this manner, the particles would have to move back and forth radially as the auger was accelerated. The resulting equations were indeterminate, and could not be solved without making unrealistic assumptions.

The second approach to radial containment involved the placement of constant radius fences on the helix. These fences prevent particles from sliding outward on the helix surface. Development of this model also resulted in an indeterminate set of equations, however reasonable assumptions were made to make the system solvable. The mathematical model was based on this type of radial containment.

The assumptions made in the mathematical model are as follows:

1. The only force in the radial direction is exerted by the fence.
2. The angular velocity is small enough to neglect coriolis effects.
3. The acceleration profile is sinusoidal.
4. Static and kinetic coefficients of friction are equal.
5. The particle stays in contact with the auger.
6. In order to find distance travelled, the angular velocity of the particle must be assumed to be equal to the angular velocity of the auger, even when the particle is sliding.

The model uses 5 parameters to determine the distance travelled by a particle during one period of motion.

Step height - In order to properly keep the particles from sliding backwards down the auger, the step height must be slightly larger than the radius of the largest particle to be transported.

Auger pitch - A large pitch will have the advantage of requiring less material, and a shorter distance for the dirt to travel; however, much greater accelerations are then needed to make the particle move.

Radius of track - The radial position affects both the acceleration of the particle and the step angle and length. Accelerations are greater at larger radial distance. The step length gets much larger, but the step angle gets smaller. These considerations indicate that a larger radial distance is more effective.

Coefficient of friction - The smallest coefficient possible is desirable. It requires work to do two things: increase the potential energy of the dirt, and overcome the friction of the dirt on the auger.

Number of steps per pitch - This is an important parameter which affects both the step angle and the step length. Ideally, the dirt particle should travel the step length and move over exactly one step in one oscillation.

4. EXPERIMENTAL MODEL

4.1 AUGER

The basis for our experimental stepped auger was a section of a 5.37 inch diameter steel auger with a pitch of 4.87 inches. The base auger had a flat radial profile and a minimum diameter of 1.56 inch. We attached steps, each covering an 83 degree segment of the helix, to the base auger. The steps rise linearly from the surface of the basic helix to a maximum height of 12 mm above the basic helix surface. The steps also have a flat linear radial profile that keeps the experimental geometry simple.

A pattern step was hand built onto the auger surface using profile sections to define the surfaces. Molds were made from this pattern and used to cast the individual steps. The steps were cast of Durham's Rock Hard Water Putty and adhered to the auger with PC-7 epoxy. Since the steps were cast from the same molds, they have very nearly identical dimensions, except for small variations.

The auger was enclosed in a thin, clear plastic sleeve to keep the dirt inside the auger and so the motion of the dirt on the steps could easily be observed. This sleeve is the only radial containment used on the experimental model. The experimental auger radial containment decision matrix is shown in Figure 4.1.

4.2 DRIVE SYTEM

The RSA requires an accelerating/decelerating rotary input to impart relative motion between the cuttings and the auger surface. The cuttings move up the steps when the auger decelerates at a rate great enough to overcome the forces as described in the mathematical model. A sinusoidal acceleration profile was chosen to drive the experimental model because a known profile could be verified with the mathematical model. The experimental drive system decision matrix is shown in Figure 4.1.

The system was driven by a A.C. motor with one-third horsepower and 1725 rpm. The speed was reduced through a series of pulleys. The final pulley had a pin on its edge which ran in a slot to give the slot linear sinusoidal motion (see Figure 4.2). Chains were connected in line with the slot to sprockets on either side of the slot. The auger was connected at the bottom of the sprocket, and so it moved in simple harmonic motion.

5. EXPERIMENTAL RESULTS

In the experiment, the auger was run at three different speeds with three different types of material. Auger frequencies of 2.34, 1.42, and 0.90 hz were achieved by changing the motor pulley. Cuttings were simulated with sand, pea gravel and bb's placed on a few steps halfway up the auger. This set-up simulates cuttings which have already traveled some distance from the bottom of the hole.

When the auger was run at 2.43 Hz with the 4 mm diameter bb's, the bb's would jump up the ramp, then the auger would swing back around and knock the bb's back again. This phenomenon is pictured in Figure 5.1 (a). The same thing happened to the sand and pea gravel when they were used in the auger. This speed may have been used successfully with no reverse motion of the auger. We concluded that a lesser speed was required to move the material up the auger with the sinusoidal motion.

When the auger was run at 1.42 Hz, it successfully moved the bb's up the auger. This test appeared to be well tuned to the bb's sa pictured in Figure 5.1 (c). After several trials, an average of eighty percent of the bb's climbed to the top of the auger after thirty seconds. When sand was put on the steps and the auger was run at 1.42 Hz, three things happened to the sand. Some of the sand moved down the steps because the sand piles were higher than the steps at the start. Some of the sand moved to the outer edge of the step and stuck there. Some of the sand moved to the edge of the steps and was caught between the step and the auger sleeve. However, none of the sand moved up the auger. The acceleration was insufficient to compel the sand to slide up the helix.

Gravel of approximately 3 mm was next used at 1.42 Hz. The gravel would move up the steps, then the opposite rotation would throw the gravel back down, and over the step. This phenomenon is pictured in Figure 5.1 (b). It was concluded that a drive system with little or no reverse motion is required in order to prevent material from being thrown back down. In this way, the gravel could be thrown up and over a step, then remain in place while the auger slowly reversed.

The bb's were also run on the auger at a frequency of 0.90 Hz. A few bb's would move up the auger, but most would start up the step and then return during reverse motion. The acceleration was not high enough to compel the bb's to move up the entire step length during positive acceleration. Neither the sand nor the pea gravel could be compelled to slide up the auger, as we could expect after their poor climbing performances at 1.42 Hz.

The only combination that moved material up the helix was the 1.42 Hz driving function, using bb's as cuttings. It is possible that the sand and pea gravel could have been made to move up the auger if our test stand had been capable of variable function amplitudes as well as frequencies. The stand, however, could only change frequency by switching motor pulleys.

6. BASELINE DESIGN FOR LUNAR ENVIRONMENT

6.1 RSA CONFIGURATION

In order to designate a baseline configuration for a lunar-based RSA, it is necessary to quantify the behavior of the cuttings with respect to the following variables: auger pitch, particle path radius, step height, steps per pitch, and the time function of auger motion.

A BASIC program called RSADESIGN was written to perform this task using the math model discussed previously. This program is listed in Appendix C. RSADESIGN allows a range of values as input for the geometry variables, and uses a sinusoidal time function to describe the auger motion. The input function takes the form

$$\omega = A\sin(ft) \quad ,$$

where amplitude A and frequency f are also allowed as a range of values. RSADESIGN will use the variable ranges to calculate the distance travelled by a particle in one period of auger motion for each possible combination of input values.

By holding all variables constant but one, it is possible to generalize about the effect of the one variable on particle motion, and pick the value out of the range that moves particles up the RSA the best. Once this has been done for all the variables, a first-pass design can be designated. Using these "best" values as the starting point levels to hold constant while a single variable is optimized, the procedure can be performed again to further refine the "best" values.

This approach can be adapted to find optimum relationships between two variables. By using an input range for two of the variables, and using two different sets of "constants," a special relationship between two variables can be spotted. For instance, it may be discovered that the "best" step height is a certain fraction of the auger pitch.

It should be noted at this point that the auger geometry determines its final weight and that the principal contribution to the RSA's weight stems from the helical section wrapped around the main stem. The simplest way to minimize the helix weight is to maximize the auger pitch, since a steeper helix angle will require fewer wraps to traverse the same hole depth. Keeping this in mind, the "best" value for auger pitch would be a compromise between light weight and desirable particle motion. The steepest helix would prevent any particle travel, but would weigh the least.

6.2 MATERIALS

The lunar environment places several constraints on the material selection process. The desired material properties are :

1) light-weight
2) heat resistant
3) wear resistant
4) fatigue resistant
5) high strength

The light-weight constraint is due to the combination of high shipping costs and minimum power requirements. A titanium alloy (5Al2.5Sn) was selected with a density of 4500 kg/m^3. In the materials design matrix (see Figure 6.1), light-weight was given a .40 weighting factor.

The heat resistant constraint is needed because there is an extreme temperature gradient (-200 to 200 ^{o}F) on the lunar surface. The titanium alloy chosen has a service temperature limit of 900 ^{o}F. This will help withstand the high temperatures caused by the friction and the lack of a cooling effect of an atmosphere.

The alloy has a Rockwell C hardness of 36 that will help withstand the abrasive conditions of use. The yield strength of 120 ksi coupled with good fatigue resistance are suitable for the fluctuating stresses encountered.

Increasing technology in the polymer science field would lead to a composite that would meet the material requirements for the lunar auger. Carbon fiber composites with tensile strength's on the order of 250 ksi, elastic moduli of 28,000 ksi, and densities around

2200 Kg/m^3 are currently available. The use of a composite should certainly be considered in any further investigation of this subject.

6.3 DRIVE SYSTEMS

A drive system with alternating acceleration/deceleration profile is required to drive the auger on the moon. Several types of systems were examined, including the sinusoidal type used in the experiment, a Geneva wheel, gears with intermittent teeth, and a computer driven motor.

The sinusoidal acceleration profile that was used on the earth-bound experiment was somewhat effective in bringing the cuttings up the auger. It is evident that a smaller reverse acceleration would be more effective. Also the frequency and amplitude could be tuned so that the dirt particles just clear the step before the auger changes direction.

Another type of drive system uses gears with intermittent teeth to provide acceleration pulses (see Figure 6.2). The constant velocity pinion has large spaces between the teeth so that when it drives the gear it produces an alternating acceleration profile. The problem with this system is that the teeth may fail due to the impact caused the pinion's teeth hitting the slower gear's teeth.

The Geneva wheel was also examined as a possible drive mechanism (see Figure 6.3). With this system, the auger will accelerate for a short period of time, then stop, then accelerate again. With a curved instead of a straight slot, the acceleration will be greater, the acceleration time shorter, and the stall time larger; this will be more effective in driving the cuttings up the ramps. The problem with the curved slot is that the slot will wear easily, so the system may have to be maintenanced often.

A computer controlled D.C. motor is another alternative for a drive system. This way there is increased flexibility in the type of acceleration profile desired so that throughput can be tuned and optimized. A drawback to this system is that the motor may overshoot the acceleration profile, or respond slowly to the computer's commands.

6.4 LUNAR POWER REQUIREMENTS AND CONSIDERATIONS

In order to remove cuttings from a hole, the potential energy of the cuttings must be increased. The power per unit mass required due to the increased potential energy is equal to the product of the gravitational constant and the velocity at which the material moves up the hole.

Additional power is required to overcome the dissipative effects of friction between the cuttings and the auger surface. This loss can be minimized by making the sliding path, the coefficient of friction, and the normal force as small as possible.

The final source of energy required is due to the losses of driving the large inertia of the auger. The weight of the auger will be minimized for cost reasons as well as for reduced power requirements. Ideally, the drive system would recover some of the power required to accelerate when decelerating. Optimization of the drive system is an important parameter that should be considered further.

7. CONCLUSIONS AND RECOMMENDATIONS

The theoretical mathematical model of the stepped rotary auger indicates that a lunar version is feasible. The computer simulation shows that the auger should be able to perform in a lunar environment with a suitable acceleration profile.

It is recommended that further investigation be undertaken on several related subjects. The experimental model should be retested with a modified drive system as previously described. Additional acceleration profiles should be examined for tuning and optimization of throughput. Some alternative driving functions are pictured in Figure 7.1. Alternate drive systems should be considered for the actual lunar auger, taking into account lunar conditions and implementation requirements. The torsion along the length of the auger should be considered since acceleration (and, therefore, movement of dirt particles) depends upon it. Various curved step profiles should be considered for radial containment of the soil when the auger is in motion. If this is possible, then weight can be greatly reduced because an outer sleeve is not required.

ACKNOWLEDGEMENTS

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APPENDIX A

FIGURES

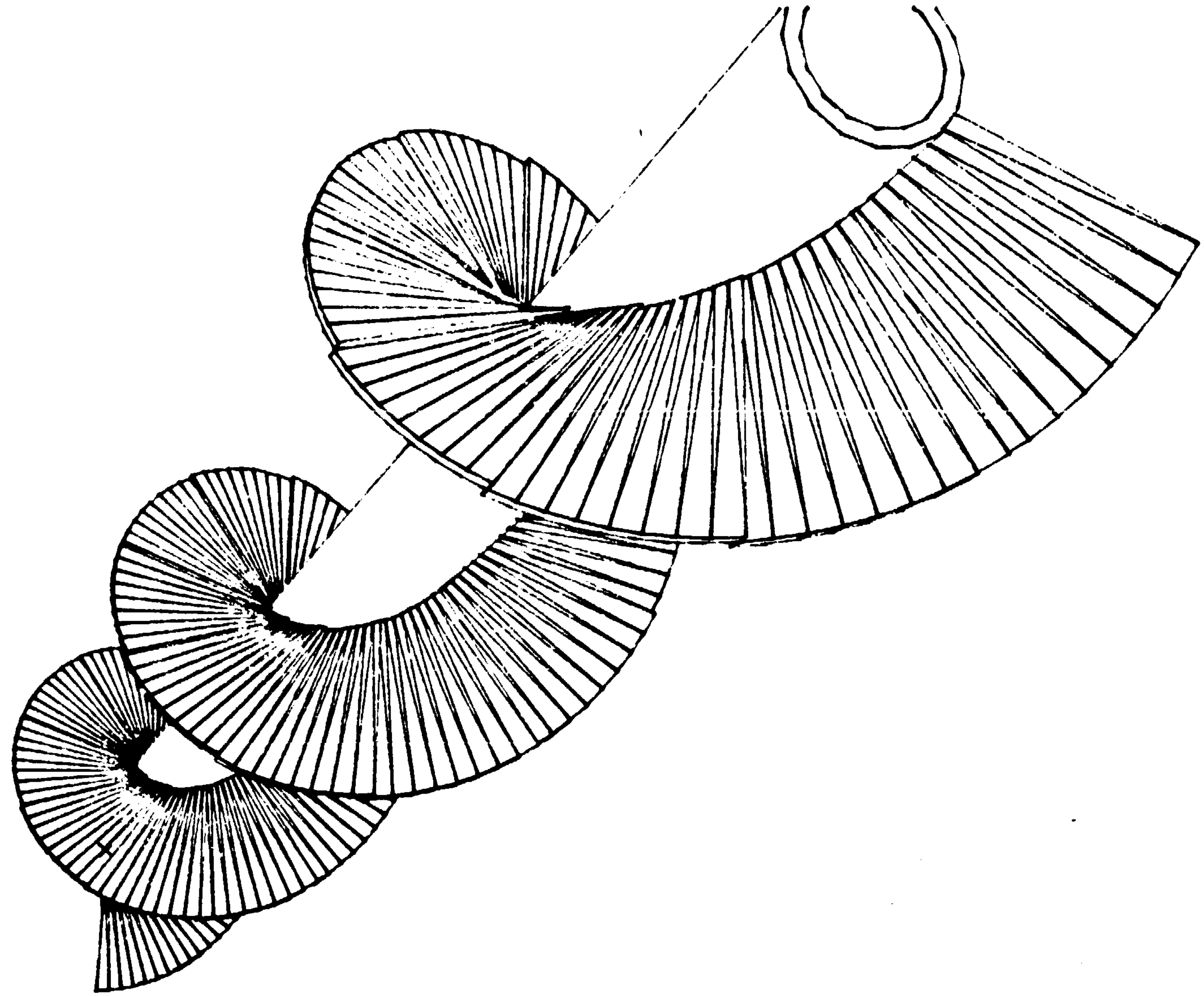
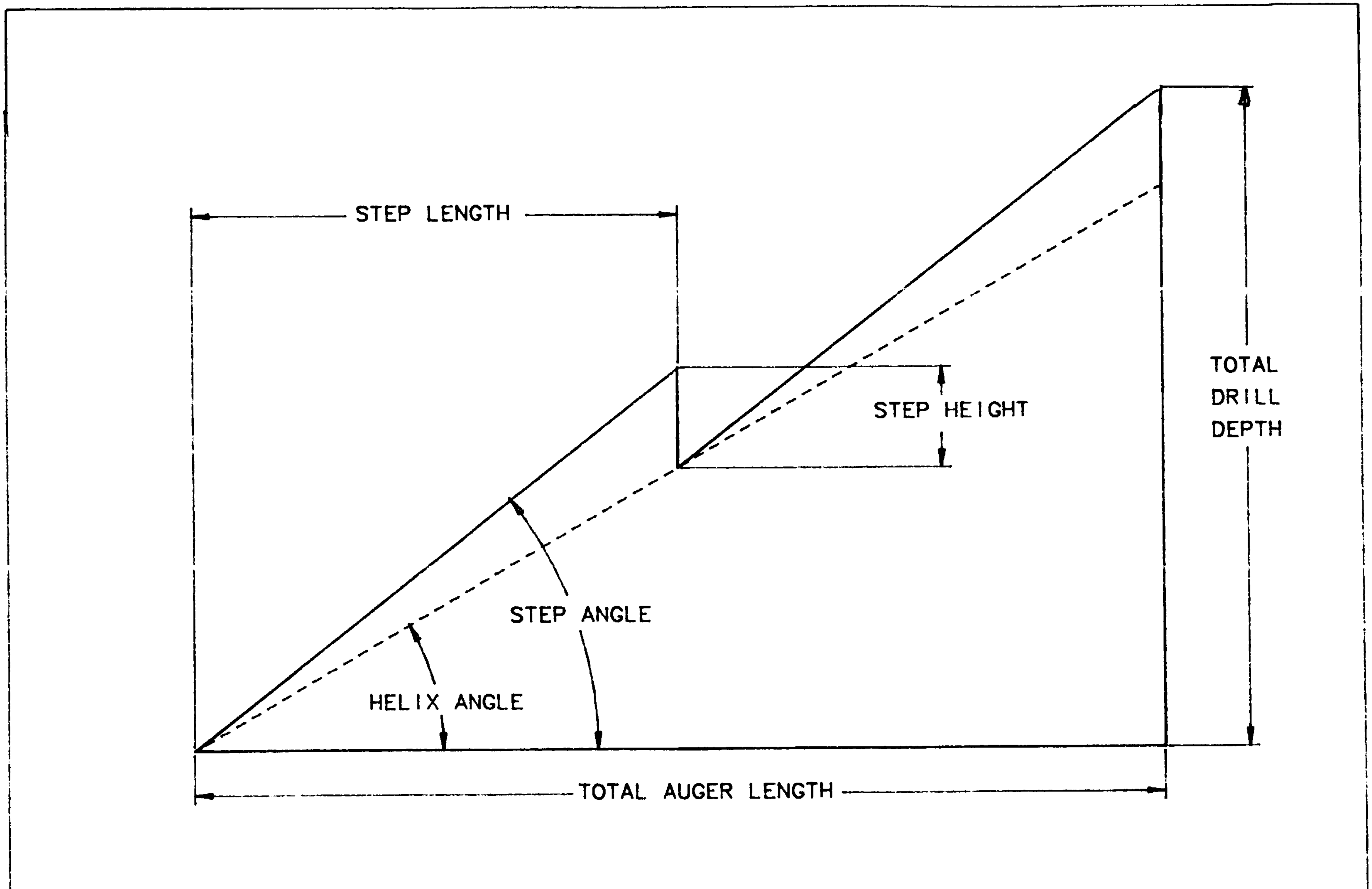


FIGURE 2.1

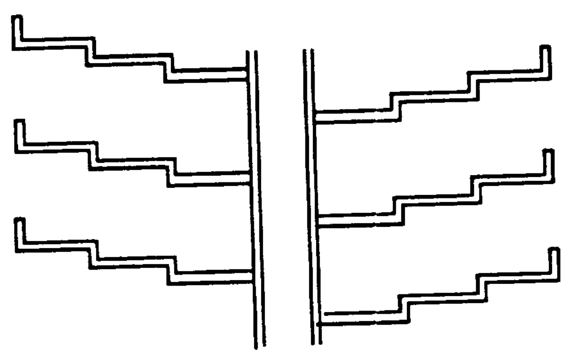


LINEARIZED STEPPED AUGER	ME 4182 ROTARY STEPPED AUGER	FEBRUARY 17, 1988 D. HART

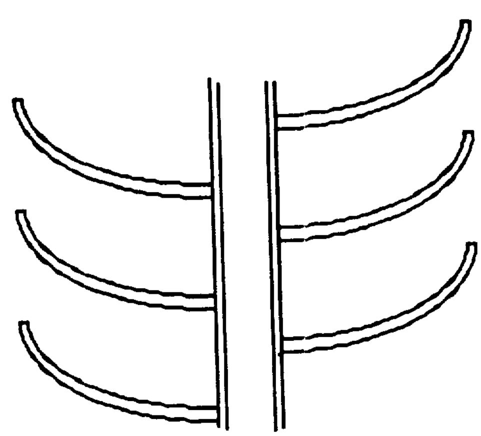
FIGURE 3.1

FIGURE 3.2

RADIAL CONTAINMENT



STEPPED PROFILE SECTION



CURVED PROFILE SECTION

Decision Matrix - Experimental Drive Mechanism

Criteria / Factor / Alternatives	project cost	assem. time	reliabi-lity	simpli-city	Motion	overall
	.20	.10	.10	.20	.40	1.0
Rack & Pinion	50% / 10	80% / 8	80% / 8	70% / 14	80% / 32	72
Rotary to Linear Slider	90% / 18	60% / 6	80% / 8	70% / 14	90% / 36	82
Computer Controlled DC motor	30% / 6	80% / 8	80% / 8	30% / 6	50% / 20	48

FIGURE 4.1

Decision Matrix - Experimental Auger Radial Containment

Criteria / Factor / Alternatives	Perfor-mance	assem. ease	model accuracy	drive rqmts	var. par.	overall
	.20	.20	.40	.10	.10	1.0
Flat Profile with fences	70% / 14	30% / 6	60% / 24	80% / 8	60% / 6	58
Flat Profile no fences	60% / 12	70% / 14	80% / 32	80% / 8	60% / 6	72
Curved Profile containment	40% / 8	20% / 4	50% / 20	80% / 8	40% / 4	44

FIGURE 4.2

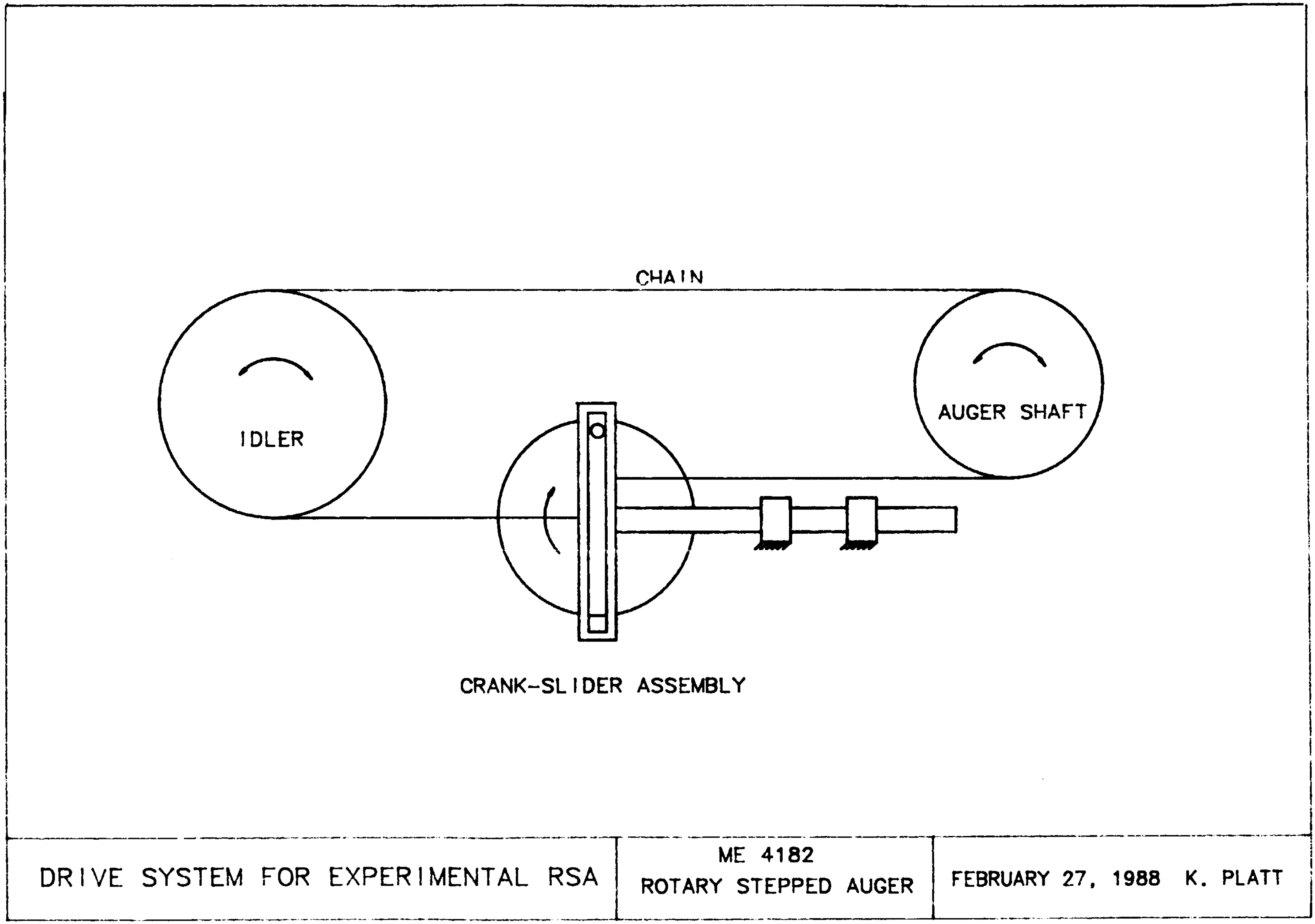

CHAIN
IDLER
AUGER SHAFT
CRANK-SLIDER ASSEMBLY
DRIVE SYSTEM FOR EXPERIMENTAL RSA
ME 4182
ROTARY STEPPED AUGER
FEBRUARY 27, 1988 K. PLATT

FIGURE 4.2

OSCILLATION TUNING FOR SINUSOIDAL AUGER MOTION

THETA(t) = Asin(ft)

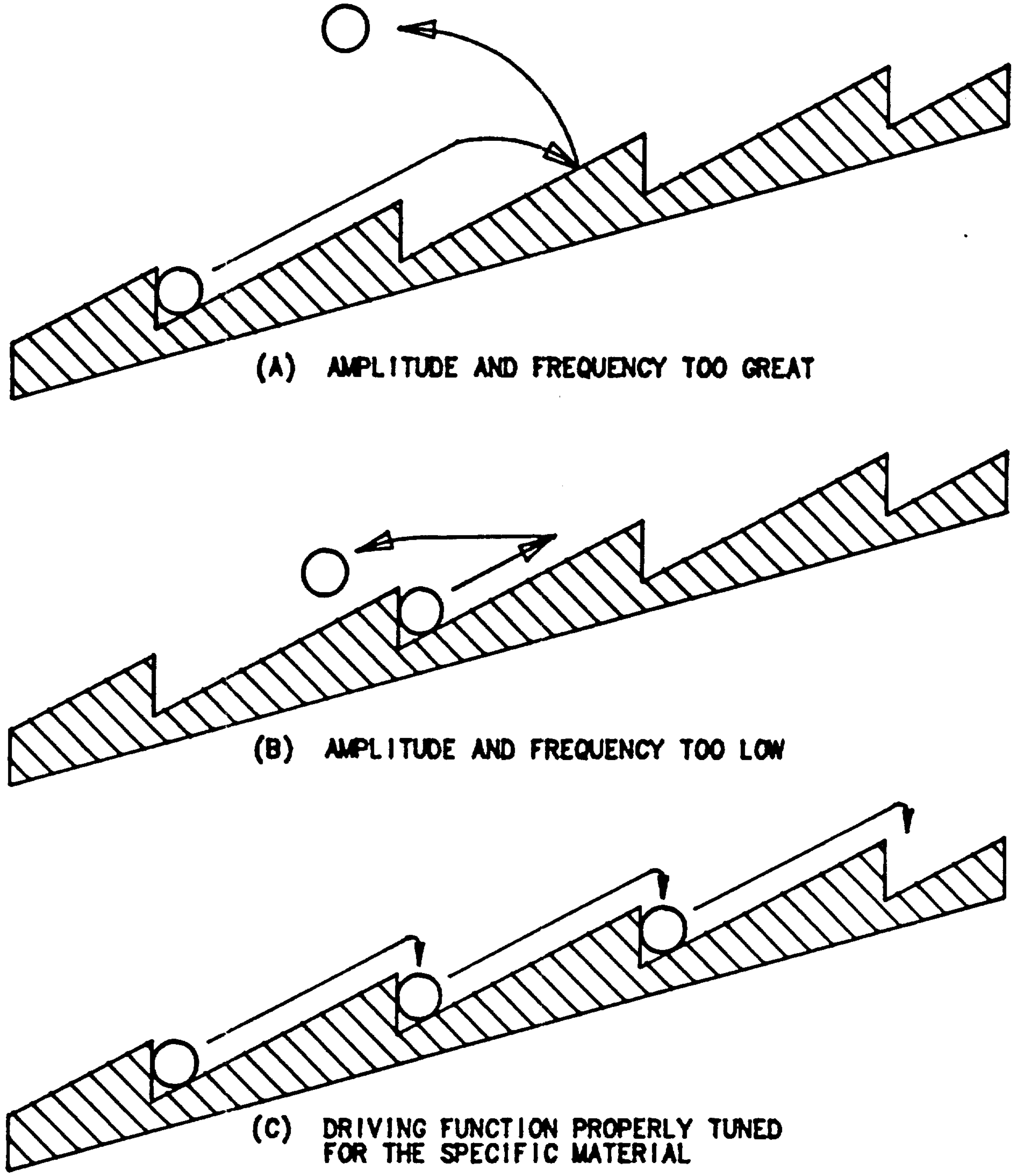
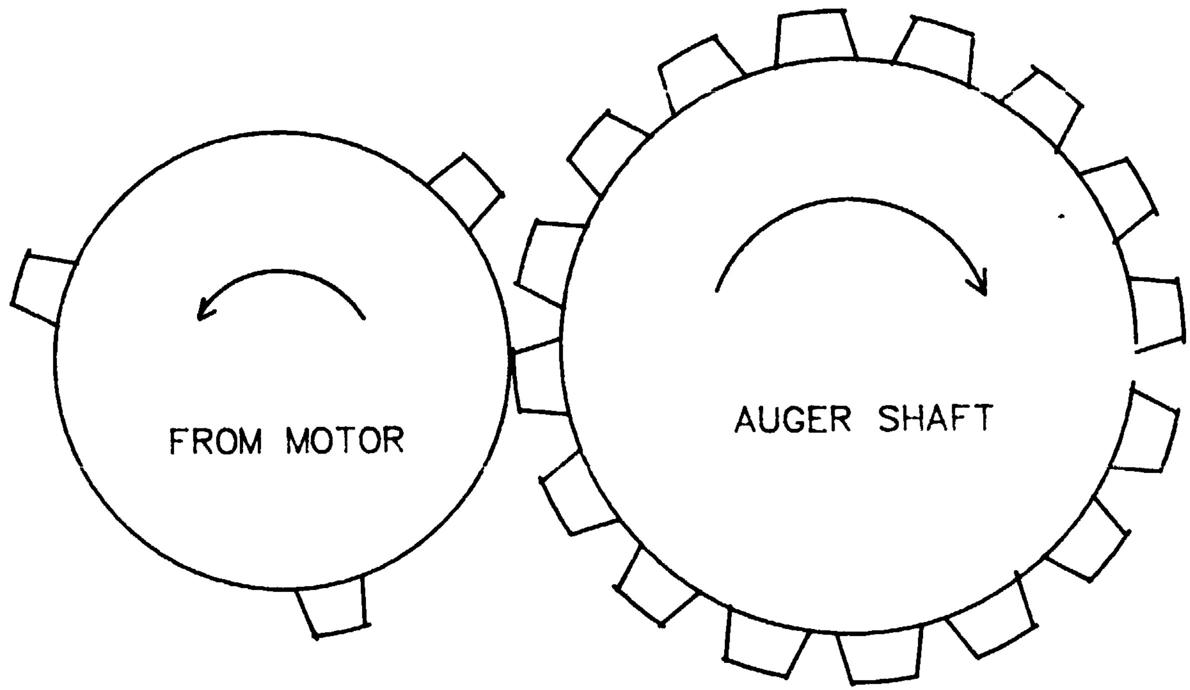


FIGURE 5.1

Decision Matrix - Auger Material Selection

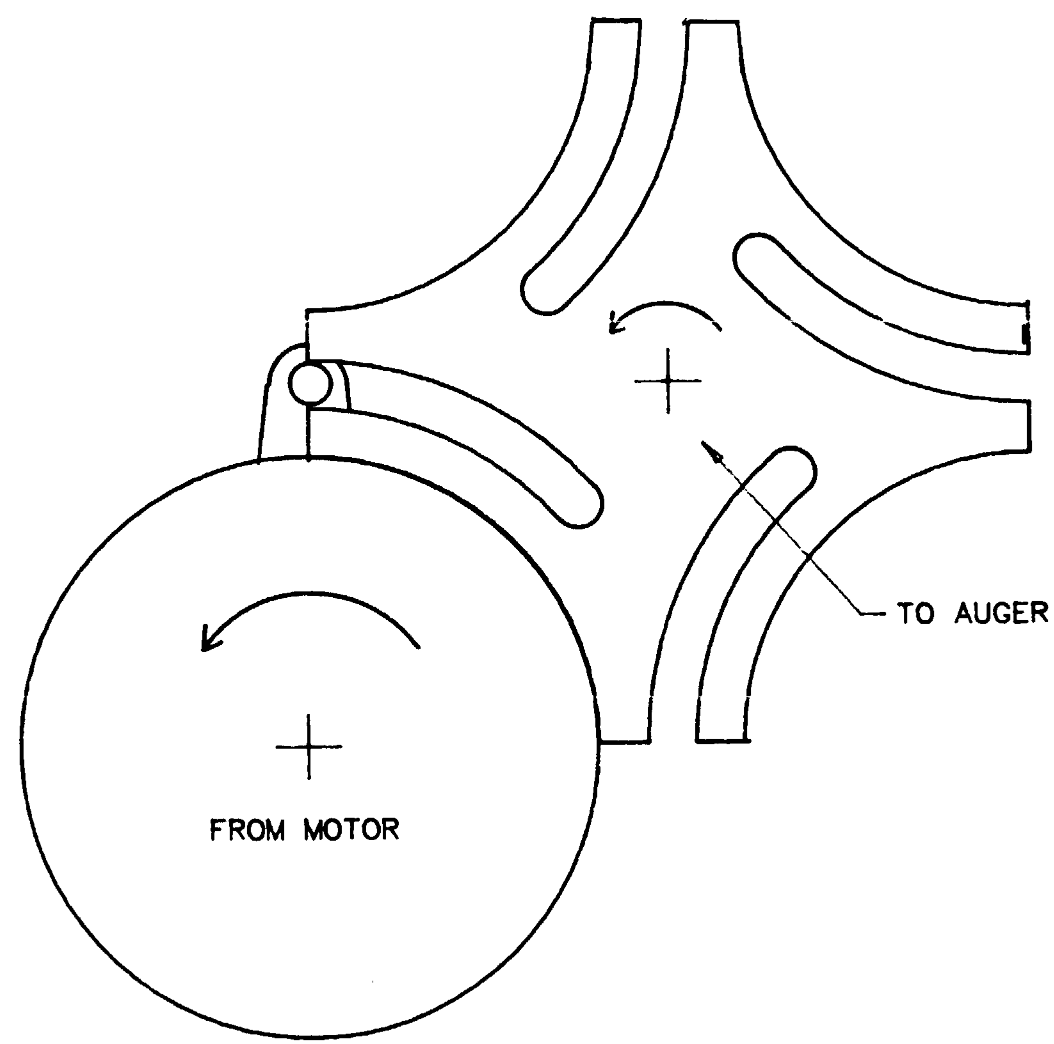
FACTOR / CRITERIA / ALTERNATIVES	LIGHT-WEIGHT	WEAR	RESISTANCE FATIGUE	HEAT	HIGH STRENGTH	OVERALL
	.40	.20	.10	.20	.10	1.0
TITANIUM 5A12.5Sn	80% / 32	70% / 14	60% / 6	90% / 18	80% / 8	78
TITANIUM 6A14V	80% / 32	70% / 14	60% / 6	75% / 15	85% / 8.5	75.5
HADFIELDS STEEL	40% / 16	90% / 18	50% / 5	65% / 13	65% / 6.5	58.5
STAINLESS STEEL J91150	40% / 16	80% / 16	90% / 9	65% / 13	90% / 9	63
ALUMINUM AA 7175	95% / 38	30% / 6	80% / 8	40% / 8	50% / 5	65

FIGURE 6.1



INTERMITTENT TOOTH PINION DRIVE MECHANISM	ROTARY STEPPED AUGER ME 4182	K. PLATT MARCH 5, 1988

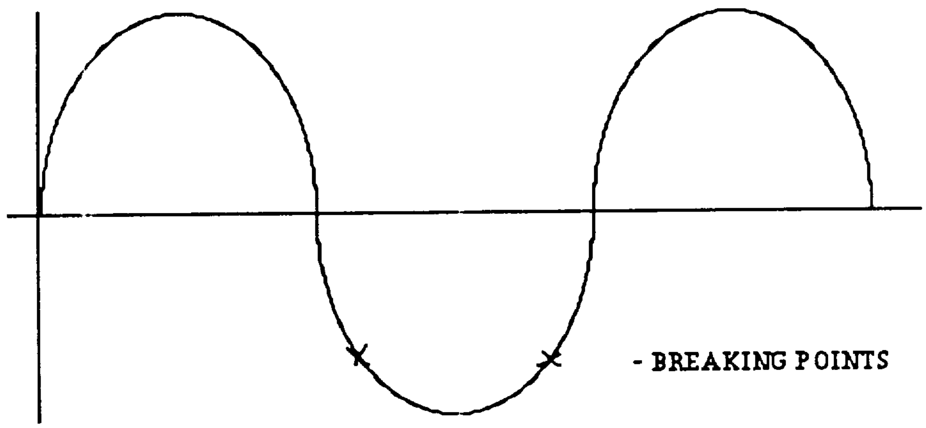
FIGURE 6.2



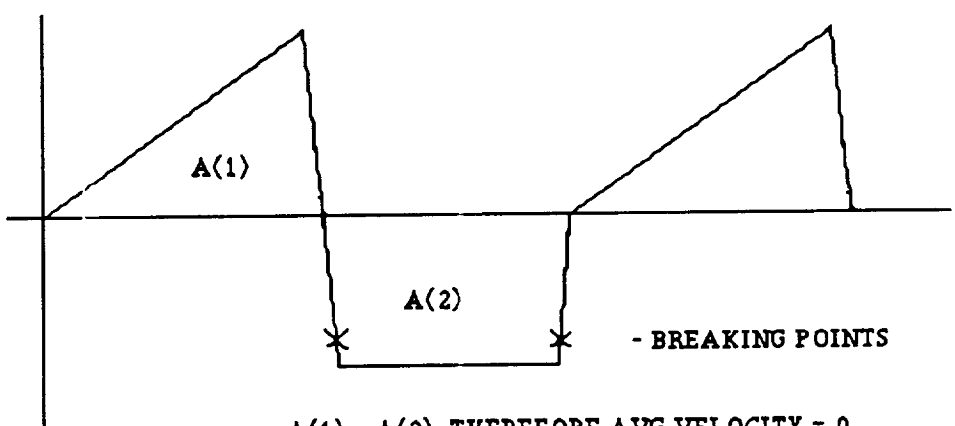
GENEVA WHEEL DRIVE MECHANISM	ME 4182 ROTARY STEPPED AUGER	K. PLATT MARCH 5, 1988

FIGURE 6.3

ACCELERATION FUNCTION EXAMPLES



EXPERIMENTAL DRIVE FUNCTION



A(1) = A(2), THEREFORE AVG VELOCITY = 0

PROPOSED DRIVE FUNCTION

FIGURE 7.1

APPENDIX B

DEVELOPMENT OF MATHEMATICAL MODEL

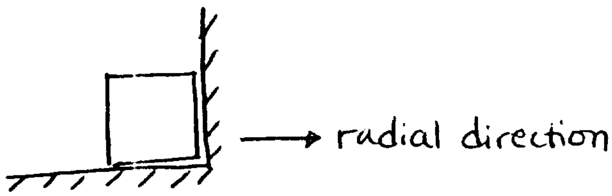
APPENDIX B

MATHEMATICAL MODEL FOR A SINGLE PARTICLE ON A ROTARY STEPPED AUGER

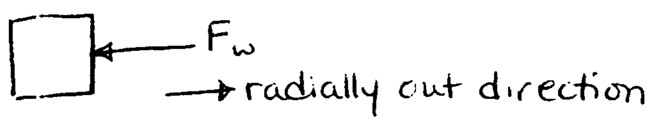
Radial Containment Achieved with Fences

I. EQUATIONS OF MOTION FOR PARTICLE:

A. Radial



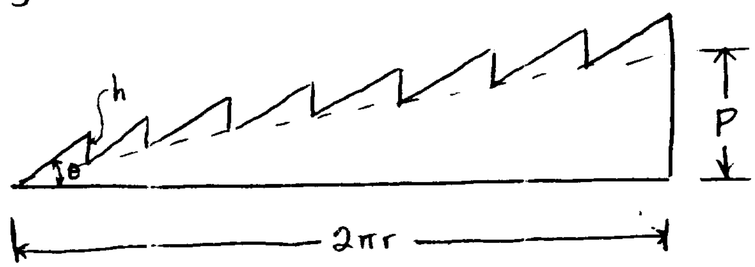
Assumption: Only force is exerted by fence (radial direction)



$$\Sigma F \text{ (radial direction)} = ma_r = m\omega^2 r = F_\omega$$

where m = mass of particle
r = radial position of particle
ω = angular velocity of the particle
(assume ω small enough to neglect coriolis effects)

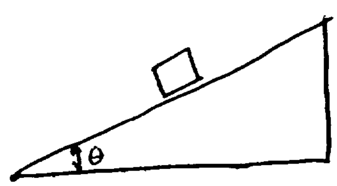
B. Tangential and Vertical



where P = auger pitch (base helix)
h = step height
S = number of steps per pitch
θ = angle of step surface with horizontal

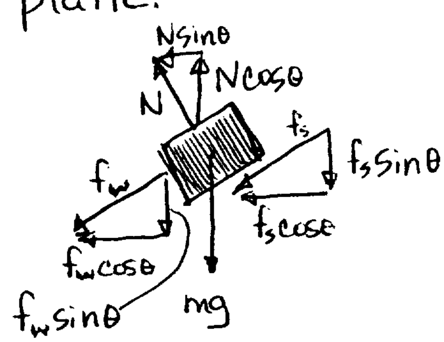
$$\tan\theta = \frac{h + \left(\frac{P}{S}\right)}{\left(\frac{2\pi r}{S}\right)} \quad \text{and} \quad \theta = \tan^{-1}\left[\frac{hS + P}{2\pi r}\right]$$

Now looking at one step



→ tangential direction

Particle is constrained so unable to move down plane (steps). And by previous assumption that no component of friction is in the radial direction, the friction of the step is in tangential direction down the plane.



→ tangential direction.

Let N = normal force
f_s = step friction (in z,t plane)
f_w = wall friction

$$\left[\begin{array}{l} \Sigma F(\text{tangential direction}) = ma_t = -N\sin\theta - f_w\cos\theta - f_s\cos\theta \\ \Sigma F(\text{vertical direction}) = ma_z = N\cos\theta - f_s\sin\theta - f_w\sin\theta - mg \\ \Sigma F(\text{radial direction}) = ma_r = m\omega^2 r = F_w \end{array}\right.$$

Then assuming friction positive in the directions indicated on the picture, the equations of motion are valid whenever the auger is undergoing negative acceleration.

II. SOLUTION OF EQUATIONS OF MOTION

This system must be solved in two steps. First solve using conditions that the particle is not sliding.

A. No Sliding

- Additional equations are
  $a_z = 0$ (no acceleration in z direction)
  $a_\theta = r\alpha$ where α = angular acceleration of auger
- Limiting Conditions:
  $f_w = \mu F_w$ (since positive, verge of sliding up the step)
  $f_s = \mu N$ (assume $\mu_{static} = \mu_{kinetic}$)

Now assume a particular auger drive function.

example: $\omega = A \sin \frac{2\pi}{T} t$

where A = maximum angular speed
T = period of sinusoidal motion
ω = angular speed of auger

then $\alpha = \frac{d\omega}{dt} = A \frac{2\pi}{T} \cos \frac{2\pi}{T} t$

Using this drive function and limiting conditions, it is possible to find the time at which the particle breaks free of the auger and the time at which it sticks back to the auger.

Substituting $a_z = 0,\ a_\theta = r\alpha,\ f_w = \mu F_w,\ f_s = \mu N$ into equations of motion

$$\begin{cases} F_w = m\omega^2 r \\ mr\alpha = -N\sin\theta - \mu F_w \cos\theta - \mu N \cos\theta \\ 0 = N\cos\theta - \mu N \sin\theta - \mu F_w \sin\theta - mg \end{cases}$$

Simplifying:

$$\frac{N}{m} = \frac{\mu\omega^2 r \sin\theta + g}{(\cos\theta - \mu \sin\theta)}$$

$$r\alpha = -\frac{N}{m}(\sin\theta + \mu\cos\theta) - \mu\omega^2 r \cos\theta$$

Eliminate $\frac{N}{m}$:

$$\left[-r\alpha = \frac{(\mu\omega^2 r\sin\theta + g)}{(\cos\theta - \mu\sin\theta)}(\sin\theta + \mu\cos\theta) + \mu\omega^2 r\cos\theta \right.$$

rewriting

$$\frac{\cancel{r}\alpha}{\cancel{r}} + \omega^2\left[\frac{\mu\cancel{r}\sin\theta(\sin\theta + \mu\cos\theta)}{\cancel{r}(\cos\theta - \mu\sin\theta)} + \frac{\mu\cancel{r}}{\cancel{r}}\cos\theta\right]$$

$$= \frac{-g(\sin\theta + \mu\cos\theta)}{r(\cos\theta - \mu\sin\theta)}$$

Now substitute $\omega = A\sin\frac{2\pi}{T}t$

$$\alpha = A\frac{2\pi}{T}\cos\frac{2\pi}{T}t$$

$$A\frac{2\pi}{T}\cos\frac{2\pi}{T}t + A^2\left[1 - \cos^2\frac{2\pi}{T}t\right][B] = C$$

where $$B = \left[\frac{\mu\sin\theta(\sin\theta + \mu\cos\theta)}{(\cos\theta - \mu\sin\theta)} + \mu\cos\theta\right]$$

$$C = \left[\frac{-g(\sin\theta + \mu\cos\theta)}{r(\cos\theta - \mu\sin\theta)}\right]$$

rewrite

$$-BA^2\cos^2\frac{2\pi}{T}t + \frac{A2\pi}{T}\cos\frac{2\pi t}{T} = C - A^2B$$

$$\cos^2\frac{2\pi}{T}t - \frac{2\pi}{TBA}\cos\frac{2\pi t}{T} = \frac{A^2B - C}{A^2B}$$

Now if $D = \frac{2\pi}{TBA}$ and $E = \frac{A^2B - C}{A^2B}$

Then $\cos\frac{2\pi t}{T} = \frac{D \pm \sqrt{D^2+4E}}{2}$

So
$$\boxed{\begin{aligned} t_{\substack{\text{break}\\\text{free}}} &= \cos^{-1}\left[\frac{D-\sqrt{D^2+4E}}{2}\right] \\ t_{\substack{\text{stick}\\\text{back}}} &= \cos^{-1}\left[\frac{D+\sqrt{D^2+4E}}{2}\right] \end{aligned}}$$

* If particle never breaks free $\sqrt{D^2+4E}$ will be imaginary or t will not be $0<t<T$

Now that these times are known they may be used in the sliding case.

B. SLIDING

Again use

$\Sigma F(\text{tangential}) = ma_t = -N\sin\theta - f_w\cos\theta - f_s\cos\theta$

$\Sigma F(\text{vertical}) = ma_z = N\cos\theta - f_s\sin\theta - f_w\sin\theta - mg$

$\Sigma F(\text{radial}) = ma_r = m\omega^2 r = F_w$

Now when sliding (forward) up the step

$f_w = \mu F_w$

$f_s = \mu N$

$a_z = (a_\theta - r\alpha)\tan\theta$ for the sliding case

assume $\omega_{part} = \omega_{auger}$ (assume not sliding very fast).

Substitute:

$$\left[\begin{array}{l} \frac{\cancel{m}}{\cancel{m}} a_t = -\frac{N}{m}\sin\theta - \mu\frac{\cancel{m}}{\cancel{m}}\omega^2 r\cos\theta - \mu\frac{N}{m}\cos\theta \\ \frac{\cancel{m}}{\cancel{m}}(a_t - r\alpha)\tan\theta = \frac{N}{m}\cos\theta - \mu\frac{N}{m}\sin\theta - \mu\frac{\cancel{m}}{\cancel{m}}\omega^2 r\sin\theta - \frac{\cancel{m}}{\cancel{m}}g \end{array}\right.$$

rewrite:

$$\frac{a_t + \mu\omega^2 r\cos\theta}{-(\sin\theta + \mu\cos\theta)} = \frac{N}{m}$$

$$\frac{(a_t - r\alpha)\tan\theta + \mu\omega^2 r\sin\theta + mg}{(\cos\theta - \mu\sin\theta)} = \frac{N}{m}$$

Now eliminate $\frac{N}{m}$:

$$\frac{a_t + \mu\omega^2 r\cos\theta}{-(\sin\theta + \mu\cos\theta)} = \frac{(a_t - r\alpha)\tan\theta + \mu\omega^2 r\sin\theta + g}{(\cos\theta - \mu\sin\theta)}$$

Solve for a_t

$$a_t = \left[\frac{((r\alpha - a_t\tan\theta) - \mu\omega^2 r\sin\theta - g)}{(\cos\theta - \mu\sin\theta)}\right](\sin\theta + \mu\cos\theta)$$

$$\left[a_t + a_t\tan\theta\,\frac{(\sin\theta + \mu\cos\theta)}{\cos\theta - \mu\sin\theta}\right] = \left[\frac{(r\alpha - \mu\omega^2 r\sin\theta - g)(\sin\theta + \mu\cos\theta)}{(\cos\theta - \mu\sin\theta)}\right.$$

$$a_t = \frac{(r\alpha - \mu\omega^2 r\sin\theta - g)(\sin\theta + \mu\cos\theta)}{[(\cos\theta - \mu\sin\theta) + \tan\theta(\sin\theta + \mu\cos\theta)]}$$

* valid between $t_{\text{break free}} \rightarrow t_{\text{stick back}}$

Now the acceleration relative to the auger is

$a_{rel} = a_t - r\alpha$ where a_t is above

Now integrate numerically to get distance travelled between $t_{break\ free} \rightarrow t_{stick\ back}$.

This distance must be $> \frac{2\pi r}{S}$ for the particle to travel to the next step.

Note that $\underline{r, \mu, h, S, P, A, T, g}$ may be varied.

With the Sinusoidal input, the acceleration may be integrated directly

Let $F = \dfrac{(\sin\theta + \mu\cos\theta)}{[(\cos\theta - \mu\sin\theta) + \tan\theta(\sin\theta + \mu\cos\theta)]}$

Then $a_{rel} = a_t - r\alpha$

$$a_{rel} = r(F-1)\alpha - \mu F r\sin\theta\,\omega^2 - gF$$

$$\omega = A\sin\frac{2\pi}{T}t \qquad \alpha = \frac{2\pi}{T}A\cos\frac{2\pi}{T}t$$

$$a_{rel} = r(F-1)\frac{2\pi}{T}\cos\frac{2\pi}{T}t - \mu F r\sin\theta\, A^2 \underbrace{\sin^2\frac{2\pi}{T}t}_{\frac{1-\cos\frac{4\pi t}{T}}{2}} - gF$$

$$V_{rel} = r(F-1)\sin\frac{2\pi}{T}t - \frac{\mu F r \sin\theta A^2 t}{2} + \frac{\mu F r \sin\theta A^2}{2}\frac{T}{4\pi}\sin\frac{4\pi t}{T} - gFt + C$$

where

since $V_{rel} = 0$ at $t_{\text{break free}}$

$$C = \left[gF + \frac{\mu F r \sin\theta A^2}{2}\right]t_{\text{break free}} - \left[r(F-1)\sin\frac{2\pi t_{b.f.}}{T} + \frac{\mu F r \sin\theta A^2}{2}\frac{T}{4\pi}\sin\left(\frac{4\pi t_{b.f.}}{T}\right)\right]$$

Now distance traveled

$$= -r(F-1)\frac{T}{2\pi}\cos\frac{2\pi t}{T} - \left[gF + \frac{\mu F r \sin\theta A^2}{2}\right]\frac{t^2}{2} - \frac{\mu F r \sin\theta}{2}\frac{T}{4\pi}\frac{T}{4\pi}\cos\frac{4\pi t}{T} + Ct$$

and evaluate between $t_{\text{break free}}$ and $t_{\text{stick back}}$

APPENDIX C

AUGER SIMULATION PROGRAM

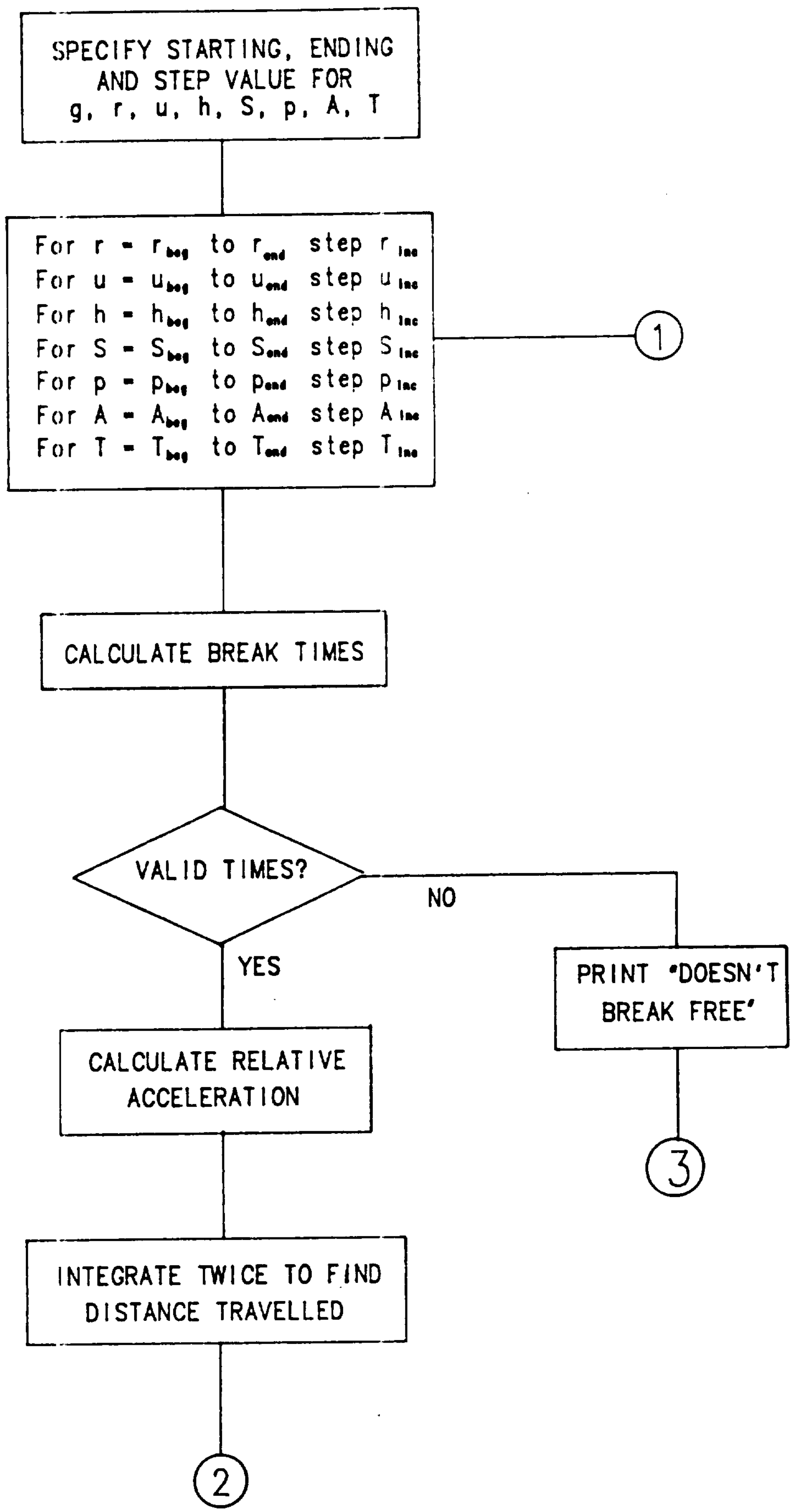
USER'S GUIDE TO RSADESIGN

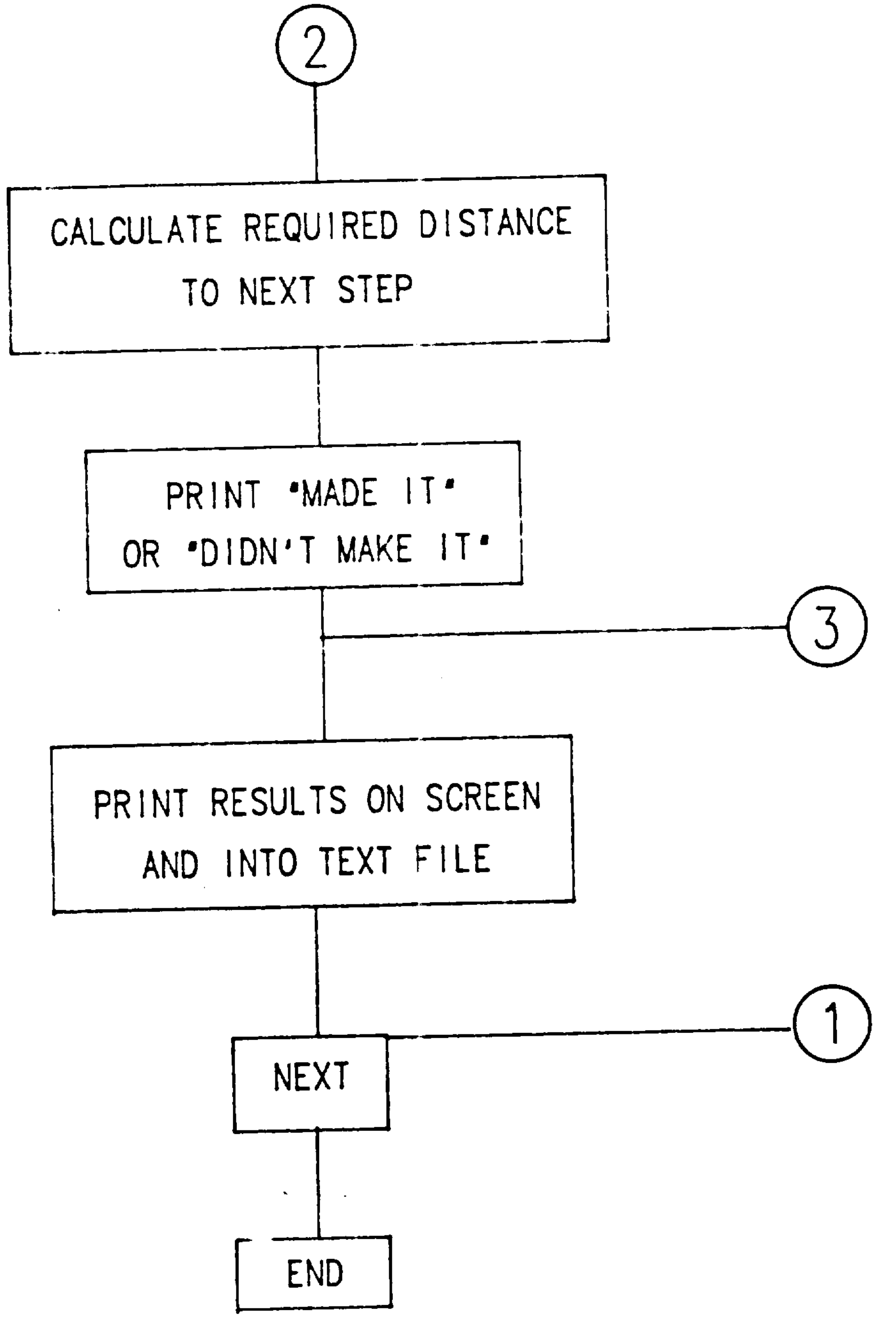
RSADESIGN is a BASIC program written to aid in the evaluation of the math model. It was written for IBM Advanced BASIC.

The program will allow beginning, ending and increment values for step height, auger pitch, number of steps per pitch, fence radius, gravitational constant, coefficient of friction, and the amplitude and period of the driving sinusoid function to be inputed. From this information and the math model outlined in Appendix B, the program determines whether the particle breaks free from the auger surface during one cycle. If it does, the distance travelled by the particle relative to the auger surface is given.

Output generated by RSADESIGN may be printed to the screen or to a text file for spreadsheet analysis. A flowchart and program listing follow.

PROGRAM TO ASSIST AUGER DESIGN




2
CALCULATE REQUIRED DISTANCE TO NEXT STEP
PRINT "MADE IT" OR "DIDN'T MAKE IT"
3
PRINT RESULTS ON SCREEN AND INTO TEXT FILE
1
NEXT
END

```
5 CLS
6 REM                             PROGRAM RSADESIGN
7 REM
8 REM TO RUN TYPE LOAD"RSADESIGN"
10 PRINT"*************************************************************************"

20 PRINT"*******                                                           *******"

30 PRINT"*******        STEPPED ROTARY AUGER DESIGN ASSIST PROGRAM         *******"

40 PRINT"*******                                                           *******"

50 PRINT"*******              GEORGIA INSTITUTE OF TECHNOLOGY              *******"

60 PRINT"*******                  ME 4182  DESIGN PROJECT                  *******"

70 PRINT"*******                          GROUP B                          *******"

80 PRINT"*******                     FEBRUARY 25, 1988                     *******"

90 PRINT"*******                                                           *******"

100 PRINT"************************************************************************
"
105 REM INITIALIZE LOOP VARIABLES
106 HINC=1:SINC=1:PINC=1:RINC=1:UINC=1:AINC=1:TINC=1:GINC=1
108 REM LINES 110-940 SIMPLY RECEIVE DATA FROM USER
110 PRINT:PRINT:PRINT
120 INPUT "READY TO ENTER PARAMETERS? (Y/N)";ANS$
130 IF LEFT$(ANS$,1)="N" THEN 2000
140 IF LEFT$(ANS$,1)<>"Y" THEN 120
150 CLS
160 PRINT "GRAVITY:  (m/s^2)"
165 PRINT
170 INPUT "RANGE OR SPECIFIC VALUE ";ANS$
180 IF LEFT$(ANS$,1)="R" THEN 210
190 PRINT:INPUT "SPECIFIC VALUE = ";GBEG:GEND=GBEG
200 GOTO 240
210 PRINT:INPUT "BEGINNING VALUE =";GBEG
220 INPUT "ENDING VALUE =";GEND
230 INPUT "INCREMENT OF G =";GINC
240 CLS
250 PRINT "RADIUS OF PARTICLE PATH:  (meters)"
260 PRINT
270 INPUT "RANGE OR SPECIFIC VALUE ";ANS$
280 IF LEFT$(ANS$,1)="R" THEN 310
290 PRINT:INPUT "SPECIFIC VALUE = ";RBEG:REND=RBEG
300 GOTO 340
310 PRINT:INPUT "BEGINNING VALUE =";RBEG
320 INPUT "ENDING VALUE =";REND
330 INPUT "INCREMENT =";RINC
340 CLS
350 PRINT "COEFFICIENT OF FRICTION:  "
360 PRINT
370 INPUT "RANGE OR SPECIFIC VALUE ";ANS$
380 IF LEFT$(ANS$,1)="R" THEN 410
390 PRINT:INPUT "SPECIFIC VALUE = ";UBEG:UEND=UBEG
400 GOTO 440
```

```
410 PRINT:INPUT "BEGINNING VALUE = ";UBEG
420 INPUT "ENDING VALUE = ";UEND
430 INPUT "INCREMENT = ";UINC
440 CLS
450 PRINT "STEP HEIGHT :  (meters)"
460 PRINT
470 INPUT "RANGE OR SPECIFIC VALUE ";ANS$
480 IF LEFT$(ANS$,1)="R" THEN 510
490 PRINT:INPUT "SPECIFIC VALUE = ";HBEG:HEND=HBEG
500 GOTO 540
510 PRINT:INPUT "BEGINNING VALUE = ";HBEG
520 INPUT "ENDING VALUE = ";HEND
530 INPUT "INCREMENT = ";HINC
540 CLS
550 PRINT "NUMBER OF STEPS PER PITCH :  "
560 PRINT
570 INPUT "RANGE OR SPECIFIC VALUE ";ANS$
580 IF LEFT$(ANS$,1)="R" THEN 610
590 PRINT:INPUT "SPECIFIC VALUE = ";SBEG:SEND=SBEG
600 GOTO 640
610 PRINT:INPUT "BEGINNING VALUE = ";SBEG
620 INPUT "ENDING VALUE = ";SEND
630 INPUT "INCREMENT = ";SINC
640 CLS
650 PRINT "PITCH OF AUGER :  "
660 PRINT
670 INPUT "RANGE OR SPECIFIC VALUE ";ANS$
680 IF LEFT$(ANS$,1)="R" THEN 710
690 PRINT:INPUT "SPECIFIC VALUE = ";PBEG:PEND=PBEG
700 GOTO 740
710 PRINT:INPUT "BEGINNING VALUE = ";PBEG
720 INPUT "ENDING VALUE = ";PEND
730 INPUT "INCREMENT = ";PINC
740 CLS
750 PRINT "AMPLITUDE OF SINUSOIDAL ANGULAR VELOCITY :"
760 PRINT
770 INPUT "RANGE OR SPECIFIC VALUE ";ANS$
780 IF LEFT$(ANS$,1)="R" THEN 810
790 PRINT:INPUT "SPECIFIC VALUE = ";ABEG:AEND=ABEG
800 GOTO 840
810 PRINT:INPUT "BEGINNING VALUE = ";ABEG
820 INPUT "ENDING VALUE = ";AEND
830 INPUT "INCREMENT = ";AINC
840 CLS
850 PRINT "PERIOD OF SINUSOIDAL ANGULAR VELOCITY : "
860 PRINT
870 INPUT "RANGE OR SPECIFIC VALUE ";ANS$
880 IF LEFT$(ANS$,1)="R" THEN 910
890 PRINT:INPUT "SPECIFIC VALUE = ";TBEG:TEND=TBEG
900 GOTO 940
910 PRINT:INPUT "BEGINNING VALUE = ";TBEG
920 INPUT "ENDING VALUE = ";TEND
930 INPUT "INCREMENT = ";TINC
940 CLS :PRINT ABEG,AEND,AINC
941 PRINT TBEG,TEND,TINC
950 FOR H=HBEG TO HEND STEP HINC
960 FOR S=RBEG TO SEND STEP SINC
```

```
970 FOR P=PBEG TO PEND STEP PINC
980 FOR R=RBEG TO REND STEP RINC
990 REM BEGIN CALCULATIONS
1000 TH=ATAN((H*S+P)/(2*3.14159*R)) :REM CALCULATE ANGLE OF STEP
1010 CTH=COS(TH)
1020 STH=SIN(TH)
1050 FOR G=GBEG TO GEND STEP GINC
1060 FOR U=UBEG TO UEND STEP UINC
1070 REM CALCULATE INTERMEDIATE VALUES
1080 B=U*STH*(STH+U*CTH)/(CTH-U*STH)+U*CTH
1090 C=-G*(STH+U*CTH)/R/(CTH-U*STH)
1100 FOR A=ABEG TO AEND STEP AINC
1110 FOR T=TBEG TO TEND STEP TINC
1120 REM CALCULATE INTERMEDIATE VALUES
1130 D=2*3.14159/T/B/A
1140 E=(A*A*B-C)/A/A/B
1150 REM CHECK TO SEE IF THERE IS A SOLUTION
1160 CHECK=D*D+4*E  :REM MUST NOT BE NEGATIVE
1165 IF CHECK>=0 THEN 1170
1167 PRINT "IMAGINARY SOLN":GOTO 1255
1170 X=ATN((D-CHECK^.5)/2) :REM CALCULATE BREAK AWAY TIME
1175 TBA=1/(X^2+1)^.5  :REM MAKING UP FOR LACK OF ARCCOSINE
1180 X=ATN((D+CHECK^.5)/2) :REM TIME IT STICKS BACK
1183 TSB=1/(X^2+1)^.5  :REM MAKING UP FOR LACK OF ARCCOSINE
1185 REM CALCULATE MORE INTERMEDIATE VALUES
1190 F=(SIN(TH)+U*COS(TH))/((COS(TH)-U*SIN(TH))+TAN(TH)*(SIN(TH)+U*COS(TH)))
1200 C=(G*F+U*F*R*SIN(TH)*A*A/2)*TBA-(R*(F-1)*SIN(2*3.1415*TBA/T)+U*F*R/2*SIN(TH
)*A*A*T/4/3.1415*SIN(4*3.14159*TBA/T))
1210 REM CALCULATE DISTANCE TRAVELED
1215 REM CALCULATE POSITION AT TBA
1220 POSTBA=-R*(F-1)*T/2/3.1415*COS(2*3.1415*TBA/T)-(G*F+U*F*R*SIN(TH)*A*A/2)*T^
2/2-U*F*R*SIN(TH)*A*A/2*T^2/(4*3.1415)^2*COS(4*3.1415*TBA/T)+C*TBA
1225 REM CALCULATE POSITION AT TSB
1230 POSTSB=-R*(F-1)*T/2/3.1415*COS(2*3.1415*TSB/T)-(G*F+U*F*R*SIN(TH)*A*A/2)*T^
2/2-U*F*R*SIN(TH)*A*A/2*T^2/(4*3.1415)^2*COS(4*3.1415*TSB/T)+C*TSB
1240 REM CALCULATE DISTANCE TRAVELLED
1250 DTRAV=POSTSB-POSTBA
1251 REM PRINT OUTPUT THIS ORDER DTRAV, H, S, P, R, G, U, A, T
1252 PRINT "DTRAV = ";DTRAV;H;S;P;R;G;U;A;T
1255 REM
1990 NEXT :REM NEW STEP HEIGHT VALUE
1991 NEXT :REM NEW NUMBER OF STEPS PER PITCH
1992 NEXT :REM NEW PITCH VALUE
1993 NEXT :REM NEW TRACK RADIUS
1994 NEXT :REM NEW GRAVITATIONAL CONSTANT
1995 NEXT :REM NEW COEFFICIENT OF FRICTION
1996 NEXT :REM NEW ANGULAR VELOCITY AMPLITUDE
1997 NEXT :REM NEW ANGULAR VELOCITY PERIOD
2000 PRINT "BYE"
2010 END
2500 REM*****************************************************************
```

APPENDIX D - LUNAR ENVIRONMENT

Atmosphere - The atmosphere on the moon is virtually nonexistent, which eliminates the possibility of using an auger which utilizes compressed air and liquid. Even if the fluid is sealed at the top of the auger, a cavern may exist along the drill hole where the fluid may gather.

Gravity - The gravity on the moon is 1.623 m/s^2, about one-sixth of earth's gravity. This means a lunar-bound mechanical system will operate more efficiently than on the earth. Lunar soil can be moved much more easily with reduced weight.

Soil - Lunar soil is also different from what is found on earth. The density is less than earth soil, ranging from 1.36 g/cm^3 to 3.24 g/cm^3. The soil is similar to basaltic sand, which is used as a lunar soil simulant in many experiments.

Temperature - Lunar temperature ranges from -200° F to 200°F, so the auger must be made of a material that can withstand these temperature extremes.

Weight must also be considered in design and material selection. The cost of transporting an object to the moon is approximately 22,000 dollars per pound.

APPENDIX E

PROGRESS REPORTS

Weekly Progress Report

Course: M. E. 4182 A

Group: B

Group Members: E. Dardet, D. Hart, C. Herod, S. Homiller, M. Meeks and K. Platt

Title: **Stepped - Rotary Auger**

Date: January 14, 1988

Data Collecting: We began by gathering initial information about augers. First, we researched the industry standards. All of the industry standards referred to agricultural conveyors and not drilling augers.

Secondly, we looked for information about the properties of lunar soil and specifically, drilling in it. We researched the technical journals and government documents. We found technical papers on drilling by rock melting techniques, but up to this point, we have not been able to locate information on drilling by the use of an auger. We were unable to find the document referred to in class, "Lunar Bases and Space Activities in the 21st Century", although we saw ample reference to it.

Weekly Progress Report

Course: M. E. 4182 A

Group: B

Group Members: E. Dardet, D. Hart, C. Herod, S. Homiller, M. Meeks and K. Platt

Title: **Stepped - Rotary Auger**

Date: January 21, 1988

Problem Statement: We drafted our preliminary problem statement. We included constraints and justification to narrow our focus down to two definite goals.

Soil research: We researched the properties of lunar soil and found that the immediate surface is fine rubble. At approximately three to six meters below the surface, igneous bedrock is encountered. This means that the auger must transport both the soil and drilling cutting to the surface.

Model Development: We reviewed projectile motion and wrote a simulation program. We have developed an experiment to determine the coefficient of friction between simulation lunar soil and the auger surface. Equations have been developed to account for this frictional effect. A conceptional model has been developed.

Geodraw Class: The entire group has attended the Geodraw class.

Weekly Progress Report

Course: M. E. 4182 A

Group: B

Group Members: E. Dardet, D. Hart, C. Herod, S. Homiller, M. Meeks and K. Platt

Title: **Stepped - Rotary Auger**

Date: January 28, 1988

Geomod Class: Our group continues to attend the bi-weekly Geodraw and Geomod classes. In addition, we are learning the VersaCad and Wordwise systems.

Models: This week, the group met three times to discuss and develop a linear model of the auger. Formulas relating the acceleration of the auger to the acceleration of a dirt [article were obtained. With the help of the linear auger model, parameters include acceleration of the dirt relative to the auger, step length and height, helix angle, step shape, and others. A drawing of our conception of the rotary auger was generated of Geomod. In addition, tasks were divided among the team. One part of the group will focus on data collection, and the other part will work on the continued development of the rotary model.

Weekly Progress Report

Course: M. E. 4182 A

Group: B

Group Members: E. Dardet, D. Hart, C. Herod, S. Homiller, M. Meeks and K. Platt

Title: **Stepped - Rotary Auger**

Date: February 4, 1988

Math model: Last week the equations of motion in the tangential direction were developed. This week motion equations were derived.

In order to maximize through-put, it is desired that the cuttings do not travel in the radial direction. the acceleration due to the rotation of the auger, (w^2r), will tend to sling the cuttings toward the outer edge of the auger. In order to reduce or eliminate the this tendency, the ramp can be given a positive slope in the radial direction. Furthermore, at low angular velocities, the friction force must be large enough to prevent the cuttings from sliding inward due to the force of gravity, and similarly at high angular velocities, the friction force must prevent the cuttings from sliding outward due to the centrifugal force. The developed statics equations for the radial direction were used to give a range of auger operating speeds for several different profiles and coefficients of friction. An example of an operating range profile is included with this report.

Search: We finished the information search on the libraries on line databases, Lunar Planetary Institute, NASA and other universities' reports. We also made a list of the subjects to search in the library's commercial search.

Presentation: We started working on the format of our report as well as looking into the requirements outlined in MS-4 "An ASME paper". Also, we made preliminary plans for next week's oral presentation, including the layout of the visuals.

Weekly Progress Report

Course: M. E. 4182 A

Group: B

Group Members: E. Dardet, D. Hart, C. Herod, S. Homiller, M. Meeks and K. Platt

Title: **Stepped - Rotary Auger**

Date: February 11, 1988

Math Model: We scheduled an appointment with Dr. Papastravridis to review out math model. We are currently writing a computer program to help evaluate the equations for various auger parameters. The current model requires geometric parameters as well as the auger drive acceleration function.

Experimental Model: We sand blasted our experimental auger to prepare it for the ramp modeling. We have considered different methods and materials to construct the ramps. The most promising method to date is to make a mold of one step and cast the others.

Report Preparations: A preliminary Table of Contents was drafted. Additional information and references were collected, including the density, shape and composition of lunar soil particles.

Weekly Progress Report

Course: M. E. 4182 A

Group: B

Group Members: E. Dardet, D. Hart, C. Herod, S. Homiller, M. Meeks and K. Platt

Title: **Stepped - Rotary Auger**

Date: February 18, 1988

Math Model: At this stage of development, it does not appear that the radial containment system is a reasonable alternative. The speed and acceleration control of the auger would have to be unrealistically precise. A series of concentric fences for radial containment should be much more tolerant of the auger drive control. Due to the addition of the fence, development of this model requires several assumptions to be made about friction forces.

Experimental Model: We decided on a preliminary design for the driving mechanism and test stand. The drive system will consist of a eccentric cam driving a rack connected to a gear on the auger. An electric motor will provide the power for the system. This drive system will give the auger a sinusoidal acceleration. By knowing the acceleration profile an accurate comparison can be made with predictions of the math model.

Weekly Progress Report

Course: M. E. 4182 A

Group: B

Group Members: E. Dardet, D. Hart, C. Herod, S. Homiller, M. Meeks and K. Platt

Title: **Stepped - Rotary Auger**

Date: February 24, 1988

Math Model : After last week's meeting, we decided to make simplifying assumptions on our math model. This enabled us to solve for the time that the particle breaks free and for the time it sticks back on the surface of the auger. This will enable us to solve for the acceleration of the particle as a function of time. Also, we have solved for the range of torques needed for our experimental simulation.

Experiment Construction: We have constructed a wooden test stand. Also, we finalized our design for the driving mechanism which will give a sinusoidal input. Also we have constructed a mold for the ramps which we will use to duplicate the individual steps along the auger.

Weekly Progress Report

Course: M. E. 4182 A

Group: B

Group Members: E. Dardet, D. Hart, C. Herod, S. Homiller, M. Meeks and K. Platt

Title: **Stepped - Rotary Auger**

Date: March 3, 1988

Modeling Program: We are making progress on the computer simulation of the auger. The idea is to detail the geometry of the auger and motion of the particles given an acceleration profile. Then different parameters may be varied such as step height, step angle, etc.

Experimental development: We made significant progress on the construction of the experimental driving mechanism over the weekend. We will use the slider mechanism we detailed last week with a 1/3 hp motor as a drive system. This will give us a sinusoidal input that will be easy to model. The original idea was to construct the entire driving mechanism from junkyard scraps (to cut cost), but we ran into difficulty with the availability and usability of bearings. Because of this we have decided to buy the bearings to fit the chosen shafts.

Search: The library's commercial search results finally came through. The search yielded a lot of relevant articles, but too late to include in our rough draft. We intend to use this to reinforce our project background.