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LUNAR MATERIAL TRANSPORT VEHICLE

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ABSTRACT

The proposed vehicle, the Lunar Material Transport Vehicle (LMTV), has a mission objective of efficient lunar soil material transport. The LMTV has been designed to meet a required set of performance specifications, while operating under a given set of constraints.

The LMTV is essentially an articulated steering, double-ended dump truck. The vehicle moves of four wheels and has two identical chassis halves. Each half consists of a chassis frame, a material bucket, two wheels with integral curvilinear synchronous motors, a fuel cell and battery arrangement, and electromechanically actuated dumping mechanism and a powerful microprocessor. The vehicle, as designed, is capable of transporting up to 200 ft^3 of material over a one mile round trip per hour. The LMTV is capable of being operated from a variety of sources. The vehicle has been designed as simply as possible with attention also given to secondary usage of components.

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PROBLEM STATEMENT

INTRODUCTION

The moon was formed approximately 4.6 billion years ago. Until recently, man has not known the physical characteristics and composition of the surface. With the U.S.A. Apollo and U.S.S.R Lunar missions, research data has been retrieved to answer many questions about the properties of the moon. Research is currently underway to possibly colonize the lunar surface.

Many advantages exist in the possibility of permanent structures and facilities for research. The combination of the gravitational setting with the vacuum environment will be capitalized by increased scientific investigation. The lunar surface can be considered a total vacuum with a pressure of 10E-12 Torr. The surface is lifeless, dry and contains oxygen abundant compounds.

Obstacles exist to construction and human operation on the surface. The surface soil is similar to sand; therefore, traction and the abrasive characteristics of the sand-like soil will create problems with any lunar vehicular machinery. The vehicles will have the same inertia but will be one-sixth of the earth weight. This reduction in weight will decrease the traction of the wheels on the surface. All moving parts must be encased to prevent damage by abrasive soil contact.

With the possibility of colonizing the lunar surface, a definite need would exist for the transport of lunar soil and other bulk materials. A suitable vehicle must be designed, within the following objectives and constraints, for this purpose.

OBJECTIVES

PERFORMANCE

SLOPE

The loaded vehicle should be able to perform on a 20% grade.

SPEED

The loaded vehicle should be able to operate in a range of 5-15 mph.

TRACTION

The vehicle should be designed in order to provide sufficient traction on the lunar surface.

SELF-RIGHTING

The vehicle must be able to maneuver itself out of all possible situations.

PRODUCTIVITY

The vehicle should transport 100 cubic feet of soil in each load or an equivalent weight of 1,800 moon pounds. The vehicle should transport this load in a 8 minute, 1 mile round trip. The time will be 6 minutes at 10 mph with 2 minutes for unloading.

SPECIFICATIONS

GENERAL

The vehicle must be as mechanically simple as possible in order to ensure maximum reliability.

LOW HORSEPOWER

The loaded vehicle must be able to operate on 5 - 15 hp.

LOW CENTER OF GRAVITY

Due to the 1/6 gravity force on the lunar surface, the center of gravity must be as low as possible to prevent easy overturning.

GROSS WEIGHT

The gross weight must be kept to a minimum due to the extremely high shipping cost.

CONTROL

The operation of the vehicle should be controllable from the following: a local controller, an earth based controller, and from the vehicle itself.

SIZE

The following factors will be considered in the determination of the vehicle size: turning radius, wheel size, bucket capacity, and overall dimensions.

The vehicle must also fit in the 15 foot wide Space Shuttle cargo bay.

BRAKING

It is desirable to engage a regenerative braking system.

CONSTRAINTS

GENERAL

BODY

The vehicle must operate on four wheels with two bodies and two buckets.

BODY PROPORTIONS

The proportion and shape of the wheels to the buckets must be constant, as it is desirable to have interchangeability with other proposed lunar devices.

OPERATIONAL

RANGE

The operating range of the vehicle is limited to line-of-sight due to the transmission characteristics of radio equipment operating in a vacuum.

TEMPERATURE

The vehicle must be able to withstand extreme temperature differences (-120°C to +120°C).

ENVIRONMENT

The vehicle must be able to operate in a vacuum.

The vehicle must reliably operate in the highly abrasive lunar environment.

DESCRIPTION OF LMTV

GENERAL DESIGN CONCEPT

The major components of the LMTV will consist of four wheels, two identical halves of the chassis frame, two soil buckets and an articulated steering system (Fig. 1). Both chassis frames are in the shape of a tuning fork. A platform is located in the V- section of the frame. The controls, fuel supplies and other operational equipment will be located in this V-section of the chassis halves.

The motors will be located at the connection of the wheels and axles. The regenerative braking and wheel speed will be a computer controlled function and will be performed, through controls, at the wheel interface. The dump mechanism will lie parallel to the inner sides of the fork of the chassis frame. Articulated steering will be utilized at the connection of the two chassis halves. The dump mechanisms and the articulated steering devices are electromagnetic actuators. The steering of the vehicle will be controlled through the actuators and by varying the speed of each individual wheel. All mechanisms and computer controls are accessed through the center section components.

The control devices can be accessed through local remote control or through teleoperator communications. Visual communications will be the major source of earth-initiated control. The teleoperator communications will have the capability of override of on-board computer-originated sensors.

CHASSIS

In formulating the design of the chassis, there were a number of constraints and objectives that had to be considered. First, the chassis is required to support the shear forces, torsional forces, and bending moments that are placed on it by the LMTV components, yet still must remain lightweight. Secondly, the chassis is designed so that it can be used in other applications once the mission of the LMTV has been completed. In addition, the material used to manufacture the chassis has to withstand the harsh lunar environment.

The final chassis design consists of four rectangular box beams (for each half of the vehicle) which are made of a fiber composite material. These beams are joined by three high strength aluminum fasteners as shown in Figure 2. This configuration provides a number of advantages. First, the chassis in its disassembled form is easily transported form earth and can be easily assembled once in orbit. Second, the materials used offer substantial weight reduction with high strength. Third, the four beams and plates can be used in almost limitless applications after the LMTV has reached the end of its usefulness. The overall dimensions of the chassis are illustrated in Figure 1.

The fiber composite beams are to be synthesized using IM6 fibers (High Modulus Graphite Fibers) with a Polyether-ether-ketone (PEEK) matrix. This provides a favorable strain to failure ratio, high toughness, and good repairability. The maximum usable temperature of the beams is 220°C. Another important advantage to using composite material is that the beams can be reused by heating to the "melting" point and reshaping.

Quasi-Isotropic stress-strain characteristics are achieved using by 0°, ±45°, and 90° fiber oriented plies. The 0° oriented fibers provide support for bending stress (in plane stress), the 90° oriented fibers support transverse stress, and the ±45° oriented fibers support torque stresses (shear).

A filament wound mandrel can be used to lay the 90° and ±45° plies. By using pegs placed in the proper positions, the fastener holes, actuator mounts, and axle holes (see Fig. 3) are provided. Next, 0° U-D Pre-Preg tape is applied to the outer surface and the entire beam is placed in an autoclave for a short period of time. The resulting laminate will have 32 plies, but will only be .34 inches thick. The weight of the beam will be very light (density= .0561 lb/in^3) in view of the strength and toughness characteristics provided. The total cubic feet of the beams for the chassis is 5.64034; this gives a computed weight of the chassis frame (composite beams only) of 546.78 lb (earth weight) or 91.13 lb (moon weight).

The section fasteners are to be constructed out of a high strength aluminum alloy, 2024AL. The aluminum density is .0975 lb/in^3 which is lighter than most alloyed metals, and it possesses good fatigue and fracture characteristics. The section fasteners provide an easy solution to the problem of angling the fibers to conform to the chassis contours which tend to reduce composite performance substantially. The fasteners will be joined to the beams using aluminum or titanium rivets.

In the front section of the vehicle will be a compartment to house the microcomputer, batteries, and fuel cell. The fiber composite compartment will be produced in the same manner as the composite beams. The compartment will be riveted to the chassis frame. This compartment will have a sealed lid, so that it is easily accessible.

SOIL BUCKETS

The buckets used on the design of the LMTV have a dimensional proportionality to the wheels which must be maintained. This is the major constraint on the buckets. Therefore, they will be constructed with the primary goal of saving weight. The relative proportions of the bucket are shown in Figure 4.

It is desirable for the buckets to serve a dual purpose, if necessary. For instance, the buckets could be used for the ends of a pressure vessel after the moon base is completed. For this reason, it is difficult, at this time, to fully specify the material and actual performance requirements of the buckets. It seems logical that the best approach would be some type of composite material. The buckets could then be made very lightweight yet the composite could be oriented in a manner to serve as a pressure vessel.

A further consideration in the structural bowl design is the reinforcement required at the dump mechanism connection and also at the stationary pivot point. The amount of reinforcement will again depend on the inherent strength of the bowl as it is designed for alternate uses. For the case of the pressure vessel, they would likely be strong enough with no additional reinforcement for use on the LMTV. On the other hand for a light duty secondary usage, the material of the bowl may be just strong enough for LMTV application.

Other factors governing the material selection must also be considered. The two other primary considerations are temperature sensitivity and abrasion resistance. Due to the tremendous temperature extremes encountered, the material will have to function with very high reliability in an environment ranging from -120°C to 120°C. It is desirable for the material properties to remain relatively constant over that range.

Abrasion resistance will be another important consideration. Due to the highly abrasive lunar soil, bowl wear must be expected even from simple loading and dumping. It may be possible to construct the bowls with an inner liner of material specifically designed to resist wear while the other layers would be designed to give strength.

For our design purposes, the bowl size was maximized based on the power requirements and motor performance. A wheel diameter of 4 feet corresponds to a torque per wheel of 246 foot-pounds which is within our theoretical limit for the motors. This wheel size defines a bowl size due to their constant proportions. Thus, this definition yields a vehicle capacity and the capacity weight is used to determine the required torque. After the final calculations, the wheel size is set at 4 feet and the bowl diameter is set at 5.33 feet.

This specifies the general size of the largest vehicle possible. The dimensions of the bowl are shown in Figure 5. By using two of theses bowls, the vehicles total carrying capacity is approximately 2,000 moon pounds of lunar material.

WHEELS

The design constraints for the LMTV specify a four-wheeled vehicle. Two wheels will be placed on each chassis half, near the line of action of the center of mass of the bowl, as shown in Figure 1. This will serve to limit the load at the steering joint. As discussed in the bowl section, the wheel diameter can be determined by capacity and torque requirements for any given bowl/wheel combination (Figure 6a,e).

The wheels will resemble those used on the Lunar Rover. The physical dimensions are a four foot wheel diameter with an 18 inch wide tread. A interwoven wire mesh design will be utilized. Eight hundred wires measuring 0.032 inches will be woven into a 0.25 inch mesh. Each wire will be crimped at fixed intervals and then woven into a flat mesh. Tubular spacers will be placed between the tread strip to prevent clamping of the wire mesh.

A cylinder will be formed with the mesh and will create the outer frame. A stiff inner frame will provide support through absorption of impact loads and this inner frame is essentially a stiff spring. The inner frame will limit vertical and lateral direction of the outer frame. The tread strips will cover approximately fifty percent of surface contact.

A stub axle will be utilized as the interface of the wheel and motor. The diameter of the axis will be 2 inches and will designed for a 1,000 pound force on each axle. The dimensions of the axle are given in Figure 3. A fender will placed over each wheel to act as a blocker of wheel-induced airborne soil.

The curvilinear synchronous motor will be incorporated into the hub of the wheel and will be discussed in the Motors section. The wheel motion will be a direct result of the power from the motor and this interaction of the wheel and motor assemblies is essential for proper performance.

DUMP MECHANISM

The dumping mechanism for the LMTV will consist of a pair of linear actuators operating under a tension load for the dump cycle. The exact position of the bowl pivot point was determined based on ground clearance and the requirement that the bowl rotate 110°. The actuators will be placed on either side of the bowl and lie along the inside of the chassis.

Because the fully loaded bowl will have a maximum capacity of approximately 1000 moon lbs., each actuator must be capable of supplying half of the force needed to dump. The maximum loading was determined to be at the very beginning of the dump cycle. Our calculations show that a total force of 800 lbs. or 400 lbs. per actuator will be required to initiate the dumping action. The exact position of the actuators and their connection points is shown in Figure 7. The line of action of the actuator remains relatively constant throughout the range of motion in order to minimize any mechanical loss due to misalignment or pulling at an angle. The actuators will be computer controlled with sufficient feedback to prohibit binding due to variations in actuator position or speed with respect to the other contributing actuator. Our design utilizes the Duff-Norton Super-Pac Electromechanical Actuators. These actuators are rated at 500 lbs. applied load and travel at approximately 36 in/min using a 12 V DC motor drawing a maximum of 15 amps. These actuators were chosen for their simplicity, compactness, and the fact that they are well sealed and maintenance free. These actuators contain their own position transducers which will be used in the feedback control system. It is estimated that using these actuators, a total dump cycle can be executed in approximately 90 seconds, including a slight pause for direction change.

MOTORS

Dr. Kent Davey (Georgia Tech Electrical Engineering Department) and personnel at the Veterans Administration Medical Center are currently designing a low speed fractional horsepower synchronous drive motor. This motor will be applied as an alternative for the electric wheelchair motor. The increased efficiency and reliability of the curvilinear synchronous motor are advantages for implementation of this motor and replacement of existing wheelchair motors.

The design of the curvilinear synchronous (CS) motor is applicable to a motor for the LMTV. Through size, electrical and structural modifications, an encased CS motor would be an excellent drive source for the LMTV. The major attraction of the CS motor is efficiency and simplification by the direct drive mechanism. Through the projections, predications, and calculations of Dr. Davey and this report, the CS motor can be utilized for the LMTV drive mechanism.

The design for the LMTV will be a 3 foot radius, double-sided stator motor. Current design of the CS motor requires a rotor as a rotating fixture of the wheel and the stator as a non-rotating component of the wheel assembly. The rotor section of the wheel is a set of magnets radially oriented in the peripheral direction around the wheel. The magnets of the rotor are currently designed with a ceramic material. The magnets are arranged in an alternating north-south pattern. The stator consists of a three phase winding embedded in a iron laminate. By alternating a three phase excitation of current on the stator winding, control and torque generation can be achieved.

Although this motor is a direct drive DC motor, it can be considered as a three-phase AC motor. The stator windings are arranged in a pattern of three groups of winding slots that allow each group to be excited by single phase. The three phase groups are offset by 120 degrees. The windings can be considered as having a pole pitch equal to twice the tooth spacing. Every other slot in a sector of the stator carries a current antiparallel to its neighbor and therefore the wavelength is twice the slot spacing. The angle between the windings is 7.20 degrees and this spacing is required for the excitation of the windings (see Fig. 11, 12, 13, 14).

In the application of this smaller design to the larger structure for the LMTV, the proportionality of the torque versus the radius of the rotor was determined to be that the torque is equivalent to the square of the radius. The LMTV design is capable of delivering a torque of 275 foot-pounds and through calculations, the greatest amount of torque needed will be approximately 246 ft-lb.

The current requirements are in direct proportional to the values of the wheelchair motor; the CS motor for the LMTV will need approximately 55 amperes (Figure 9). The voltage will be 12 volts DC and this will be provided by the fuel sources that also power the other mechanism controls.

STEERING

The vehicle will be steered by an articulated mechanism utilizing electromechanical linear actuators (power screws). The steering of the vehicle will also be aided by varying the wheel speed in sequence with actuator motion.

The steering mechanism is located between the two bodies. A pin connects the point of the chassis to a plate thus providing a swivel for turning. A bearing is located between the plate of each respective body (Figure 10). this bearing provides free roll rotation of each body (i.e., when one body is on an incline and the other is not). There are four actuators; two located on each plate. The actuators are pinned to opposite sides of the plate and connected to the chassis. The coordinated retraction and extension of these actuators provides the forces necessary to turn the vehicle.

The actuators that we have chosen are Duff-Norton Mini-Pac Electromechanical units. These actuators are rated for a maximum 100 pound load with a speed of 145 inches/minute utilizing a special high speed motor. At maximum load, these 12 V DC motors will require 21 amperes.

The action of the actuators and the individual wheel speed are controlled by the on-board microcomputer. It has been determined through calculation that the vehicle will have a turning circle radius of 16.5 feet (total turning circle of 33 feet diameter).

This central section of the vehicle must also support the "tongue" weight of each chassis half. The loading at the hinges has been calculated to be 148 pounds on each side at full load. For this reason, the pins have been oversized at 2 inches diameter and 18 inches in length. It should be noted that problems occur with the pin joints due to the extreme temperatures incurred and the lack of liquid lubrication. This problem can be solved by using a pressure and temperature impregnated teflon-like coating on the pins. Coatings are now available which will easily withstand the temperature extremes and provide dry permanent lubrication of the pins. The entire steering mechanism will be enclosed with a flexible type structure in order to keep out the abrasive lunar dust.

POWER

BATTERY SOURCE

The Viking Lander (Mars) contains two series-connected 35-watt radioisotope thermoelectric generators (RTG) and four, 24-cell Nickel Cadmium batteries. These batteries are long-usage batteries and can be regenerated with the RTG apparatus after prolonged usage. This long-life characteristic could be utilized in the power of the LMTV.

Research must be done for the adaptability of the battery system. Currently, the voltage output is approximately 28 volts with a current of 8 amperes-hours. The weight of the batteries is 50.5 pounds per unit. The necessity of the RTG and regenerative systems could be included but the weight of this system must be compared with the recharging advantages.

NiCd batteries are utilized in satellites and provide specific energy densities of 10 Whr/kg at a 10% to 20% depths of discharge. In the recharging process, there is a need to prevent overcharging due to the sensitivity of the NiCd batteries.

FUEL CELLS

Regenerative monolithic fuel cell systems seem to attractive for space application. The key qualities of this system is the simplicity of a solid state system and the minimal heat rejection requirements. The fuel cell is highly efficient in that there is no need for the heat rejection apparatus associated with other systems.

The fuel cells utilize hydrogen and oxygen to provide power. Reactants are stored as gas in tanks at elevated temperatures and pressures. The gases,hydrogen and oxygen, are combined into water and the heat produced is utilized to provide DC power. The products are stored after the temperature has been reduced.

The system is capable of a regenerative process. The cell proceeds in a reverse mode and the regenerative process is determined by the external power source. The gases are stored into the product tanks.

The system can operate at temperature of 1,000°C and additional heat injection may be required. The voltage and current output must be analyzed before this system. The overall efficiency of this system is projected to be 66% in the overall electrical round trip from electrolysis back to regeneration.

POWER REQUIREMENTS

The fuel cells and batteries are the energy sources to provide power for the motors, actuators, and electronic and computer systems. All power sources are ocated in the V-sections of the chassis and the connectors will run from this area to the power demand.

The torque required for rolling only is estimated to be 50 ft-lb per wheel. For a 20% grade, the per wheel torque demand is approximately 245 ft-lb. The maximum theoretical torque output is calculated to be 295 ft-lb per wheel. The horsepower per wheel is computed to be 0.664 hp for a flat surface and 3.93 hp for a 20% grade. Calculations show that the dump mechanism actuators must supply at least 0.0727 hp each.

CONTROLS

The on-board microcomputer controls all the functions of the vehicle. This microcomputer is teleoperated from a base station on earth and/or the lunar surface. This computer is located in the environmentally controlled compartment which is located just in front of the bowl.

The computer must control the amperage from the batteries and fuel cell supplied to the motors in each wheel, thus controlling the speed of the vehicle. The computer must also control the activation and coordinated control of the dump mechanism power screws for each bowl. The computer also activates and coordinates the action of the steering actuators and the wheel speed in order to turn the vehicle.

An extensive feedback control system will be required for the vehicle to operate correctly. Each aspect of the LMTV's operation must be continuously monitored for position and status. It may also be desired for the computer to operate and receive input from some type of navigation/control system. It is obvious that this vehicle will require a very powerful system. Due to the complexity of the system and the rapidly changing technology, a system specification is beyond the scope of this report.

HUMAN FACTORS - TELEOPERATION

An efficient interaction of humans and automation is necessary for maximum productive output in space. The factors that need to be analyzed are the role of humans in space, the man/machine interfaces, tools and procedures. Start-of-the-art, totally autonomous robotic systems will not be available in the near future. Remotely controlled systems utilizing human flexibility and adaptability are in use and are being developed to increase the capability of space operations.

The key element in the teleoperator process is the human operator. The human interaction utilizes the perceptive, cognitive and decision-making abilities and incorporates the natural human body and manual skills. The performance of these factors will determine the overall efficiency of the teleoperator process.

The efficiency issues are the time-constrained capabilities, perceptive and cognitive limits, and the endurance and information assimilation rate and capacity of the operator. The number of operators and the response time must also be analyzed. The components of the teleoperator system are the workstation, the interface unit, and the remote end effector and actuating systems.

CAMERAS

Definite perceptual limitations are inherent in a narrow field of view system. Depending of the orientation of the Line of Sight (LOS) and the video system relative to the longitudinal axis of the vehicle, a steep approach may cause the horizon to be lost from view. If the vehicle is pitched up, the runaway view may not be seen by the viewing system.

Variable Acuity Remote Viewing System (VARVS) was conceived as a technique of integration of the human eye acuity function. The human eye only requires 130,000 pixels for full support of vision. This factor is well within the capabilities of conventional video systems.

The technique of the VARVS incorporates a non-linear optical system for both the sensing and display equipment. A special lens is utilized and is translated from a uniform pixel array on its image plane into the object field as a variable angular array. This lens records the same angular detail the eye would view and compresses the detail into a uniform matrix of equal-sized picture elements on its image plane. Conventional transmission equipment can be used to send the image information to a remote location.

The projected image must be viewed by the observer's eye aligned with the projector optical axis to ensure high acuity and correct geometric perspective. This optical system has very unique properties and a series of psychophysiological studies on the interaction of human operators and remotely controlled vehicles must be performed.

COOLING/HEATING

The problem of controlling the temperature in the equipment housing is a very difficult one. It is evident that during the lunar day a means of dissipating heat must be incorporated into the design, and during the lunar night, some equipment may need to be heated to function properly. A possible solution to the cooling problem is that the equipment compartment be slightly pressurized with any non-reactive gas. This would allow convection within the compartment. A simple cooling system could then be installed in the compartment utilizing a heat exchanger mounted on the underside of the chassis in the shade. By using this approach, the equipment could be evenly cooled with a very simple system. This system would also incorporate thermal insulating and reflective blankets on the upper surfaces of the compartment.

During the lunar night, it may be necessary to allow the heat in the equipment housing to remain, or the heat generated by the fuel cell and computer system may still need to be dissipated. It is not possible at this point to determine this aspect.

The second aspect of cooling is for the motors. These motors will dissipate heat to the integral motor housing/heat sink and also to the entire wheel. This method will effectively block the heat flow from the motors to the chassis. All heat can be dissipated to the lunar soil and the wheels.

PRODUCTIVITY

The LMTV has been designed to operate at 10 mph. The design objectives call for an average 1 mile round trip (loading and dumping cycle).

The actual travel time per trip is approximately 6 minutes and a dump cycle takes approximately 1.5 minutes. If two additional minutes are allowed for any unforseen obstacles and turnaround or direction reversal procedures, a total round trip, excluding loading, can be accomplished in approximately 9.5 minutes. The capacity of the LMTV is estimated at 100 ft^3 of material weighing approximately 2000 lunar lbs. A loading rate has arbitrarily been assumed at 5 ft^3 of material per minute. Using this value the loading time would be 20 minutes. Therefore, the vehicle could carry out 2 complete cycles per hour, thereby transporting 200 ft^3 of material per hour.

CONCLUSIONS

The LMTV has been designed in an attempt to meet the needs of a lunar construction process as set forth in the problem statement. The vehicle must operate with high reliability under extreme conditions. The proposed vehicle will meet the design objectives and constraints, although due to the size of this project, future specialized development will be required. This project is meant to serve more as a concept study than a finalized designed study due to its wide scope and our relatively short allotted time period. The vehicle has been designed based around an experimental DC motor. The largest vehicle possible due to power considerations has been specified. The general layout consists of three parts. There are two identical chassis halves, each of which contains or supports a material carrying bucket, two individually powered wheels, a fuel cell, a battery storage system, a variety of electromechanical actuators, and a computer system. The third part of the system is the articulated steering mechanism. This component allows the vehicle to be steered by rotating the chassis halves relative to each other. It also allows the chassis half to roll independently. The LMTV will be monitored by the redundant computer systems and is capable of being remotely operated from the lunar surface, earth and manually from the vehicle itself.

RECOMMENDATIONS

The design of a vehicle such as the LMTV is very complex because each system must be evaluated on its own and with regard to the vehicle as a whole.

We feel that this project should be broken into smaller sections or more time allotted for the development of the project. Some major areas that could be further studied include:

1) REGENERATIVE BRAKING

A worthwhile method of incresing the LMTV power efficiency would be through the recovery of the kinetic energy during deceleration or of the potential energy created in the descent of an incline. The kinetic energy is recovered through the charging of an on-board storage unit and the load applied in the charging process will create a braking effect. The recovery of the energy will increase the efficiency of the vehicle. This form of energy recovery is referred to as regenerative braking and this process could be used for the braking mechanism on the LMTV.

Regenerative braking involves a storage device to hold energy received during braking until it is reused for propulsion. There must be a means of transmitting the energy between the wheels and the storage device and a means of controlling the degree of braking. Several methods of storage are available including: mechanical, hydropnematic, thermal, and electrochemical. The environmental constraints prohibit usage of the hydropnematic system and size limitations restrict usage of the thermal and electrochemical systems. A mechanical system could be utilized through a flywheel mechanism or through capacitance storage. These options are discussed in the conclusions.

The mechanical system allows substantial power levels of charging and discharging and the energy efficiencies can be high since no conversion of energy states is necessary. The useful life is many million deep discharge cycles. However, high quality and costly gear reduction systems may be necessary for the drives. The environmental constraints need to be analyzed before the storage system can be chosen.

Regenerative braking will greatly increase the efficiency of the total vehicle and will recoup some of the expended energy. The LMTV will operate in a straight line motion without frequent stops. The utilization of the braking system should be limited to the complete stop of the LMTV at the end of the haul process and to the deceleration of the vehicle at declines and at the upper limits of the speed range. The assessment of energy impact and recovery outweigh the cost and design factors of regenerative braking.

The regenerative braking could utilize the same electronic control elements for motoring and braking functions. The method of storage could be mechanical through a storage process and a battery system. By maintaining computer monitored control with available human interaction, the speed of the vehicle can be regulated from a small decrease in speed to a complete stop. Through proper control and design, the regenerative braking could increase the efficiency of the LMTV.

2) CHASSIS AND STEERING MECHANISM

It is recommended that an in depth study be made of the composite chassis including a thorough stress analysis and more research be done on the articulated steering joint. We also feel that the chassis could be made considerably smaller with a next generation design by better utilization of space available.

3) VEHICLE SIZE (SCALING)

An in depth study should be conducted to evaluate different sizes and speeds of the LMTV. This project has attempted only to set an upper limit on size based upon present motor technology.

4) SELF-RIGHTING

The problem of self-righting can be approached in many ways. It seems that one of the simplest and most eloquent solutions is that of an oval shaped roll over hoop. Using this method, if the vehicle were to overturm, it would have no choice but to roll back onto its wheels. An entire study could be conducted on self-righting possibilities.

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SAMPLE CALCULATIONS:

POWER → Given: Load/wheel ≃ 500 moon/lbs.

Coeff. rolling friction ≃ .05

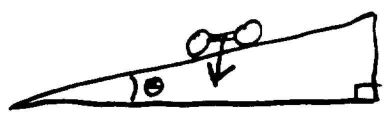
radius of wheel = 2 ft

Friction Force $P = L f_r = (500)(.05) = \underline{25 \text{ lbs}}$.

Torque to overcome Rolling Resistance $T = Pr = (25)(2) = 50 \frac{\text{ft}\cdot\text{lbs}}{\text{wheel}}$

FOR 20% GRADE

$\theta = 11.3099^\circ$



$F = W \sin\theta$
$= (2500) \sin\theta$
$= 490.3$ lbs total

$= 122.6$ lbs/wheel

Torque = Fr

Torque/wheel = 245 ft·lbs For Grade ONLY

Maximum Torque Required Per wheel: 245 ft·lbs (incline) + 50 ft·lbs (rolling) = 295 ft·lbs

$H.P. = \frac{TN}{5252}$

$T = 50$ ft·lbs (flat ground)
$= 295$ ft·lbs (20% grade)

Speed is 10 M.P.H. ∴ N = 70 rpm.

$\text{H.P.}/\text{wheel} = \frac{(50)(70)}{5252} = \underline{.666 \text{ hp.}}$ Flat Ground	$\text{H.P.}/\text{Wheel} = \frac{(295)(70)}{5252} = \underline{3.93 \text{ hp.}}$ 20% Grade Max.

Power For Dump Mechanism

$V = .05$ ft/sec

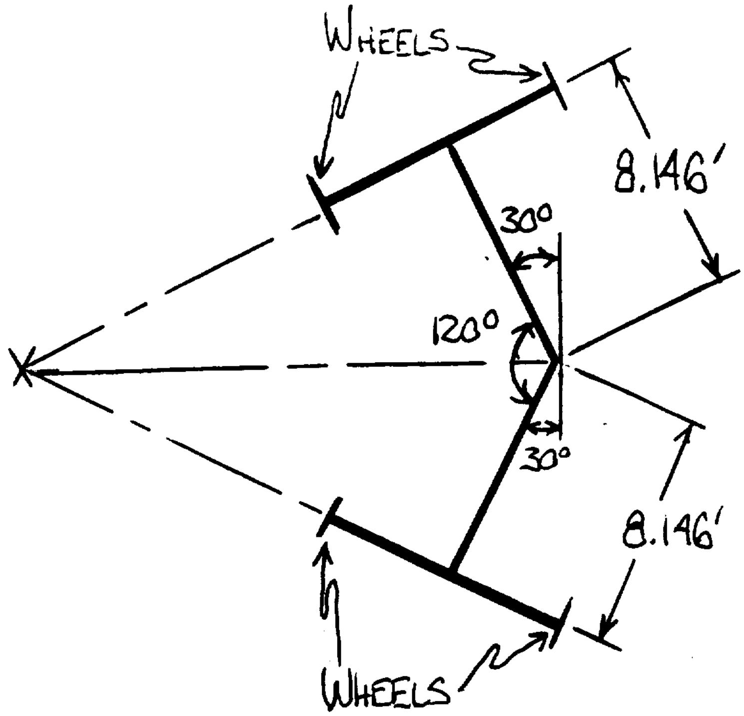
$L = 800$ lbs max.

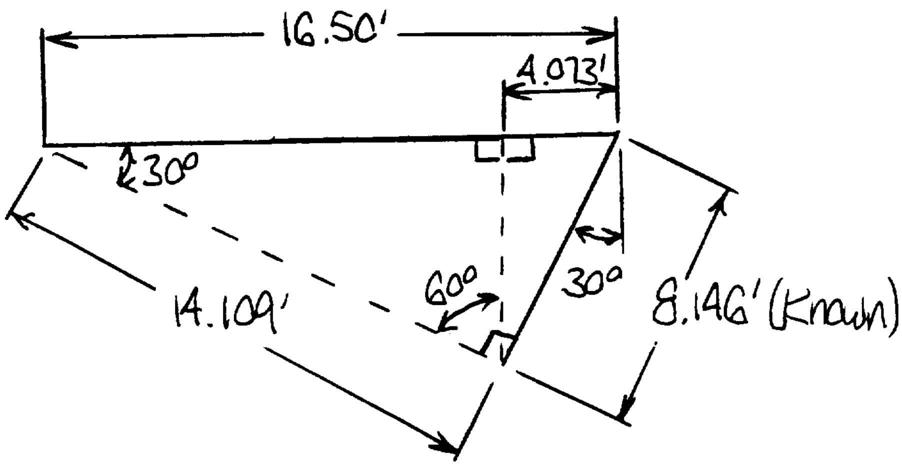
$$H.P. = \frac{L \cdot V}{550}$$

$$H.P._{(max)} = \frac{(800)(.05)}{550} = .0727 \text{ hp.}$$

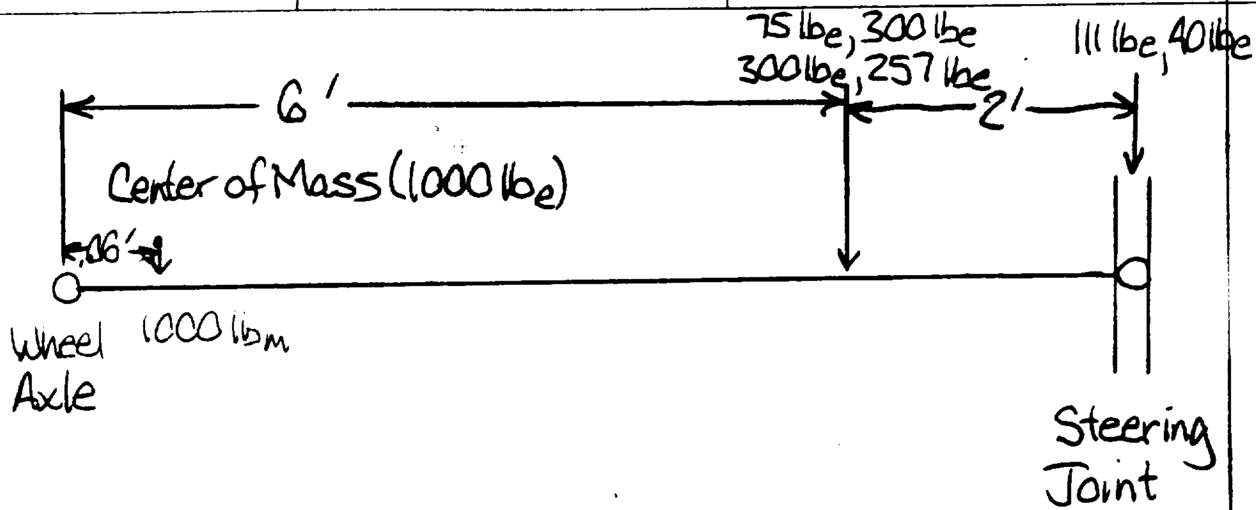
(2) Actuators together must supply at least this amount.

Turning Circle Calculation





The turning circle radius is 16.5' feet



In lunar weight:

$$(.06)(1000\,lb_m) + \frac{(930\,lb_e)(6\,ft)}{6\,lb_e/lb_m} + \frac{(150\,lb_e)(8\,ft)}{6\,lb_e/lb_f}$$

$= 148\,lb_m$ at joint

Weight Calculations

Chassis

Beams – Volume of composite material

@ 9' * 1.33' * .0283' = 1.355 ft^3

@ 9' * .6667' * .0283' = .6792 ft^3

@ 3.75' * 1.33' * .0283' = .2823 ft^3

@ 4.5216' * 1.33' * .0283' = .3404 ft^3

@ 3.75' * .6667' * .0283' = .1415 ft^3

(½)(.6667)(.385)(.0283) = .00726 ft^3

(½)(.6667)(.7698)(.0283) = .01452 ft^3

Total for ½ vehicle = 2.82017 ft^3

Total for whole = 5.64034 ft^3

density = 96.94 lb/ft^3

∴ Total weight of Chassis Frame (composite beams) = 546.78 lbs

---

Equipment Section

triangle 2 x 1.876 x 3.25 x .0283 = .34509 ft^3

rect. sect. 2 x 6.5 x 2 x .0283 = .73580 ft^3

back 6.5 x 1.333 x .0283 = .24526 ft^3

Total ~~for~~ = 2.6523 ft^3

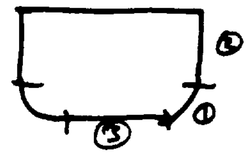
~~Total~~ =

Weight Equipment Housings = 257.11 lbs

Buckets

Pt 1 .54829 ft^3
Pt 2 .930026 ft^3
Pt 3 .232709 ft^3

1.711 ft^3/bowl



3.422050 ft^3 total

∴ 331.736 lbs for both bowls

Motors

2 plates @ 1/8" 1.5' radius - mild steel

$\pi r^2 t \rho = w$

71.7 lbs for two rotors

so estimate total

motor weight ≈ 150 lbs/motor

Steering Section

Plates Stainless Steel

Volume = .08333 ft^3 /Plate

$\rho = 467$ lbs/ft^3

$W_{Tot} = 77.833$ lbs for both Plates

2 Pins

1.5" dia = .125' High Carbon steel
18" long = 1.5' w/ poly coating for lube

$Vol = \frac{\pi D^2}{4} \ell = .0184077\ ft^3/pin$ $\rho = 487$ lbs/ft^3

$W_{Tot} = 17.93$ lbs for both pins

Roll axis bearing
Approx. 15 lbs

Total for joint
110.8 lbs

Chassis Connecting Plates

$\rho_{aluminum} = .0975 \text{ lb/in}^3 = 168.48 \text{ lb/ft}^3$

$24 @ 1' \times 1.5' \times \frac{1}{8}'' \; (.0104166') = .3749976 \text{ ft}^3$

$24 @ 1' \times .666' \times \frac{1}{8}'' \; (.0104166') = .166666 \text{ ft}^3$

$12 @ 1.5' \times 1.5' \times \frac{1}{8}'' \; (.0104166') = .2812482 \text{ ft}^3$

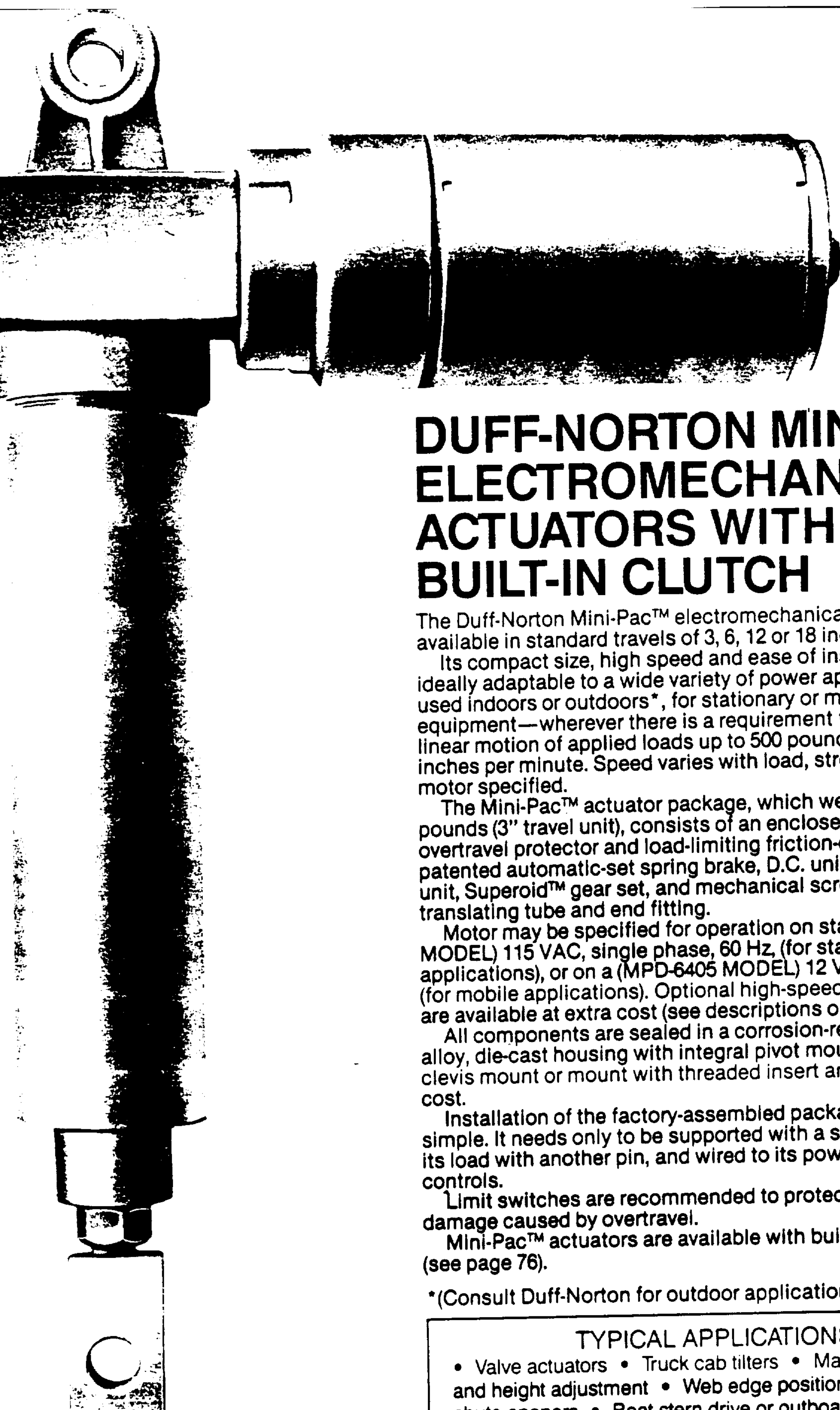
Vol = .8229124 ft³

$W_{Total} = 138.644 \text{ lbs}$
for connecting Plates

Weights

	(earth pounds)
Dump Mechanism actuators	~ 120 #
Steering actuators	~ 40 #
Chasis	~ 547 #
Bowls	~ 332 #
Equipment Housing	~ 257 #
Chasis connecting plates	~ 138 #
Steering joint	~ 111 #
Motors	~ 600 #
Wheels	~ 100 #
Batteries	~ 300 #
Fuel Cells	~ 300 #
Computer equipment	~ 75 #
Misc (fasteners, wire, stub axles, etc)	~ 100 #

Total 3020 lbs.
OR
503 moon lbs.



MPD-6405

DUFF-NORTON MINI-PAC™ ELECTROMECHANICAL ACTUATORS WITH BUILT-IN CLUTCH

The Duff-Norton Mini-Pac™ electromechanical actuator is available in standard travels of 3, 6, 12 or 18 inches.

Its compact size, high speed and ease of installation make it ideally adaptable to a wide variety of power applications. It can be used indoors or outdoors*, for stationary or mobile equipment—wherever there is a requirement for up to 18 inches of linear motion of applied loads up to 500 pounds at speeds to 145 inches per minute. Speed varies with load, stroke and type of motor specified.

The Mini-Pac™ actuator package, which weighs about eight pounds (3" travel unit), consists of an enclosed electric motor, an overtravel protector and load-limiting friction-disc clutch, a patented automatic-set spring brake, D.C. unit & ball brake A.C. unit, Superoid™ gear set, and mechanical screw and nut with steel translating tube and end fitting.

Motor may be specified for operation on standard (SPA-6405 MODEL) 115 VAC, single phase, 60 Hz, (for stationary applications), or on a (MPD-6405 MODEL) 12 VDC battery system (for mobile applications). Optional high-speed AC or DC motors are available at extra cost (see descriptions on page 75).

All components are sealed in a corrosion-resistant, aluminum alloy, die-cast housing with integral pivot mount. Optional 90° clevis mount or mount with threaded insert are available at extra cost.

Installation of the factory-assembled package is fast and simple. It needs only to be supported with a single pin, attached to its load with another pin, and wired to its power source and controls.

Limit switches are recommended to protect motor and prevent damage caused by overtravel.

Mini-Pac™ actuators are available with built-in limit switches (see page 76).

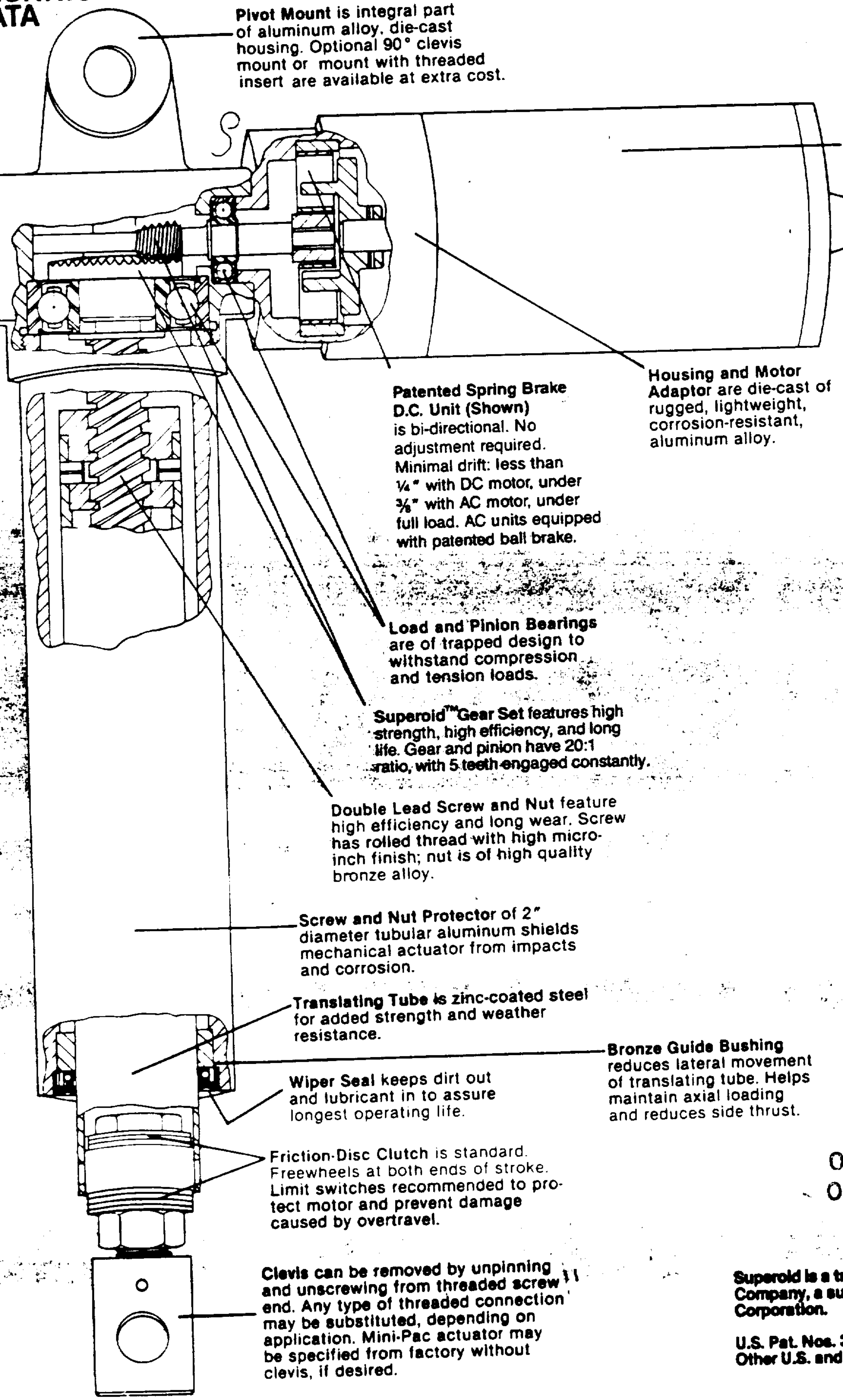
*(Consult Duff-Norton for outdoor applications)

TYPICAL APPLICATIONS

• Valve actuators • Truck cab tilters • Machinery leveling and height adjustment • Web edge positioning • Feed chute openers • Boat stern drive or outboard motor tilters • Hospital bed adjustment • Fixture positioning • Flue or damper actuation • Bus door operators • Spreader control • Farm implement adjustments • Medical examination table height adjustment • Dental chair inclining mechanism

UFF-NORTON MINI-PAC™ ELECTROMECHANICAL CTUATORS

CHNICAL ATA



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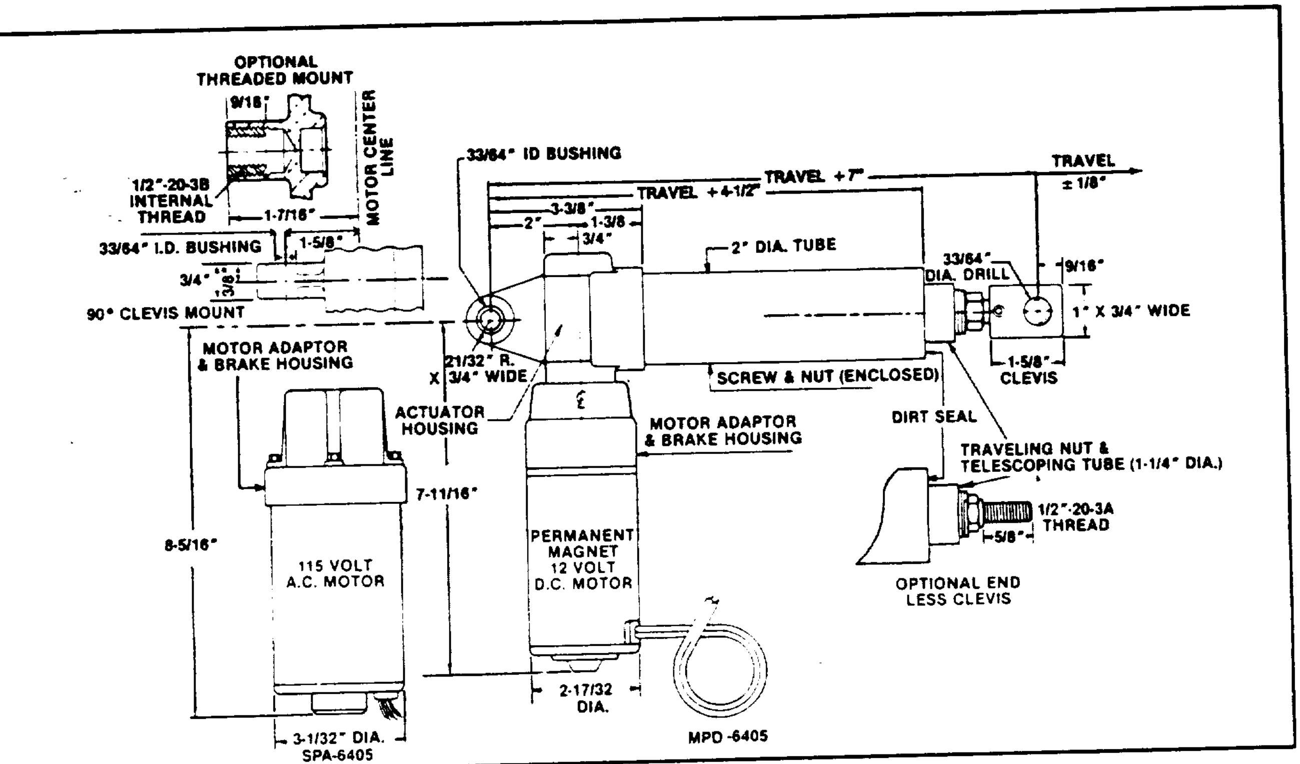
Superoid is a trademark of Duff-Norton Company, a subsidiary of Amstar Corporation.

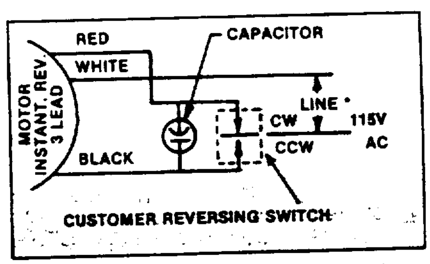
U.S. Pat. Nos. 3,559,499; 3,587,796; 3,704,765 Other U.S. and Foreign Patents applied for.



Note: Dimensions are subject to change without notice.

TH 115 V. 60 Hz AC MOTOR

...lied ...d ...s.)	Speed (in/min) Standard Motor (SPA-6405)	Speed (in/min) Optional High Speed Motor (HSPA-6405)	Amps Standard Motor	Amps Optional High Speed Motor
0	42	80	2.5	4.50
0	41	75	2.55	4.60
0	39	73	2.6	4.65
0	37	70	2.65	4.70
0	35	68	2.7	4.80



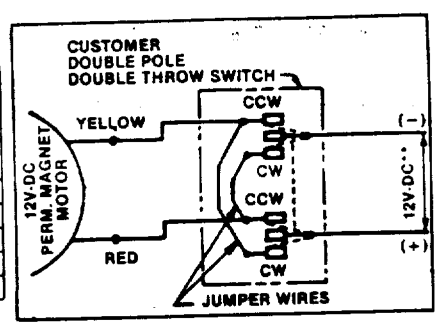
Minimum voltage 103.5
CW = Retract; CCW = Extend

Low Voltages reduce the Load Rating of the Actuator

115 VAC Motor is enclosed, permanent split capacitor induction type. Load/no-load speeds are approximately equal. Equipped with thermal overload which opens and resets automatically. Standard motor requires 28-33 mfd capacitor (supplied by customer, or by Duff-Norton at additional cost) for loads up to 500 pounds. A capacitor box is available on AC models only, to provide an enclosure for electrical connections and to give a convenient conduit installation.

TH 12 V. DC MOTOR

...lied ...ad ...bs.)	Speed (in/min) Standard Motor (MPD-6405)	Speed (in/min) Optional High Speed Motor (HMPD-6405)	Amps Standard Motor	Amps Optional High Speed Motor
00	68	145	6	21
00	60	132	10	28
00	52	120	13	36
00	42	—	17	—
00	32	—	22	—



*22 amps running; 30 amps stall
CW = Retract; CCW = Extend

12 VDC Motor is totally enclosed, weather-resistant, permanent magnet type. Magnets act as secondary brake for added safety. Smaller, more efficient, cooler running, with higher duty cycle than series-wound designs. Lower current draw for longer battery life. Equipped with thermal overload that opens and resets automatically. Rotation reversible by reversing two color-coded leads; torque equal in both directions. A high-speed DC motor is available at extra cost.

TY CYCLE CHART

...pplied ...oad ...Lbs.)	#Duty Cycle (Inches Per Hour) AC Motor Standard 28-33 mfd Capacitor	AC Motor High Speed 64-77 mfd Capacitor	DC Motor Standard DC Motor	DC Motor High Speed DC Motor
100	560	490	2800	1350
200	540	485	1750	1000
300	520	470	1050	700
400	500	465	650	—
500	480	450	380	—

...l inches travel (up and down) per hour with equally timed intervals ...ween cycles.

NOTE: Some actuator external surface temperatures may reach 230°F during use at or near maximum duty cycle. All ratings are nominal and are based on actuator being broken-in for approximately 2500 inches of travel.

NOTE: The data listed is from our test results. Your data may differ.

The thermal overload relay resets in 10 sec. for std. DC motor; 4 min. for high speed motor; 10 min. for AC motors (both standard and high speed).
Duty chart based on 75° ambient temperatures.

NOTE: The new SPA Series Mini-Pac™ actuators (AC models without limit switches) supersede the previous MPA Series equivalent models. The SPA actuators incorporate major internal advancements, principally in the brake design, while the external dimensions remain unchanged. SPA Series models will serve as direct field replacements for MPA Series actuators.

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UFF-NORTON SUPER-PAC™ LECTROMECHANICAL ACTUATORS

Duff-Norton Super-Pac™ electromechanical actuator is able in standard travels of 3, 6, 12, 18 and 24 inches. compact size, light weight, high speed and ease of llation make it especially adaptable to a variety of ications requiring the movement or positioning of heavier s. Models are available for stationary or mobile pment—wherever there is a requirement for linear motion of ied loads up to 1500 pounds, at speeds to 50 inches per ite.

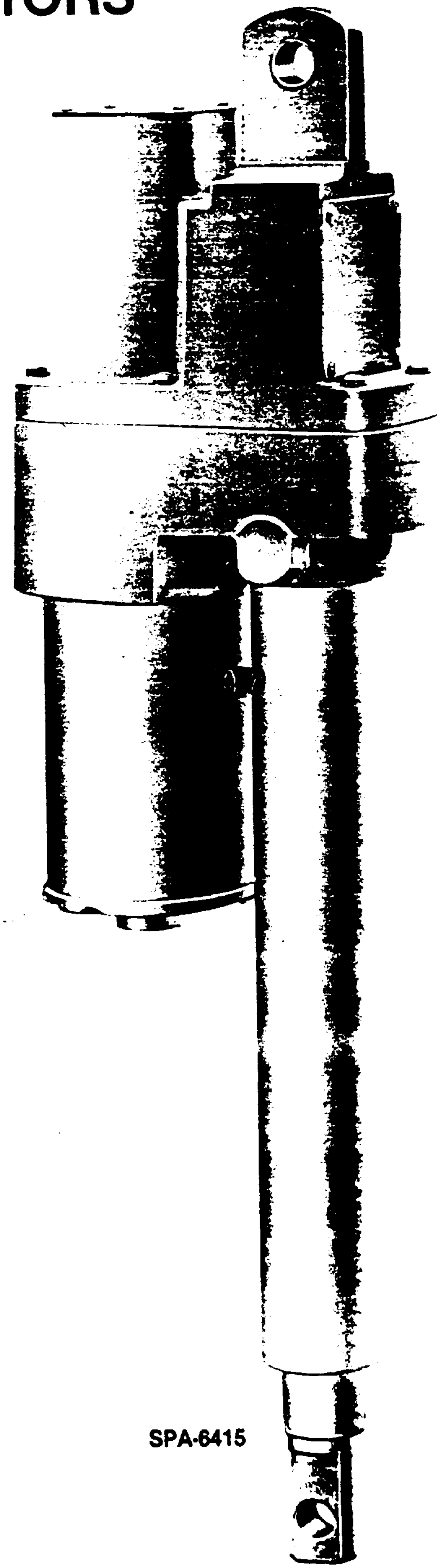
beed will vary with the load and the type of motor specified. or may be specified for operation on standard 115 VAC, single se, 60 Hz (for stationary applications), or on a 12 VDC system nobile applications).

ne standard AC unit has built-in adjustable limit switches to rol the stroke. The limit switches can be set to stop the motion e lifting screw at any point required by the application. The age weighs only 25 pounds, including motor. (For 3" travel

ne standard DC unit has a built-in friction-disc clutch. ne built-in friction-disc clutch can be set externally to slip at desired capacity, thereby protecting the actuator and your pment from excessive shock loads. However, limit switches ecommended to protect the motor.

oth AC and DC Super-Pac actuators have an automatic-set ng brake, Evoloid* gear set and mechanical screw and nut steel translating tube. All components are sealed in a osion-resistant, cast aluminum alloy housing. The unit comes ou complete—ready to be installed. Optional trunnion mount ailable at extra cost. **An optional weather-resistant treatment ailable for outdoor applications.**

o install, just support with one pin, attach the load with ther pin and wire the package to its power source and controls. remote screw position indicating system is available onal, extra cost) in case the actuator is operated from a ote location, such as from another building or from a central rol console.



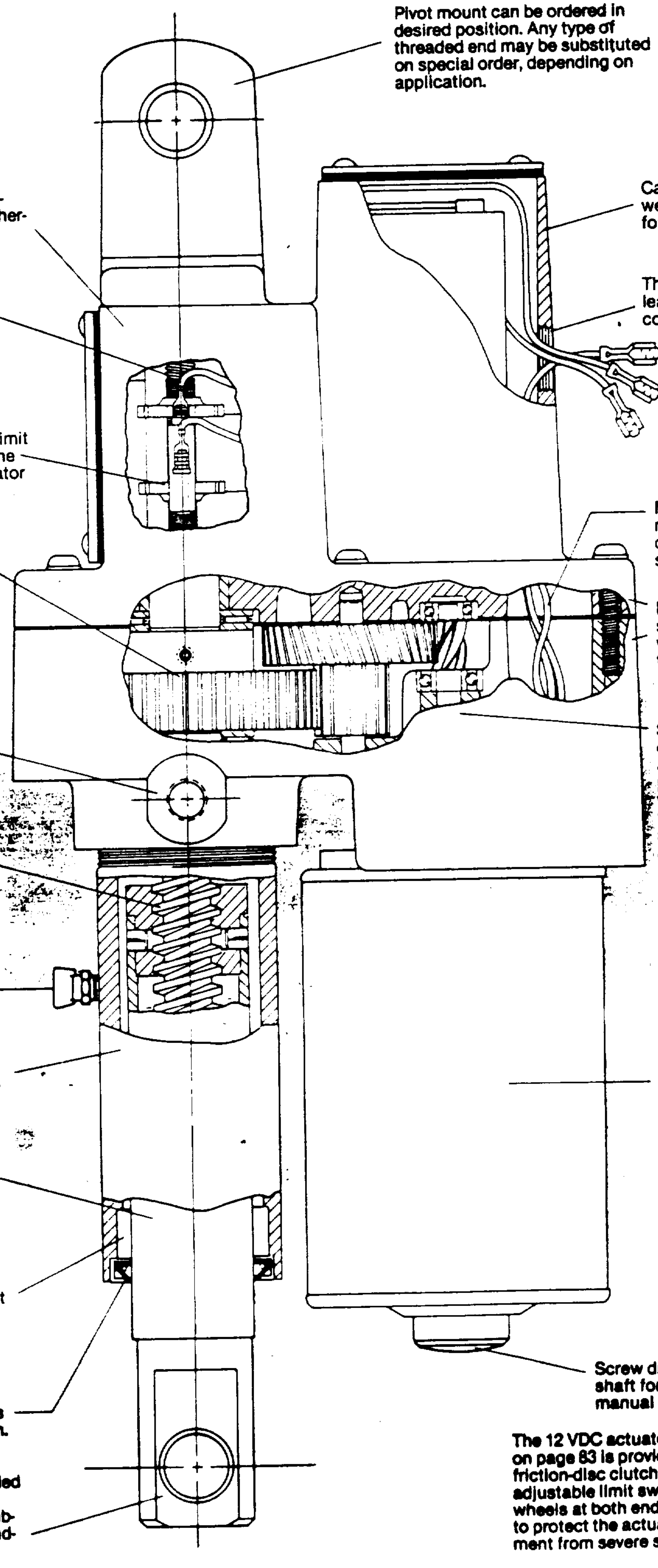
SPA-6415

TYPICAL APPLICATIONS

• Valve actuators • Farm implement adjustments
• Heating/air conditioning flue and damper actuators
• Fixture positioning • Door openers for laundry extractors, urnaces, incinerators, freezers • Conveyor height adjust- ment • Solar collector positioning • Printing press roll adjustment • Feed chute openers • Idler wheel position- ng for belt-tension

ublished trademark of Quaker City Gear Company, Incorporated

HNICAL DATA



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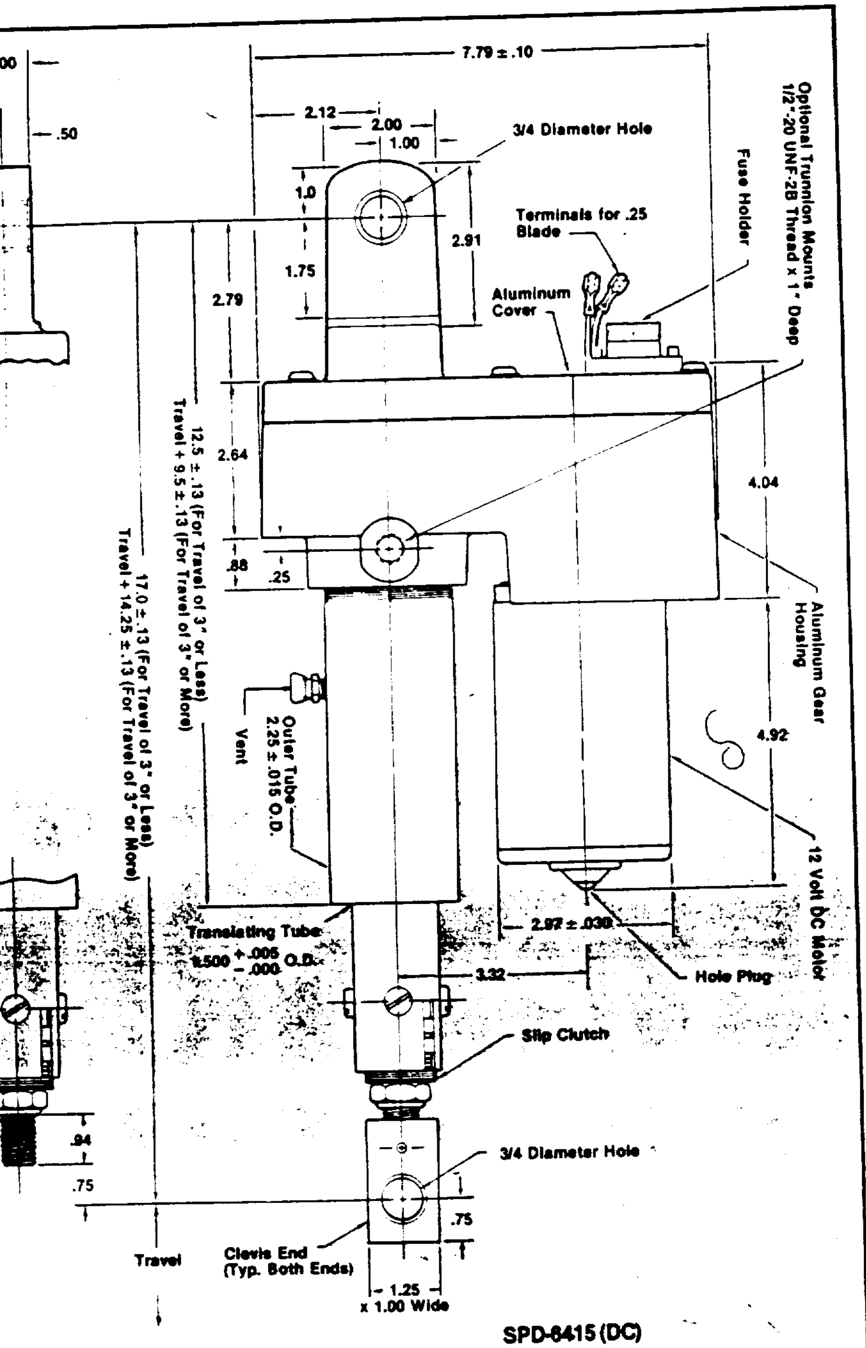
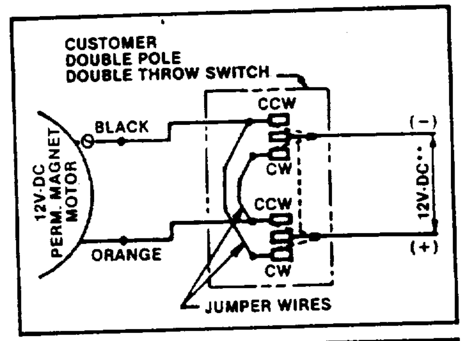
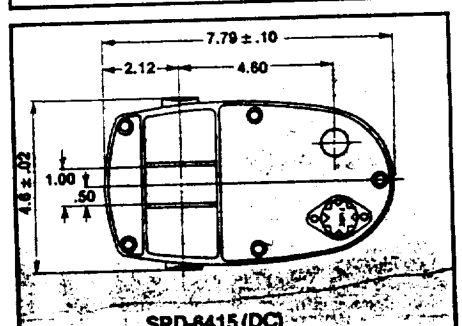
The 12 VDC actuator as shown on page 83 is provided with a friction-disc clutch in place of adjustable limit switches. It free-wheels at both ends of the stroke to protect the actuator and equipment from severe shock loads.



12 VDC Motor is totally enclosed, weather-resistant, permanent magnet type. Magnets act as secondary brake for added safety. Smaller, more efficient, cooler running, with higher duty cycle than series-wound designs. Lower current draw for longer battery life. Rotation reversible by reversing two color-coded leads; torque equal in both directions.





WARNING:
1. Severe overload will cause actuator clutch to slip and allow the load to self lower.
2. Maximum allowable bending moment on 5/8" threaded shank under normal operating conditions is 300 inch-pounds.
3. Position hooded vent to prevent moisture and dirt from entering actuator (see instruction and maintenance sheet).
4. Some actuator external surface temperatures may reach 230°F during use at or near maximum allowable duty cycle.
5. Duty cycle and continuous duty ratings of the actuator should not be exceeded. To do so could cause damage to the motor thus voiding any warranty on the motor. See instruction and maintenance sheet for these ratings.
6. For fuse replacement use only Littlefuse Part No. 511025 (5 ag, 32 volt, 25 amp) medium acting fuses.
7. Do not place foreign objects in the fuse holder or use fuses not recommended by Duff-Norton Co.

WITH 12 V. DC MOTOR

Applied Load (lbs.)	Speed (in/min)	Amps	#Duty Cycle (in/hr)
500	36	15	1500
1000	31	21	750
1500	26	27	280

#Total inches of travel (up and down) per hour with equally timed intervals between cycles.

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E: Both duty charts are based on 75°F ambient tempera-
All ratings are nominal and are based on actuator being
n-in for approximately 2500 inches of travel.
The data listed is from our test results. Your data may differ.

Note: Dimensions are subject to change without notice.

PROGRESS REPORT

WEEK 1-------------LUNAR DUMP TRUCK

ME 4182

Charlie Fisher

Cass Whitehead

Allen Wilkens

This week we had our first group meeting and received the initial information about our project. We will be developing one possible design for a lunar dump truck. This first week was devoted purely to organization and initial background research. The following items have been addressed.

1. We have reviewed the report submitted by last quarters group and discussed some rough ideas.

2. We have set up two group meetings per week, one on Mondays at 3:00 and one on Thursdays at 3:00.

3. We have made an initial attempt to locate available information which may be of use on this project.

4. Plans for next week include assigning specific areas of research for team members and defining the constraints exactly for the entire project.

Progress Report

Week 2

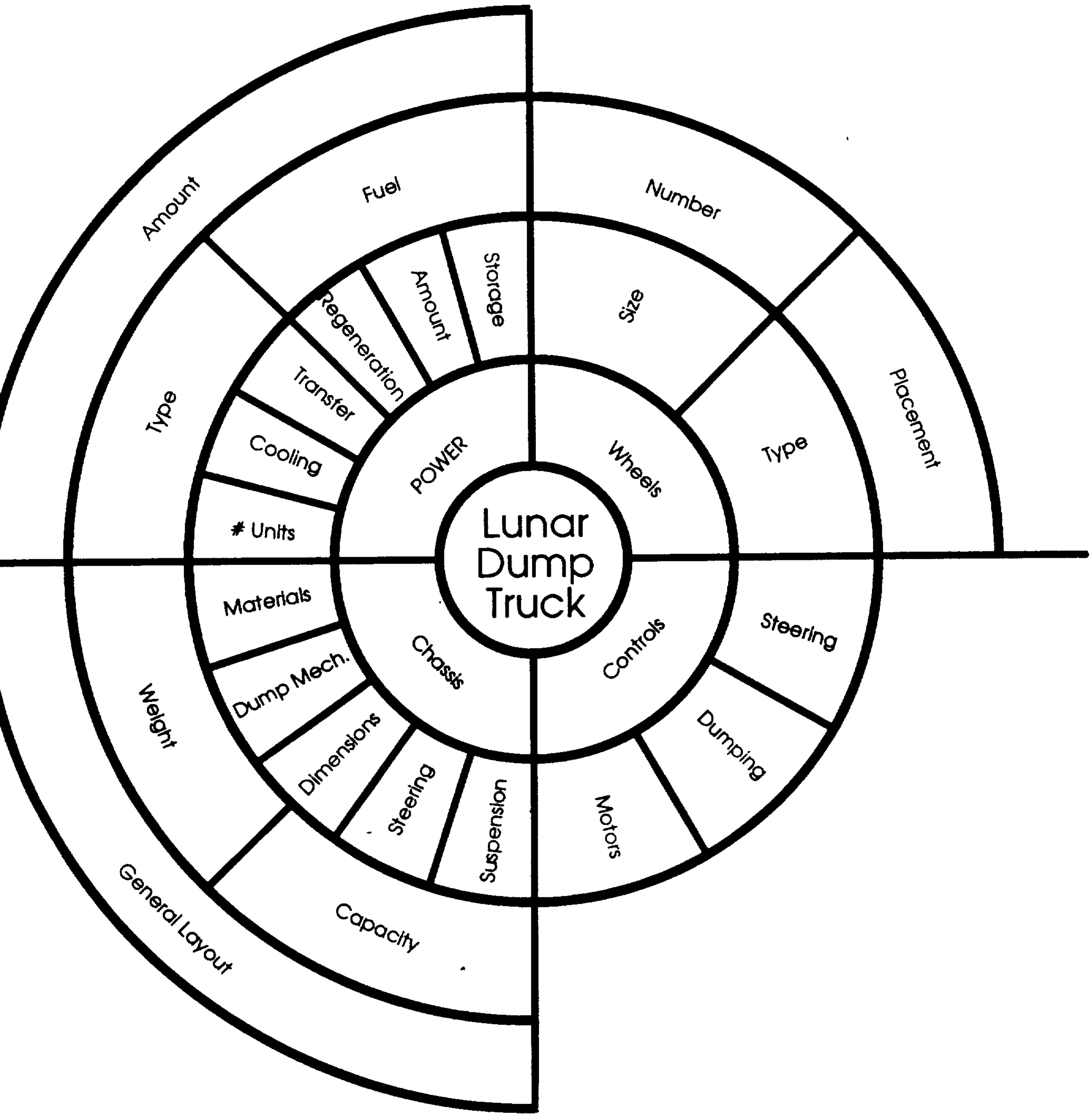
Charlie Fisher
Doug Lyons
Harry Whitehead
Allen Wilkins

January 20, 1987

We have identified a large number of reports of significance to our project. A considerable amount of time will be devoted to the study of these reports and noting problems incurred along with technology developed.

We have divided our project and research into four basic areas: Power, Wheels, Controls, and Chassis. These areas were then broken down into more specific areas as shown in our organization wheel. This wheel will serve to organize our research and pinpoint areas needing further investigation

Our plans for the upcoming week include a series of brainstorming sessions in order to solidify the basic concept for the project design. At this time the group will assign specific areas of concentration for each team member..



Lunar Dump Truck
POWER
Storage
Amount
Regeneration
Transfer
Cooling
Units
Fuel
Type
Amount
Wheels
Size
Type
Number
Placement
Controls
Steering
Dumping
Motors
Chassis
Materials
Dump Mech.
Dimensions
Steering
Suspension
Weight
Capacity
General Layout

Progress Report

Week 3 ---------Lunar Material Transport Vehicle

Charlie Fisher
Doug Lyons
Harry Whitehead
Allen Wilkins

January 27, 1987

This week the group concentrated mainly on formulating a concise problem statement consisting of a set of performance objectives and a set of system constraints. A copy of this problem statement is attached. In addition, the following items were acted upon as indicated.

- The reports identified last week are not available in the GT library and must be ordered from NASA.

- The management of the four basic areas to be developed has been divided as follows.
  - Wheels & Chassis -- Cass and Allen
  - Power -- Charlie
  - Controls -- Doug

- Several brainstorming sessions were held this week. This has resulted in a solidification of the general layout for the vehicle as shown on the attached graphic.

- Measurements were made to the scale model from last quarter in order to specify the dimensional relationship between the wheels and buckets.

- During the brainstorming sessions some rough calculations were done to evaluate the power needed to drive the vehicle. We have determined that somewhere between 1000 and 2000 ft.-lbs. of torque will be required per wheel in order to climb a 20 degree incline. We have made several attempts to contact Dr. Davey in order to discuss future power predictions for his motors.

- Charlie is currently in the process of gathering power information from truck manufacturers to see if any power to capacity relationship can be made.

- We have decided that it may be beneficial if all or several members of our group could visit the Huntsville center in order to study the lunar rover which is on display there.

LUNAR BULK MATERIAL TRANSPORTER

PROBLEM STATEMENT

With the possibility of colonizing the lunar surface, a definite need would exist for the transport of lunar soil and other bulk materials. A suitable vehicle must be designed, within the following objectives and constraints, for this purpose.

OBJECTIVES

PERFORMANCE

SLOPE
The loaded vehicle should be able to perform on a 20% grade.

SPEED
The loaded vehicle should be able to operate in a range of 5 to 15 mph.

TRACTION
The vehicle should be designed in order to provide sufficient traction on the lunar surface.

SELF-RIDING
The vehicle must be able to maneuver itself out of all possible situations.

SPECIFICATIONS

GENERAL
The vehicle must be as mechanically simple as possible in order to ensure maximum reliability.

LOW HORSEPOWER
The loaded vehicle must be able to operate on 5 - 15 hp.

LOW CENTER OF GRAVITY
Due to the 1/6 gravity force on the lunar surface, the center of gravity must be as low as possible to prevent easy overturning.

GROSS WEIGHT
The gross weight must be kept to a minimum due to the extreme high shipping cost.

CONTROL
The operation of the vehicle should be controllable from the following: a local controller, an earth based controller, and from the vehicle itself.

SIZE
The following factors will be considered in the determination of the vehicle size: turning radius, wheel size, bucket capacity, and overall dimensions.

BRAKING

It is desirable to engage a regenerative braking system.

CONSTRAINTS

GENERAL

BODY

The vehicle must operate on four wheels with two bodies and two buckets.

BODY PROPORTIONS

The proportion and shape of the wheels to the buckets must be constant, as it is desirable to have interchangeable parts with other proposed lunar devices.

OPERATIONAL

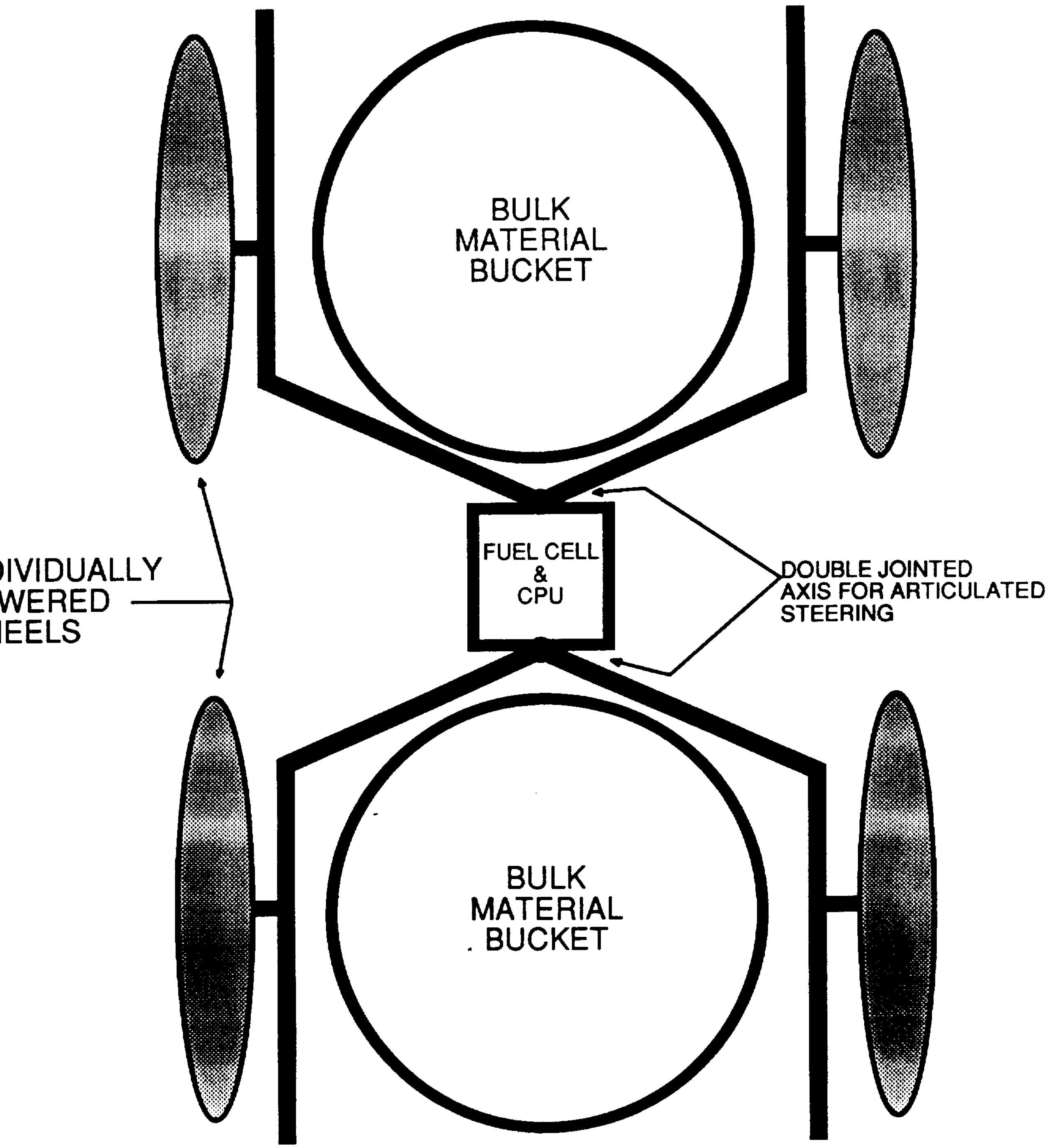
The operating range of the vehicle is limited to line-of-sight due to the transmission characteristics of radio equipment operating in a vacuum.

The vehicle must be able to withstand extreme temperature differences (-120°F to +120°F).

The vehicle must be able to operate in a vacuum.

The vehicle must reliably operate in the highly abrasive lunar environment.

LUNAR MATERIAL TRANSPORT VEHICLE



INITIAL DESIGN CONCEPT

Progress Report

Week 4 ---------Lunar Material Transport Vehicle

Charlie Fisher
Doug Lyons
Harry Whitehead
Allen Wilkins

February 3, 1987

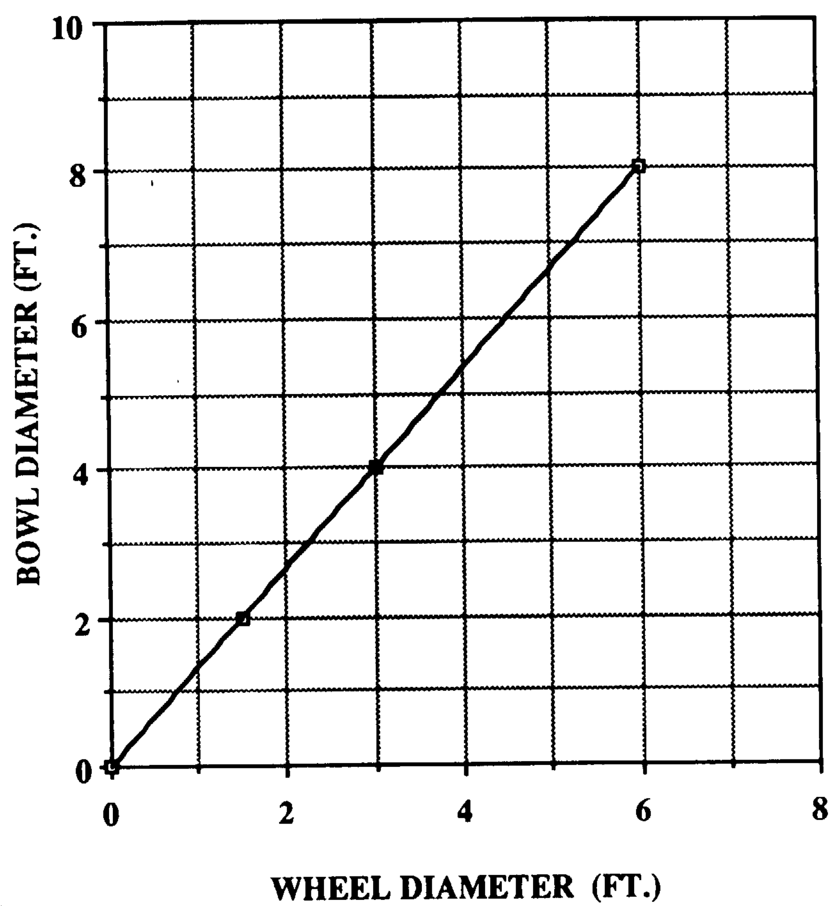
This week the calculations were begun in order to determine the realistic size envelope for the LMTV. Simplified calculations were performed and the attached graphs show their results. The group has set up a meeting with Dr. Davey from the EE department for Friday February 5 at 4:00 p.m. At this time we will discuss the realistic possibilities for his motors.

This week we have also gathered some information on the lunar soil characteristics and mechanics. This information was required on order to determine the load capacities etc.

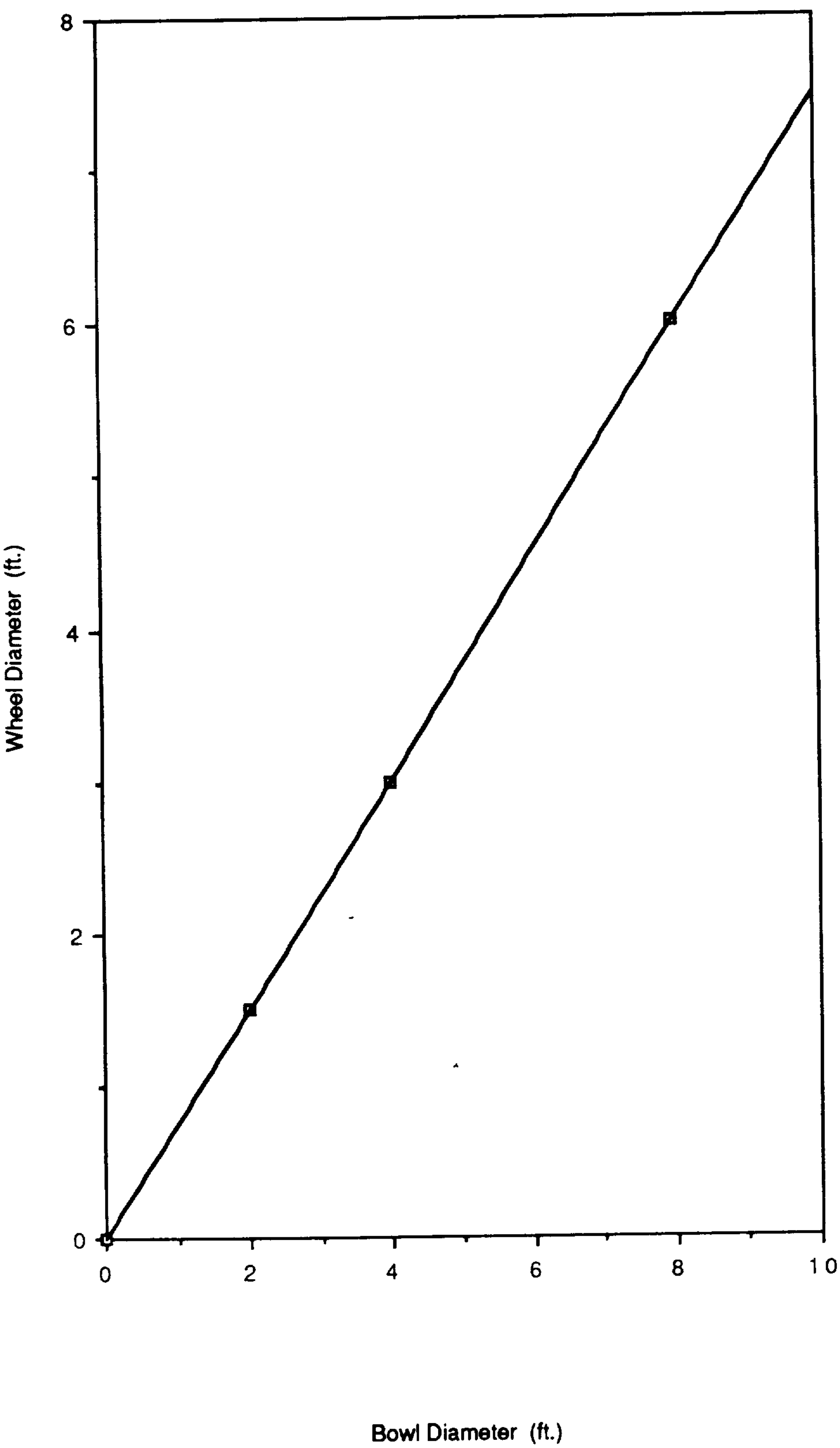
As a result of our meeting last week we now have a more realistic idea of the general size that the vehicle should be. We have therefore redefined our constraints somewhat in order to reflect these changes.

Following our meeting on Friday we hope to be able to define the maximum size vehicle possible. From that point we can scale down in order to achieve any desired possible size. This will enable us to optimize the vehicle size for a given application. For example, the capacity will depend on the length of the trip that the vehicle will be needed for. We hope that for next weeks presentation we will have a well defined vehicle.

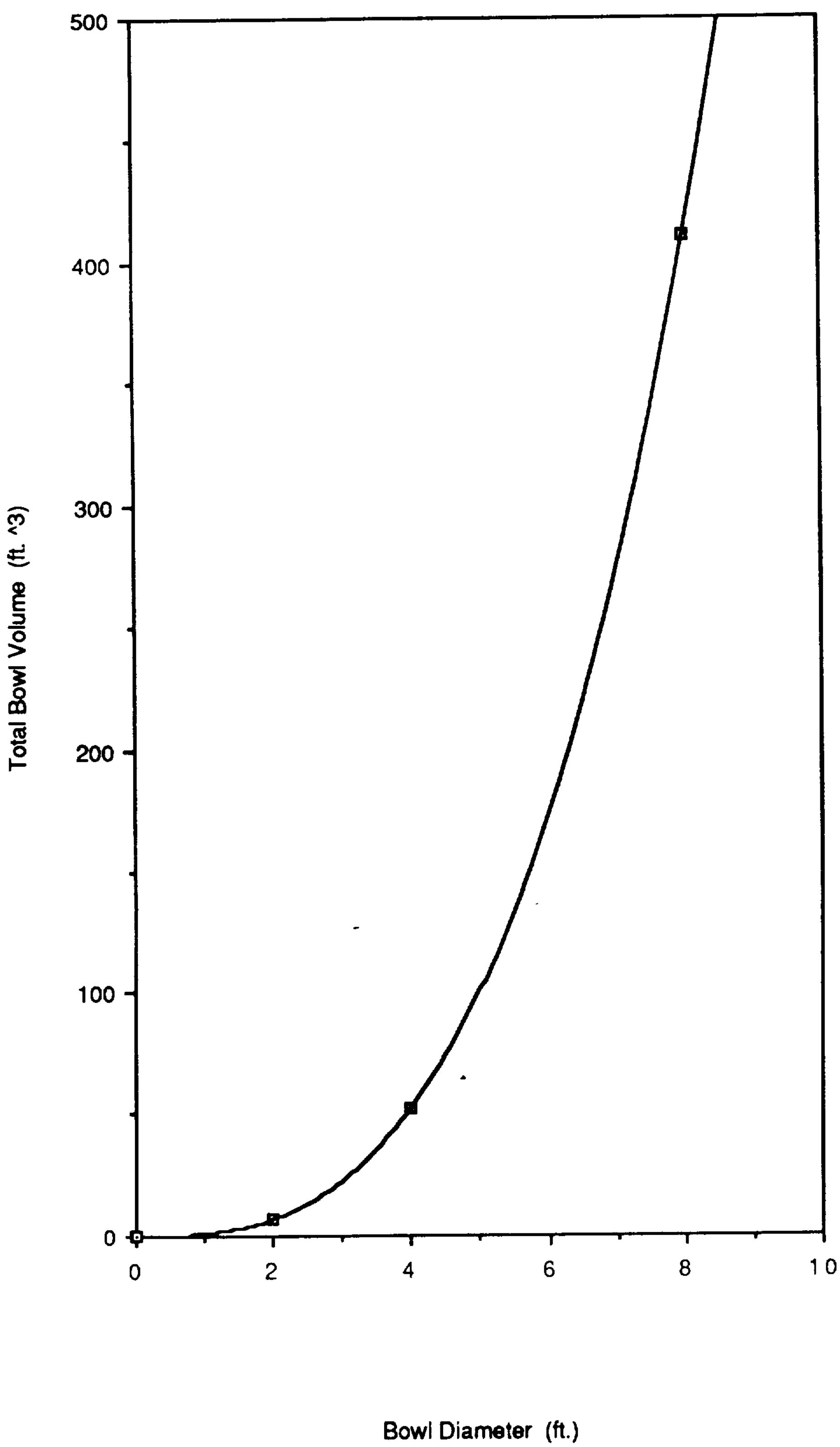
WHEEL DIAMETER VS. BOWL DIAMETER



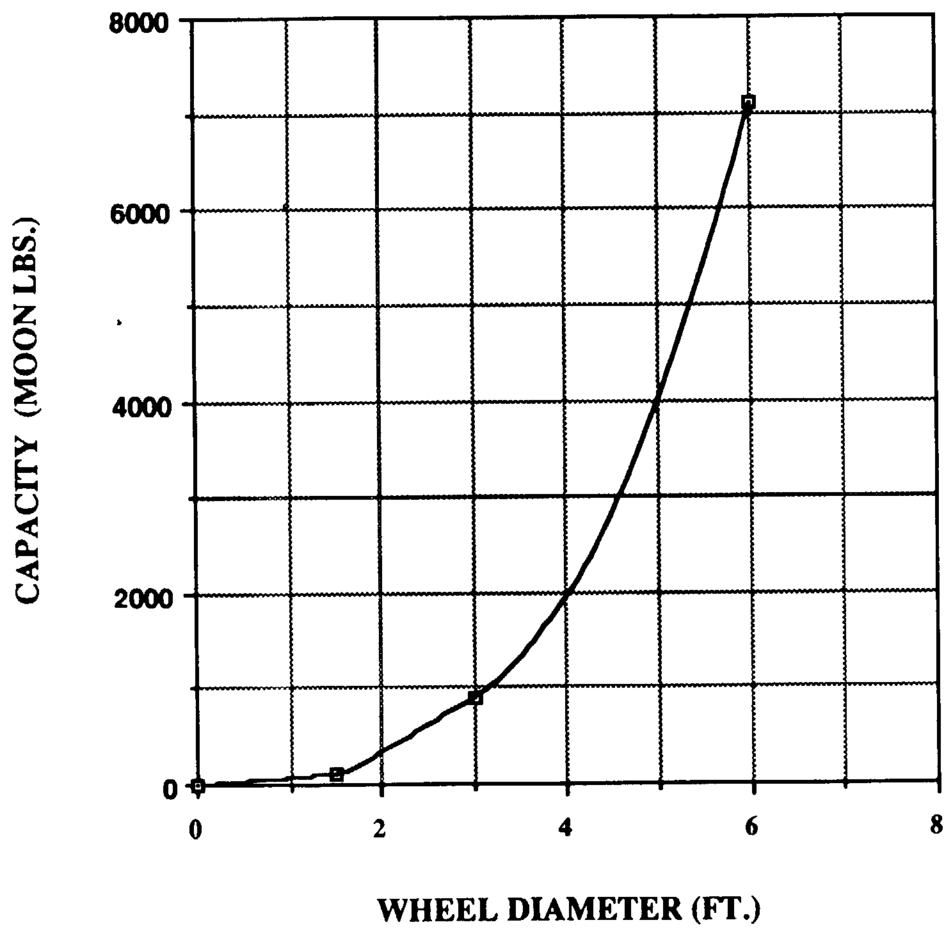
Bowl Diameter VS. Wheel Diameter for LMTV



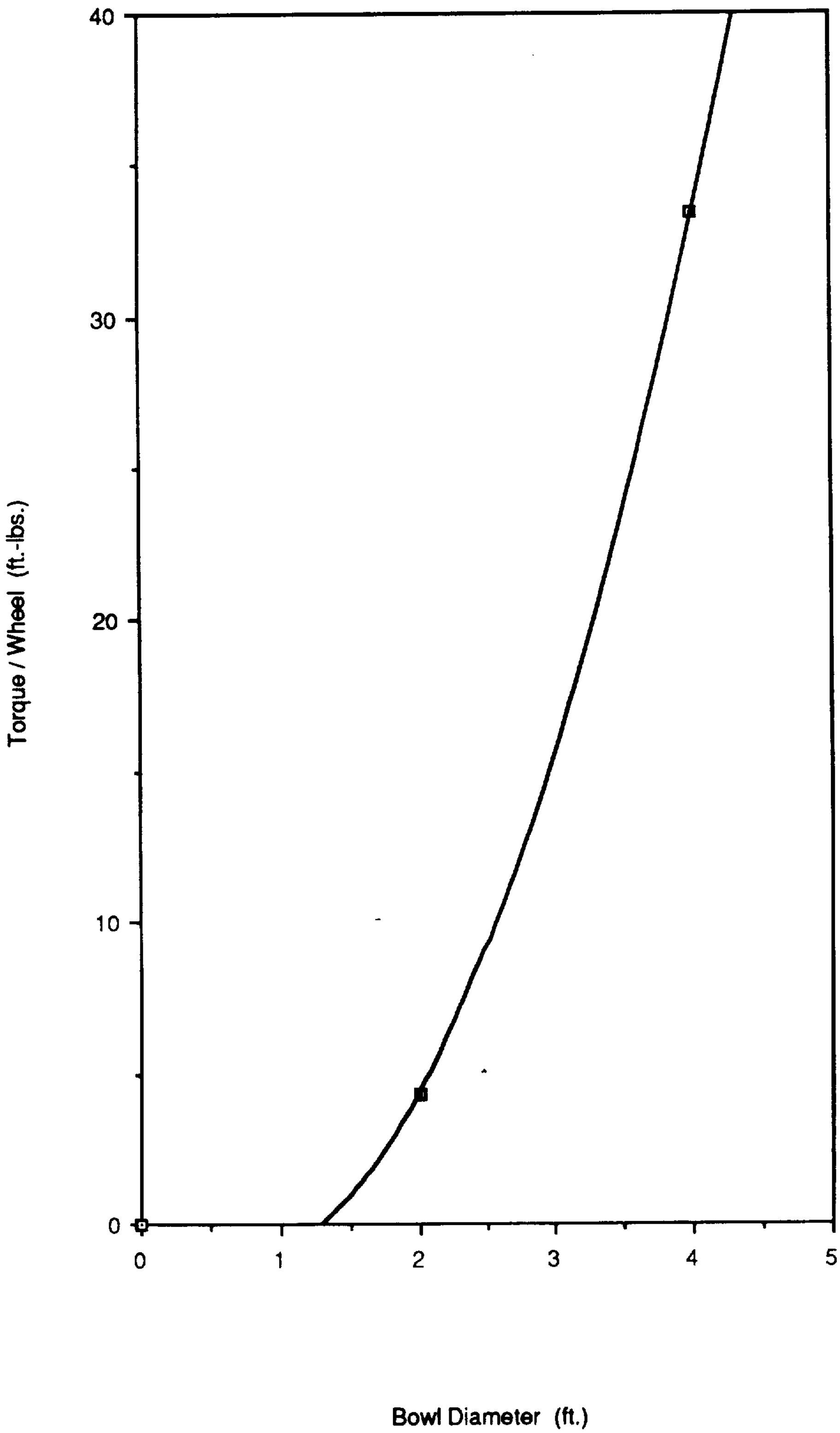
Bowl Diameter VS. Total Volume for LMTV



WHEEL DIAMETER VS. CAPACITY



Bowl Diameter VS. Torque / Wheel for LMTV



Progress Report

Week 5 ---------Lunar Material Transport Vehicle

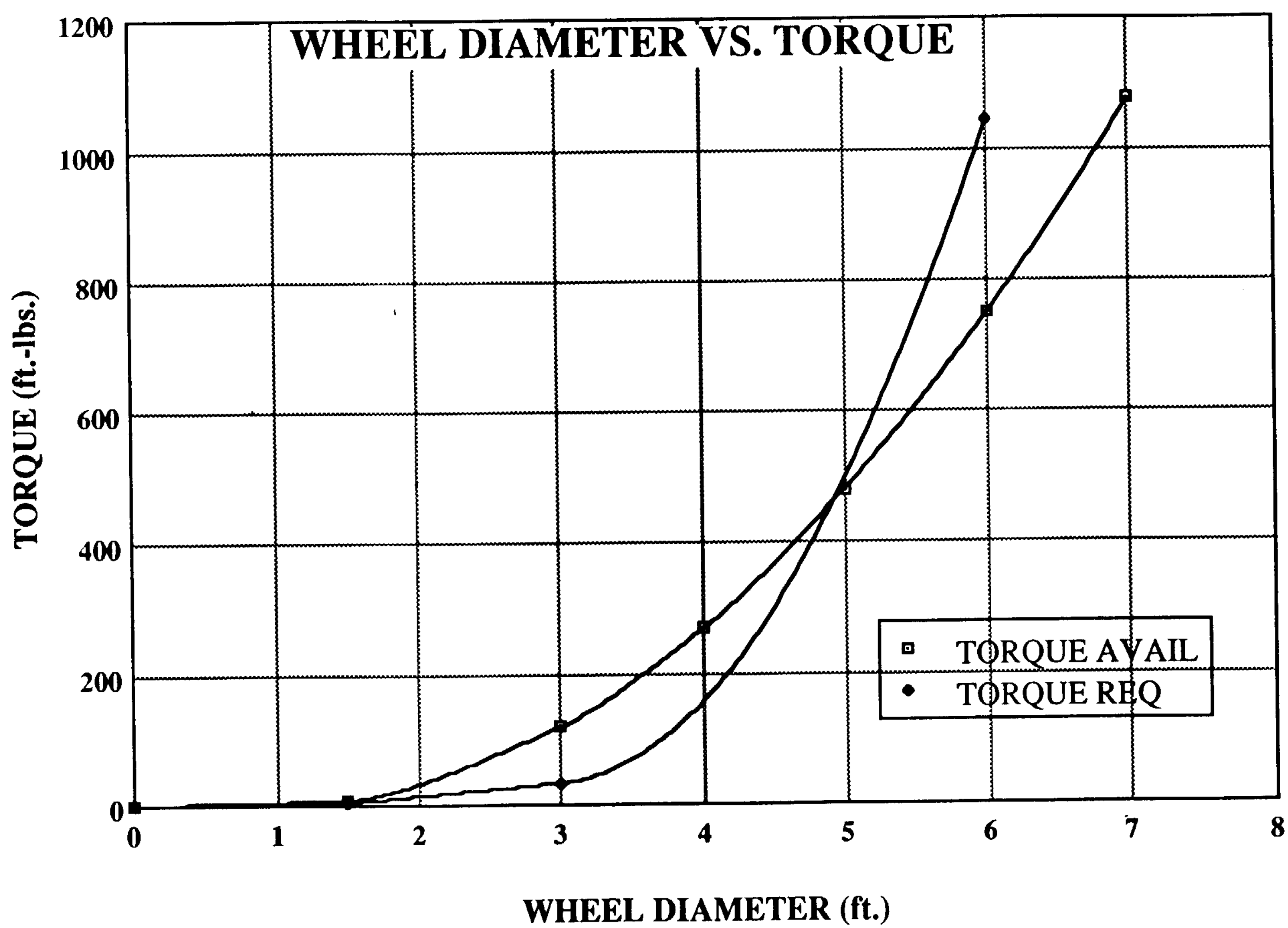
Charlie Fisher
Doug Lyons
Harry Whitehead
Allen Wilkins

February 10, 1987

This week our group met with Dr. Davey to discuss the curvilinear synchronous motors. We discussed scaling and size parameters for the motors. This has enabled us to generate graphs showing motor performance versus motor size. By comparing this information with the power required information we have narrowed our vehicle size to a specific range as shown on our graphs.

Also this past week we have begun gathering information on fuel cells. We hope to define the power requirements during the upcoming week. After this has been done we should be able to specify a particular fuel cell setup.

We have begun a material study for the vehicle chassis. We have contacted a graduate student who is involved in material science specializing in composites. In the coming week we hope to narrow the possibilities to only a few very good alternatives.


WHEEL DIAMETER VS. TORQUE
TORQUE (ft.-lbs.)
1200
1000
800
600
400
200
0
0
1
2
3
4
5
6
7
8
WHEEL DIAMETER (ft.)
TORQUE AVAIL
TORQUE REQ

Progress Report

Week 6 ---------Lunar Material Transport Vehicle

Charlie Fisher
Doug Lyons
Harry Whitehead
Allen Wilkins

February 17, 1988

This week we continued to look for information concerning fuel cells. We looked at several technical papers in the Intersociety Energy Conversion Engineering Conference (1984,1986) publications. Several systems were analyzed and the H/O regenerative fuel cell system seems to be the most suitable for our application. However, this system presents some difficulties (i.e. temperature and efficiency relationships) which will require further study.

A study is being performed concerning bowl rotation geometries in order to determine ground clearance at various pivot points. This study will aid in the determination of dump mechanism requirements, center of gravity calculations, limits for ground clearance, and rate of material dump.

We are also continuing our search and analysis of composite structure design. The arrival of NASA reports concerning the lunar rover and wheel design is anticipated, so that more information can be gathered in these areas. In the upcoming week, we expect to identify and analyze types and geometries of various dump mechanisms.

Progress Report

Week 7 --------Lunar Material Transport Vehicle

Charlie Fisher
Doug Lyons
Harry Whitehead
Allen Wilkins

February 24, 1988

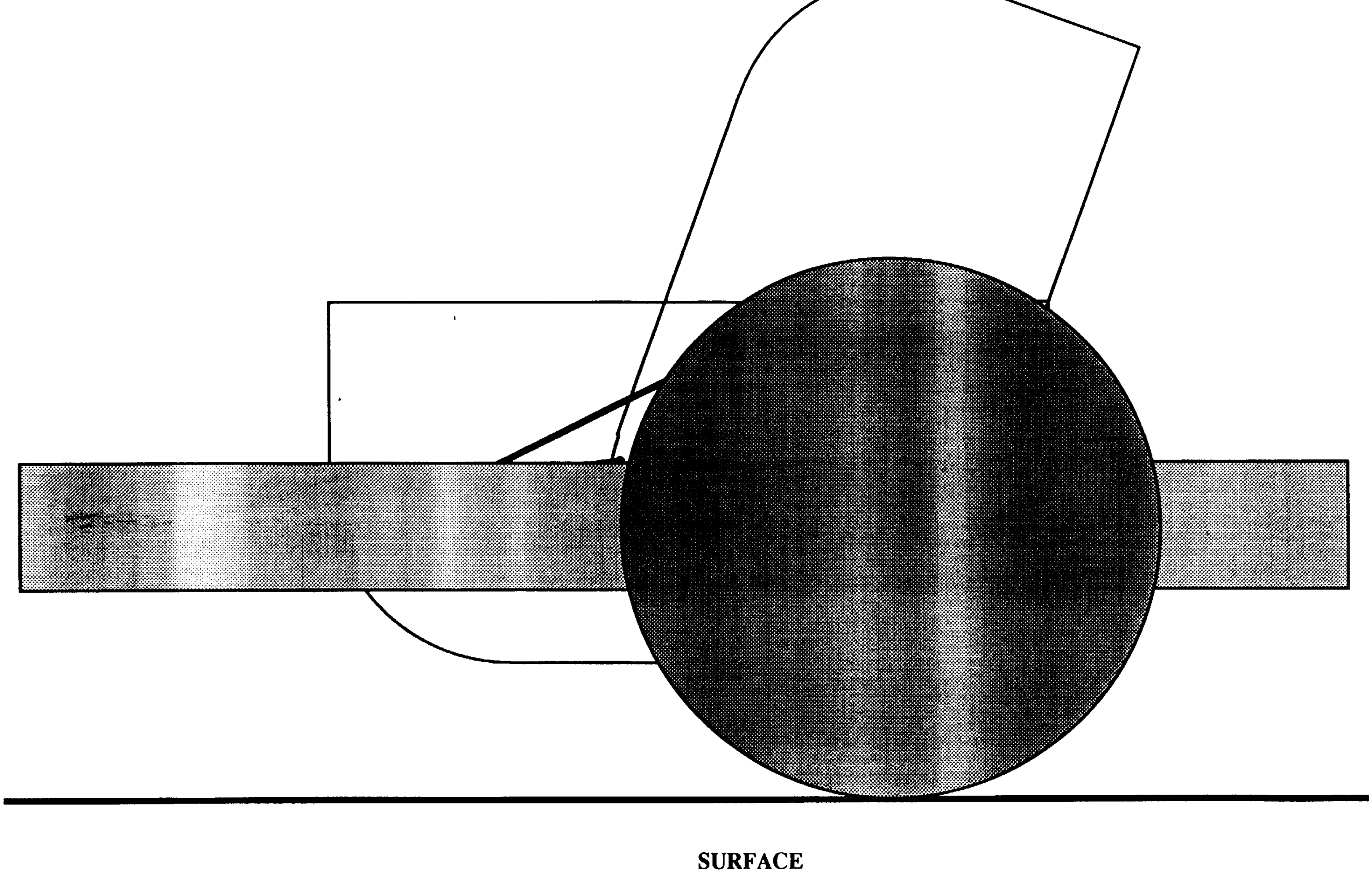
This week our group made a check list for all areas of our project. Thus we recognized areas that require further concentration.

The pivot point of our bowl has been determined as shown in the graphic. This pivot point allows for adequate ground clearance when the bowl is rotated a full 110 degrees. The dump mechanism for this bowl will be a slider crank mechanism which will be mounted to the frame on each side of the bowl. This mechanism will be computer controlled to insure exact simultaneous motion on each side of the bowl.

The chassis for our vehicle will be a composite with a box cross section. The size of this cross section will be determined as the composite characteristics are determined.

The power for the vehicle will consist of hydrogen/oxygen fuel cells which will be mounted in the controller section. The environment of this controller section will be maintained at a workable temperature. Lead acid batteries will be mounted in the frame box section near each motor. The fuel cells will constantly recharge these batteries.

In the upcoming week, our group plans to observe an articulated steering machine at the Yancey Bros.-Caterpillar location in west Atlanta. We also plan to calculate the slider crank forces and their exact positioning.


SURFACE

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

GEORGIA INSTITUTE OF TECHNOLOGY

APPROVAL SHEET (Attach to DISCLOSURE OF INVENTION)

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

1. Title of Invention:

   Lunar Material Transport Vehicle

2. List of Inventor(s):

   Harry C. Whitehead, Jr. — Charles D. Fisher

   W. Allen Wilkins, Jr — Douglas Lyons

3. Ownership:

   In my opinion this invention:

   __x__ A. Is owned by the Institute in accordance with the Patent Policy.

   _____ B. Was developed by the inventor(s) without use of Institute time, facilities or materials, and is not related to the inventor's area of technical responsibility to the Institute and hence belongs to the inventor(s).

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

____________________ __________
Advisor — Date

Reviewed for Institute ownership by laboratory or school director.

____________________ __________
Name — Date

____
Title/Unit

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

GEORGIA INSTITUTE OF TECHNOLOGY
DISCLOSURE OF INVENTION

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

1. **Title**

Technical Title: Lunar Material Transport Vehicle

Layman's Title (34 characters maximum, including spaces): A moon surface mover of bulk material

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

A. Signature Harry C. Whitehead Jr. Revenue Share% ____ Date 3/9/88

Printed Name Harry (First) Cass (Middle) Whitehead, Jr. (Last) Citizenship U.S.A.

Home Address 914 Collier Road, Apt S1

City Atlanta County Fulton State Georgia Zip Code 30318

Campus Unit/Mail Address 34595 Campus Phone 355-8895

B. Signature W. Allen Wilkins Jr. Revenue Share% ____ Date 3/9/88

Printed Name WAYMON (First) ALLEN (Middle) WILKINS (Last) Citizenship USA

Home Address 7200 BLACK JACK COURT

City RIVERDALE County CLAYTON State GA Zip Code 30296

Campus Unit/Mail Address 31609 Campus Phone 892-2861

C. Signature Charles D. Fisher Revenue Share% ____ Date 3/9/88

Printed Name DOUGLAS (First) (Middle) LYONS (Last) Citizenship USA

Home Address 401 REGENCY WOODS DRIVE

City ATLANTA County ~~GA~~ DEKALB State GA Zip Code 30319

Campus Unit/Mail Address 34620 Campus Phone 636-3882

D. SIGNATURE ~~Douglas Lyons~~

CHARLES DAYTON FISHER USA

3712 SYLVAN DR

BALTIMORE MD 21207 BOX 34124 676-0104

DISCLOSURE OF INVENTION

2. **Statement of Invention:**

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

Our project developed a lunar dump truck. This
ar Material Transport Vehicle (LMTV) is a double-sided,
culatedly steered vehicle. The design consists of 2 bowls,
composite chassis, 4 steering actuators, 4 dumping actuators,
wheels, and a microcomputer (teleoperated). The LMTV is
wered by fuel cells and batteries. There is a curvilinear
nchronous motor mounted in each wheel hub. Stub axles
re used to mount the wheels to the frame.

Inventor(s) [signature] Date 3/9/88
W. Allen Wilkins Jr. Date 3/9/88
Charles D. Fisher Date 3/9/88
[signature] 3/9/88

Witness* [signature] Date 3/9/88

______ Date______

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

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

DISCLOSURE OF INVENTION

3. Results Demonstrating the Concept is Valid:

Cite specific results to date. Indicate whether you have completed preliminary research, laboratory model, or prototype testing.

Preliminary research has shown that the vehicle proposed is well within the theoretical envelope. Scale cad drawings have been produced which prove the spacial design. Mathematics have been performed which give power requirements within our power availabity. The vehicle is of ~~the~~ approprite size for use in the space shuttle.

4. Variations and Alternative Forms of the Invention:

State all of the alternate forms envisioned to be within the full scope of the invention. List all potential applications and forms of the invention, whether currently proven or not. (For example, chemical inventions should consider all derivatives, analogues, etc.) Be speculative in answering this section. Indicate what testing, if any, you have conducted on these alternate forms.

The vehicle designed has been done so with a very specific set of constraints and objectives. The only possible alternative uses of the vehicle would be for personel transportation on the lunar surface.

Inventor(s) [signature] Date 3/9/88

[signature] W. Allen Wilkins Jr. Date 3/9/88

[signature] Charles D. Fisher Date 3/09/88

[signature] 3/9/88

Witness* ____________________ Date________
(printed name)

____________________ Date________
(printed name)

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

DISCLOSURE OF INVENTION

5. Novel Features:

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

The monolithic fuel usage in space application. The curvilinear synchronous motor is in the development stages.

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

The power requirements have not been fully developed

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

Refer to references for sources of scientific literature.

Inventor(s) Henry Whitehead Jr. Date 3/9/88
W. Allen Wilkins Jr. Date 3/9/88
Charles D. Fisher Date 3/09/88
Douglas Lyons 3/9/88

Witness __________ Date _____
(printed name)
__________ Date _____
(printed name)

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

DISCLOSURE OF INVENTION

6. **Application of the Technology:**

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

The high torque
Space application monolithic fuel cells
The advancement of teleoperator communications

Inventor(s) [illegible] Jr. Date 3/9/88
W. Allen Wilkins Jr. Date 3/9/88
Charles A. Fisher Date 3/09/88
[illegible] 3/9/88

Witness ____________________ Date ________
(printed name)
____________________ Date ________
(printed name)

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

DISCLOSURE OF INVENTION SUPPORTING INFORMATION

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

SEE REFERENCES

. On what date was the invention first conceived? 1/6/88 Is this date documented? NO Where? ______ Are laboratory records and data available? Give reference numbers and physical location, but do not enclose. YES

PROGRESS REPORTS

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

N/A

. Was the work that led to the invention sponsored by an entity external to Georgia Institute of Technology? Yes ✓ No______

a) If yes, has sponsor been notified? Yes ✓ No______

b) Sponsor Names: NASA GIT Project Nos.

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

NASA – SPACE APPLICATIONS

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

DISCLOSURE OF INVENTION
SUPPORTING INFORMATION

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

The power requirements and the total output of the motor.

7. Alternate Technology and Competition:

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

None

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

None

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

NASA, Space Laboratories

8. Future Research Plans:

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

15 years

b. Is this additional research presently being undertaken? Yes___ No X

c. If yes, under whose sponsorship?

d. If no, should corporate sponsorship be pursued? Yes X No____

Suggested corporation(s) NASA

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

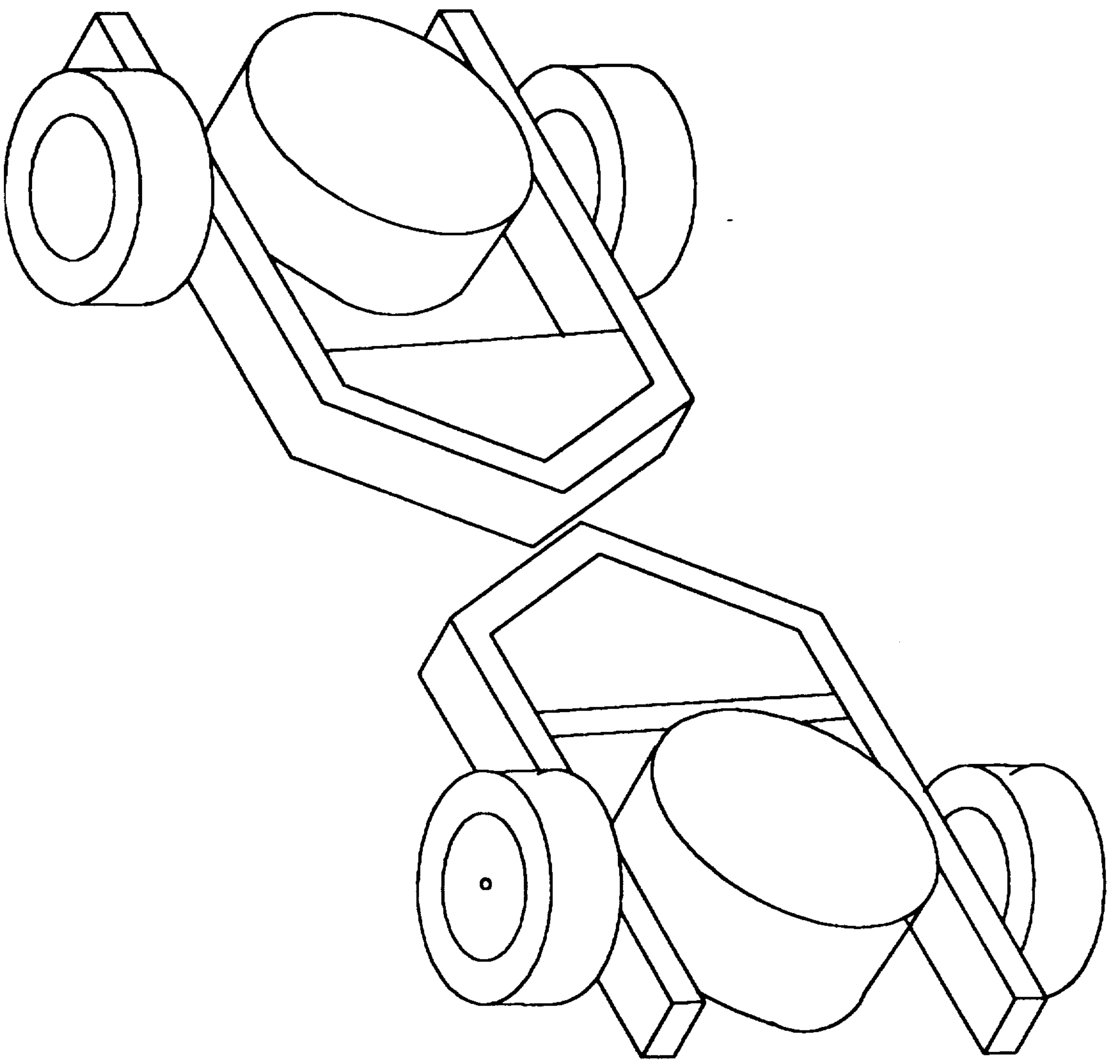


FIGURE 1a

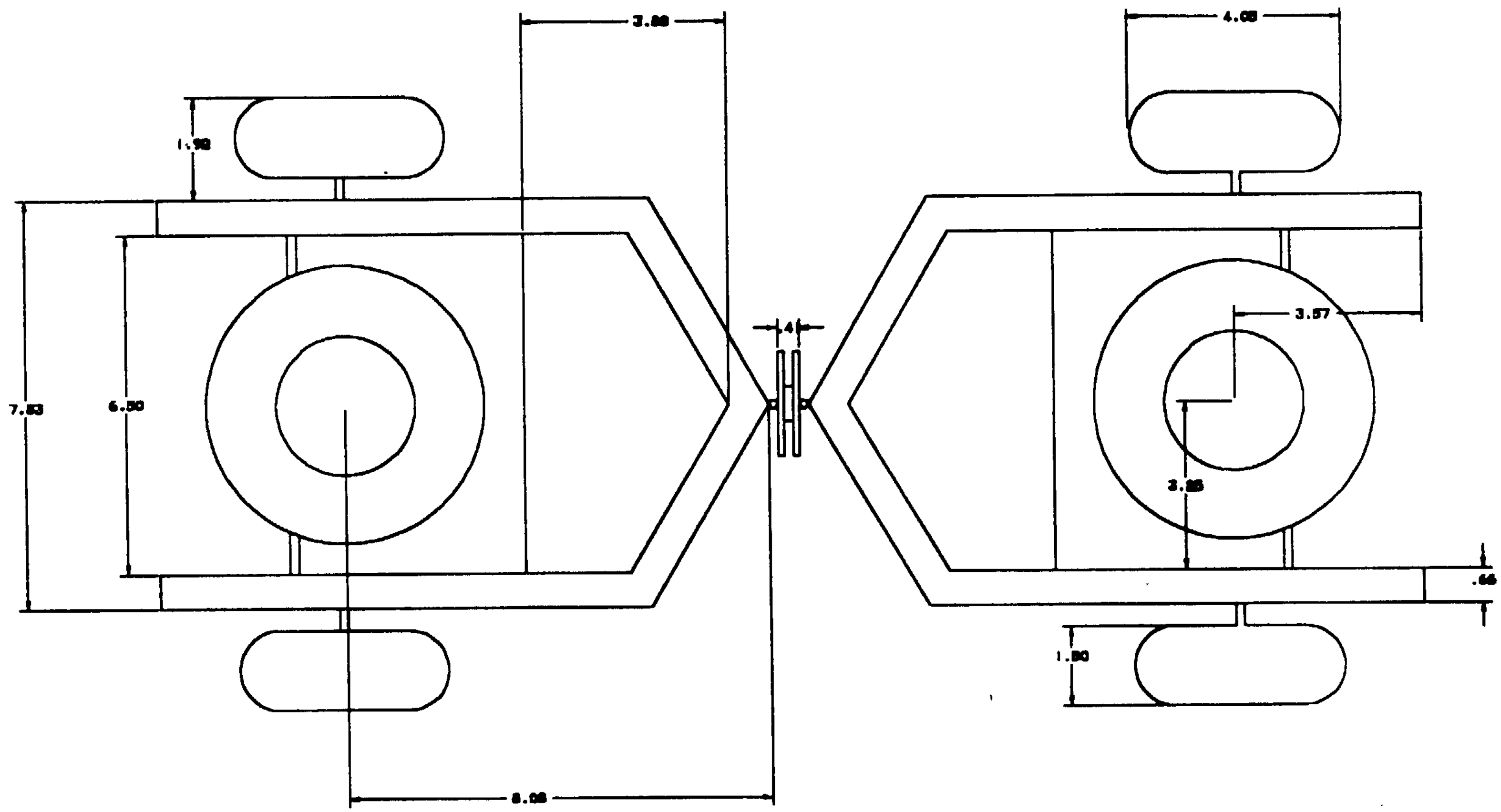


FIGURE 1b

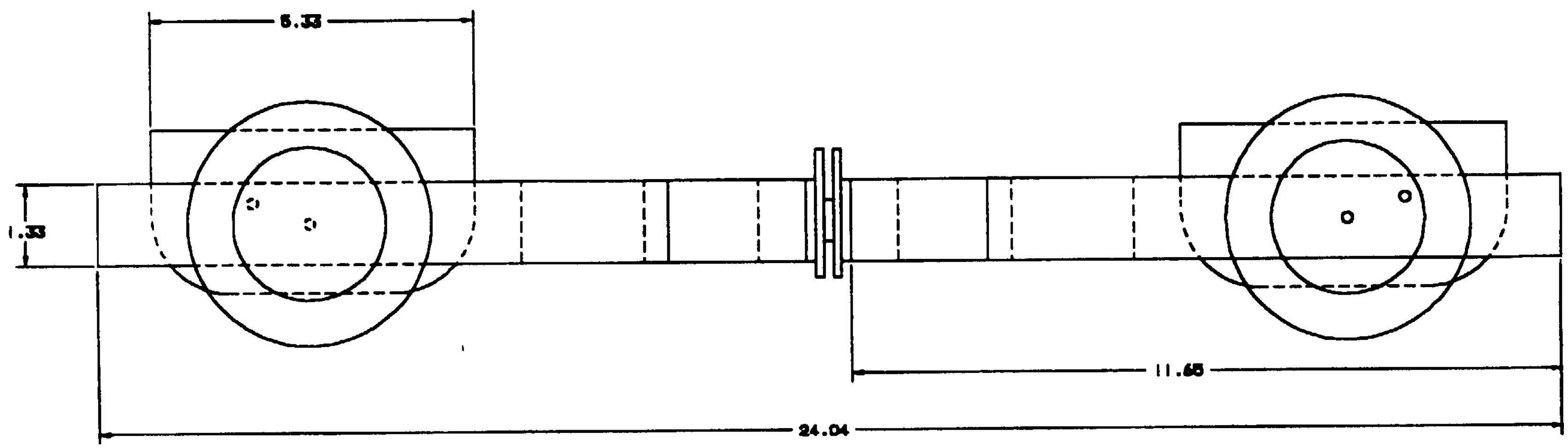


FIGURE 1c

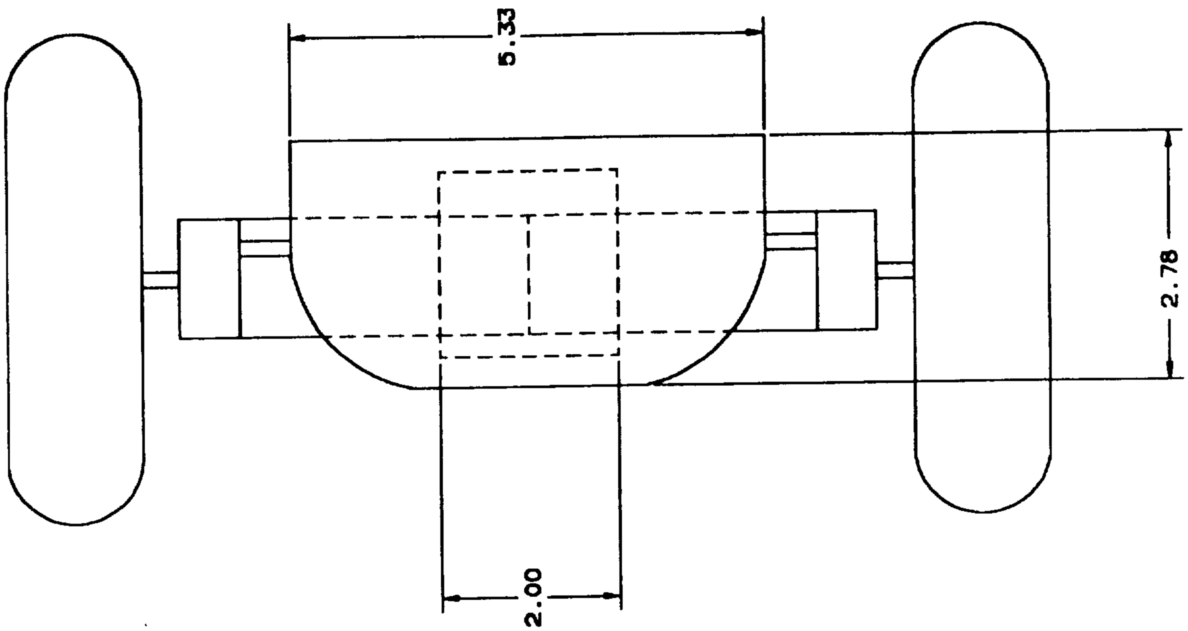


FIGURE 1d

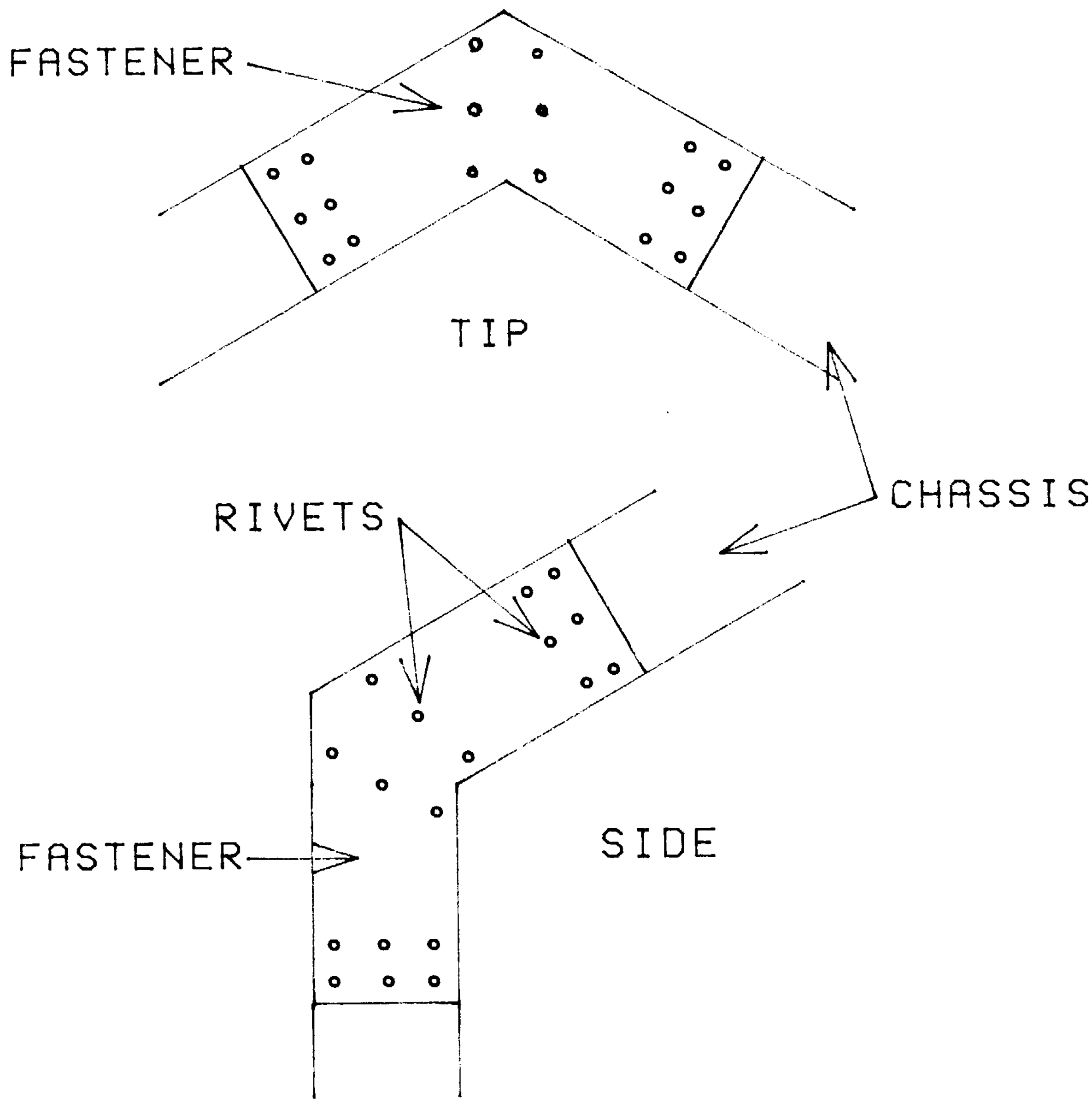


FIGURE 2

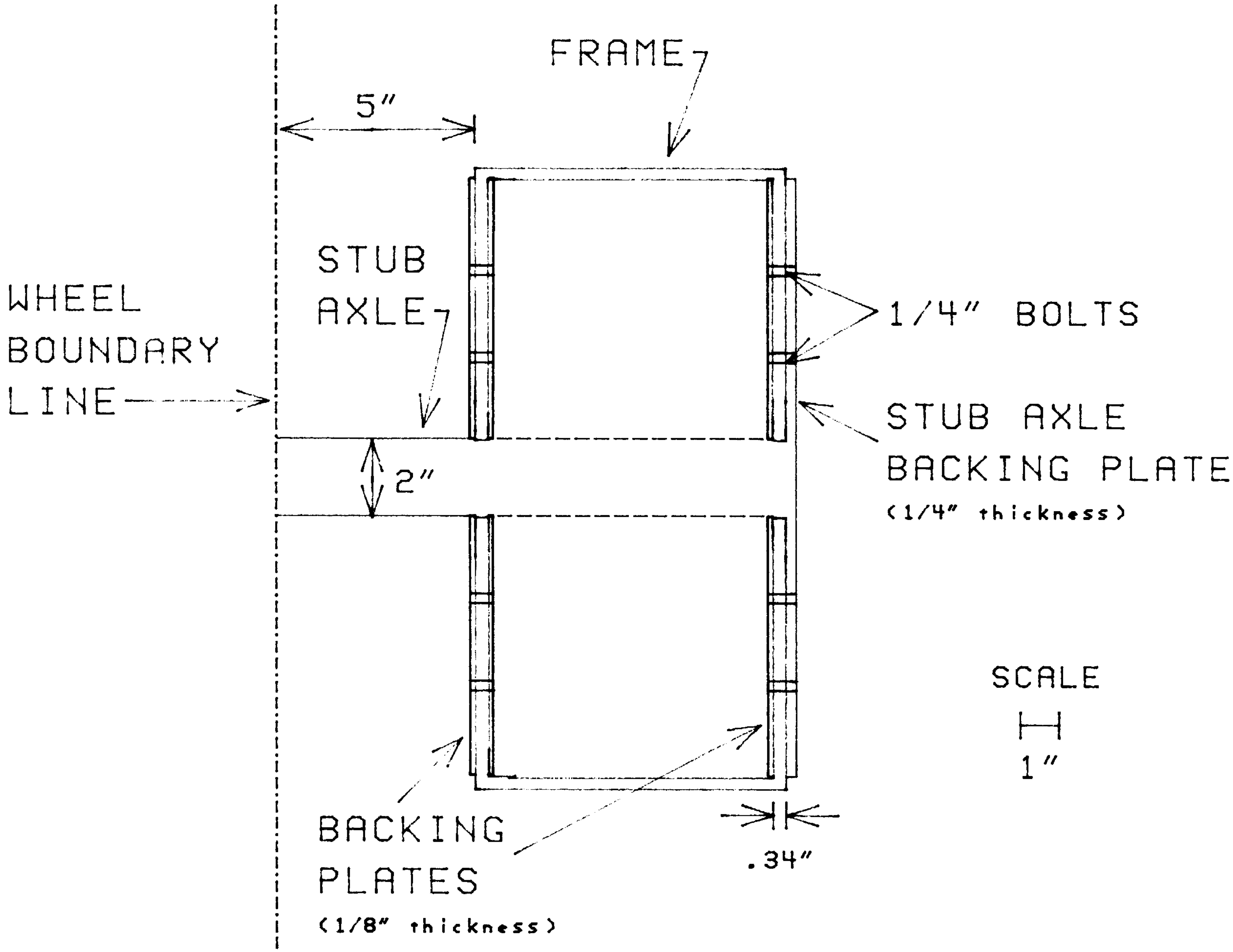

FRAME
5"
STUB
AXLE
WHEEL
BOUNDARY
LINE
1/4" BOLTS
STUB AXLE
BACKING PLATE
(1/4" thickness)
2"
SCALE
1"
BACKING
PLATES
(1/8" thickness)
.34"

FIG 3

BUCKET AND WHEEL RELATIVE PROPORTIONS

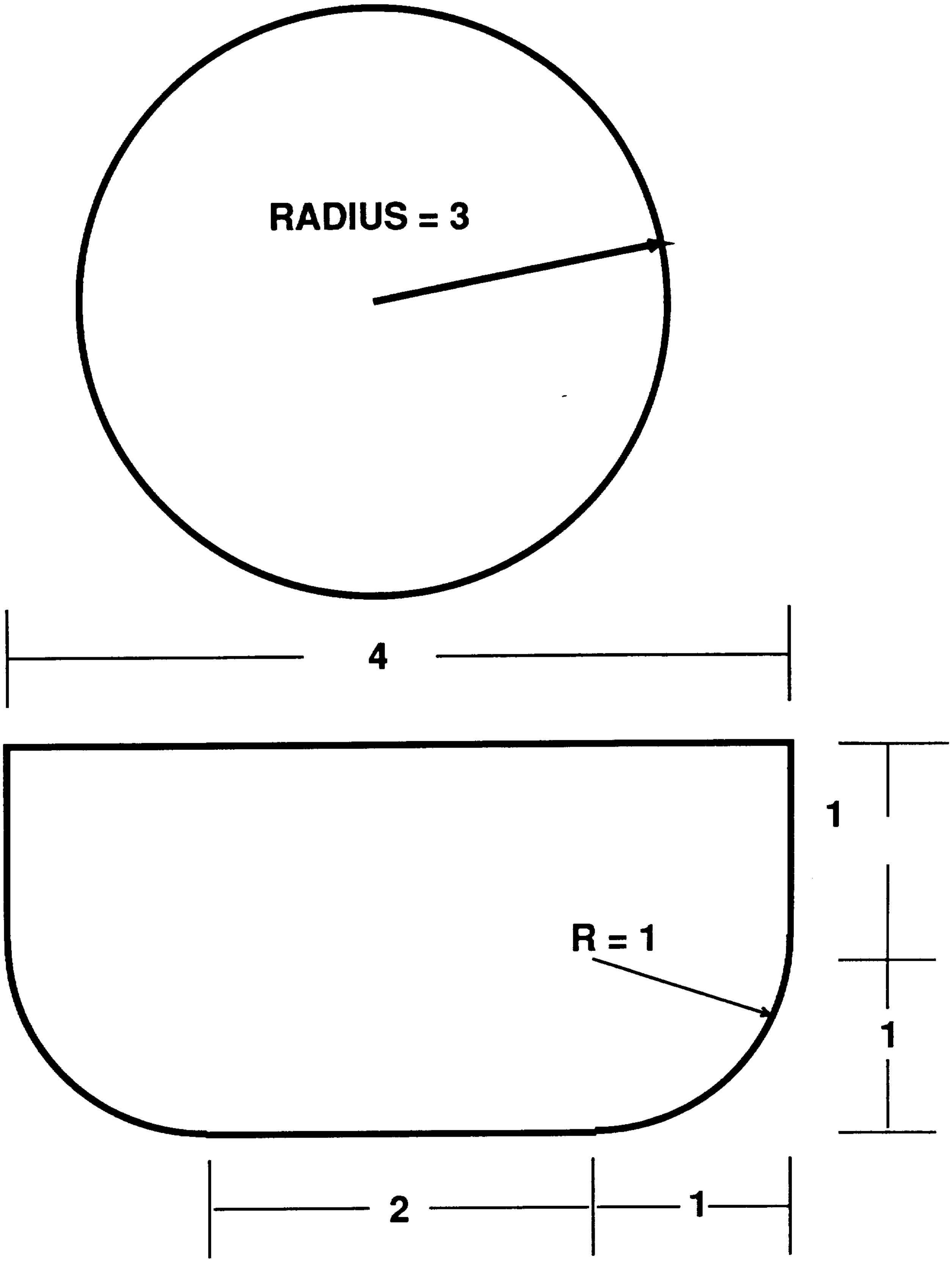


FIGURE 4

ACTUAL BUCKET DIMENSIONS (FT.)

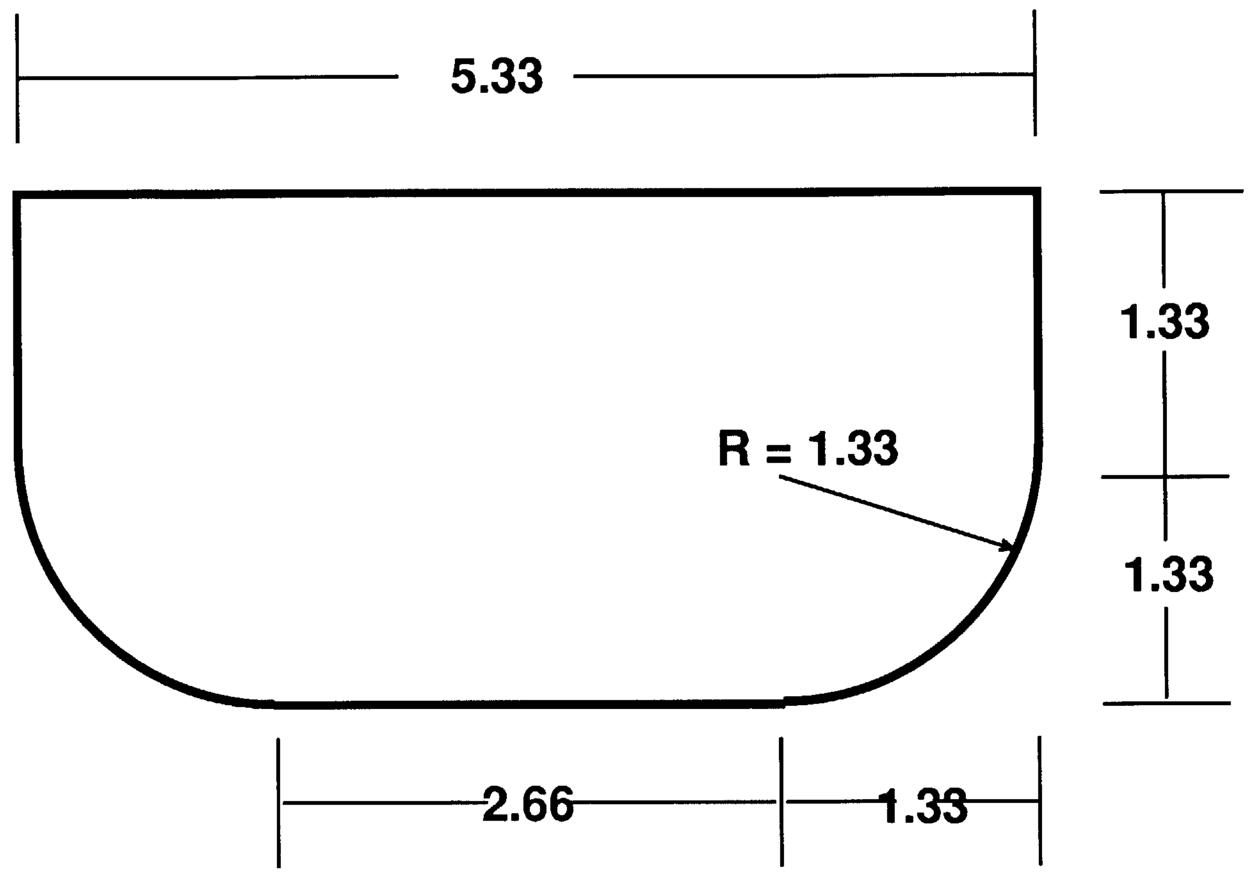


FIGURE 5

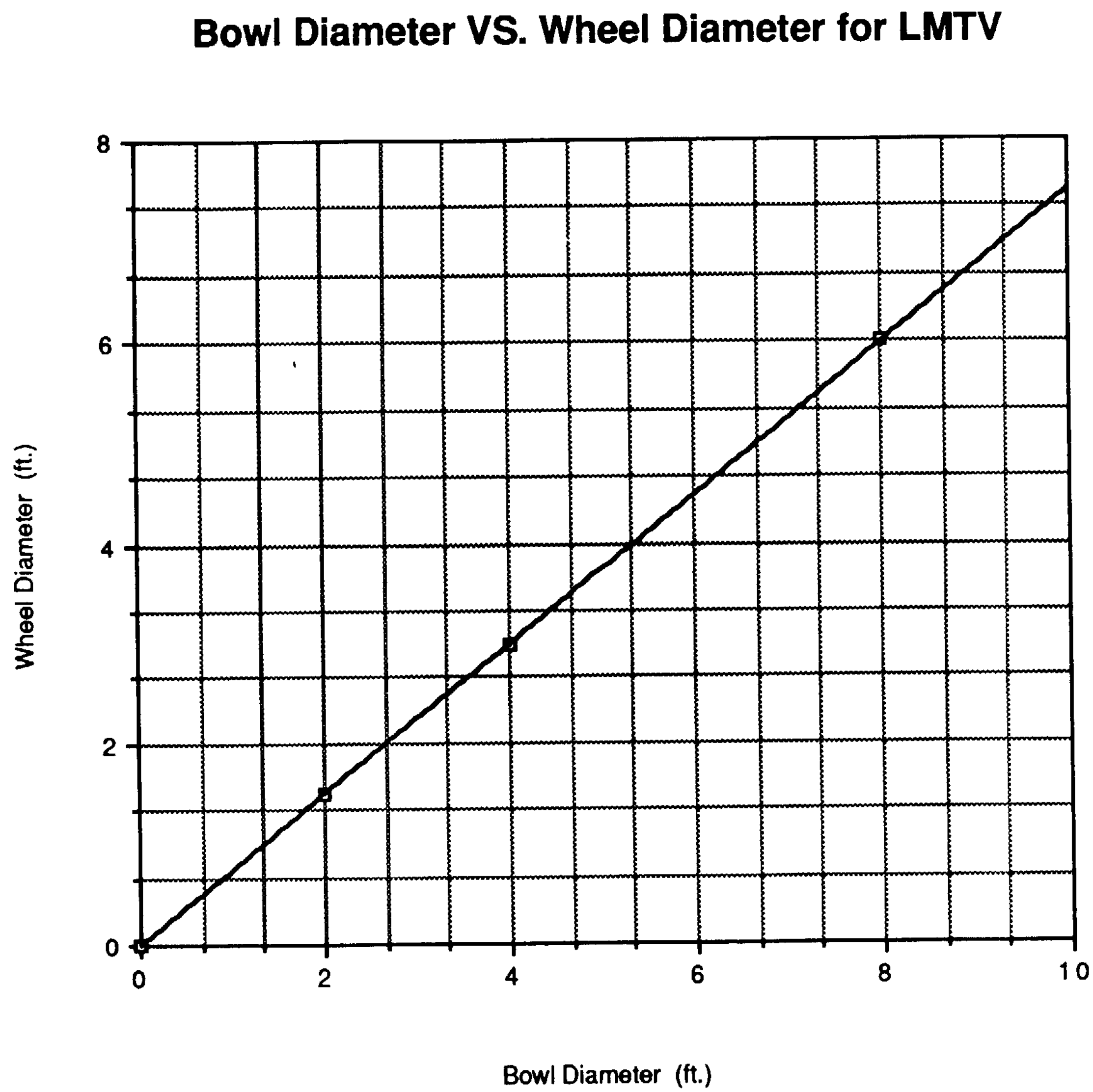

Bowl Diameter VS. Wheel Diameter for LMTV
Wheel Diameter (ft.)
0
2
4
6
8
0
2
4
6
8
10
Bowl Diameter (ft.)

FIGURE 6a

Bowl Diameter VS. Total Volume for LMTV

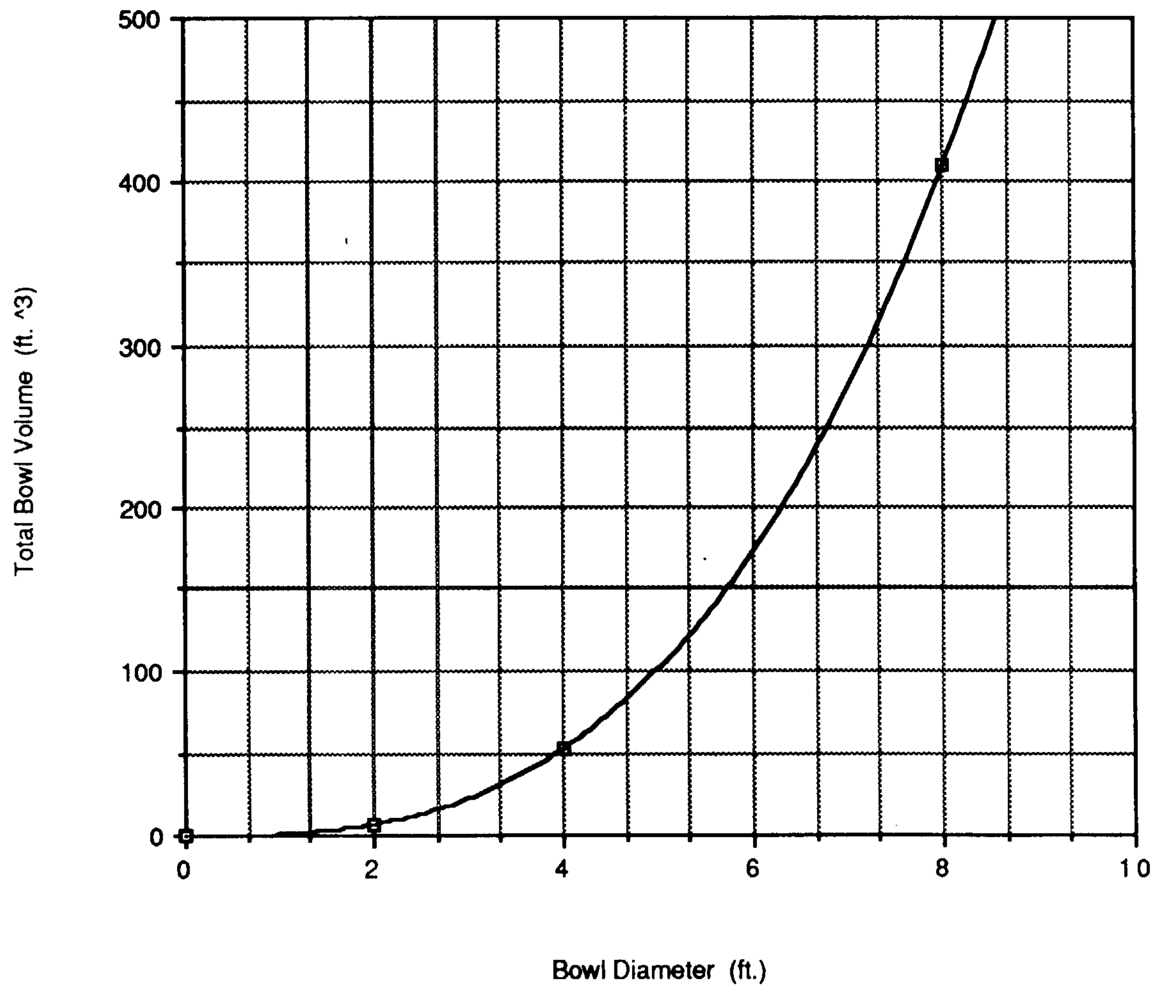


FIGURE 6b

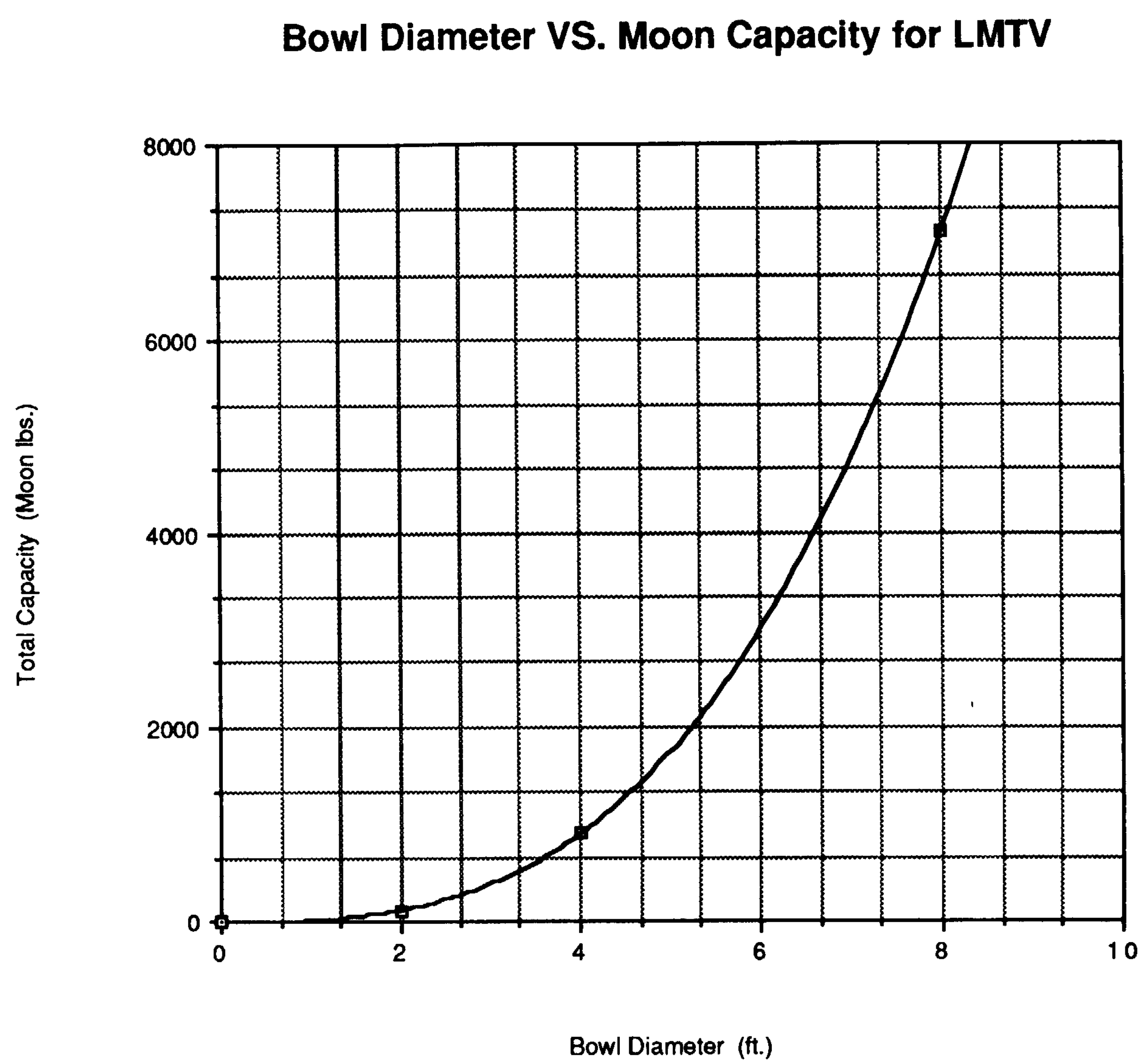

Bowl Diameter VS. Moon Capacity for LMTV
Total Capacity (Moon lbs.)
8000
6000
4000
2000
0
0
2
4
6
8
10
Bowl Diameter (ft.)

FIGURE 6c

Bowl Diameter VS. Torque / Wheel for LMTV

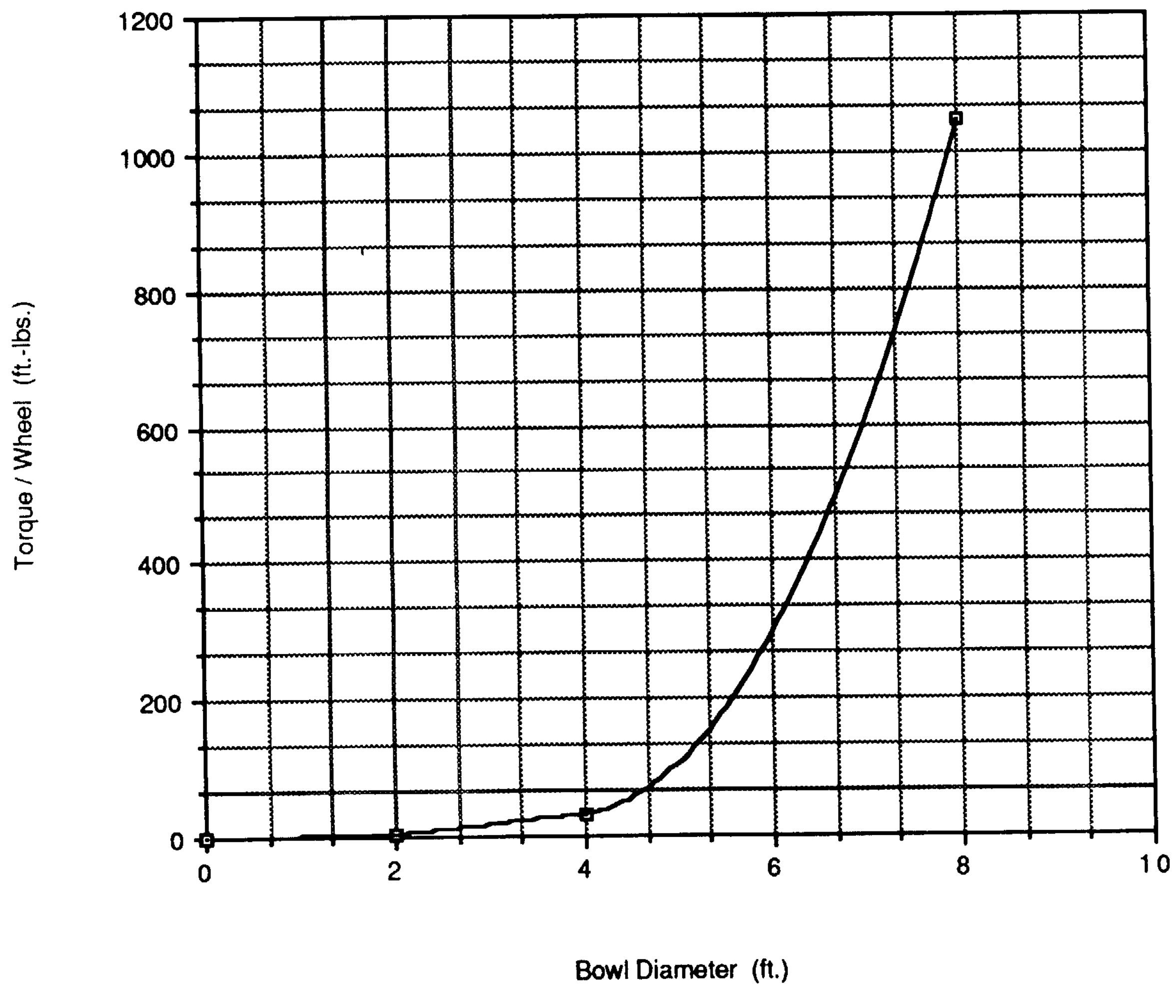


FIGURE 6d

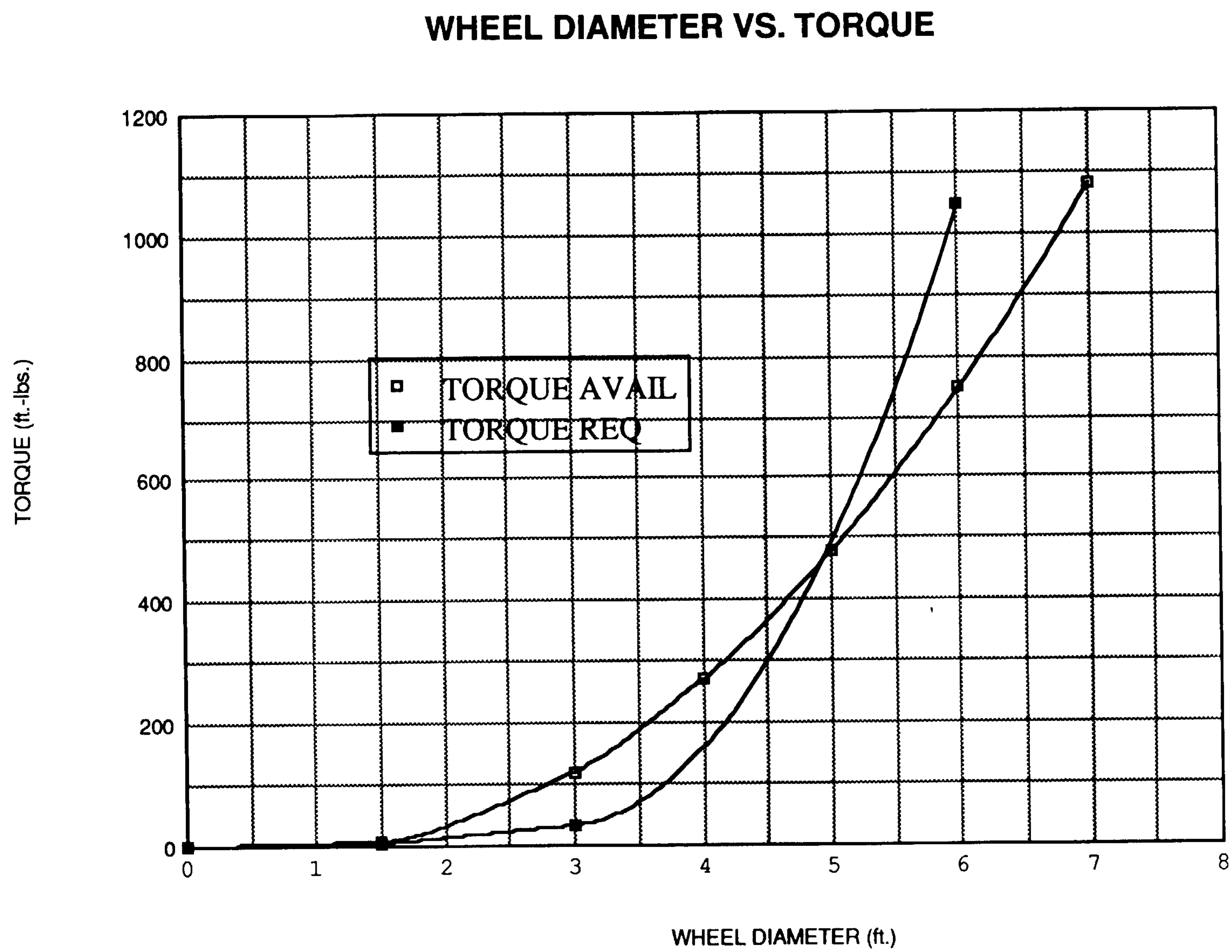

WHEEL DIAMETER VS. TORQUE
TORQUE (ft.-lbs.)
1200
1000
800
600
400
200
0
TORQUE AVAIL
TORQUE REQ
0
1
2
3
4
5
6
7
8
WHEEL DIAMETER (ft.)

FIGURE 6e

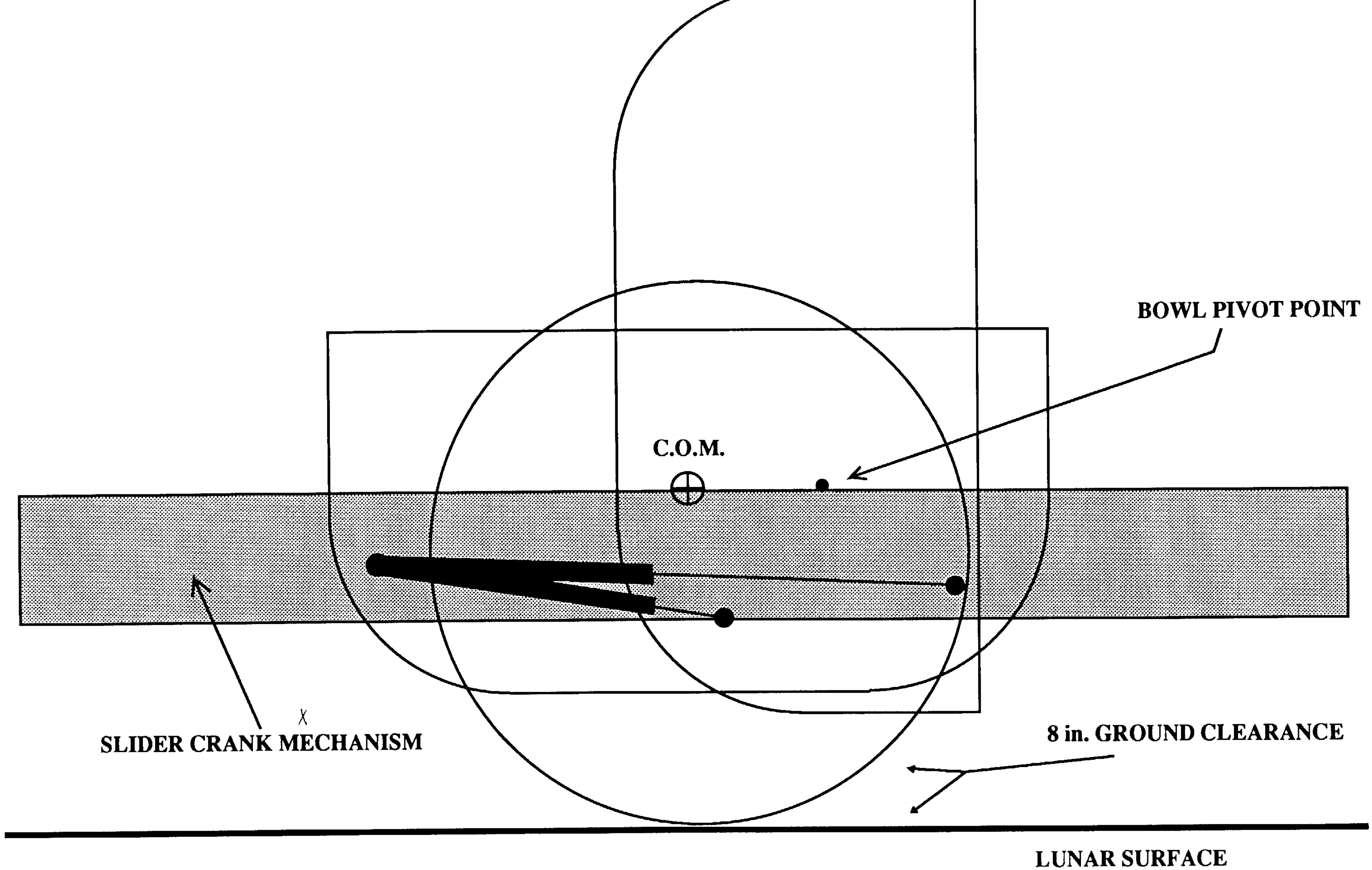
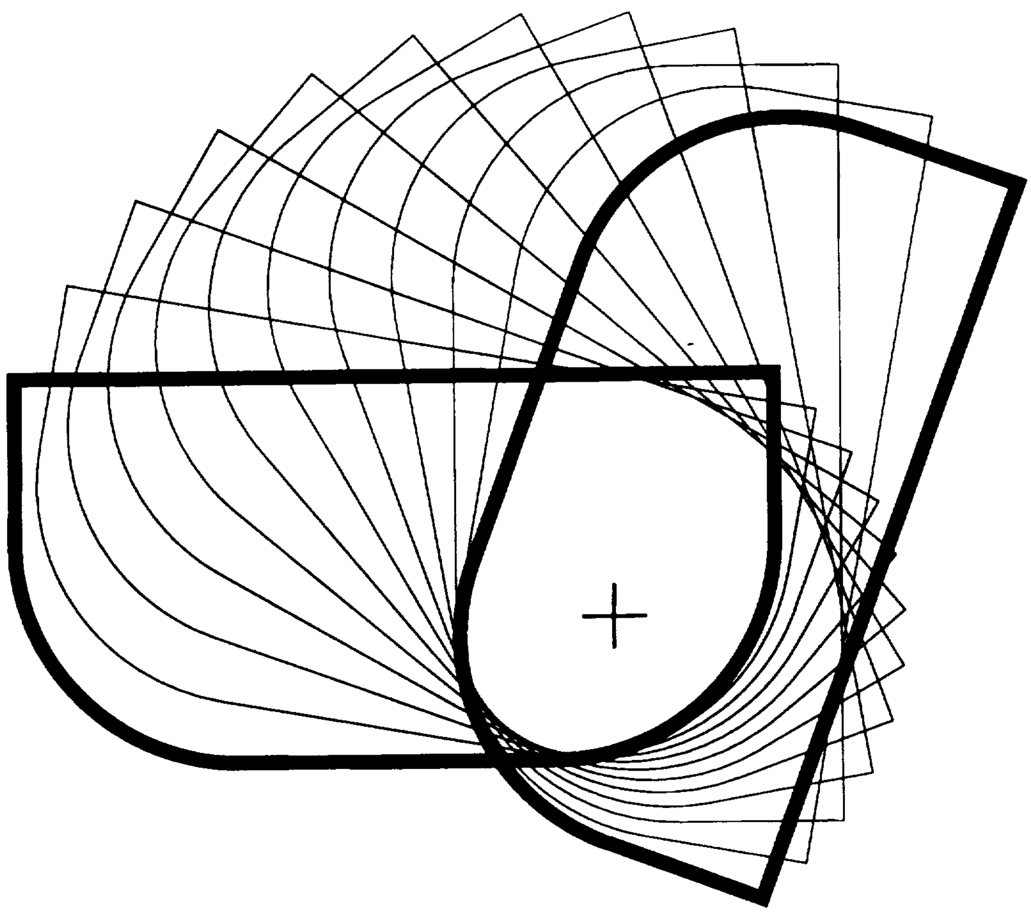

BOWL PIVOT POINT
C.O.M.
SLIDER CRANK MECHANISM
8 in. GROUND CLEARANCE
LUNAR SURFACE

FIGURE 7



BOWL ROTATION THROUGH 110 DEGREES

FIGURE 8

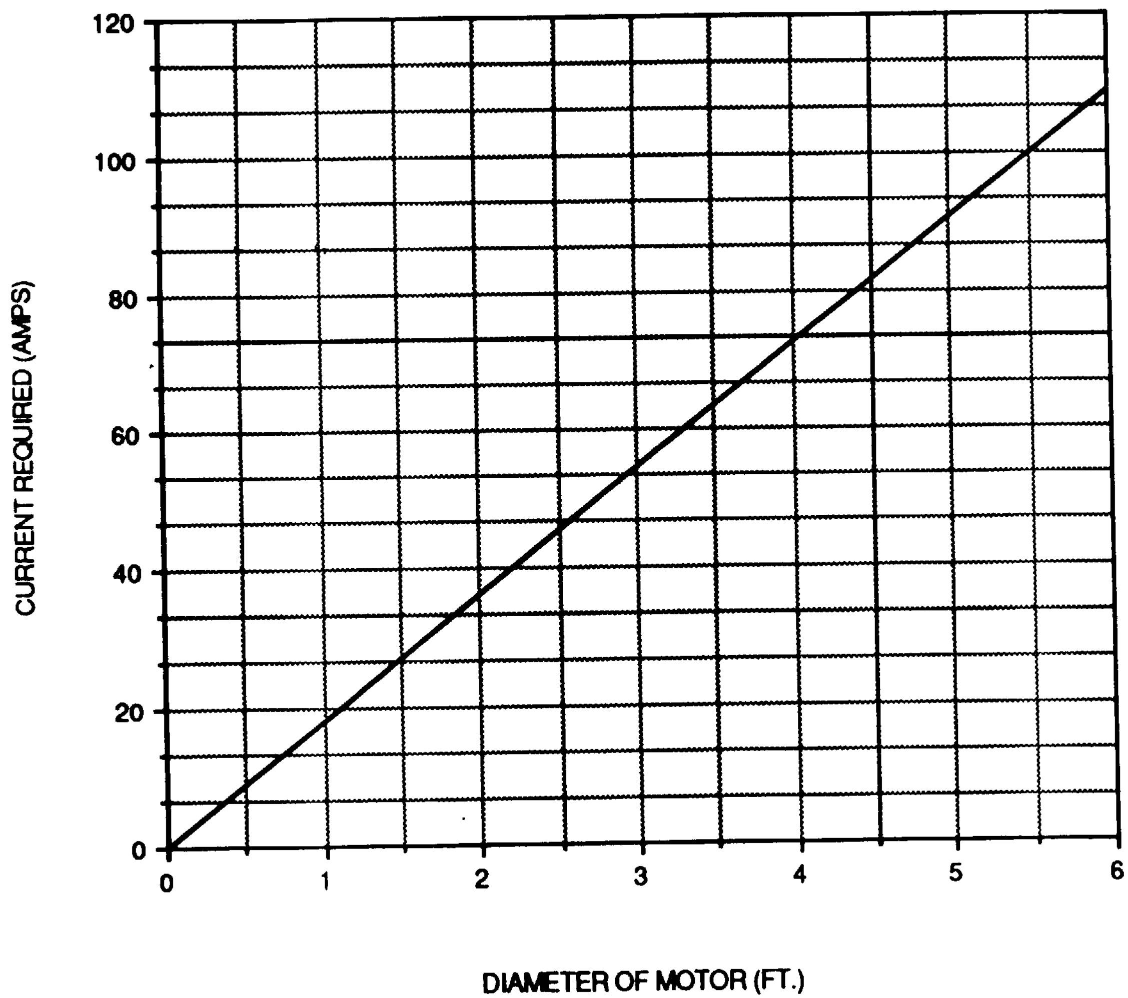
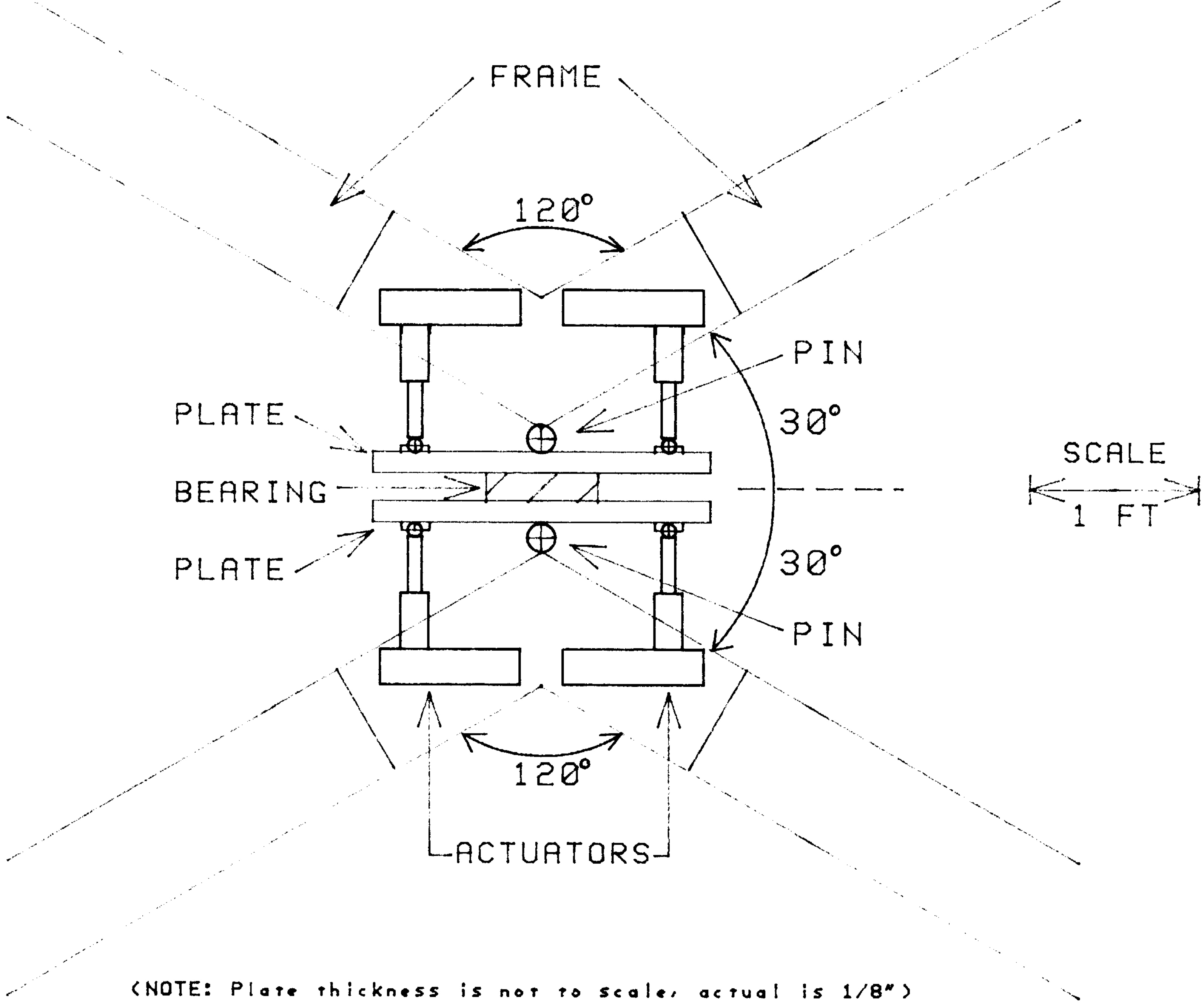

120
100
80
60
40
20
0
0
1
2
3
4
5
6
CURRENT REQUIRED (AMPS)
DIAMETER OF MOTOR (FT.)

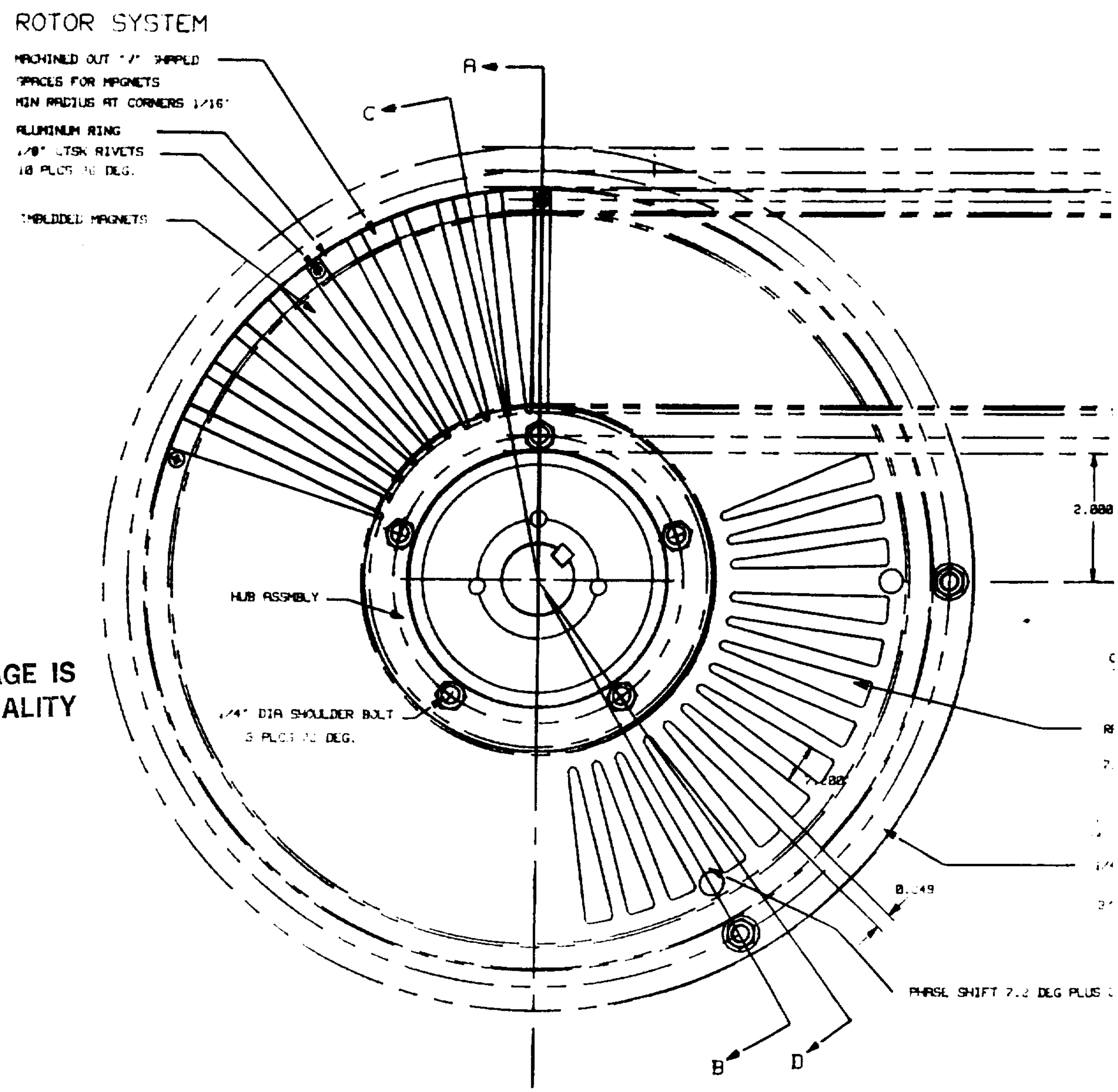
FIGURE 9



(NOTE: Plate thickness is not to scale, actual is 1/8")

FIGURE 10

FOLDOUT FRAME /

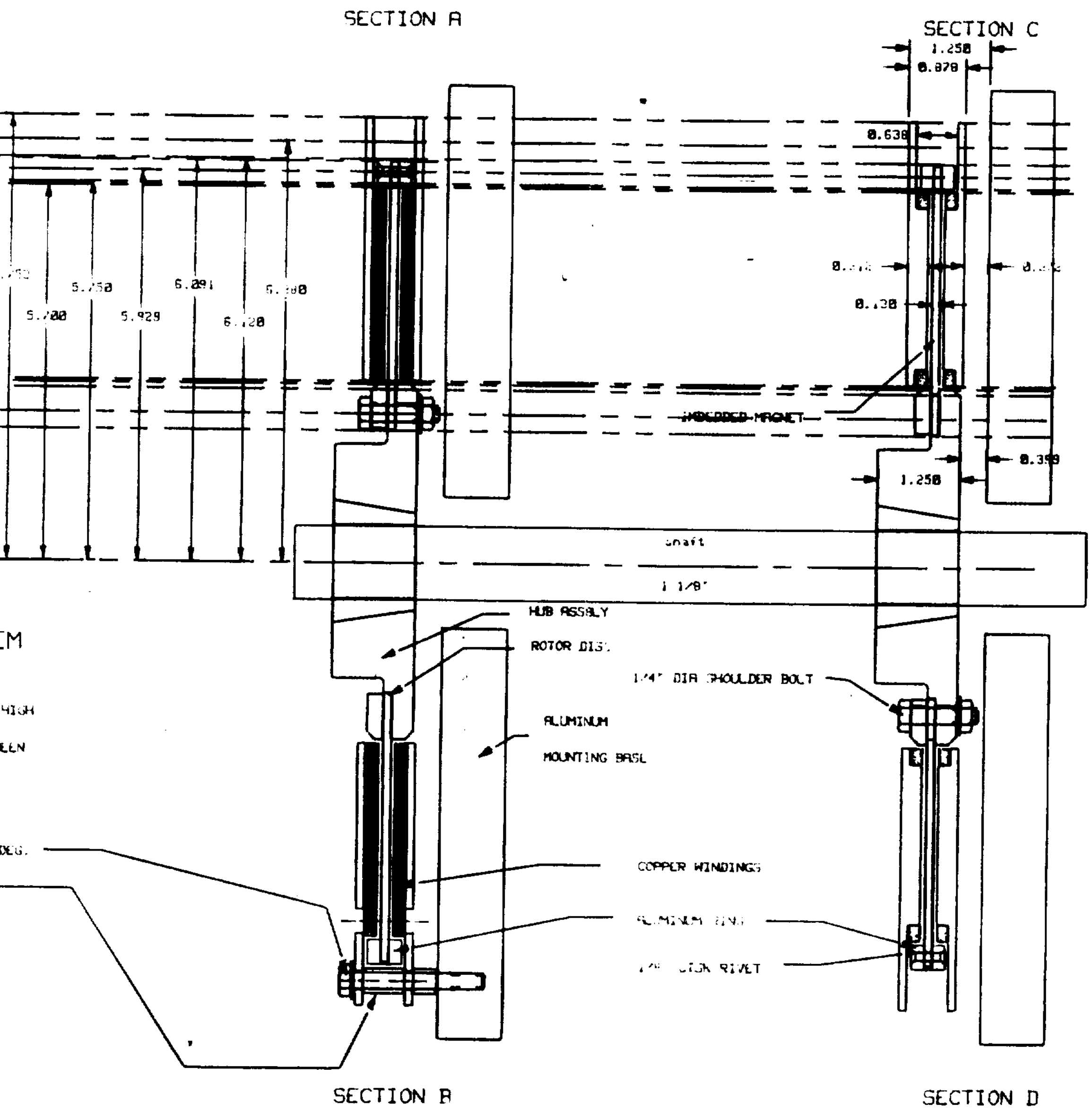


ORIGINAL PAGE IS OF POOR QUALITY

FI

FOLDOUT FRAME 2

ORIGINAL PAGE IS OF POOR QUALITY



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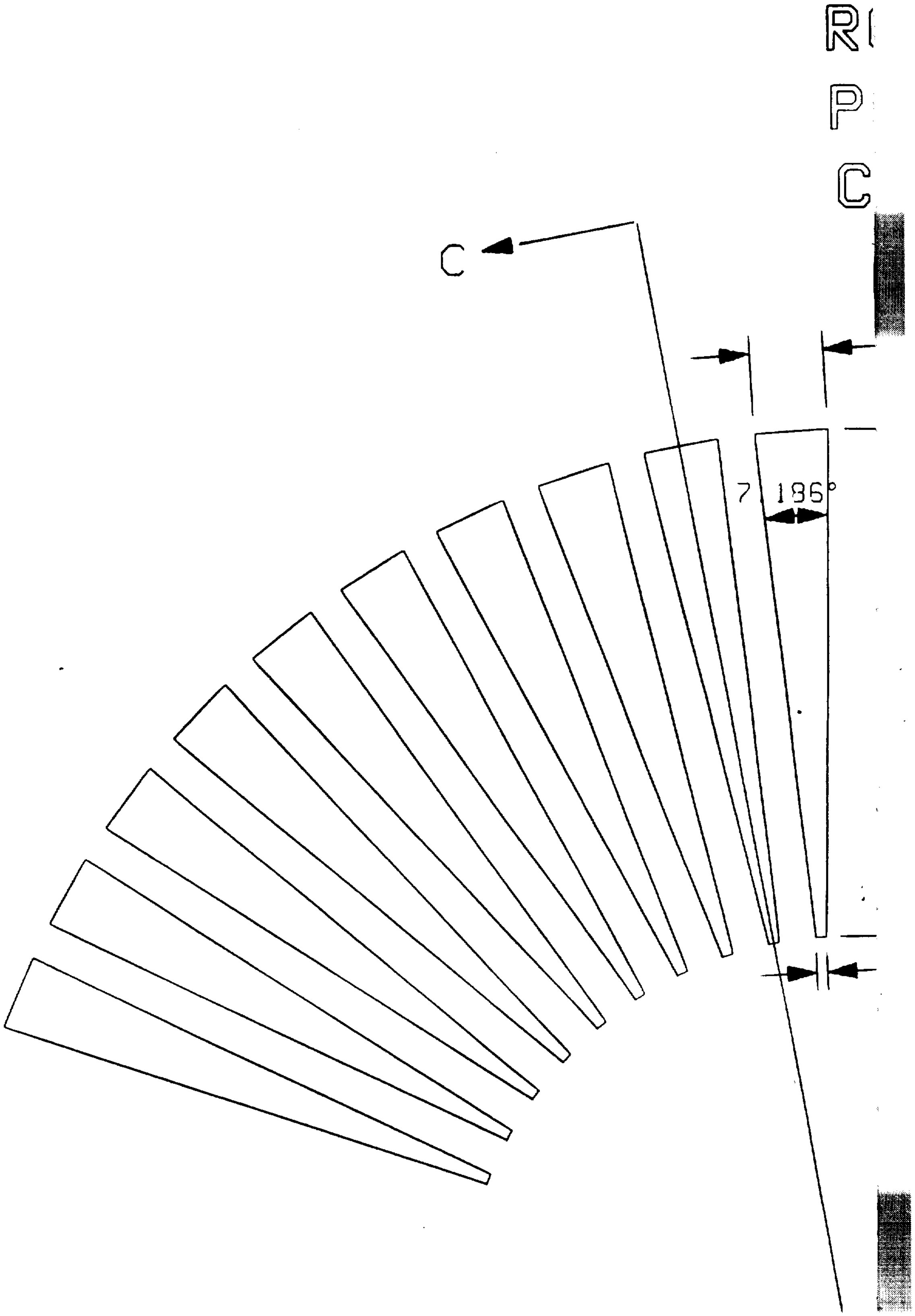


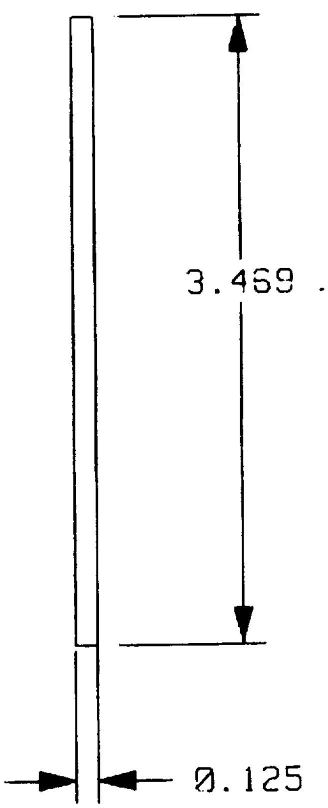
FOLDOUT FRAME 2

MAGNETS 50 PIECES

SPARES

IIC

SECTION C



GURE 12

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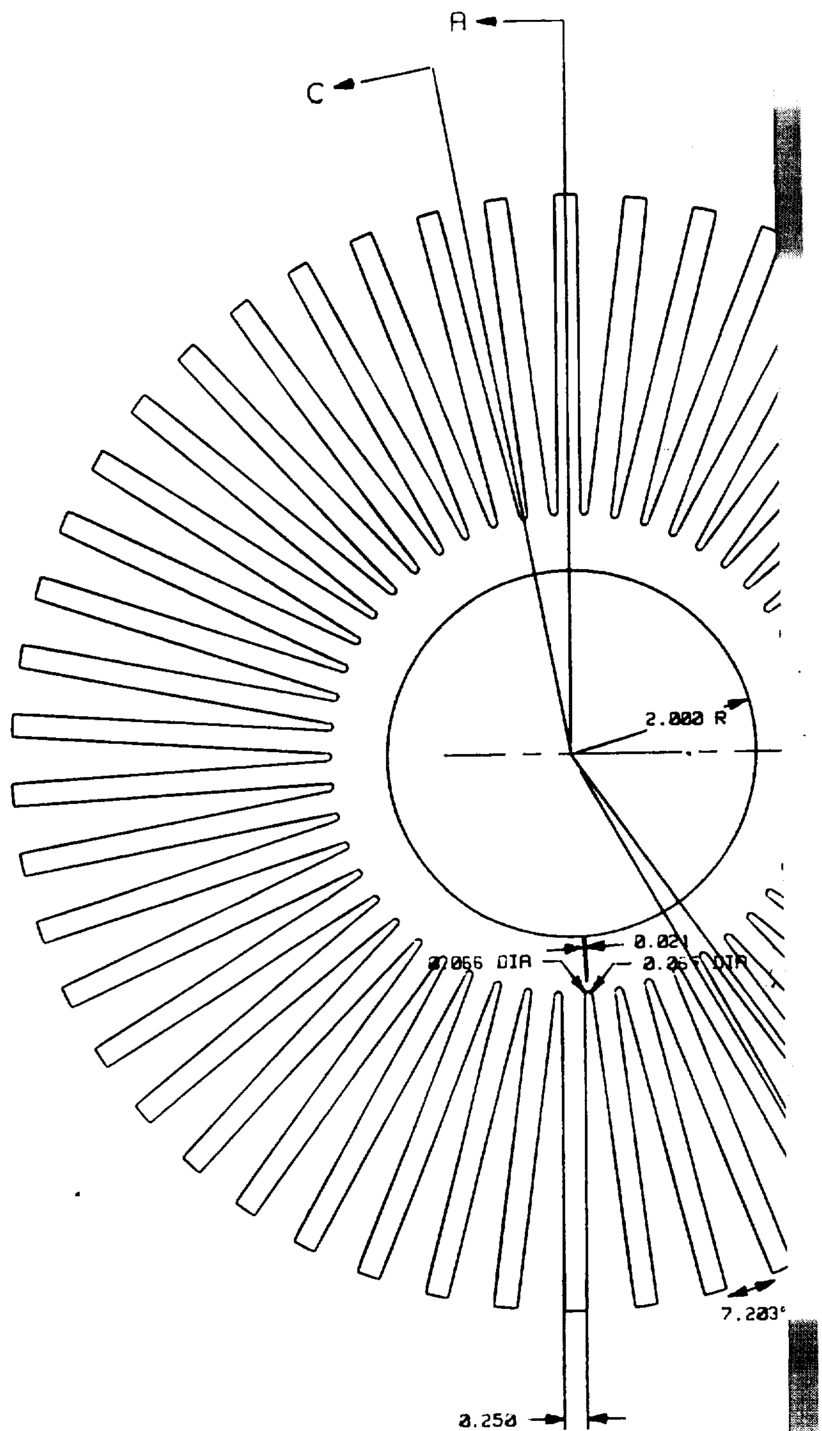
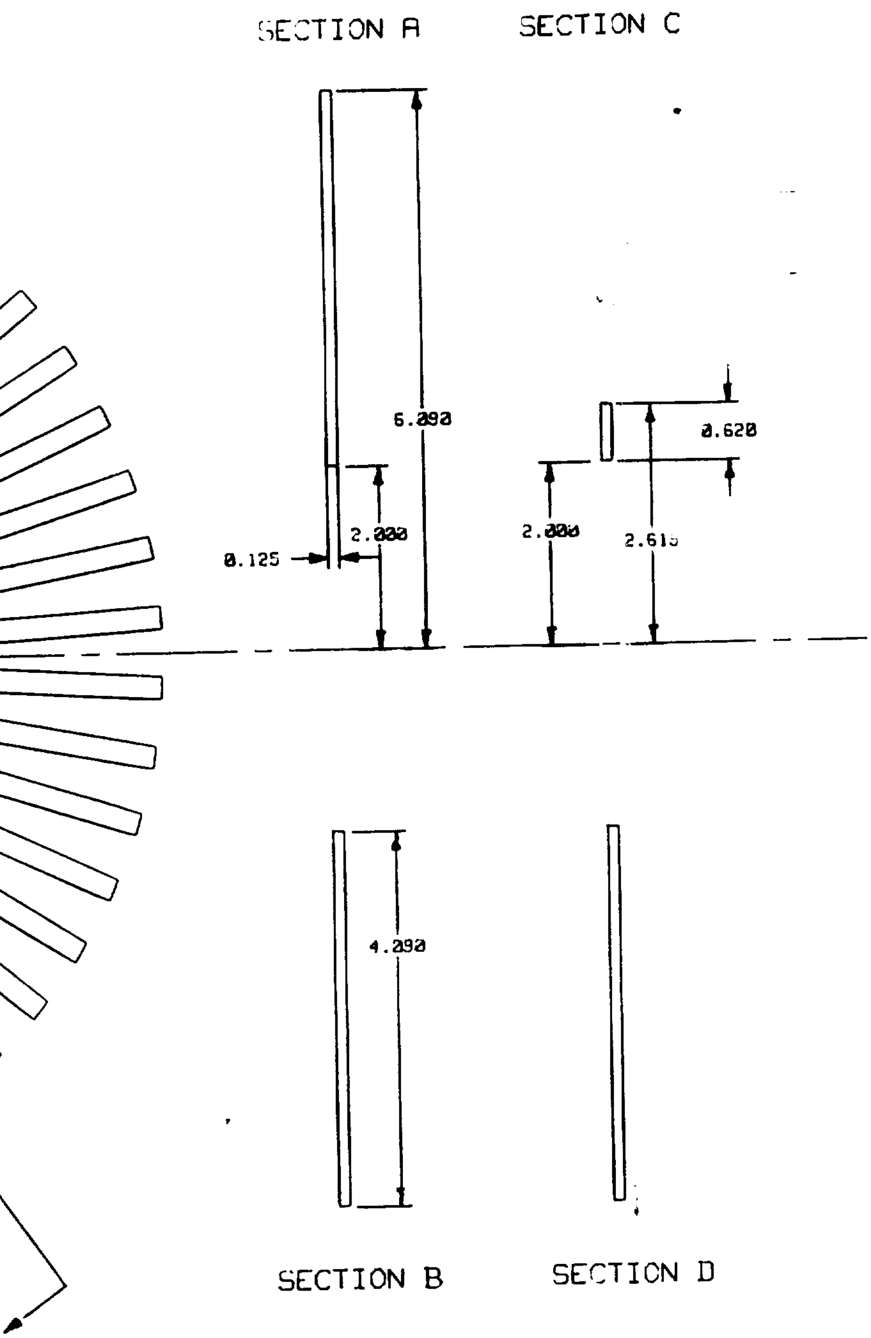


F

FOLDOUT FRAME 2

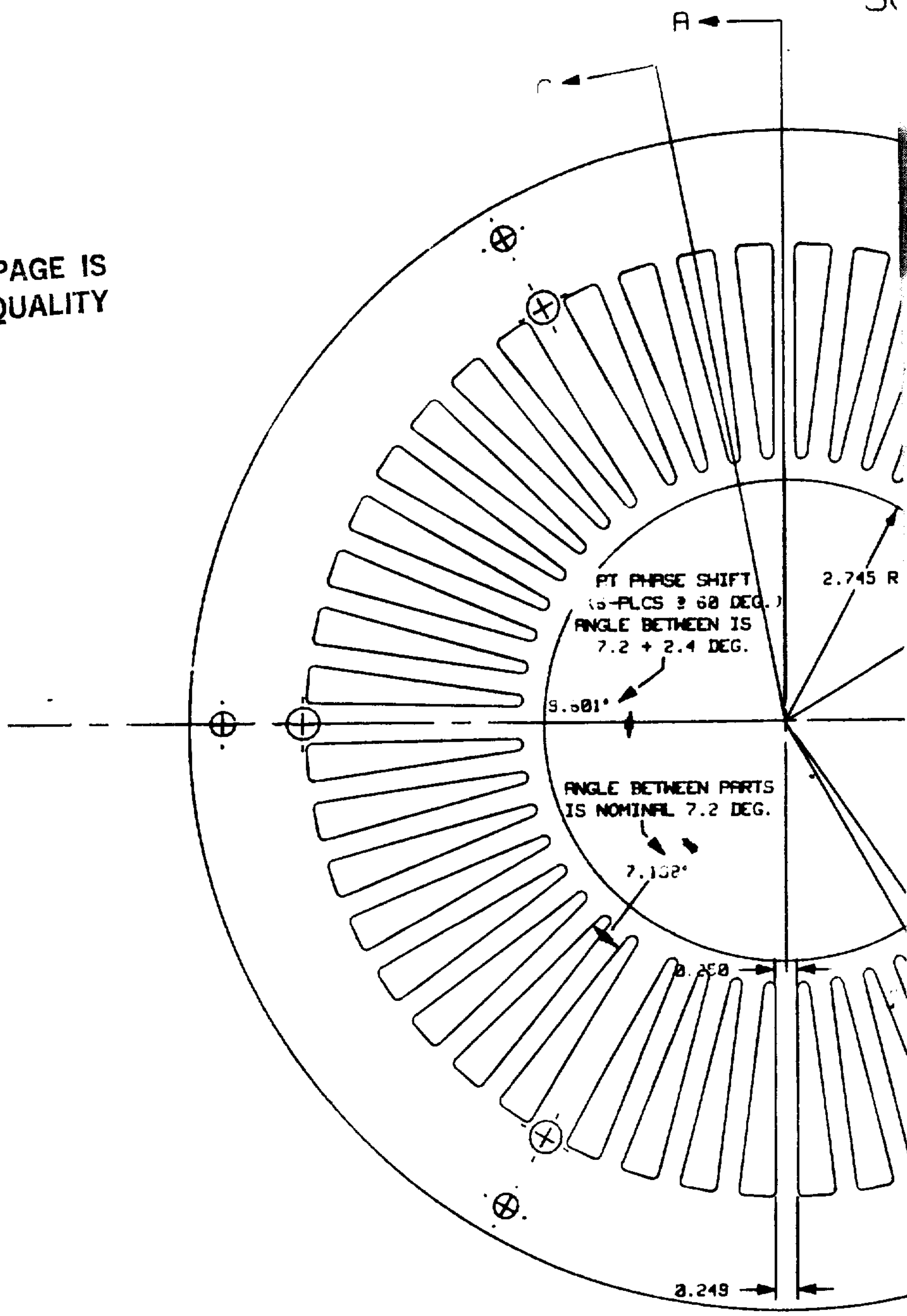
1 PIECE

TEEL



UT FRAME

ORIGINAL PAGE IS OF POOR QUALITY



FIGURE

FOLDOUT FRAME 2

ORIGINAL PAGE OF POOR QUALI

TOR

OR 2 IDENTICAL PIECES

T LOW CARBON MILD STEEL