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MECHANICAL DESIGN ENGINEERING

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ADVANCED DESIGN PROGRAM

SOIL TRANSPORT IMPLEMENT

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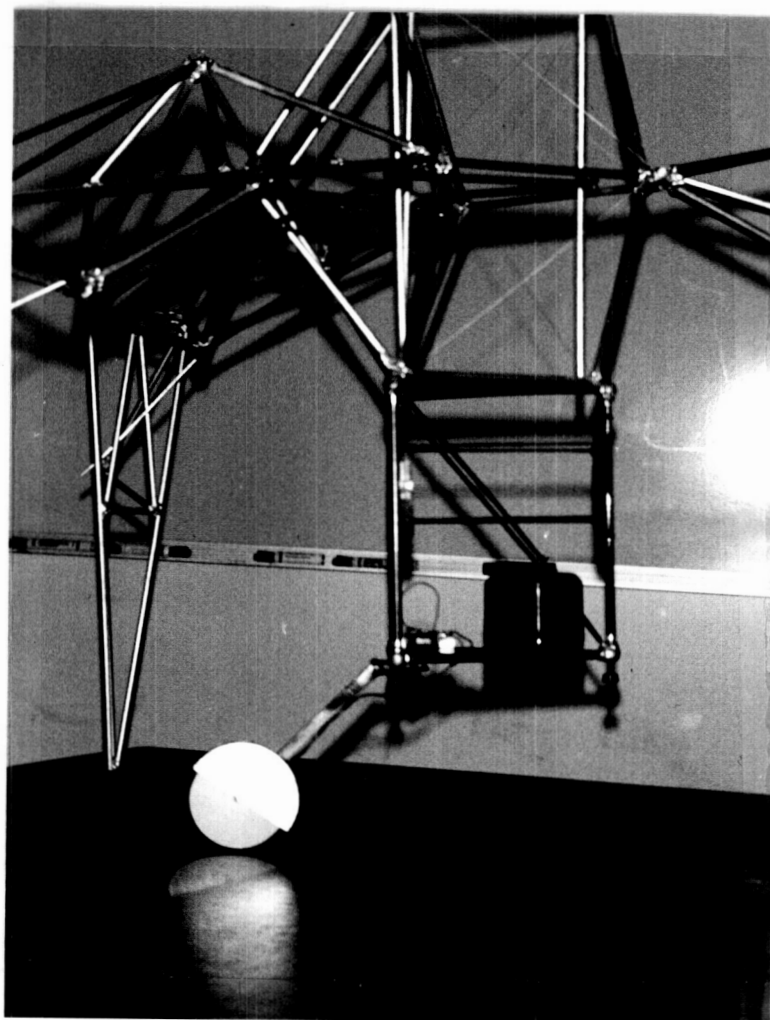
TABLE OF CONTENTS

ABSTRACT

The design of the Soil Transport Implement (STI) for SKITTER is the subject of this report. The purpose of STI is to provide a protective layer of lunar soil for the lunar modules. STI's objective is to cover the lunar module with a layer of soil approximately two meters thick within a two week period. The amount of soil required to cover the module is roughly 77 dump truck loads or three million earth pounds. STI employs a spinning disk to accomplish its task. STI is an autonomous, teleoperated system. The design incorporates the latest advances in composite materials and high strength, light weight alloys to achieve a high strength to weight ratio. The preliminary design should only be used to assess the feasibility of employing a spinning wheel as a soil transport implement. A mathematical model of the spinning wheel was used to evaluate the performance of this design.

PROBLEM STATEMENT

Modules that are landed on the surface of the moon are subjected to cosmic radiation and alternating extreme high and low temperatures. A method is, therefore, needed to cover these modules with the moon's soil to provide protection. The design of a soil transport implement (STI) for SKITTER was proposed to perform the task. The implement must include a spinning wheel as its main mode for moving the soil.

STI is required to perform specific tasks as well as meet certain criteria. The implement must be able to move seventy-seven dump truck loads of soil, the amount of soil needed to cover one module. It is necessary for STI to complete its task within a two week period. Also, due to the abrasive nature of lunar soil, the spinning wheel is subjected to extreme wear. The design should, therefore, facilitate easy replacement of the wheel. The implement will be an autonomous, teleoperated machine. Furthermore, the implement must be able to endure long periods of disuse and still remain in operational condition.

Since the moon's gravity is one-sixth that of the earth, the time required for dust to settle is considerably longer. Measures must be taken to prevent dust from contaminating mechanical and electrical components. Lastly, the total weight of STI cannot exceed 1,000 earth pounds.

SYSTEM OVERVIEW

STI has a triangular base and top whose sides are 7 feet long. Its overall height is 9 feet including the leg and footpad. The volume of the frame is approximately 190 cubic feet. The total weight of STI is 954 earth pounds. The robotic arm can be extended 5.25 feet. Since the robotic arm of STI can be raised, STI will fit in a crate wth the dimensions of 8 ft. wide, 8 ft. deep, and 9 ft. high. The wheel has a three foot diameter and four pitching blades on each side of the wheel. To completely cover the module requires the consumption of roughly 800 KW-hr of energy. STI can cover the module in 105 hours. The amount of fuel required is 470 pounds. Since weight is limited, the amount of fuel that STI can carry is 200 pounds. To complete the task, requires two refuelings. Three legs and footpads are attached to the underside of the frame. The feet provide a stable platform for parking STI when it is not in use. STI will be controlled by an on board computer using teleoperation technology. The computer will incorporate a power management system to limit peek power requirements. Cameras needed to operate STI will be attached in such a way to provide maximum visability.

DETAILED COMPONENT DESCRIPTION

FRAME DESIGN

The frame is the main structural component of STI. All of the

hardware necessary to make STI autonomous is attached to or contained

within the frame. The frame is similar in construction to the Warren-truss

with a triangular top and bottom. The top and bottom are equilateral

triangles whose sides are seven feet long. The total height of the frame is

nine feet, giving a total volume of approximately 190 ft^3. The front side of

the frame contains the sub-frame. The function of the sub-frame is to store

and dispense the replacement soil pitching wheels. In order to attach the

necessary hardware to the frame, a base plate is connected to the bottom

triangle. Since weight is a critical factor, the structural two-force members

are made of APC-2 PEEK/Carbon Fibre, a light weight, high strength

composite material. The sleeve joints used to connect the members are

made of magnesium die cast alloy AZ91B. The base plate is constructed of a

half inch magnesium alloy honeycomb structure sandwiched between two

thin sheets of magnesium alloy for added strength.

The total load which the frame must support is 1000 earth pounds. In

addition, it must resist a maximum moment of 1378 ft. lb. generated by

the robotic arm and wheel assembly. Since the motor/wheel assembly

rotates about the arm's axis, a gyroscopic torque is generated. The frame must be designed to withstand all of these moments.

Structural analysis reveals that the APC-2 PEEK/Carbon Fibre tubing which make up the two-force members require an outside diameter of 3 in. and an inside of 2 in. Correspondingly, the magnesium sleeve joints are made to accomodate the design. APC-2 PEEK/Carbon Fibre is used for the frame's two-force members because of its outstanding mechanical properties. APC-2 PEEK/Carbon Fibre is 30% lighter than aluminum; has high impact toughness; has good creep and fatigue resistance; is capable of high temperature applications up to 143 ^{0}C (290 ^{0}F); has excellent hot/wet strength; and is easily repairable. For tension and compression, the fiber is arranged with a zero degree orientation. With a zero degree fiber orientation, APC-2 PEEK/Carbon Fibre has a tensile strength at 23 ^{0}C (73 ^{0}F) of 392 ksi and a tensile modulus of 25.5 ksi. The compressive strength at the same temperature is 152 ksi. However, these values are initial test data; so a greater factor of safety was used in the design of the frame.

SUB-FRAME DESIGN

The sub-frame is an essential component of the frame. As the soil pitching wheel wears, it may become necessary to replace it. The sub-frame is the storage compartment for replacement wheels. The wheels are held in place by guide rods which do not allow the wheels to rotate in the sub-frame. The wheels are only allowed to translate in a direction parallel to the guide rods. The circular front facing of the sub-frame contains a retention spring mechanism that holds the wheels in the sub-frame until dispensed for use.

The sub-frame is constructed of two component materials: magnesium die cast alloy AZ91B and APC-2 PEEK/Carbon Fibre. The front and rear circular facing are made of the magnesium alloy. The guide rods are made of the Carbon Fibre with a 0/45/45/0 degree fiber orientation. With this orientation the rods can best withstand the bending generated by the replacement wheels.

The front facing contains the retention spring mechanism (Fig. 6). The mechanism has a u-shaped cross section. On the inner side of the cross section, grooves allow a retention clip forced by a compression spring to translate radially inward and outward. In their extended position, the retention clips act to hold the wheels in the sub-frame. When a force

strong enough (ie. the force of the robotic arm extracting a wheel) to compress the spring, the retention clips will be forced radially outward and a wheel will be released. Tension springs connected between the front facing and a forcing plate in the rear force the next wheel to advance to the front when a wheel is extracted.

ROBOTIC ARM DESIGN

One of the major components of STI is the manipulating arm. The overall sweeping pattern of the wheel is ultimately determined by the kinematics of the arm. The arm was designed to provide maximum maneuverability of the pitching wheel with minimal overlapping of duty that SKITTER can perform.

The arm allows limited three degrees of freedom movement. Since the lunar soil is very abrasive, the pitch direction of the wheel is restricted in order to prevent structural damage to SKITTER. From the frame STI , the arm can be extended 5.25 feet. When SKITTER is in the normal position, the tibia and femur of each leg are perpendicular. In the normal postion the arm will allow digging up to 3 feet deep.

The arm consist of a hollow 6 in. magnesium tube. The tube will be coated with a viscoelastic material for passive damping of the arm vibrations. Three actuators are intrinsicly incorporated into the magnesium tube. Magnesium die cast alloy-AZ91B is used for structural components of the arm. AZ91B has one of the best strength to weight ratios. The magnesium links of the arm are coated with Scotchdamp SJ2015X Type 110. Scotchdamp is a viscoelastic material which dampens the vibrations caused by the wheel. The Scotchdamp is covered by a very

thin constraining layer of magnesium.

Next to the wheel, the arm is the most dynamic component of STI.
Major design considerations include: static and dynamic loading, kinematic
analysis, and vibration damping. The components of the arm include two
links, three actuators, and mounting assembly for the frame and motor
connection.

The links have lengths of 3.25 ft. and 1.5 ft. The links are hollow
tubular structures capable of withstanding forces imposed by the soil
pitching wheel. The inner and outer diameters of the links are 5.5 in. and
6.0 in. respectively.

The three actuators of the arm provide great flexibility for
maneuvering around objects and facilitate the changing of replacement
wheels. The actuator at the base of the frame (shoulder pivot) allows
rotation around the z-axis of 18 degrees on either side of the center
position (Fig. 7). The 36 degrees sweep angle enables STI to cover a wide
angle without subjecting SKITTER's legs to the abrasive spray from the
wheel of lunar soil.

The second actuator is located directly in front of the base actuator
which provides rotation about the x-axis. This actuator raises and lowers
the arm. The range of motion of the actuator is 180 degrees from the

downward normal position to the vertical wheel exchange position.

The third actuator, located near the motor assembly, allows 135 degrees rotation about the y-axis. This enables the soil pitching wheel to rotate 90 degrees clockwise and 45 degrees counterclockwise from its vertical position. The 90 degrees rotation is necessary for maneuvering into a position which allows for the extraction of a replacement wheel. The plus or minus 45 degrees rotation provides aiming flexibility for STI.

WHEEL DESIGN

The wheel is the tool used to move the lunar soil. When driven by a 3

hp motor, the wheel can move 5,590 ft^3 of soil a distance of 102 ft in one

hour. The rim of the wheel is made of titanium for abrasion resistance,

thermal stability, and impact toughness. Each wheel assembly consists of a

wheel with blades and a dust shield. The incorporation of the wheel and

hood makes for easy wheel replacement. The total weight of the wheel

assembly is approximately 90 lbs.

The wheel assembly (Fig. 4) is constructed of four major parts: the rim,

the hub, the midsection, and the shield. The titanium rim has four blades

on each side for pitching soil. The rim's outside and inside diameters are

36 in. and 28 in. respectively. The hub and the midsection are made of

magnesium die cast alloy AZ91B. The midsection is constructed of

a honeycomb center sandwiched between two thin plates. Both the

midsection and the hub are insulated from each other by a ceramic coating

to prevent heat conduction from the wheel to the motor. The dust shield is

made of magnesium alloy and should be designed with the same effective

life as that of the wheel. The blades on each wheel extend 1.5 in. outward

from the plane of the wheel and are 4 in. long. The blades are oriented 30

degrees from the normal to the curve at that point (Fig. 4). The blade is

angled in order to more easily cut through the soil. The angle of the blade's leading edge should be equal to the internal angle of friction of the lunar soil. The full scoop volume is 0.313 ft^3, but the effective volume is about half of that. The effective volume is the actual volume that reaches the target.

In order to estimate the soil distribution delivered by the wheel, a mathematical model was developed. The first assumption is that the soil particles do not interact with each other. The soil was divided into discrete particles for the purpose of calculating their trajectories. The initial velocity and angle of each particle are calculated according to the position of each particle relative to the blade. The distance each particle travels is then calculated and added to the distribution (see Appendix).

Friction between the soil and spinning wheel is calculated in the Appendix. A coefficient of friction of 0.8 was assumed. The power dissipated due to friction was estimated. The power necessary to accelerate to soil was also calculated. It was determined the power due to friction was much smaller than that for acceleration. Therefore, in subsequent calculations, the power loss due to friction was neglected (see Appendix). Also, a calculation was performed to determine if moving the soil in multiple smaller steps was more efficient than one big step. The

calculations show that the same total energy is required for both multiple and single steps (see Appendix). Therefore, a plan for covering the module would be to start from STI's outer range and work inward in a sweeping fashion to cover the module. The total energy required to cover the module was calculated using a sweeping area with a 4 in. depth. The total energy required is approximately 800 kw-hrs and would require 105 hrs. or 8 days working 50% of the time (see Appendix). Because STI can only carry 200 lbs. of fuel, it requires two refuelings to cover a module.

As the wheel moves the soil, friction/heat will be generated. Since the moon lacks atmosphere, convection is impossible. The heat, therefore, must be transferred away by radiation or conduction. Conducting the heat would be detrimental to the motor; so radiation is the only alternative. A heating analysis was performed on the wheel assuming the worst case (see Appendix). The analysis assumes that the entire 3 hp from the motor is converted to heat and absorbed by the wheel. Also, the background temperature is set at 200 ^{0}C (392 ^{0}F) and the wheel radiates with a low emissivity from only one side. Under these conditions, the temperature of the wheel never exceeded 680 ^{0}C (1250 ^{0}F), which is well below titanium's melting point of 1500 ^{0}C. Therefore, heating is not a problem the spinning wheel.

POWER SOURCE

Power will be supplied from oxygen-hydrogen fuel cells. These fuel cells were chosen because of their favorable energy density and proven reliability as power sources for space applications. Also, the fuel cells provide dc current which is needed to power the brushless dc motors used to drive the wheel and actuators. The oxygen-hydrogen fuel cell provides 1660 w-hrs per pound of reactant.

A fuel consumption analysis was performed for STI and it was determined that to complete the task would require 470 lbs. of fuel. The analysis was based on the assumption that STI would be limited to a peak horsepower of 15 hp at any time. Because this is a large amount of fuel for STI to carry, it was decided that STI will have fuel storage capacity of 200 lbs. This will require STI to refuel twice. The 200 lb. value was chosen because it is the maximum amount of fuel STI can carry while not exceeding the imposed 1000 lb. limit.

The fuel cell is 14 in. high x 15 in. wide x 40 in. long. and weighs 250 lbs. The fuel cell will be attached to the base plate at the rear of the frame to help counterbalance the moment generated by the robotic arm and wheel assembly. Since the oxygen-hydrogen fuel is cryogenically stored, it may be used as a refrigerant to cool the motors. Refrigerant lines carrying

the fuel will be routed through the motors' casings to conduct the heat

away.

BRUSHLESS DC MOTORS

Brushless dc motors will be used to drive the wheel and actuators. Brushless dc motors can provide high torque at low rpm. The speed of these motors may be accurately controlled electronically. Brushless dc motors are not subjected to the same kind of wear as brush motors which makes them ideal for use in areas where maintenance is almost impossible, such as the moon. In addition, brushless dc motors have no commutator bars to become oxidized and can, therefore, sit idle for years with no loss of performance. This is of important concern because STI will have long periods disuse. Brushless dc motors generate less radio frequency interference than other types of motors which is advantageous in situations where machines are teleoperated. There is no brush friction in brushless dc motors which reduces the amount of heat generated. Lastly, because of its design, a brushless dc motor can be made smaller than a conventional brush motor and still improve control.
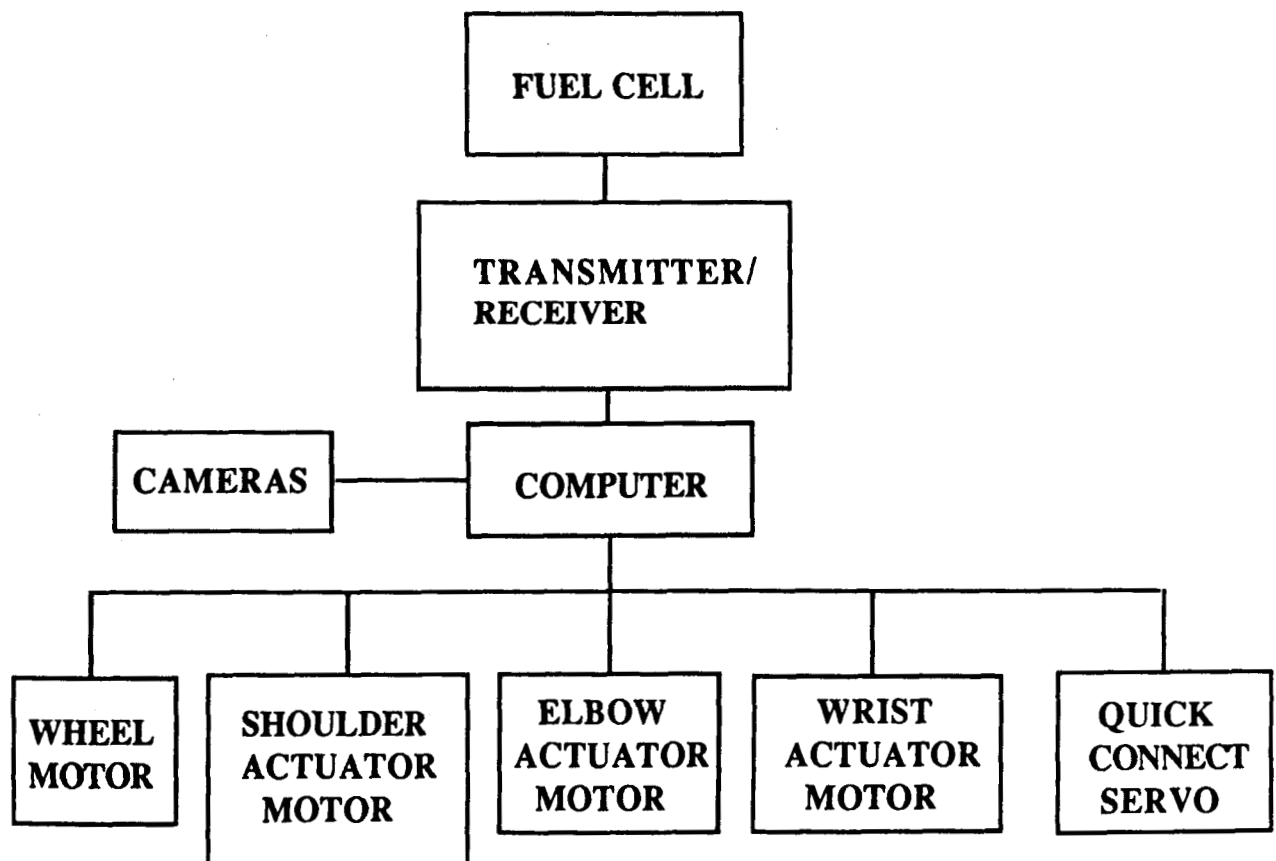
A 3 hp motor with a speed range of 60 - 350 rpm will be used to turn the wheel. Three fractional horsepower motors will be used to drive the actuators of the robotic arm. The housing of all the motors will be made of magnesium die cast alloy AZ91B to help reduce the weight. The housings will incorporate refrigerant lines from the fuel cell to provide cooling.

CONTROLS

STI will be controlled by teleoperation. Signals will be sent and received by a trasmitter/receiver device which relays the signal to STI's on board computer. The computer will regulate all of STI's functions. Visual feedback will be provided by cameras mounted on STI. At the present, the design assumes that all operations will be performed in daylight. Therefore, no provisions are made for lighting.

The on board computer will keep the peak power consumption to a minimum. Actuators will then only be allowed to operate one at a time.

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                    ┌─────────────┐
                    │  FUEL CELL  │
                    └──────┬──────┘
                    ┌──────┴──────┐
                    │ TRANSMITTER/│
                    │  RECEIVER   │
                    └──────┬──────┘
     ┌───────────┐  ┌──────┴──────┐
     │  CAMERAS  │──│  COMPUTER   │
     └───────────┘  └──────┬──────┘
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    ┌────┴──┐┌──┴─────┐┌───┴────┐┌────┴────┐┌────┴────┐
    │ WHEEL ││SHOULDER││ ELBOW  ││  WRIST  ││ QUICK   │
    │ MOTOR ││ACTUATOR││ACTUATOR││ ACTUATOR││ CONNECT │
    │       ││ MOTOR  ││ MOTOR  ││  MOTOR  ││ SERVO   │
    └───────┘└────────┘└────────┘└─────────┘└─────────┘
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OPERATIONS

ATTACHMENT TO SKITTER

SKITTER provides for three ball socket attaching points. The frame of STI will be attached rigidly to SKITTER at these points. This will be the only connection between SKITTER and STI.

REPLACING BLADES

Wear of the soil pitching wheel is to be expected because of the abrasive nature of the lunar soil. In order to facilitate changing the wheel and reduce downtime of STI, a dispenser for the replacement wheel was incorporated into the design of the frame.

The drive shaft of the motor for the pitching wheel will incorporate a quick connect mechanism actuated by a small servo. The quick connect mechanism is similar to the quick connector used for compressed air hoses. The female portion of the connection is attached to the motor shaft and the male portion is integrated into the design of the wheel's shaft. The removal of the worn wheel is achieved by simply disengaging the quick connector, rotating the wrist of STI's arm, and discarding the wheel. To engage a new wheel, the motor is rotated so that the shaft is directed vertically upward. The arm is then raised to mate male and female

connections. The servo locks the connection together, and the arm pulls the new wheel from the dispenser.

PARKING

Attached to the base of STI's frame are three legs, one at each apex of the triangular base. The legs are one foot high with a circular magnesium footpad. The footpads have a surface area of 1 ft^2. The legs are made of a 3 in. outer dia./2 in. inner dia. tube of APC-2 PEEK/Carbon Fibre.

During periods of disuse, it will be necessary to park STI. The legs and footpads provide the support platform that STI will rest on. When parked, the robotic arm will be resting on the ground.

FAILURE AND HAZARDS

FAILURE

WHEEL FAILURE

There are two possible ways in which the wheel may fail. First, the wheel may fracture upon striking a large rock. This problem has been reduced by the use of a titanium alloy for the outer rim of the wheel. The blades for pitching the soil are also made of titanium. The titanium alloy is a high strength, high impact toughness metal. The honeycomb structure of the midsection of the wheel has also increased the wheel's strength in bending and torsion.

Overheating beyond the melting temperature is the second way that the wheel may fail. However, as analysis shows (with the worst possible case assumed), the melting temperature of titanium will never be reached. Furthermore, the titanium outer rim is insulated from the midsection and hub of the wheel by a ceramic coating, thereby, preventing overheating of the midsection. By choosing the proper materials, the possibility of failure due to overheating has been pratically eliminated.

MOTOR FAILURE

To insure that the motor does not fail due to overheating, refrigerant lines have been integrated in the motor housing to cool the motor. The motors are, thus, cooled by conduction and radiation.

HAZARDS

In the design of STI, two major hazardous areas that were considered were damage to SKITTER and damage to the module. Damage to SKITTER has been eliminated by placing a protective shield over the spinning wheel. This prevents stray rocks or particles from being thrown upward into the underside of SKITTER and STI's frame. The motion of the arm (Fig. 7) is restricted so that the trajectory of the thrown soil does not come near SKITTER's legs.

The problem of damage to the module was solved in the design of the blades of the wheel. It was given that the largest rock that can be thrown at the module is about the size of a baseball (dia. = 3 in.). With this in mind, the blades were designed with a width of 1.5 in. The largest rock that can be thrown with this design would be a 3 in. diameter rock, and the module is safe.

CONCLUSIONS

According to the analyses, STI was able to complete its task consuming less power than the maximum allowed amount of 15 hp. Initially, the goal was for STI to accomplish the job in fourteen days working twenty-four hours a day. However, analysis of the design showed that the job could be done in 105 hrs. (4.375 days). It was then decided that STI would take eight days to perform its task working 50% of the time. The extra time will allow for downtime due to blade changing, repositioning by SKITTER, and any necessary resting for heat radiation.

The use of the titanium alloy eliminated the possibility of failure caused by overheating. The high strength titanium with good impact toughness reduced the concern of lunar rocks damaging the wheel easily. Including in the design the automation of wheel replacement eliminates the need for other implements to change the wheel. The honeycomb midsection provided extra structural strength while keeping the weight down to a minimum. Positioning the blades on the wheel at a 30 degree angle from the radius proved to provide the optimum soil distribution at all speeds and distances. All of these factors were advantageous to the design of STI.

With the present design, in order to meet the 1000 lb. weight limit, STI

can only carry one extra replacement wheel. Also, accomplishing the task

requires STI to consume more fuel than it can carry. This requires STI to

refuel, thereby, making it not a completely autonomous system. With the

present brushless dc motor technology, the range at which the soil can be

thrown is limited by the maximum horsepower output of the motor.

RECOMMENDATIONS

The present design of STI meets the imposed limit of 1000 lbs.
However, only one extra wheel can be carried by STI, and STI must refuel
twice to complete its task. It may be possible to reduce the weight of the
wheels by using a thinner wheel or by designing a smaller diameter wheel.
Also, the frame size may be decreased to decrease the weight even further.
If the weight of STI can be reduced, it will, then, be able to carry more fuel
and possibly perform its task without the need to refuel. This will make
STI a truely autonomous system.

Wear of the wheel will be critical in determining the feasibility of this
design. An evaluation of wear should conducted to determine the life of
the wheel and dust sheild. Designing the dust sheild so that both the shield
and wheel wear out simultaneously can further reduce the weight of STI.

Measures should be taken to protect all of the components of STI that
are sensitive to dust contamination. Motors, actuators, and electrical
devices are the components most susceptible to dust contamination.
Stratigically placed brushes may be incorporated into the design to remove
excess dust from critical areas using the flexibility and movement of the
robotic arm.

More detailed analysis is required to determine the exact size and

weight of the actuators and motors required for the robotic arm. Further

structural analysis is needed to insure the frame integrity.

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APPENDIX

Trajectory Analysis

$$V_x = \omega r \cos\phi \cos(\theta + \phi) \qquad V_y = \omega r \cos\phi \sin(\theta + \phi)$$

$$r = \frac{R - d + j\Delta x}{\cos\theta} \qquad \theta = \text{Tan}^{-1} \frac{i\Delta x}{R - d + j\Delta x}$$
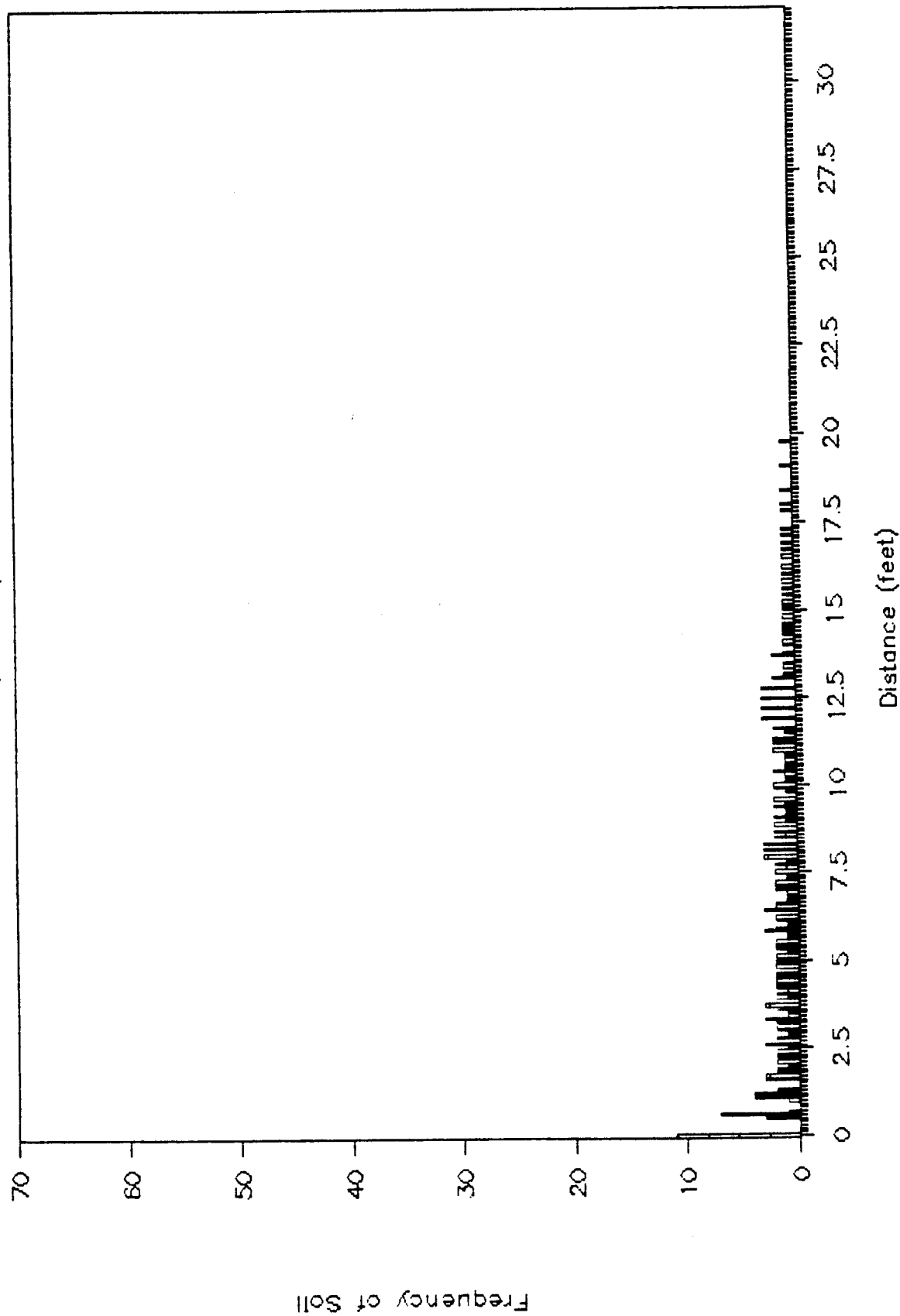
$$V_x = \frac{\omega(R-d)\cos\phi \cos\left(\text{Tan}^{-1}\frac{i\Delta x}{R-d+j\Delta x} + \phi\right)}{\cos\left(\text{Tan}^{-1}\frac{i\Delta x}{R-d+j\Delta x}\right)}$$

$$\theta_{max} = \text{Cos}^{-1}\left(\frac{R-d}{R}\right)$$

$$\Delta x = \frac{R-d}{i_{max}} \tan\left(\theta_{max}\right)$$

$$V_y = \frac{\omega(R-d)\cos\phi \sin\left(\text{Tan}^{-1}\frac{i\Delta x}{R-d+j\Delta x} + \phi\right)}{\cos\left(\text{Tan}^{-1}\frac{i\Delta x}{R-d+j\Delta x}\right)}$$

$$D \approx \frac{2 V_x V_y}{g}$$

$$D_{max} = \frac{(\omega R)^2}{g}$$

Soil Distribution

R = 1.5, w = 4pi, D = 0

Frequency of Soil

Distance (feet)

Soil Distribution

R = 1.5, w = 4pi, D = 10

Distance (feet)

Frequency of Soil

0.4572 2.4   4.9   7.4 9.899999 12.4 14.9 17.4 19.9 22.4 24.9 27.4 29.9

0   10   20   30   40   50   60   70

Soil Distribution

R = 1.5, w = 4pi, D = 20

Distance (feet)

Frequency of Soil

70 60 50 40 30 20 10 0

0.4572 2.4 4.9 7.4 9.899999 12.4 14.9 17.4 19.9 22.4 24.9 27.4 29.9

Soil Distribution

D = 40; R = 1.5 ; W = 4pi

Feauency of Particles

Distance (feet)
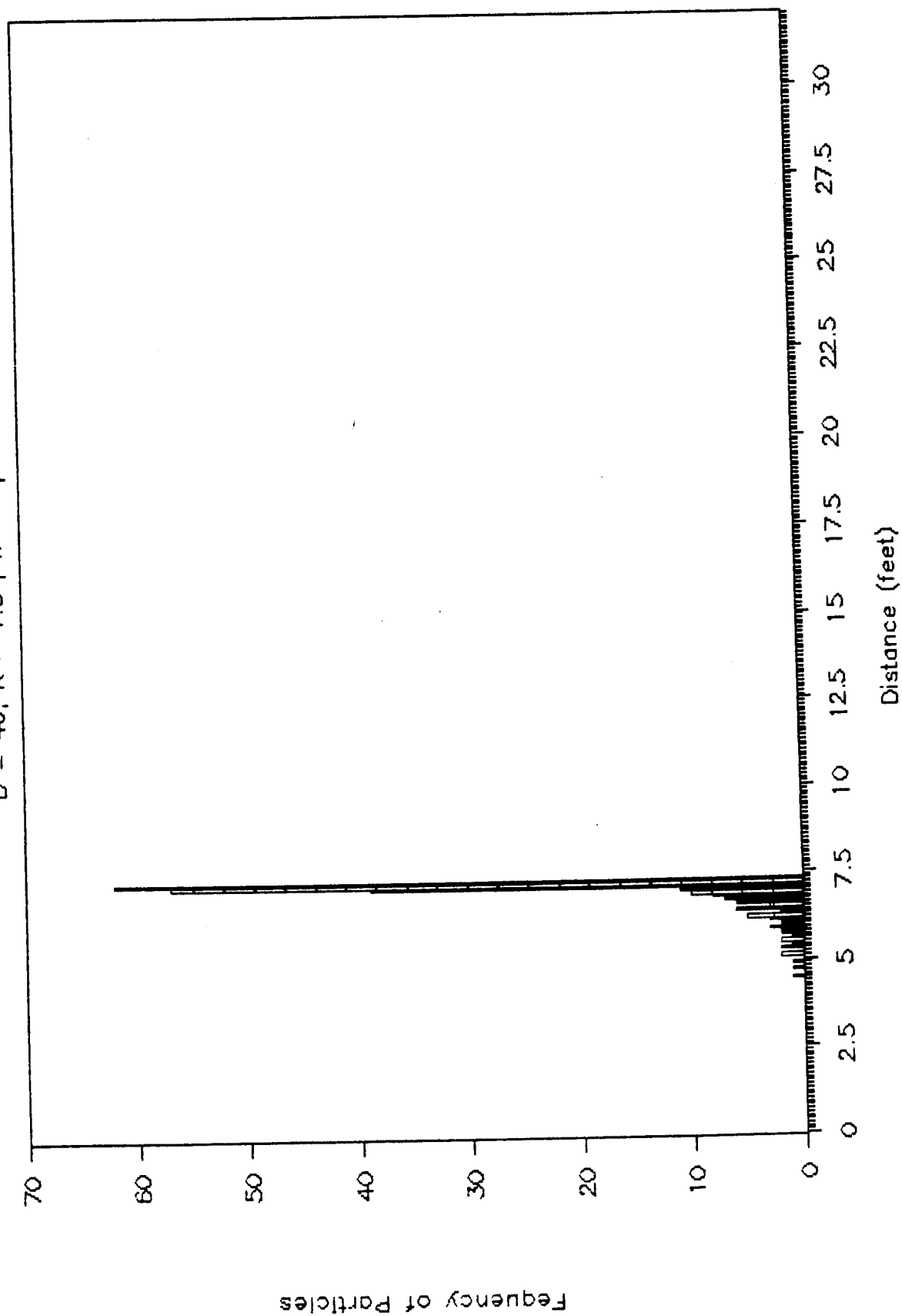
Power Due To Friction

$$\theta_m = \text{Tan}^{-1}\left(\frac{\sqrt{2Rd - d^2}}{R - d}\right)$$
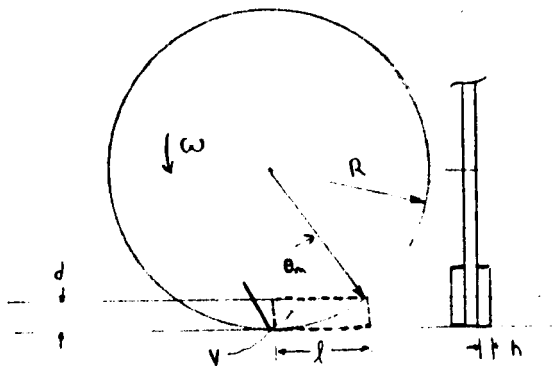
$$\ell = \sqrt{2Rd - d^2}$$

$V = \ell h d$

Normal force of soil

$F_n \Leftarrow \nabla \qquad F_s = \frac{1}{2}\ell d^2 \rho g$

Tangential force

$F_T = \mu F_N \qquad (\text{let } \mu = 0.8)$

Power

$P_f = -T\omega$

$T = F_T \cdot r_{1/3}$

$r_{1/3} = R - \frac{2}{3}\frac{(\theta_m - \theta)}{\theta_m} d$

$P_f = -\int_0^{\theta_m} F \cdot r_{1/3} \cdot \omega \cdot d\theta$

$F_T(\theta) = \frac{1}{2}\ell d^2 \rho g \mu \left(\frac{\theta_m - \theta}{\theta_m}\right) \qquad (\text{approximation})$

$P_f = -\int_0^{\theta_m} \frac{1}{2}\omega \ell d^2 \rho g \mu \frac{(\theta_m - \theta)}{\theta_m}\left(R - \frac{2}{3}\left(\frac{\theta_m - \theta}{\theta_m}\right)d\right)d\theta$

$\text{let } \bar{\theta} = \frac{\theta_m - \theta}{\theta_m}$

$P_f = \frac{-1}{2}\ell d^2 \rho g \mu \omega \int_1^0 \bar{\theta}\left(R - \frac{2}{3}\bar{\theta} d\right)d\bar{\theta}$

$\boxed{P_f = \frac{1}{2}\ell d^2 \rho g \mu \omega \left[\frac{1}{2}R - \frac{3}{4}d\right]}$

$P_f' = P_f \cdot N$

Power to Accelerate the Soil
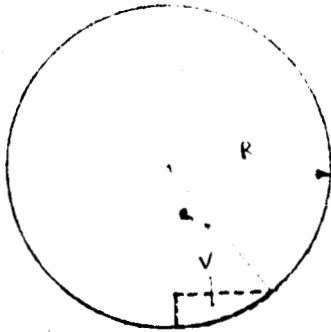
$$V = \frac{R^2 h}{2}\left(2\theta_m - \sin 2\theta_m\right)$$

$$\bar{v}_0 \approx \omega\left(R - \frac{d}{2}\right)$$

Energy

$$E = \tfrac{1}{2} m V^2$$

$$E = \tfrac{1}{2} \rho V \left[\omega\left(R - \tfrac{d}{2}\right)\right]^2 \cdot N$$

Power

$$P_a = E \cdot rps$$

$$P_a = \tfrac{1}{2} \rho V \left[\omega\left(R - \tfrac{d}{2}\right)\right]^2 \cdot N \cdot rps$$

Soil Flow Rate

$$Q = \rho \cdot V \cdot N \cdot rps$$

Two hop calculation

$R = .4572\ m\quad (18")$ $D_1 = 152.4m = 500\ ft$

$d = .0508\ m\quad (2")$ $D_2 = 76.2m = 250\ ft$

$h = .0381\ m\quad (1\frac{1}{2}")$

$\qquad\qquad\qquad\qquad g = 1.633\ \frac{m}{s^2}$

$N = 4$

$\qquad\qquad\qquad\qquad \rho = 1000\ \frac{kg}{m^3}$

---

500 ft hop

$\omega_1 = \dfrac{\sqrt{D_1 g}}{R} = \dfrac{\sqrt{(152.4)(1.633)}}{.4572} = 34.5\ \frac{r}{s}$ $\theta_m = Cos^{-1}\left(\dfrac{.4572 - .0508}{.4572}\right) = 27.266°$

$\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad .47588\ rad$

$rps = \dfrac{\omega}{2\pi} = 5.49\ rps$ $V = R^2 h\left(2\theta_m - Sin(2\theta_m)\right)/2$

$\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad V = 5.467 \times 10^{-4}\ m^3$

$P_1 = \frac{1}{2}\rho V\left(\omega(R - \frac{d}{2})\right)^2 \cdot N \cdot rps$

$\qquad = 1.332\ kW\ \ -or-\ \ 1.786\ hp$

$E_{day} = P \cdot 604,800\ sec = 806\ MJ/day$ $Q_{day} = V \cdot N \cdot rps \cdot 604800$

$\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad = 7262\ m^3$

$\omega_2 = 24.4\ \frac{r}{s}$

$rps = 3.88$

$P_2 = .471\ kW$

$E_{day} = 284.9\ MJ$

$Q_{day} = 2,566.5\ \frac{m^3}{day}$

$T_2 = 2.829\ days$

$E_2 = E_{day} \cdot 2.829$

$E_2 = 806\ MJ/load$

Results			
Method	Volume	Energy	Time
1 hop	$7262 m^3$	806 MJ	1 day
2 hop	$7262 m^3$	806 MJ	2.829 day
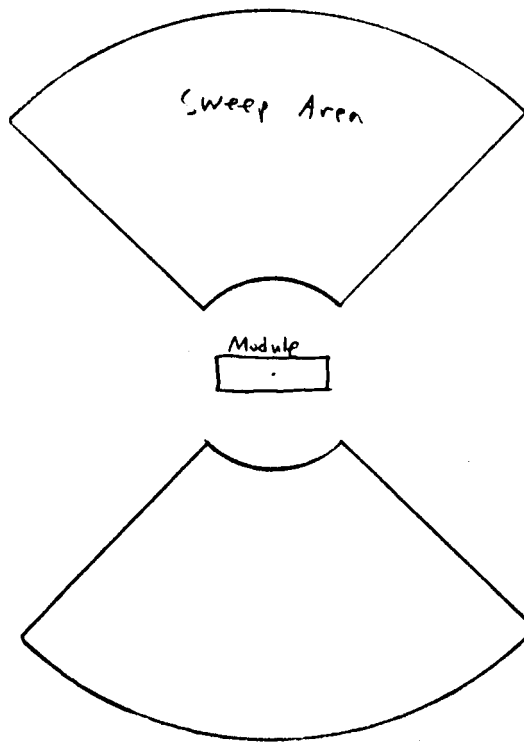
Total Energy Calculation

Sweep Area

Module

77 dump trucks
20 tons per truck
2000 lbs per ton

3,080,000 lb
6,776,000 kg

$\rho = 1000 \frac{kg}{m^3}$

$V_T = 6776 \ m^3$

$d = .1016 m \quad \therefore \ A_T = 66,693 \ m^2$

$D = \sqrt{\frac{2A}{\pi} + 100}$

$D = 206 \ m$

$\Delta E_T = E \cdot d \cdot r \ dr \ d\theta$

$E_T = \int_0^{\pi} \int_{10}^{200} E \cdot d \cdot r \cdot dr \cdot d\theta = 2.78 \times 10^9 \ J \cdot s$

$$\boxed{E_T = 772.5 \ kW \cdot hr}$$

Time Calculation

$R = .4572$

$d = .1016$

$V_c = 8.863 \times 10^{-3} \frac{m^3}{scoop}$ $V_{eff} = 4.43 \frac{m^3}{scoop}$

$\omega = 15.59$

$N = 4$

$D = 31\,m$

$P_a = 2237\,w$

$$A_n = \int_0^{\pi} \int_{r_i}^{r_2} r\,dr\,d\theta = \frac{\pi}{2}(r_2^2 - r_i^2)$$

$V_n = A_n \times .1016$

$Q_n = V_{eff} \cdot N \cdot \frac{\omega}{2\pi} = 0.044 \frac{m^3}{s}$

$T_n = \dfrac{V_n \cdot Haps}{Q}$

n	r_2	r_i	V_n		T_n (hrs)
1	200	169	1726		69
2	169	138	1519		479
3	138	107	1212		30.6
4	107	76	905		17.1
5	76	45	599		7.6
6	45	14	292		1.8
					105 hrs
					4½ days

Wheel Heating

worst case

Heat Capacity $= HC = \rho V C_p$

$A = \pi (18^2 - 14^2) = 402.124 \, in^2$
$= .2594 \, m^2$

$V = At = 201.062 \, in^3$
$= .003294 \, m^3$

$\rho = 4500 \, \frac{kg}{m^3}$ $C_p = 523 \, \frac{J}{g \, k}$

$HC = (4500)(3.294 \times 10^{-3})(523)$
$= 7,752.4 \, \frac{J}{K}$

Power $= 2237 \, W$

$q = A \cdot \varepsilon \cdot \sigma \cdot F_{12} \cdot (T^4 - T_0^4)$

$\sigma = 5.66 \times 10^{-8} \, \frac{W}{m^2 K^4}$
$\varepsilon = .2$
$F_{12} = 1$
$T_0 = 473 \, K$

$T = \sqrt[4]{\dfrac{q}{A \cdot \varepsilon \cdot \sigma \cdot F_{12}} + T_0^4}$

$\boxed{T_{max} = 949.2 \, {}^\circ K}$

VOLUME vs RPS

ft^3/hr
(Thousands)

RPS

| □ 2 | + 3 | ◇ 4 | △ 5 | × 6 |

VOL/POWER RATIO vs RPS

ft3/(hp*hr)
(Thousands)

RPS

POWER vs RPS

hp

RPS

□ 2   + 3   ◇ 4   △ 5   × 6
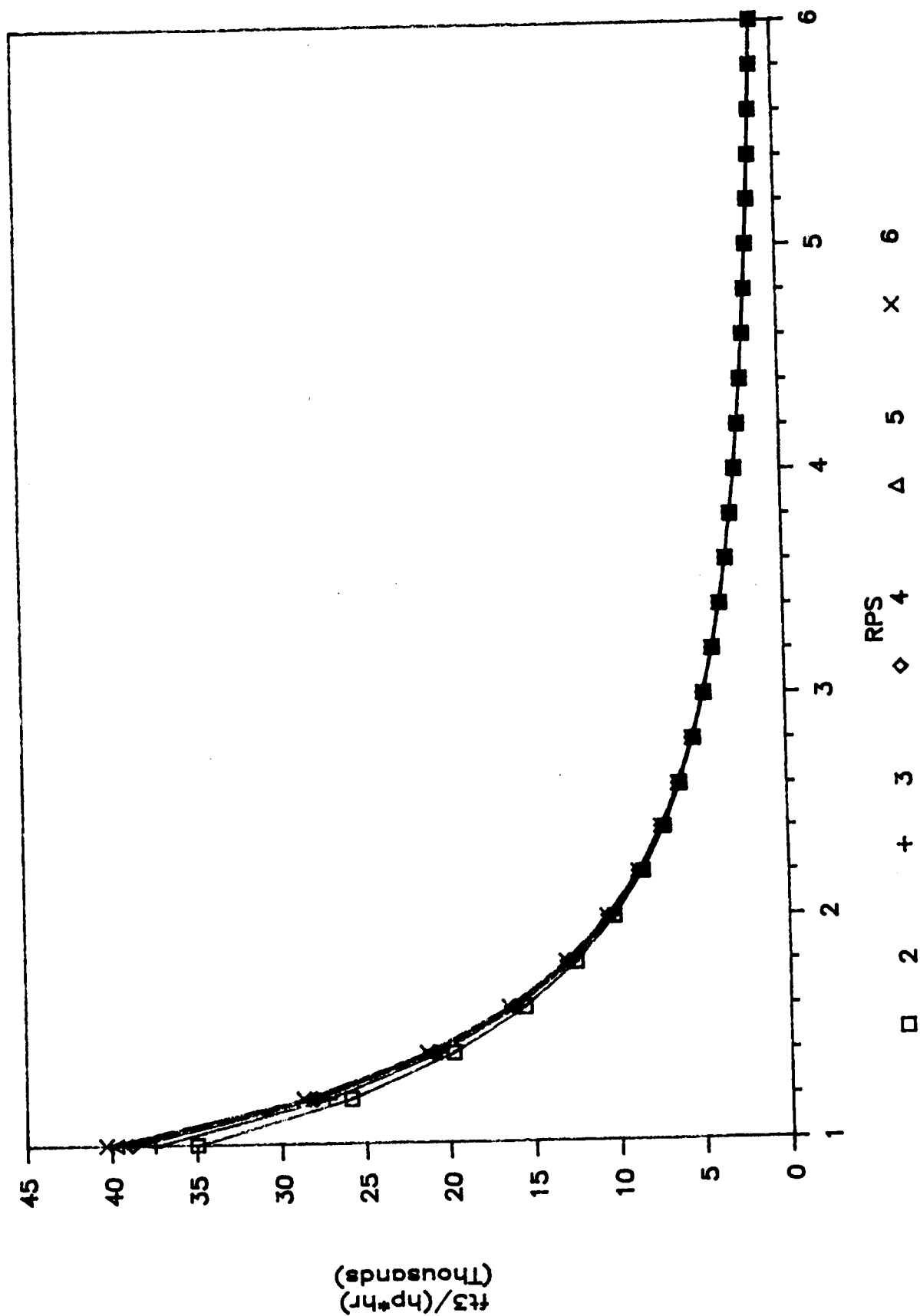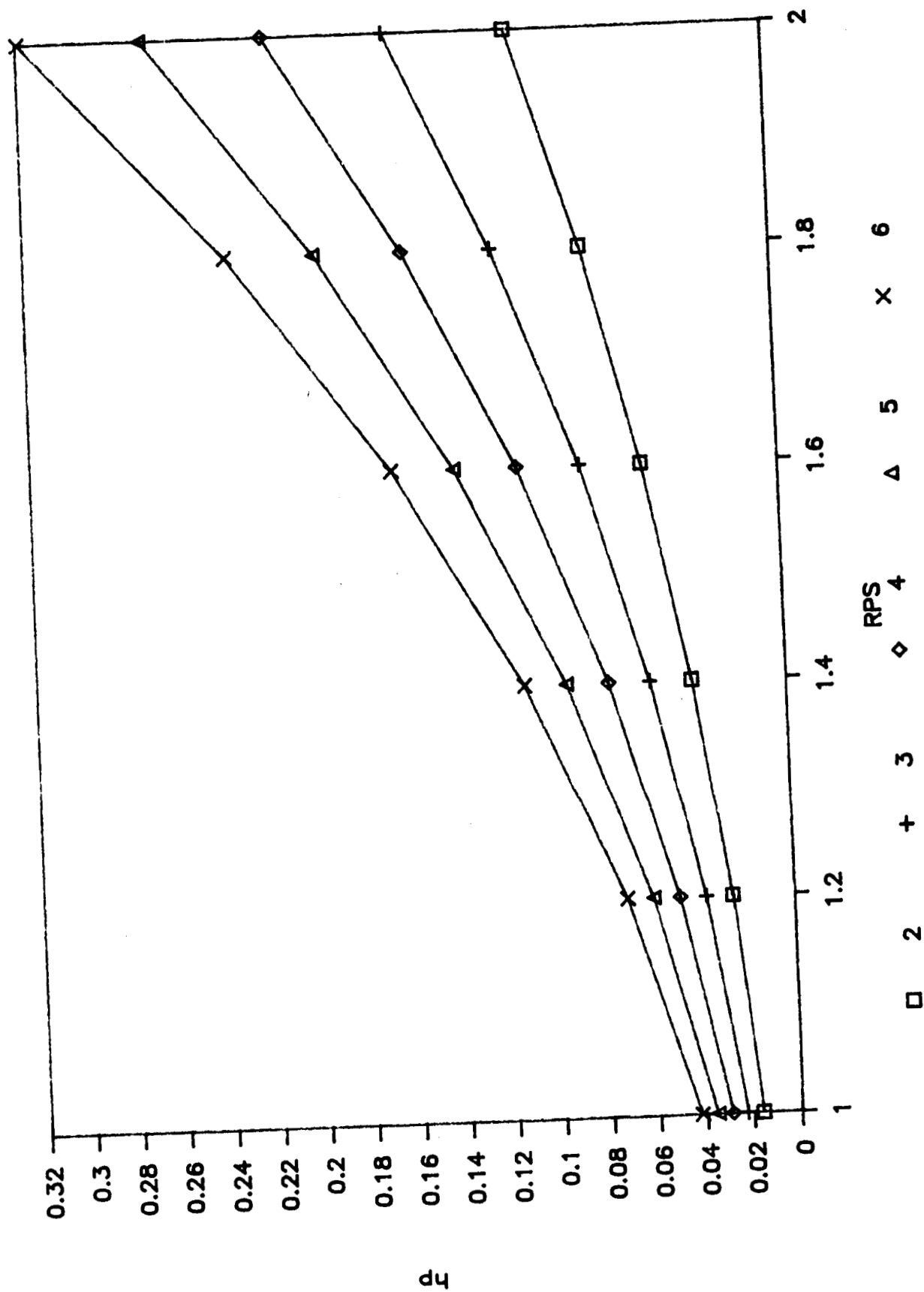
MAXIMUM DISTANCE vs RPS
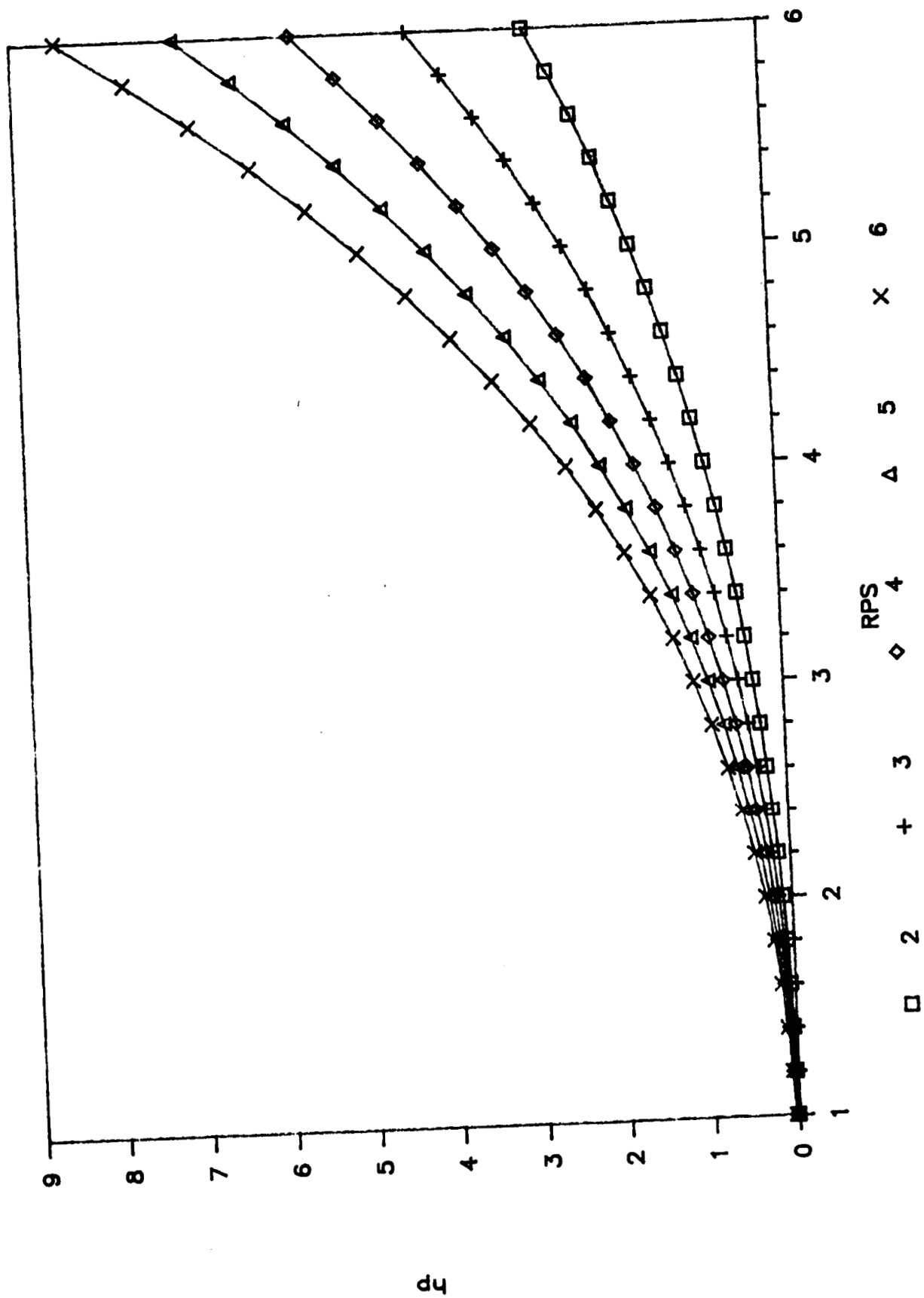

ft (Thousands) vs RPS
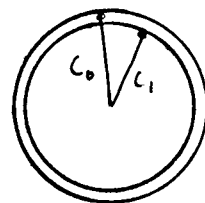
POWER vs RPS

Maximum Bending Stress — used for calculating arm dimensions

maximum Bending moment

$$m = Fd = \left(\frac{200\,lb}{6}\right)\left(5.25\ ft\right)\left(12\,\frac{in}{ft}\right) =$$

$$m = 2100\ in\,lbs$$

for magnesium alloy — AZ61A-F — the maximum tensile strength at $260°C$ = 16.0 Ksi

for bending $\quad \sigma_{max} = \dfrac{(2100\ in\,lbs)(c_0)}{\frac{\pi}{4}(c_0^4 - c_1^4)}$

$$16000\ \frac{lb}{in^2} = \frac{(2100\ in\,lb)(c_0\ in)}{\frac{\pi}{4}(c_0^4 - c_1^4)\,in^4}$$

Deflection

$$V = \frac{PL^3}{3EI} \qquad\qquad 1\,in = \frac{(33.33\,lb)(5.25\,in)^3}{3\left[\frac{\pi}{4}(c_0^4 - c_1^4)\,6.5\times10^6\,\frac{lb}{in^2}\right]}$$

$$c_0^4 - c_1^4 = 3.149\times10^{-4}$$

With the material we are using and the torque requirements. we choose a magnesium tube for the arm with $\quad OD = 6''\quad ID = 5.5''$.

Acuator Torque Requirements:

for shoulder swing acuator:

The maximum allowable resistance force
of Lunar soil will be 40 lbs force.

$M = Fd$

$M = (40\,lbs)(5.25\,ft)(12\,\frac{in}{ft})$

$= 2520\ in\ lbs$

$M = (1.5)(2520\ in\ lbs) = \underline{3780\ in\ lbs}$

for shoulder rotation acuator:

The maximum force for bending will
caused by the 200 lbs (25 lbs. on
moon) arm. A factor of safety of
1.5 is used

$M = Fd$

$= (1.5)(200\ lbs)(5.25\ ft)(12\ in/ft)$

$= \underline{3150.00\ in\ lbs}$

for wrist acuator

The maximum force will be caused by
the motor and wheel. The combined
weight is 130 lbs. factor of safety = 1.5

$M = Fd = (1.5)(\frac{130}{6}\ lbs)(5.25\ ft)(12\ in/ft$

Power Requirements for Acuators:

Small RPMs were chosen in order to minimize the inertia of the arm and to cut power requirements

for shoulder swing; acuator:

$$HP = \left(\frac{1\ RPM}{63000}\right)(3780\ in\ lbs) = .06\ Hp$$

for shoulder rotation acualor

$$HP = \frac{(3\ RPM)}{63000}(3150\ in\ lbs) = .150\ Hp$$

for wrist acuator

$$HP = \frac{(3\ RPM)}{63000}(2047.5\ in\ lbs) = .098\ Hp$$

$$\approx .1\ HP$$

Weight Analysis

Frame: Density of APC-2 PEEK/Carbon Fibre $= .0294 \; lb/in^3$

     6 - 7 ft members   (3" outer dia. , 2" inner dia.)

     3 - 8 ft members   ("   "   )

     2 - 10.63 ft members   (2" outer dia, 1" inner dia.)

$$Volume = \pi(1.5^2 - 1^2)\left[(84)(6) + (96)(3)\right] + \pi(1^2 - .5^2)(127.56)$$

$$= 2410.73 \; in^3$$

$$Weight = (3110.17)(.0294) \approx \underline{100 \; lbs}$$

Sub-Frame: 4 - 6 ft members   (2" outer dia. , 1" inner dia.)

     2 - circular facing ($\approx$ 25 lbs/each)

$$Volume = \pi(1^2 - .5^2)(72)(4) = 678.58 \; in^3$$

$$Weight = (678.58)(.0294) + 2(25) = \underline{70 \; lbs}$$

Joints: (Made of magnesium die cast alloy)

$$weight \approx (5 \; lb/joint)(6 \; joints) = \underline{30 \; lbs.}$$

Robotic Arm: $\underline{24 \; lbs.}$ (made of magnesium alloy)

Motor & Wheel Assembly: $\underline{150 \; lbs.}$

Fuel Cells: $\underline{250 \; lbs.}$

Extra Wheel: $\underline{90 \; lbs}$

Actuators: $\underline{75 \; lbs}$

Parking footpads: 3 - 1 ft members
     3 - circular footpads (1 m²) $\Big\}$ $\approx \underline{15 \; lbs}$

Weight Analysis (cont.)

Controls : electrical components, on board computer, cameras, refrigerant lines, any necessary hardware.

$$\text{weight} \approx \underline{150 \text{ lbs}} \text{ (estimated guess)}$$

Total Weight : $\boxed{954 \text{ lbs}}$

APC-2 AROMATIC POLYMER COMPOSITES PEEK/CARBON FIBRE

APC-2 PEEK/carbon fibre, aromatic polymer composites, have opened up new horizons for lightweight structural materials.

The benefits of engineering with composites utilising high performance fibres of carbon, boron, and so on have been known for some years.

APC-2, a thermoplastic system, benefits from an engineering approach to fabrication processes and the economics of rapid, automated and controlled part production that this brings.

APC-2 is based on carbon fibre and Victrex® PEEK aromatic polymer from ICI. Compared with other types of thermoplastic matrix PEEK has a higher operating temperature and is unaffected by solvents.

But the real secret of APC-2 is the specially developed interface science which, together with a process designed to ensure thorough impregnation of the carbon fibres, results in negligible void content and maximises the matrix dominated properties. By providing effective stress transfer, the PEEK matrix allows the full properties of carbon fibre to be obtained.

APC-2 PEEK/CARBON FIBRE

* 30% lighter in weight than aluminium.
* uses rapid, automated, economic fabrication processes.
* high impact toughness and excellent damage tolerance.
* good creep and fatigue resistance.
* high temperature performance—Tg 143°C (290°F).
* excellent hot/wet strength.
* low water absorption and excellent solvent resistance.
* outstanding fire resistance, negligible smoke generation.
* easily repairable.

APC-2—the most *cost-effective* route to second generation advanced composites.

APC-2
PEEK/CARBON FIBRE COMPOSITE
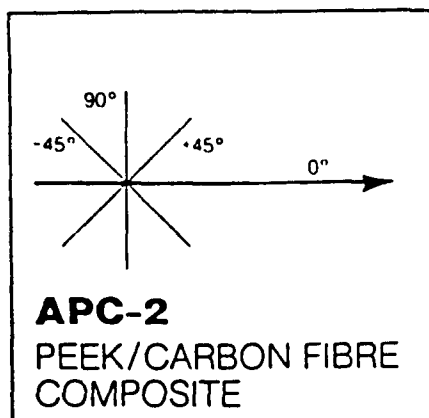
ICI FIBERITE®

DATA SHEET 3b:

Provisional Property data of aromatic polymer composite, APC-2/Hercules Magnamite® IM-6 carbon fibre

This data is from initial testing of a development material and should not be used as design data.

PHYSICAL PROPERTIES			
Carbon fibre volume fraction	61%	Carbon fibre areal weight	150 g/m²
Carbon fibre weight fraction	68%		

MECHANICAL PROPERTIES				
Property	Test Method	Temperature	Values	
0°	ASTM D-3039	23°C (73°F)		
Tensile strength			2700 MPa	392 ksi
Tensile modulus			176 GPa	25.5 ksi
Tensile strain to failure			1.48 %	
Compressive strength	IITRI Test	23°C (73°F)	1050 MPa	152 ksi
Flexural strength	ASTM D-790 Span-to-depth ratio 60:1	23°C (73°F)	2170 MPa	315 ksi
Flexural modulus			151 GPa	21.9 msi
90°	ASTM D-3039	23°C (73°F)		
Tensile strength			—	—
Tensile modulus			—	—
Tensile strain to failure			—	—
Flexural strength	ASTM D-790 Span-to-depth ratio 25:1	23°C (73°F)	160 MPa	23.2 ksi
Flexural modulus			9.3 GPa	1.35 msi
Short beam shear strength ° Specimens do not fail in shear.	ASTM D-2344	23°C (73°F)	116 MPa°	16.8 ksi

MODE I INTERLAMINAR FRACTURE TOUGHNESS (G_{IC}) Test method	Temperature	Cleavage Mode kJ/m^2	Ductile Mode kJ/m^2	Cleavage Mode in lb/in^2	Ductile Mode in lb/in^2
Straight-sided double cantilever beam test. Data reduction by Area Method	23°C(73°F)	2.5	3.3	14.3	18.8

DAMAGE TOLERANCE			
Impact Energy		Residual strain to failure	
in lb/in	J/mm	%	
1000	4.45	0.71	
1500	6.68	0.54	
2000	8.90	0.60	

*PEEK is an ICI product sold under the trade mark Victrex®

© Fiberite Corporation, 1986

Data Sheet 3b

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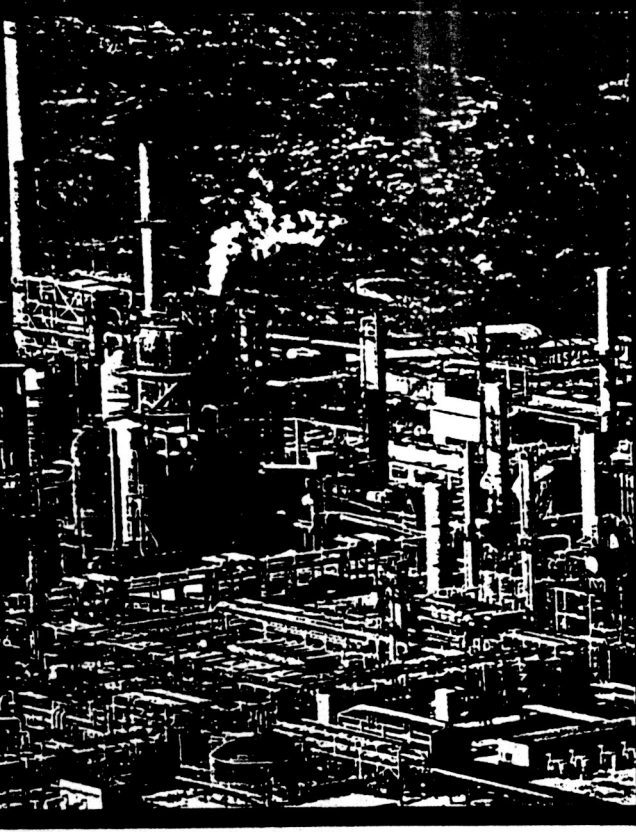Tel: (302) 575-8173
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Materials

Phillips Petroleum has developed proprietary technology to combine *long fiber reinforcement* with a *thermoplastic* matrix. The current product line features two basic types of products, both utilizing polyphenylene sulfide as the matrix resin. One contains reinforcement in the form of a fiber mat specially designed for processing by a rapid compression molding process, often referred to as *thermoplastic stamping*. The other contains reinforcement in fabric form specifically designed for *laminating* and *thermoforming*. Unidirectional carbon fiber/PPS prepreg tape is also available and is the subject of a companion brochure.
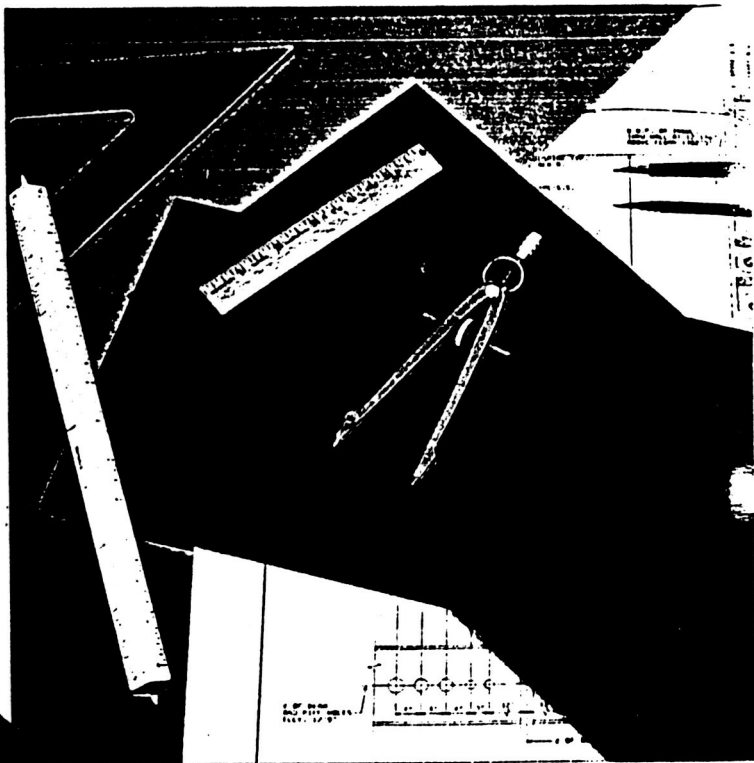
Stampable Sheet

Mat Reinforced Stampable Sheet

These materials are supplied in sheet form up to 30 inches wide and 70 mils thick. Typical fiber content is 40 wt. %, but can be varied. Both glass and carbon fiber reinforced products are available. This product family includes the following composites:

AG10-20: 20 wt. % chopped glass mat/80 wt. % PPS.

AG20-40: 40 wt. % continuous glass mat/60 wt. % PPS.

AC10-20: 20 wt. % chopped carbon mat/80 wt. % PPS.

Fabric Reinforced Composites

These materials are supplied in thin sheet form ready for lamination and thermoforming. Sheets are available in 30 inch widths with a nominal thickness of 0.012 inch. Typical fiber contents are in the 40-60 wt. % range. Both glass and carbon fabric reinforced products are

ndustrial - Replacing stainless steel, aluminum and expensive alloys in chemical ...ps, compressors, heat ex- ...angers, valves, and seals requires exceptional toughness, high- ...emperature strength and excellent chemical resist- ... PPS ...posite...

able. This product family includes the following
posites:

0: Plain weave glass fabric PPS/Prepreg.
0: Satin weave glass fabric/PPS Prepreg.
0: Plain weave carbon fabric/PPS Prepreg.
0: Satin weave carbon fabric/PPS Prepreg.

r Bar Stock

emolded stampable sheet is available for
hing prototype or production parts. Bar stock is
le in pieces 4 inches in diameter and 2½ inches
Flat slab stock is made to order.

Table I
Properties of Random Mat and Fabric
### Reinforced Polyphenylene Sulfide Composites

Fiber Type	AG 20-40 Glass Mat	AC 10-20 Carbon Mat	AG 30-40 Glass Fabric	AC 30-60 Carbon Fabric
Tensile Strength, (10^3 psi)	23	20	26	75
Flexural Strength, (10^3 psi)	34.5	31	21	93
Flexural Modulus, (10^6 psi)	1.8	1.7	2.16	6.8
Elongation, %	1.9	—	—	0.84
Compressive Strength, (10^3 psi)	38	—	—	—
Izod Impact, ft-lbs/in				
Notched	14	1.3	8	12.5
Unnotched	25	5.0	17	21.5
Heat Deflection Temp., °F at 264 psi	523	527	523	536
Specific Gravity, g/cc	1.66	1.36	1.66	1.6
Elect. Conductivity, ohm^{-1} cm^{-1}	—	0.501	—	—
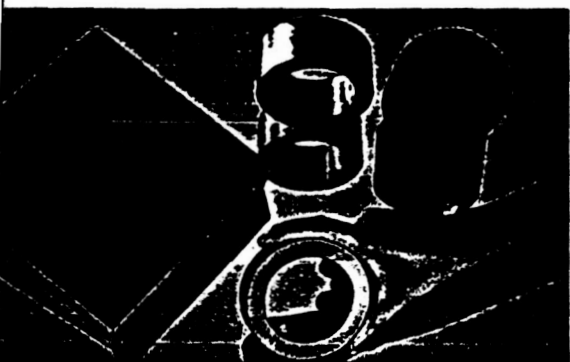
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Prepregs
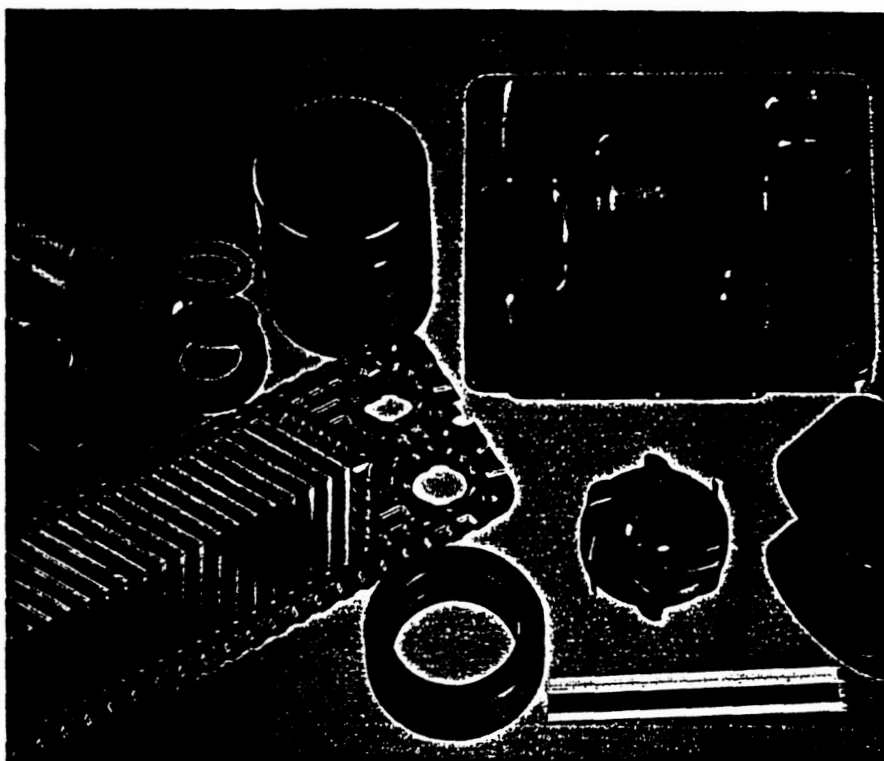
Molded Parts

inates

reconsolidated laminates of the plain woven fabric
posites are available in standard 8-ply thicknesses
090 inch. Other thicknesses are available upon
est.

Table II
Material Property Comparison

Property	Ryton PPS AG 20-40	Aluminum Die Cast	Cast Gray Iron	Polyester SMC
Reinforcement	Glass	—	—	Glass
Specific Gravity, g/cc	1.66	2.57-2.96	7.20	2.1
Tensile Str., 10^3 psi	23	8-26	25	20
Tensile Mod., 10^6 psi	1.8	10	13	2.0
Elongation, %	1.9	50	0.5	1.5
Flex. Mod., 10^6 psi	1.8	10	—	2.0
Flex. Str., 10^3 psi	34.5	8-26	10	30
Comp. Str., 10^3 psi	38	9	25	30
Izod Impact, ft-lbs/in				
Notched	14	a	a	22
Unnotched	25	a	a	b
Heat Deflection Temp. @ 264 psi, °F	523	a	a	500
Continuous Heat Resistance, °F	400	b	b	400

a. *not applicable*
b. *not available*

roperties

chanical Properties

Typical mechanical properties for mat and fabric
forced materials are shown in Table I and compared
other competitive materials in Table II. Retention of
se properties at elevated temperatures is very good. *In
eral, 50-60% of the properties listed are retained at
°F.*

Product Information

Scotchdamp

SJ2015X Viscoelastic Polymer
Types 110, 112, 113, 830
Material Damping Properties

Description:

SJ2015X designates a family of high energy dissipative polymers which when properly incorporated into a constrained layer damping system can afford excellent control of resonance-induced vibration problems.

Material damping properties are expressed as a complex number in which the dynamic shear modulus (G') is the real portion while the dimension-less quantity η (loss factor) is associated with the imaginary portion. Both these quantities interact to provide the polymer damping capacity. Density of all these polymers is 0.98 g/cm³ (0.035 lb/in³).

Discussion:

Both the dynamic shear modulus and the loss factor of these polymers are temperature and frequency dependent. When selecting a polymer for a constrained layer damping treatment, these variations in temperature and frequency must be taken into account. As a general rule, good constrained layer damping performance can be achieved when the polymeric components are chosen to insure that the inservice operation temperature frequency requirements over which the control is desired are between the 10⁻¹ and 10⁴ region of the reduced frequency scale.

The performance of most damping devices are highly dependent on the interaction between the device and the system to which it is applied. A constrained layer control system is no different than a typical damping device and its ability to provide the desired performance is affected by parameters other than temperature and frequency. Namely the geometry, stiffness, mass, and resonance mode shape at the structure to which the control system is applied will affect the performance. For more details concerning the proper choice of constrained layer configuration, contact the Structural Products Department.

Data Interpolation:*

To determine the damping properties at the desired temperature and frequency from the following data graphs, proceed as follows:

1. Locate the desired frequency on the right vertical scale.
2. Follow the chosen frequency line to the desired temperature isotherm.
3. From this intersect, go vertically up and/or down until crossing both the modulus and loss factor curves.
4. Read these modulus and loss factor values from the appropriate left vertical scale.

See sequenced example numbered below:
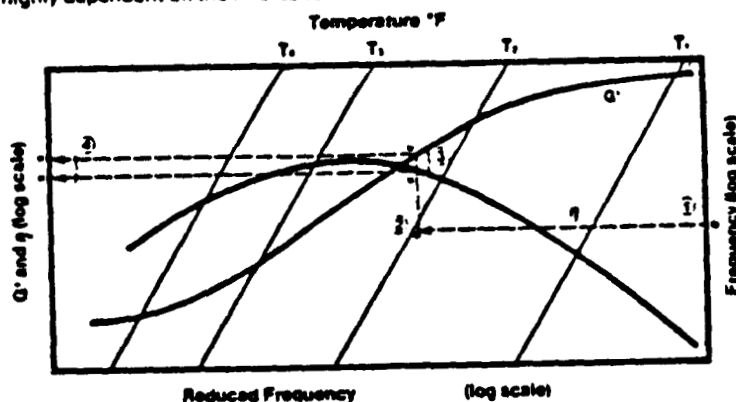
Caution:
The oblique constant temperature lines are separated by non-uniform spacings. Hence a linear extrapolation of temperature not explicitly shown cannot be used to obtain other temperature data.

*Note: The material damping properties are in the "reduced temperature format". This format is being considered by the American National Standards Institute for acceptance as a standard form of expressing the damping properties of linear polymers. Further information concerning this proposed standard is available from the ANSI S2-73 committee or the Structural Products Department of 3M.
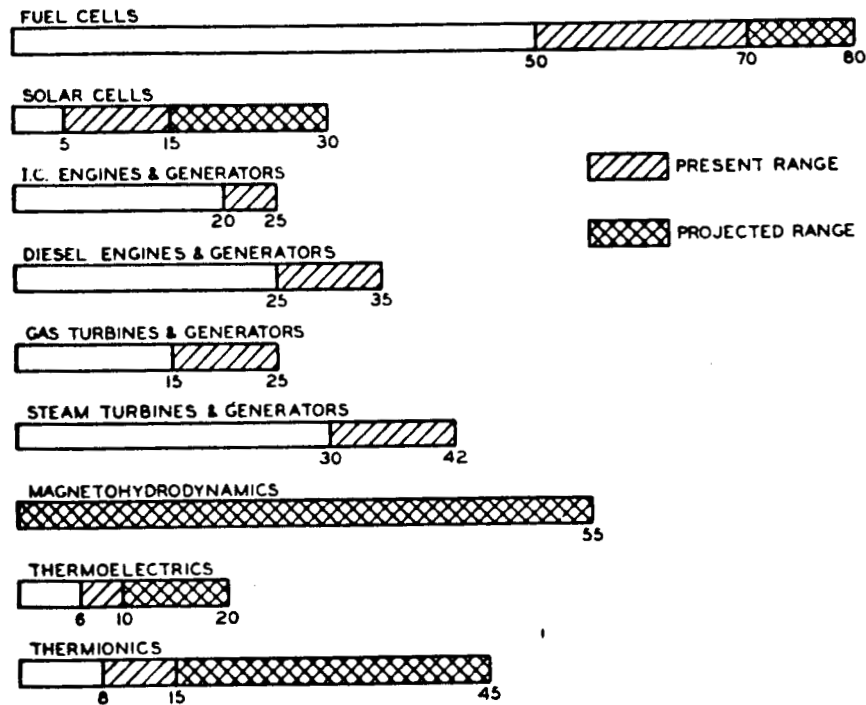
FIG. 1

FUEL CELLS

50 70 80

SOLAR CELLS

5 15 30

I.C. ENGINES & GENERATORS

20 25

DIESEL ENGINES & GENERATORS

25 35

GAS TURBINES & GENERATORS

15 25

STEAM TURBINES & GENERATORS

30 42

MAGNETOHYDRODYNAMICS

55

THERMOELECTRICS

6 10 20

THERMIONICS

8 15 45

PRESENT RANGE

PROJECTED RANGE

FIG. 1. Efficiencies of energy converting devices.

FIG. 2

WATT - HOURS/FT.^{3}

4,000 8,000 12,000 16,000 20,000 24,000 28,000

LEAD - ACID

BATTERIES SILVER-ZINC

ENG. - GEN. SET I-KW. UNIT AT FULL LOAD, LIQ. H_2 & O_2

ENG. - GEN. SET I-KW. UNIT AT FULL LOAD, GASOLINE & LIQ. O_2

FUEL CELL I-KW. H_2-O_2 CELL WITH LIQ. H_2 & O_2

WATT - HOURS/LB.

1000 900 800 700 600 500 400 300 200 100 0

FUEL CELL I-KW. H_2-O_2 UNIT WITH LIQ. H_2 & O_2

ENG.- GEN. SET I-KW. UNIT AT FULL LOAD, LIQ. H_2 & O_2

ENG.- GEN. SET I-KW. UNIT AT FULL LOAD, GASOLINE & LIQ. O_2
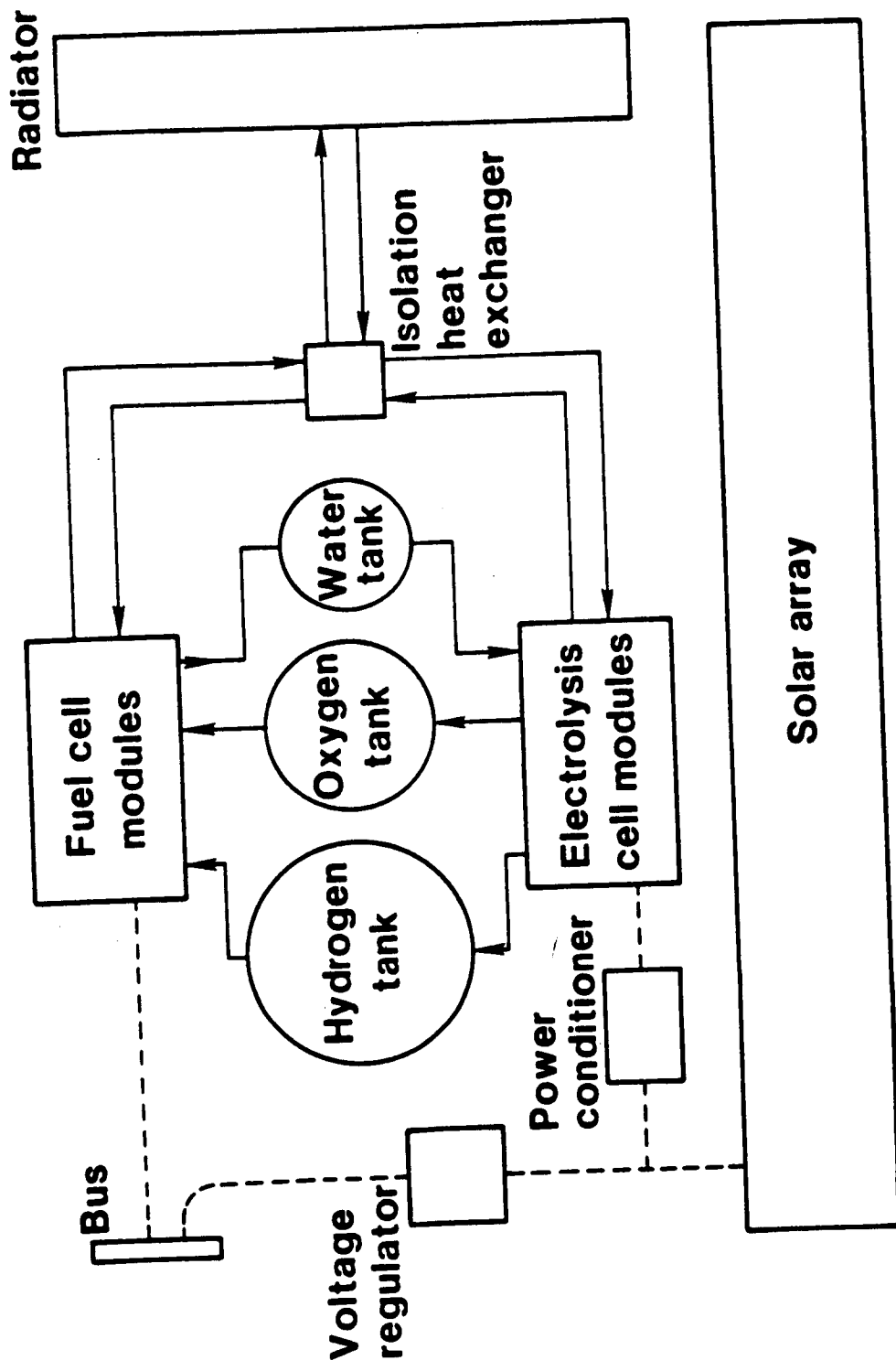
BATTERIES SILVER-ZINC

LEAD -ACID

.1 1 10 100 1,000

TIME - HOURS

FIG. 2. Power vs. weight ratios for fuel cells, batteries, and engine generator sets.

ALKALINE REGENERATIVE FUEL CELL CONCEPT

Radiator

Isolation heat exchanger

Water tank

Oxygen tank

Hydrogen tank

Fuel cell modules

Electrolysis cell modules

Power conditioner

Voltage regulator

Bus

Solar array

- Efficient • Reliable • Low-weight

January 14, 1988

MEMORANDUM

TO: Mr. James W. Brazell

FM: ME 4182 Design Group D

RE: Design Group's Progress for the Week of January 11 - 15

Group Members: William Dixon, William Fan, Joey Lloyd, Nam-Anh Pham, Mike Stevens.

Project Description: The Design of a Soil Transport Implement for Skitter.

Group's Progress:

(1) A weekly time for group meetings was established.

(2) The group discussed preliminary design considerations concerning the development of machinery for lunar uses. These considerations included the moon's lack of atmosphere, surface, and gravity.

(3) Several references have been located which provide information about the lunar evironment.

January 21, 1988

MEMORANDUM

TO: Mr. James W. Brazell

FM: ME 4182 Design Group D

RE: Design Group's Progress for the Week of January 18 - 22

Group Members: William Dixon, William Fan, Joey Lloyd, Nam-Anh Pham, Mike Stevens.

Project Description: The Design of a Soil Transport Implement for Skitter.

Group's Progress:

(1) Preliminary designs for the implement were discussed.

(2) We decided on the main areas that must be taken into consideration for our design. They include the following: fuel cells, motors, heat sinks, bearings & lubricants, abrasive resistant materials, temperature, pressure, gravity, and dust.

(3) A rough draft of the problem statement was sketched out.

(4) The group planned to meet with civil engineering professors next week to talk about soil mechanics.

January 28, 1988

<u>MEMORANDUM</u>

TO: Mr. James W. Brazell

FM: ME 4182 Design Group D

RE: Design Group's Progress for the Week of January 25 - 29

<u>Group Members</u>: William Dixon, William Fan, Joey Lloyd, Nam-Anh Pham, Mike Stevens.

<u>Project Description</u>: The Design of a Soil Transport Implement for Skitter.

<u>Group's Progress</u>:

(1) The problem statement was finalized.

(2) Each member got his computer account and we started learning how to use the Apollo system.

(3) The group is still in the brainstorming stage of the design. We want to come up with as many different ideas as possible before we start narrowing down our design.

(4) Bill Dixon went to talk to Dr. Myers about abrasive resistant materials.

(5) The different design considerations were divided among the members to be researched on further.

February 4, 1988

<u>MEMORANDUM</u>

TO: Mr. James W. Brazell

FM: ME 4182 Design Group D

RE: Design Group's Progress for the February 1 - 5

<u>Group Members</u>: William Dixon, William Fan, Joey Lloyd, Nam-Anh Pham, Mike Stevens.

<u>Project Description</u>: The Design of a Soil Transport Implement for Skitter.

<u>Group's Progress</u>:

(1) A magnesium alloy is being looked into as a possibility for the abrasive resistant material to be used in our design. The alloy was suggested by Dr. Myers.

(2) The mechanical properties of the moon's soil is being looked into. Then an analysis will be done to determine the soil's trajectory when it is thrown by the spinning blade.

(3) Bill Dixon has been learning Auto-CAD and has been able to do some preliminary drawings on the system.

(4) The problem statement was revised.

February 11, 1988

MEMORANDUM

TO: Mr. James W. Brazell

FM: ME 4182 Design Group D

RE: Design Group's Progress for the Week of February 8 - 12

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Group Members: William Dixon, William Fan, Joey Lloyd, Nam-Anh Pham, Mike Stevens.

Project Description: The Design of a Soil Transport Implement for Skitter.

Group's Progress:

    (1)   A simple mathematical model of a rotating disc was made to analyze the
          trajectory and distribution of thrown soil. From this analysis, the proper speed
          and blade angle can be determined to achieve the desired height and distance
of   the thrown soil.

    (2)   Further research is being made on abrasive resistant materials for the
spinning
          disc. A silicon compound is presently being considered.

    (3)   Preparation was made for the midterm oral presentation.

February 18, 1988

<u>MEMORANDUM</u>

TO: Mr. James W. Brazell

FM: ME 4182 Design Group D

RE: Design Group's Progress for the Week of February 15 - 19

<u>Group Members</u>: William Dixon, William Fan, Joey Lloyd, Nam-Anh Pham, Mike Stevens.

<u>Project Description</u>: The Design of a Soil Transport Implement for Skitter.

<u>Group's Progress</u>:

    (1) A preliminary power consumption analysis was done on the spinning disc.

    (2) Bill and William worked on the IBM CAD system.

    (3) An attempt was made to finalize the design of the implement.

    (4) A report outline was drafted and various deadlines were set for the different parts of the project.

February 25, 1988

MEMORANDUM

TO: Mr. James W. Brazell

FM: ME 4182 Design Group D

RE: Design Group's Progress for the Week of February 22 - 26

_____

Group Members: William Dixon, William Fan, Joey Lloyd, Nam-Anh Pham, Mike Stevens.

Project Description: The Design of a Soil Transport Implement for Skitter.

Group's Progress:

(1) Mike and Bill contacted Fuel Cells Div. of United Technologies and Gates Energy to ask about fuel cells.

(2) A commercial search was done on composite and ceramic materials.

(3) Research was done on the types of motors and actuators needed for our design.

(4) With the design approaching its final stage, some definite design parameters were set.

March 3, 1988

MEMORANDUM

TO: Mr. James W. Brazell

FM: ME 4182 Design Group D

RE: Design Group's Progress for the Week of February 29 - March 4

_____

Group Members: William Dixon, William Fan, Joey Lloyd, Nam-Anh Pham, Mike Stevens.

Project Description: The Design of a Soil Transport Implement for Skitter.

Group's Progress:

(1) We started construction on a scale model of the implement. The model is
     presently 90% complete.

(2) Several companies were contacted regarding brushless dc motors. All of the
     companies contacted only manufactured motors with fractional horsepower
     output. Further research will be done to find out more about motors with more
     than 1 hp output.

(3) Several members of the group worked on the rough draft of the final report.

DRAWINGS

ME 4182

DESIGN GROUP D

FIGURE NO. 1

SIDE VIEW

OF STI

8.0'

6.0'
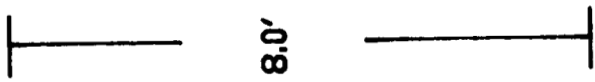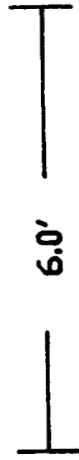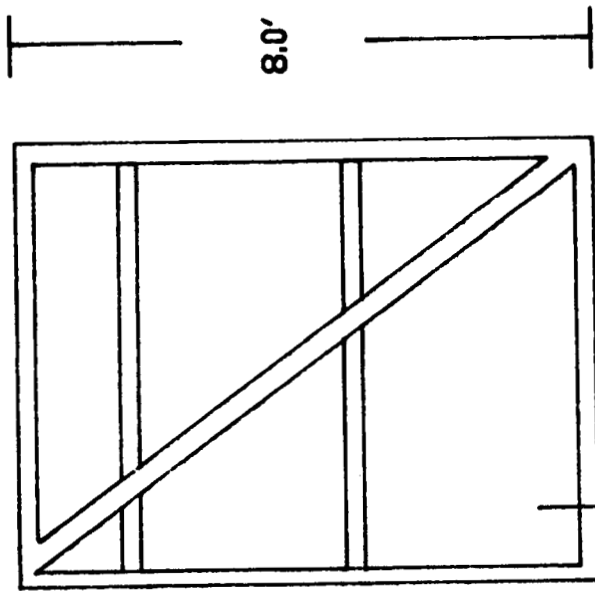
TRIANGULAR STRUCTURE
TUBES' DIAMETER =
3 INCHES

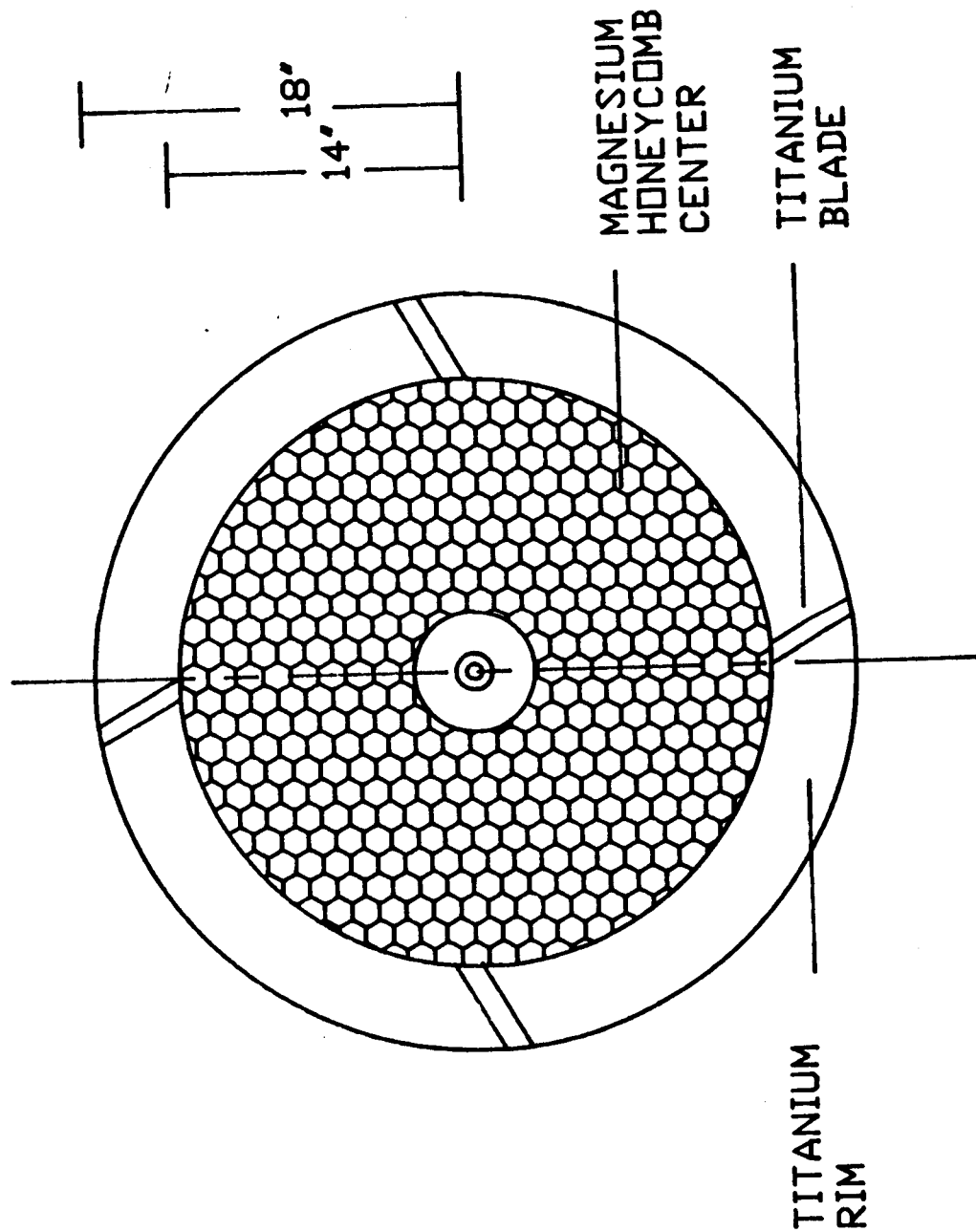SUBFRAME STRUCTURE
TUBES' DIAMETER =
2 INCHES

6.0'

1.25'

3.5'

1.5625'
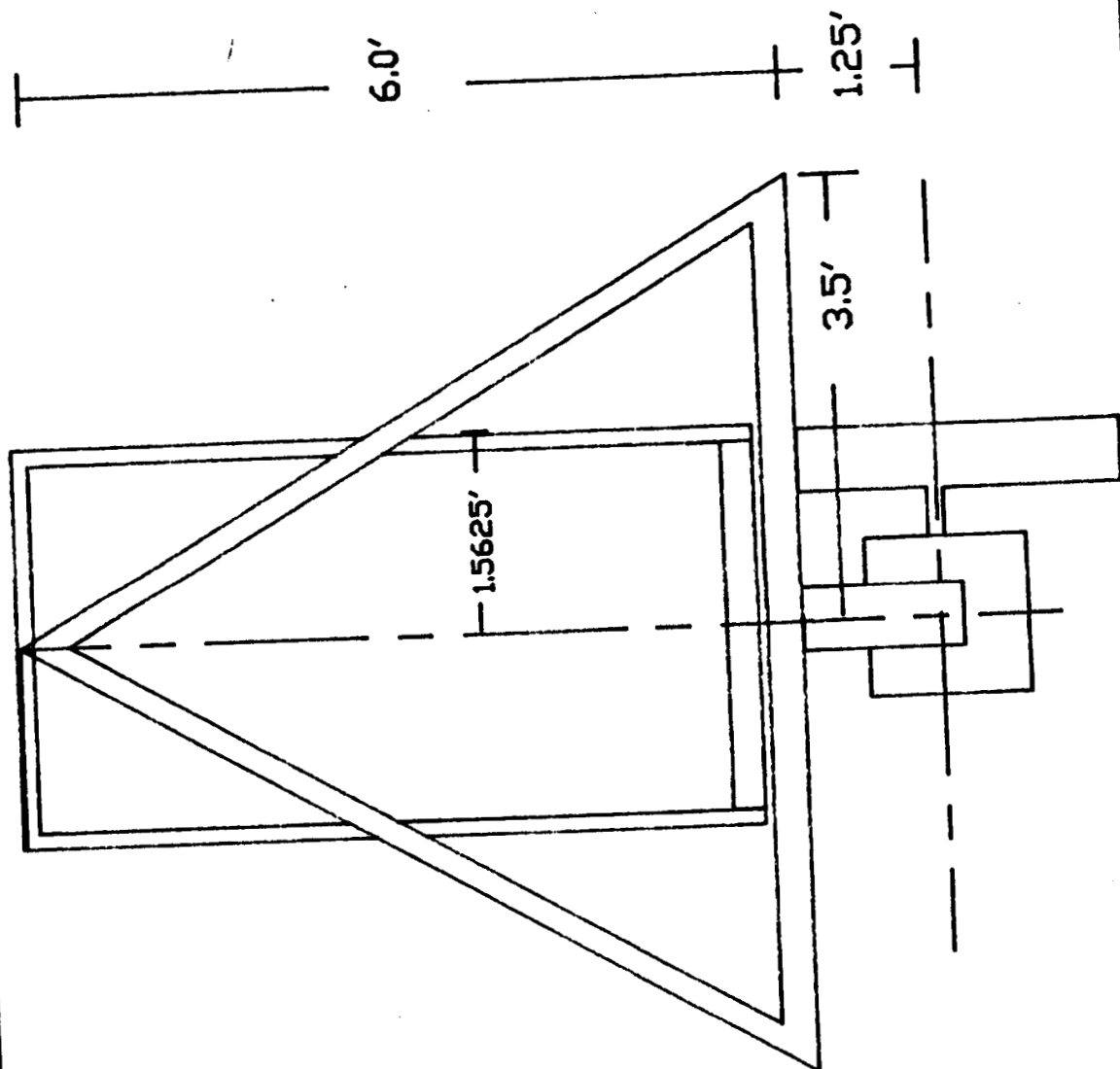
| ME 4182 |
| DESIGN GROUP D |
| FIGURE NO. 2 |
| TOP VIEW |
| OF STI |

ME 4182

DESIGN GROUP D

FIGURE NO. 3

FRONT VIEW

OF ST1

3.0'

5.0'

0.75'

3.5'

0.5'

1.25'

0.5'

18"

14"

MAGNESIUM
HONEYCOMB
CENTER

TITANIUM
BLADE

TITANIUM
RIM
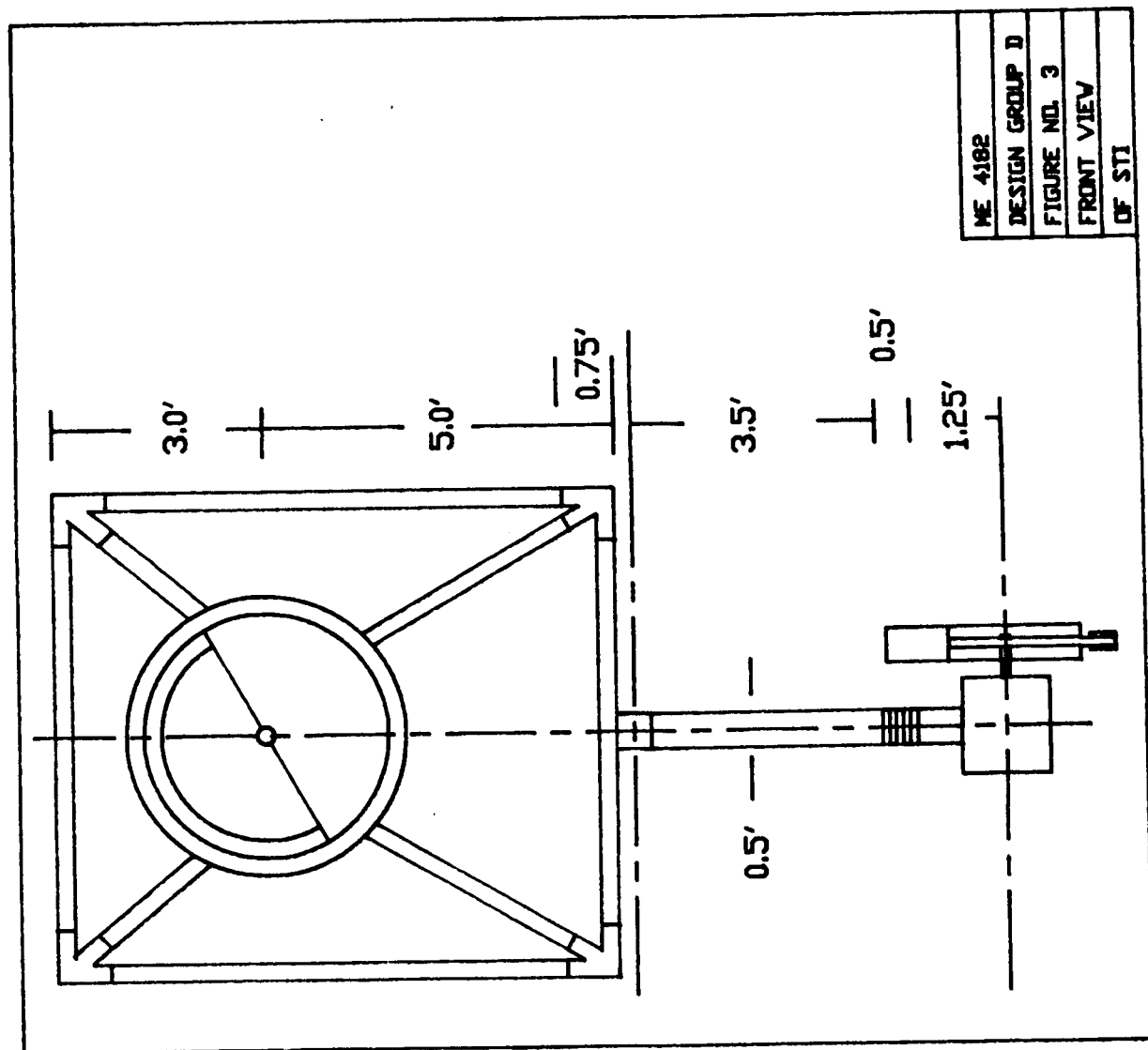
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DESIGN GROUP D

FIGURE NO. 4

SOIL PITCHING

WHEEL

BEARINGS

CERAMIC
HUB

WHEEL
DRIVE SHAFT

MAGNESIUM
OUTER
SHELL

5.75'

1.75'   .75'
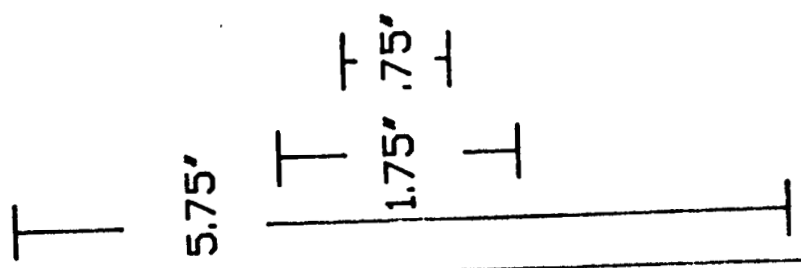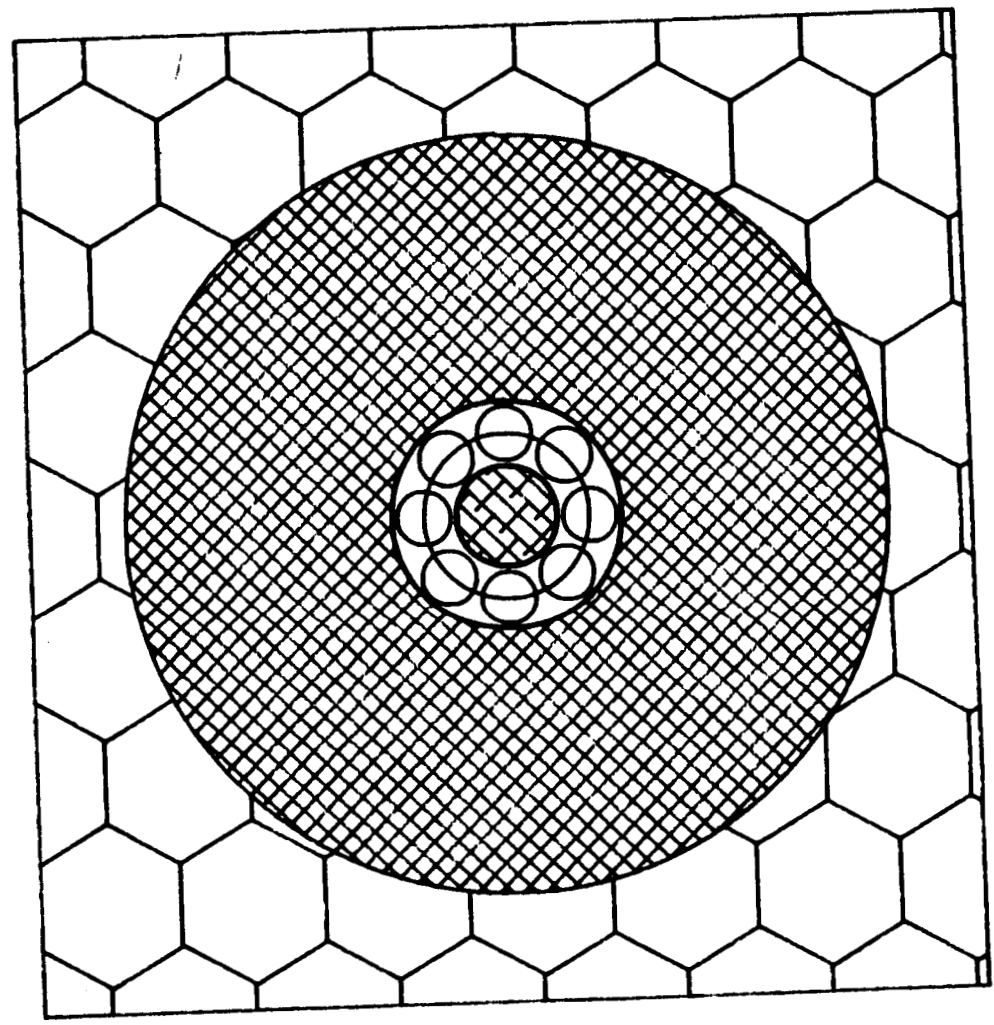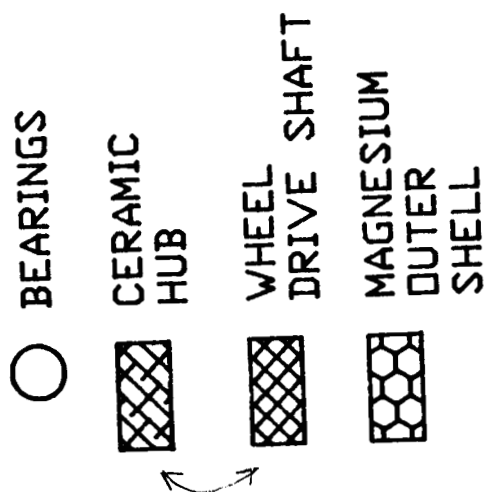
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DESIGN GROUP D

FIGURE NO. 5

HUB AND BEARING

ASSEMBLY

RETAINER
CLIP
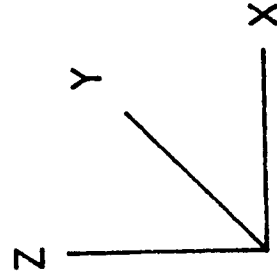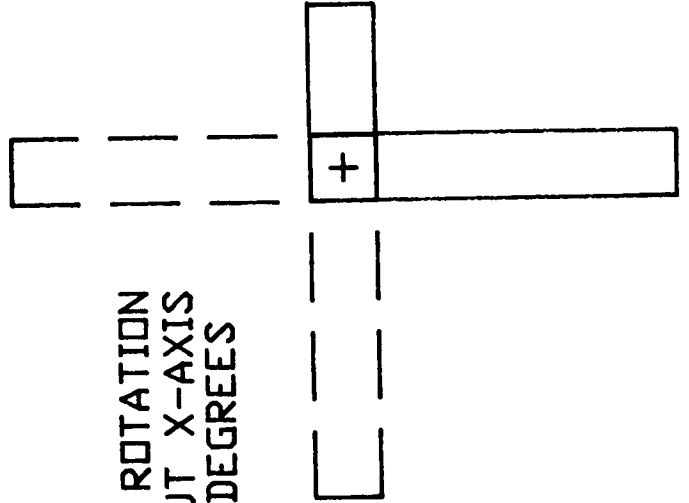
PEEK
COMPOSITE
TUBE

RETAINER
SPRING

1'

1'

3'

3"
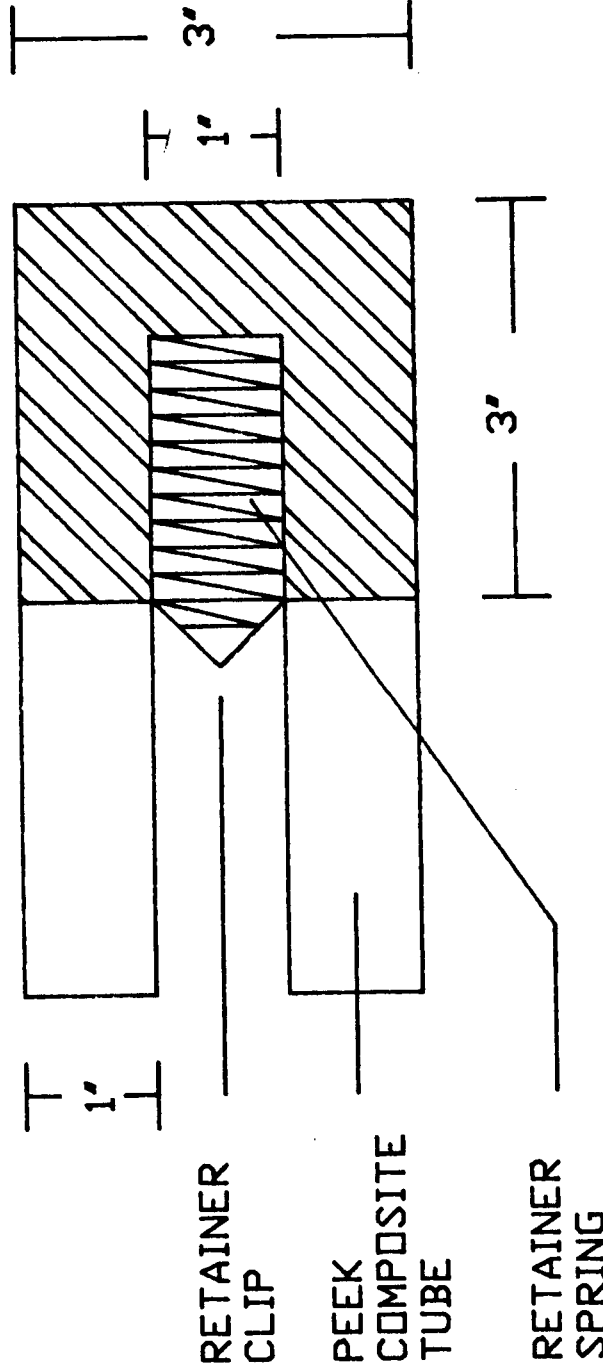
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DESIGN GROUP D

FIGURE NO. 6

X-SECTION OF

WHEEL DISPENCER

ARM ROTATION
ABOUT Z-AZIS
+ 45 AND - 90
DEGREES
(WRIST)

ARM ROTATION
ABOUT Z-AXIS
+/- 18 DEG
(SHOULDER)

ARM ROTATION
ABOUT X-AXIS
180 DEGREES

Z

Y

X

| ME 4182 |
| DESIGN GROUP D |
| FIGURE NO. 7 |
| ARM MOVEMENT |
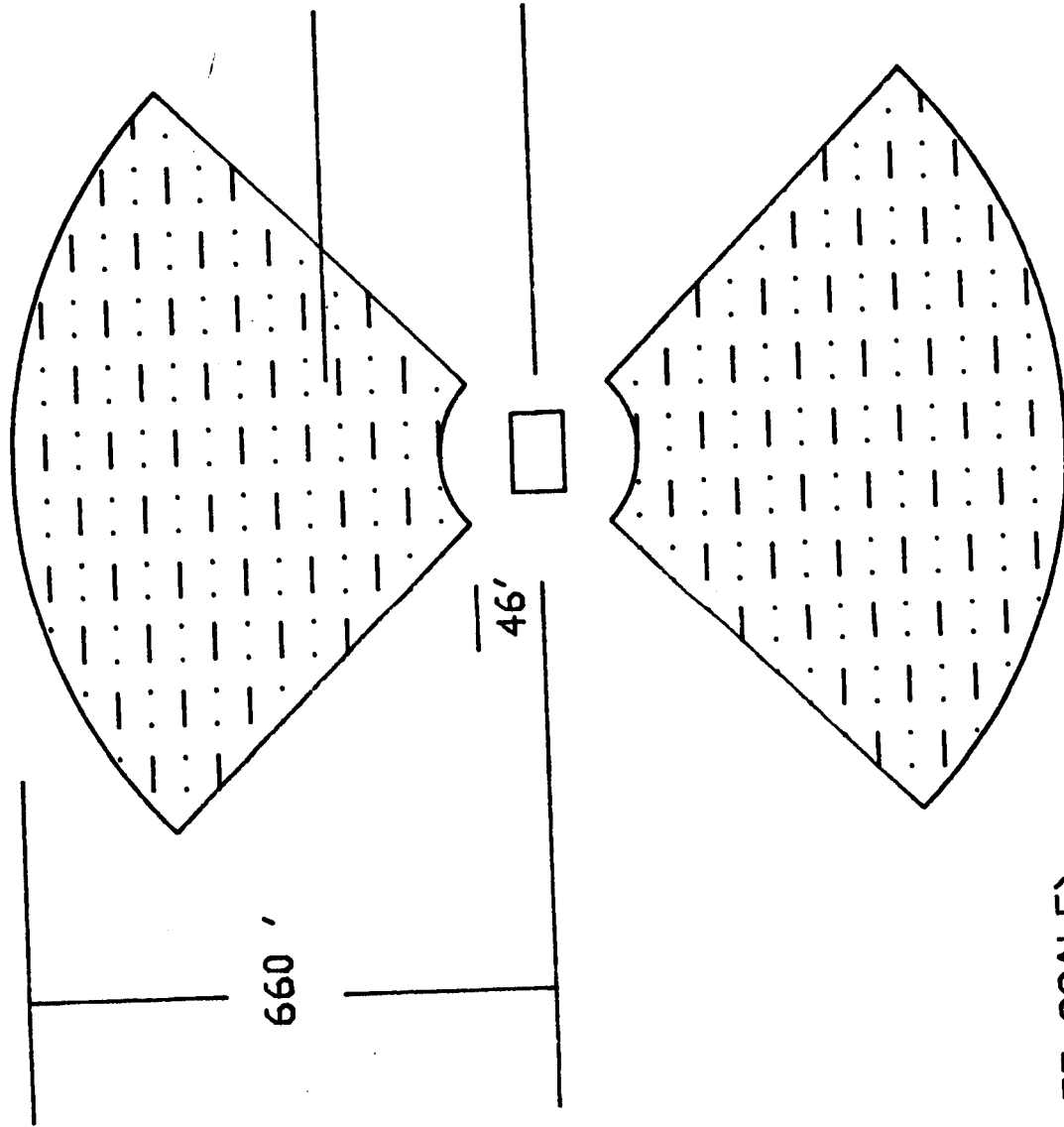
SWEEPING AREA
FOR STI

MODULE

46'

660'

(NOT TO SCALE)

| ME 4182 |
| DESIGN GROUP D |
| FIGURE NO. 8 |
| SWEEPING AREA |
| FOR COVERAGE |

WHEEL DRIVE SHAFT

SPLINES

SPLINE LOCKING BALLS

WHEEL LOCKING SLEEVE

MOTOR DRIVE SHAFT

WHEEL ENGAGE LINKAGE

MOTOR HOUSING

| ME 4182 |
| DESIGN GROUP D |
| FIGURE NO. 9 |
| POSSIBLE MOTOR |
| WHEEL INTERFACE |