A Functional Vehicle for Autonomous Mobile Robot Research

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Abstract

Neptune is a tethered vehicle built for autonomous mobile robot research. Included are: the design considerations, the resulting design, and details of the mechanical structure and electrical control system. Detail is sufficient to enable replication or adaptation by others. A discussion of the performance with respect to the design considerations is also included.

Every instrument, tool, vessel,
if it does that for which it is made,
is well.

Marcus Aurelius

1. Introduction

Basic research in mobile robotics requires real-world mobile vehicles without which many topics are limited to thought experiments. In developing any vehicle, its *applications* are the source of design considerations. One of the arenas of study is Artificial Intelligence (AI). Our application is in *autonomous* mobile robots, that is, robots which can carry out tasks with no human intervention, attaining knowledge of their environment, and interacting with it, by using Artificial Intelligence, (AI).

A vehicle with complex control requirements or inconsistent reliability can contribute inefficiency to the experimental process [2]. Another, often substantial portion of the total time available for research is consumed in fabrication and debugging the vehicle. By default, a vehicle itself, with its associated subsystems, can become a research project within the major objectives [3].

Robot vehicles and their basic controls are certainly worthy topics for research in their own right [5]. However, a separation of concerns may contribute to a more rapid advancement of the art. By minimizing the 'lower-level' subsystems of a vehicle, the functionality should be more stable. The use of such a vehicle in 'higher-level' research should result in a less interrupted study.

For the purposes of some of our AI research, an uncomplicated functional mobile base was designed and built. Its reliability, and simplicity of operation continue to facilitate experimentation in our lab.

2. Design Requirements

The fundamental design requirement is: a self-propelled vehicle, with provisions for computer control of direction and motivation. This mobile base should be capable of carrying:

- cameras and lights for vision research,

- infrared and Sonar sensors for ranging and proximity research,

- on-board processing for local control,

- communication for monitoring, remote control, and off-board processing,

- manipulators for actively modifying the environment.

The off-board processing may include vision, navigation, and path planning among other AI topics.

The vehicle should be very simple to build, control, and maintain. It should be flexible enough to use indoors or out, and capable of carrying a variety of experimental equipment. Calibrated steering and travel are required for accurate movements. Considering the computation time necessary for navigation based on visual servoing,[1] high speed is unsuitable.

Maneuverability is required to facilitate research in crowded environments such as those typical to indoor experimentation. Indoor use provides the conveniences of close physical proximity of the vehicle to the researchers, and the possibility for a controlled environment. The additional capability for outdoor use allows more extensive environments. These two abilities, together in a single vehicle, allow the investigation of a broader set of topics.

For size and maneuverability the vehicle should:

1. fit through doorways,

2. turn around in hallways,

3. steer between obstacles, and

4. negotiate mildly rough terrain such as grass and sidewalks.

The width of a small closet door may be 24 inches (60cm), and a small hallway in an office building might be as narrow as 48 inches (1.2m) wide. Therefore, a width under 24 inches and a 'curb-to-curb' turning length less than 48 inches is desired.

To get in and out of tight places, the vehicle should be able to turn sharply and reverse direction; 'large' compliant tires are appropriate for bumps and uneven ground; and it should be strong enough to propel itself and any attached equipment up an incline of say, 10 degrees.

Our schedule required designing and building a fully functional vehicle within a few months, a major design consideration. Our AI researchers required a vehicle which could be easily controlled and which would perform consistently and without breakdowns. Therefore, the design had to employ techniques which minimized both the time for fabrication and the propensity of the hardware to fail. The resulting design shows elegance in very simply and reliably fulfilling the functional requirements.

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[1]With our current Vision software, we can move about one-half meter at three minute intervals.
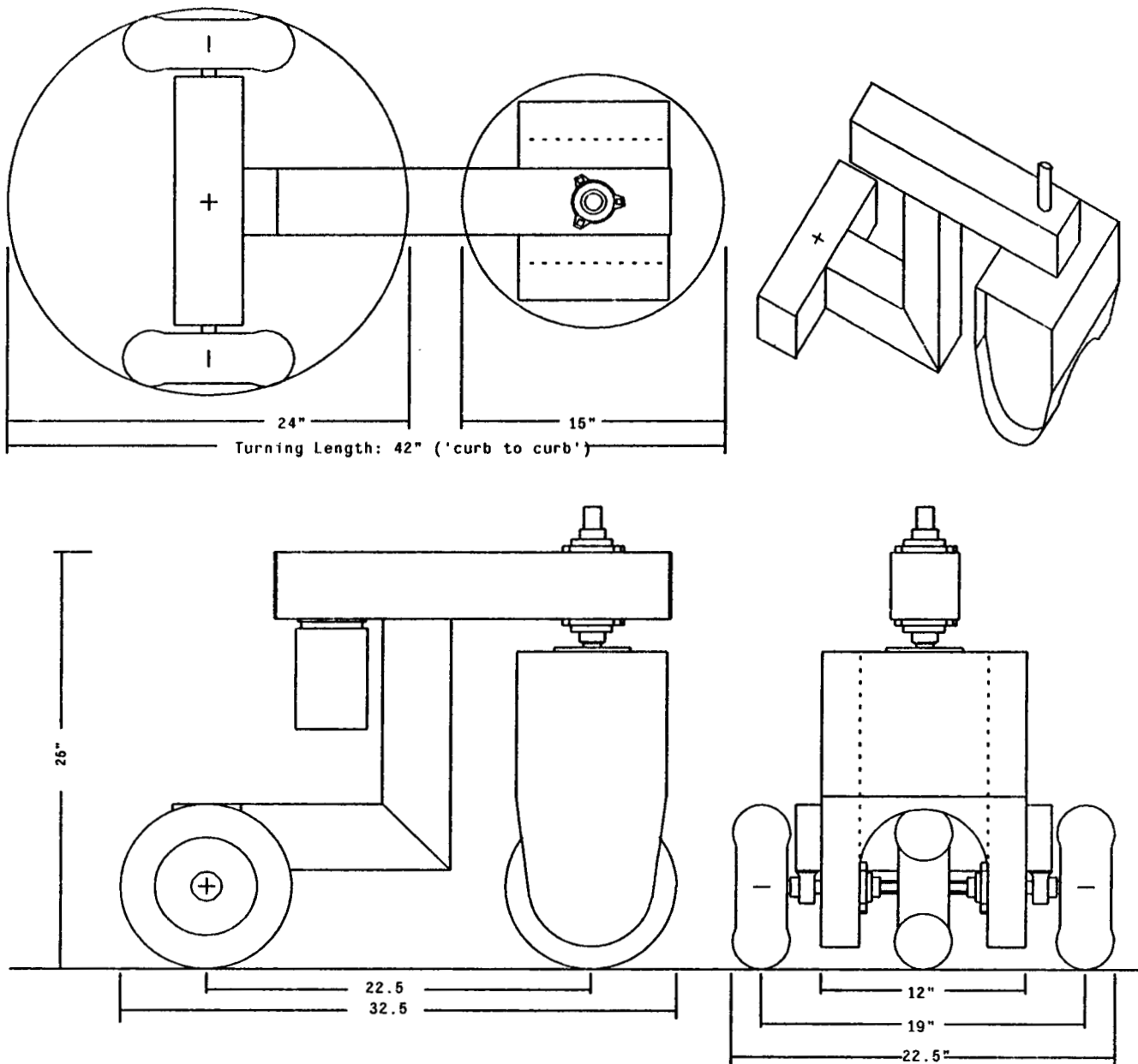
Turning Length: 42" ('curb to curb')

Figure 2-1: *Neptune*

3. Design Decisions

3.1 Chassis and Suspension

To simplify suspension, a tricycle configuration is used. Ten inch (25cm) diameter pneumatic tires[2] are used to provide spring, compliance, and traction on soft ground. Since the vehicle will travel at walking speed and slower, no additional springing or damping is considered necessary.

One fork-mounted wheel is used in the front, and two parallel wheels in the rear. To accommodate sharp turning, the steered wheel is the driven wheel. The fork can turn at least 90° left or right, and the wheel can be driven forward or back, which enables the vehicle to rotate about a point located directly between the two rear wheels. This is a prime feature in the design.

A 'curb-to-curb' turning lenth of under 48 inches is required. The wheelbase is 22.5 inches (57cm) and the rear track is 19 inches (48cm). With the 10 inch tires, the overall width is 22.5 inches, and the length is 32.5 inches (83cm). With allowances for the fork, this gives a turning length 'curb-to-curb' of 42 inches (1.07m). The section on Structure provides more detail.

3.2 Tether

An untethered vehicle is not a requirement for much of the basic experimentation. It is certainly desirable to have wireless vehicles with the flexibility of path traveled and the extended range. However, with this vehicle, an umbilical is used in order to minimize the number of subsystems.

3.3 Power

To eliminate on-board power storage and recharging, power is supplied through the umbilical. In addition, by using 120VAC motors, the vcomplication and weight of power conversion equipment is eliminated. Therefore, 120VAC is distributed for all on-board electrical equipment via outlets mounted in the vehicle frame. A 15AMP circuit breaker protects against overloads. Each piece of equipment provides its own power conversion/protection. For more detail see the section on Electrical Control starting on page 19.

3.4 Motors

Synchronous motors were chosen for drive and steering as this allows elimination of feed-back and servoing systems. The motors are run for a length of time, and the revolutions are *calculated*. This technique, without optical encoders or resolvers, enhances reliability.

One motor is used to propel the vehicle. It is a 72RPM synchronous motor,[3] that developes 1800 oz.in. of torque, and weighs about 45 pounds (20kg). It is coupled to the drive wheel with a 3:1 reduction. The steering motor is a gearhead synchronous motor[4] with a final speed of 3.32RPM, and a substantial torque. It is coupled to the steering neck with a 1:1 ratio.

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[2]Tires are 10x3.40-5 pneumatic hand truck tires rated for about 200 pounds load each.

[3]A Slo-Syn SS1800, the most powerful, commercially available, 110VAC synchronous motor, with a short delivery time.

[4]Slo-Syn SS400-P2, 400 oz.in. at 72RPM with a planetary reduction gear giving about 8000 oz.in. at 3.32RPM.

For study, it may be appropriate to further reduce the drive speed, while increasing the steering speed, thus allowing more fluid moves. The drive speed may be reduced to 67.5% of its present 1 FPS by substituting the appropriate stock sprockets. Adding an additional stage of step-down gearing to the drive can reduce the final speed substantially (also effecting a substantial increase in torque). As the sensory systems become more responsive, an increase in speed may be preferred.

3.5 Control

An on-board processor accepts commands from an RS-232C link. This processor controls switches and reports on operation of vehicle components. The direction and duration of run for each motor is controlled, and the fork position is monitored via limit switches. To select one of the cameras a relay is switched. This processor may also provide control and monitoring for other vehicle-mounted equipment. For more detail of the on-board computer see the section starting on page 25. A means of manual control is also provided.

3.6 Communication

Together with the power, the umbilical carries a number of cables:

- a coax for video signal from the cameras,

- a coax for Sync to the cameras, and

- a multi-conductor cable with shielded bundles.

Serial communication is carried over the multi-conductor cable. Spare conductors allow for expansion. Once the commitment is made to an umbilical, the overhead for communication to any device desired to be mounted on the vehicle is low.
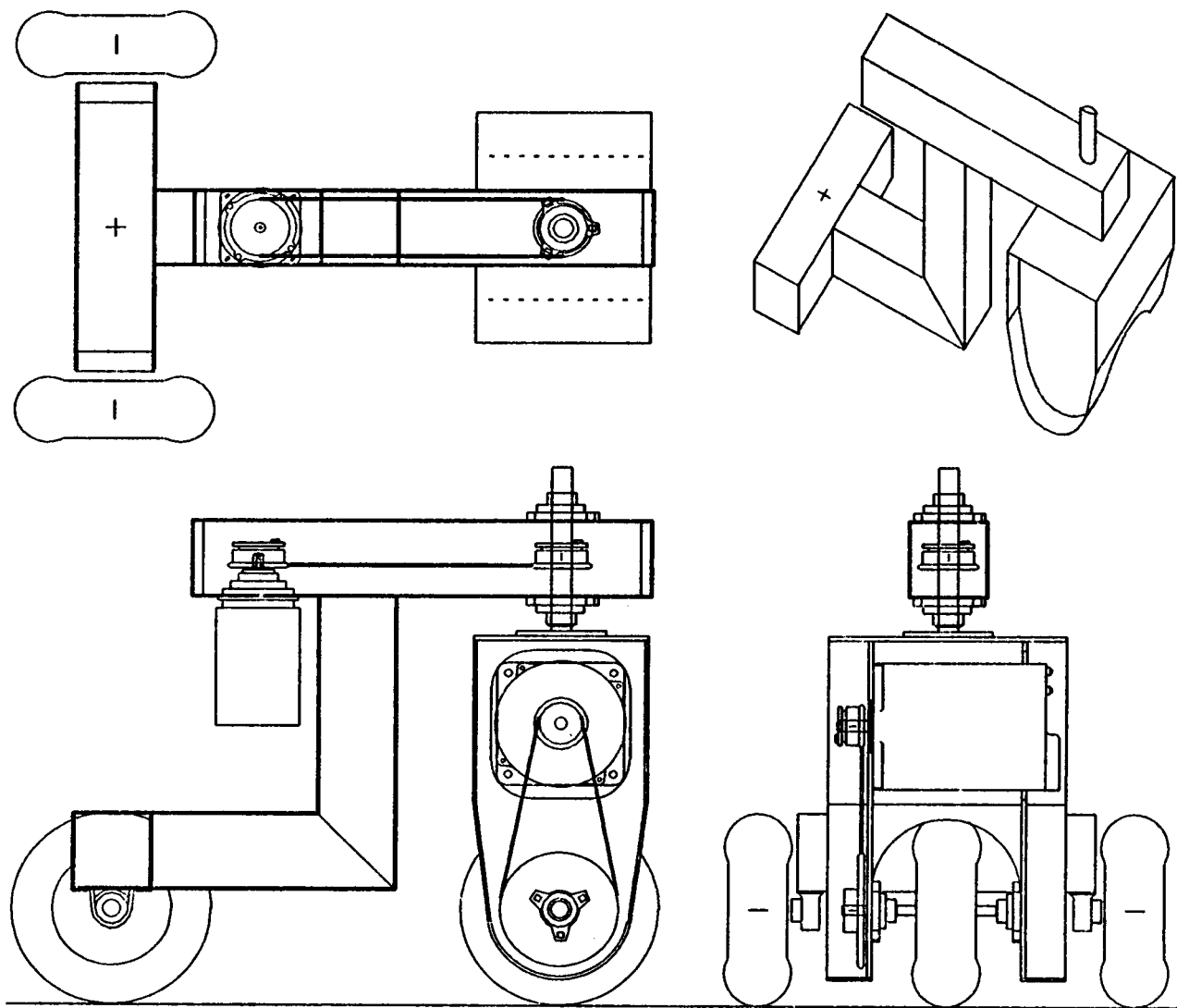
Figure 3-1: *Neptune* - Cutaway

4. Structure

Neptune is made from two basic assemblies, the **fork** and the **frame**. Both parts were designed to have an excess of structural fortitude to withstand abuse and provide secure mounting points for auxiliary experimental equipment. Aluminum was chosen for structural components due to its machinability, which facilitated quick construction and allows subsequent modification to be more easily accommodated.
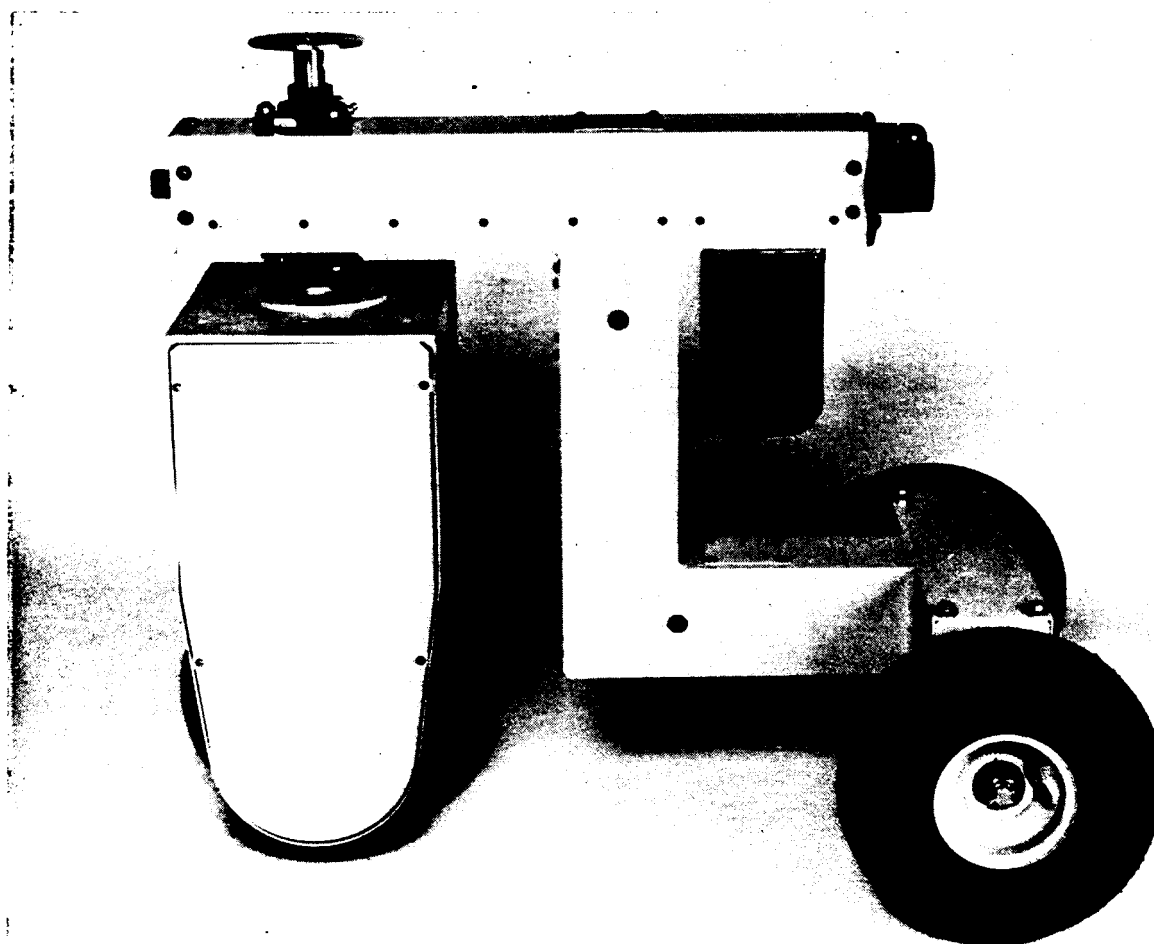

Figure 4-1: *Neptune* - The basic vehicle (port side view).

4.1 The Fork

The drive motor is incorporated into the fork, directly above the drive wheel. This simplifies the transmission of drive power. Because this motor weighs almost 50 pounds (20kg) and develops quite a bit of torque, the fork was designed for strength. All the aluminum used is 6063-T5 or stronger. There are four pieces: the top and two side plates are .250" thick; the piece which forms the front and back is .125" thick.

The side plates are square at the top and taper and curve at the bottom. They are welded to the top plate inboard a few inches on each side. When the piece which forms the front and back is bent and welded around, an angle is formed which provides great stiffness to the whole assembly.

The drive motor is mounted to the starboard plate and can be slid up and down to adjust the tension of the drive chain. A simple screw jack is provided on this plate to aid adjustment of the motor with a wrench. There is a reasonable amount of room here to include clutches, additional gearing, etc.

The port plate has a cutout through which the back end of the drive motor protrudes. In this position, the motor and drivetrain are well balanced above the drive wheel. Below this cutout is an adjustable bracket to help support the motor, taking some stress off the starboard side.

One bearing flange block on each side plate supports the drive axle. There is room on the port side, around the drive axle, for an accessory such as a resolver. Side covers provide protection.

The fork top is bolted to a steel flange which is welded to a hollow steel neck. There is no castor on the front wheel. This was the decision because the vehicle drives slowly, and the geometry of the steering affects calculation of direction, and the drive motor is heavy. The fork neck extends up beyond the top frame piece. A hole in the side of the neck allows the cable from the motor to pass, up through the neck, and out above the top frame section. This cable simply winds and unwinds as the fork is turned. A round plate is screwed onto to top of the fork neck for mounting of sensors or perhaps a manipulator. These will turn as the fork turns.

4.2 The Frame

The frame is made of 4 inch square, extruded aluminum tubing (6061-T5), with a .125" wall thickness. There are four pieces. In addition to the high strength to weight ratio, the tubing provides a convenient raceway for cabling and housing for small components.

The top section provides mounting for the steering motor and the fork. As the fork is heavily loaded with the drive motor, the steering motor was placed aft as much as possible. The steering motor mounting provides for steering chain tension adjustment. The chain runs *inside* this section, thus providing protection. The fork neck is supported with bearing flange blocks above and below. Snugly fitting end caps, fore and aft, provide additional torsional stiffness to this member. These caps can also be considered as strong and adaptable chunks of metal on/in/from which to mount accessory equipment. For instance, the current camera support is mounted to one of these.

The vertical section attaches to the mid-part of the top section. It has a lower end cut at 45° to mate with the next section towards the back.

The rear section is attached like a "T" and spans across the back. It has end plugs, again for torsional stiffness, which also serve as strong mounting for the two pillow blocks which support the rear axle. These pillow blocks are a variety which have rubber in them, and provide additional shock absorbing.

Holes

A number of 2.75 inch diameter access holes are let into the sections of the frame at convenient places. They each have four tapped holes around them to affix coverplates. Consideration to stresses in the frame dictated placement. A line of holes is provided on each side of the top frame piece to facilitate mounting auxiliary equipment. Other holes are provided for passing cables. The frame, and the fork (see above) have been designed to be robust enough to accommodate many additional holes, to facilitate the mounting of auxiliary equipment.

Counterweights

Neptune has a fairly high center of gravity due primarily to the position of the drive motor. Considering the addition of other equipment, this center of gravity may be made higher still. When the fork is steered at right angles to the rear wheels, there is a possibility that the vehicle will fall over because of the vehicle's narrow track and the instantaneous starting nature of the synchronous drive motor. To avoid this, counterweights are hung below the rear axle. These are simple rectangular plates of steel, the same size as the rear frame section, 4 inches x 15 inches (10cm x 38cm), with mounting holes aligned with the rear axle pillow block holes. Each is 0.5 inches thick (12.7mm) and weighs over eight pounds (3.7kg). Three weights provide enough counterbalance to prevent the basic vehicle from tipping, *at rest*, when on a surface of 45°. With this ballast the basic vehicle, weighs in at about 175 pounds (80kg). Additional compensating weights may be hung here when the vehicle is more highly loaded.
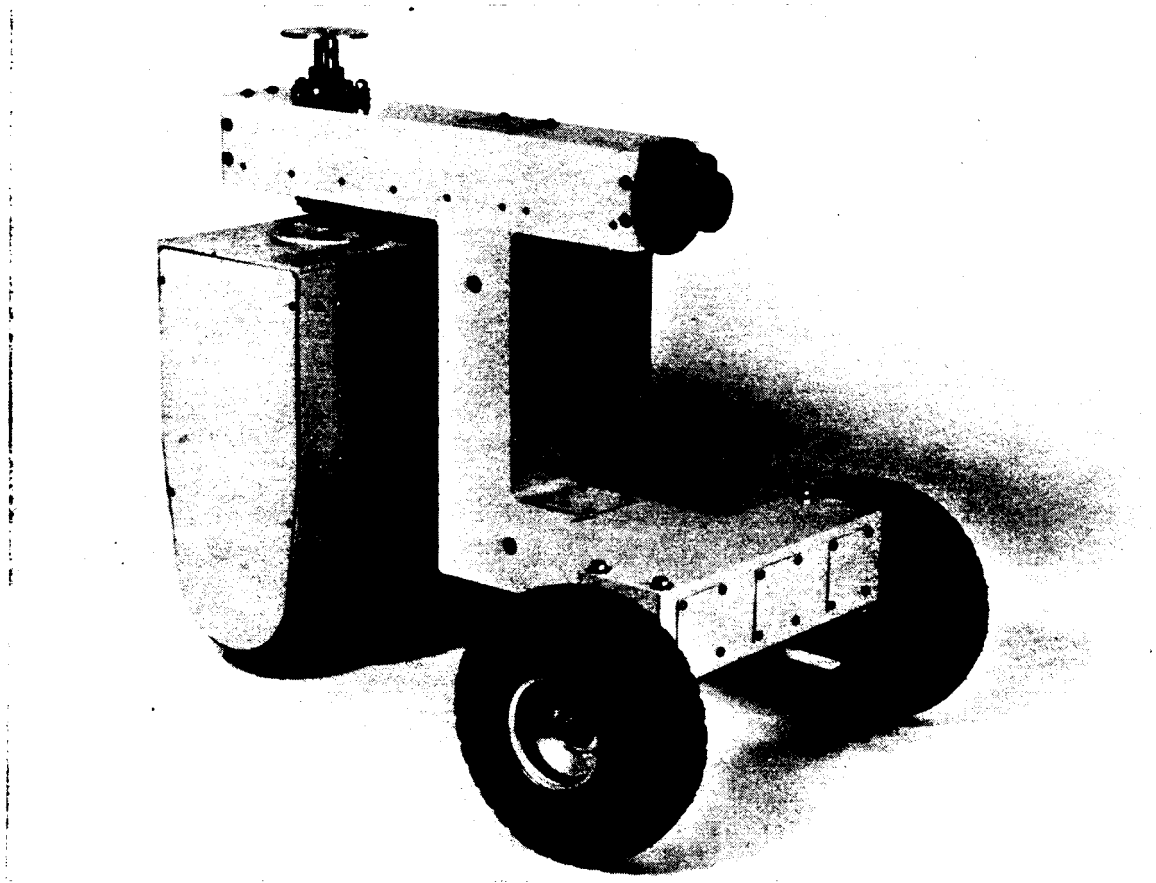

Figure 4-2: *Neptune* - Aft of port. (Counterweights not installed.)

4.3 Construction

The frame and the fork assemblies are welded for strength and simplicity of construction. A few threaded holes were made in the fork side plates for jigging before welding.

Off-the-shelf housed bearings are used to mount the three rotating shafts (the two axles and the fork neck). In

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the same way, the chains[5] and sprockets for driving and steering are standard components. The wheels and tires are units manufactured for handtrucks. Delivery time on these items is short, on the order of one to three weeks. By employing these pre-fabricated components, shop time for custom parts was minimized. About one man-week of machine shop time was required.

The chain sprockets are all keyed to their shafts with stock split-taper bushings. The bearing housings, frame caps, motors and the rest of the parts are bolted or screwed together. Once all the pieces were made (including sizing the chains), assembly of the mechanical parts required less than a man-week.

Full shop drawings are provided in **Appendix I.**

4.4 Phase Shifting Components

Each motor has two windings; one receives the AC current directly, the other through a phase shifting network (a resistor and capacitor). These components are mounted near their respective motors. While the steering motor has components small enough to mount *inside* the vertical frame section, the drive motor has a capacitor measuring 2.5" x 5" x 7" (6cm x 13cm x 18cm), and a 40Ω resistor of 375 Watts!

4.5 Manual Control

A pendant control box is provided to allow for manual control (such as positioning the vehicle in a convenient spot before starting an experiment and parking it afterwards). Its functions include switches for turning the steering motor left and right, powering the drive motor forward and back, and emergency stop for safety. Also included in this hand-held controller are indicator lights which show the status of the limit switches. A connector is provided on the vehicle to accept the controller, however, it may also be used at the other end of the umbilical.

Manual control is also possible by sending appropriate commands to the on-board processor via the RS232-C link.

4.6 Limit Switches

Three limit switches provide calibration information for the fork. A Center switch, a Left/Right switch, and an Out-of-Range switch.

The Center switch has a deadband of about ±4°. This allows for:

  1. the ±1° play in the fork due to backlash in the steering planetary gear, and

  2. overrun of the steering motor.

As the backlash in the steering gear increases with wear, a more accurate indication of wheel centering can be had by monitoring transitions of the Left/Right switch while in the center range.

Out-of-Range is indicated when the fork turns more than 135° in either direction.

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[5]Both the drive and steering chains are 40LL which is, 0.5 inch pitch and lifetime lubricated (to minimize required maintenance).
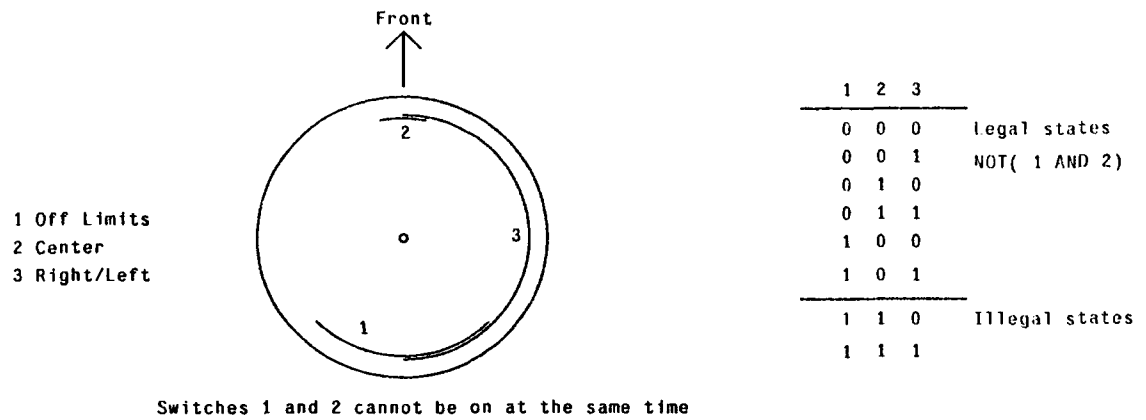
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Front

1 Off Limits
2 Center
3 Right/Left

1	2	3	
0	0	0	Legal states
0	0	1	NOT(1 AND 2)
0	1	0	
0	1	1	
1	0	0	
1	0	1	
1	1	0	Illegal states
1	1	1	

Switches 1 and 2 cannot be on at the same time

Figure 4-3: Limit Switch Ranges

4.7 Camera Mount
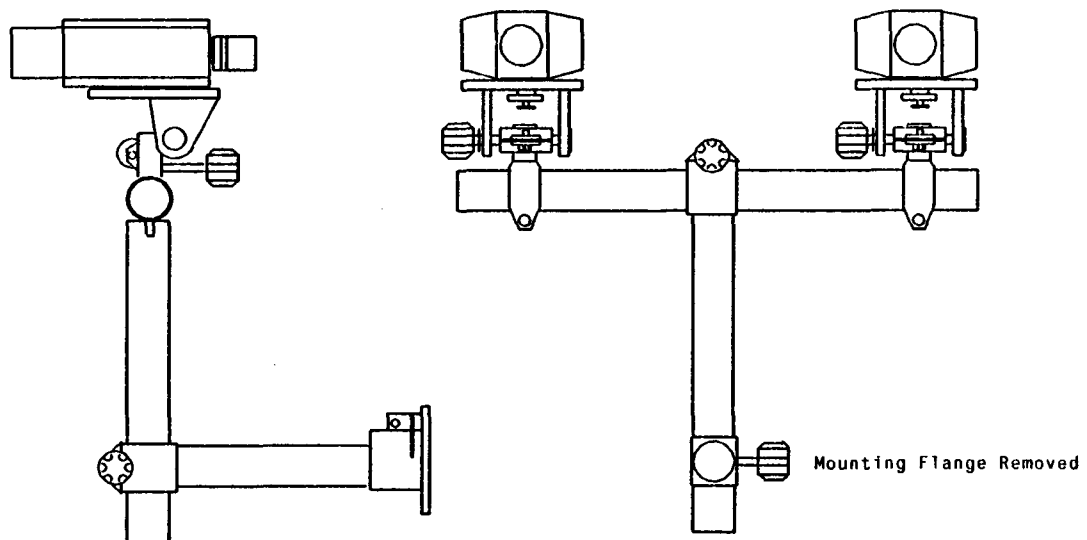
Figure 4-4: *Neptune* - Camera Support

A mounting system from a professional tripod manufacturer[6] is employed to support the two television cameras required by the current Vision research. The flange, couplings, lengths of tubing, and camera mounting heads allow considerable adjustment of the cameras up and down as well as inboard and outboard. This system provides great flexibility for mounting a wide range of cameras and other sensors.

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[6]Davis and Sanford

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Figure 4-5: *Neptune* - The first run
Kevin Dowling attending.

5. Performance

5.1 Mechanical

With a 3:1 chain reduction from the motor, the drive wheel runs at 24RPM. This is about one foot per second; less than 1 MPH. A set of sprockets reducing the ratio to 4:1 is also available.

With the drive motor providing 1800 oz.in. of torque and the 3:1 reduction gearing, about 67 pounds of draw-bar pull is calculated. This should take a 350 pound vehicle up about an 11° slope. An early test involved loading *Neptune* to achieve a combined gross weight of about 350 pounds, starting on a level surface, and driving it up a 9° slope in a hallway near our lab. It did just succeed.[7]

The nature of a synchronous motor is such that it can drive a greater load than it can start. Therefore, a more useful number is the actual slope on which the vehicle can be *started*. Fully loaded with control box, processor, cameras, etc., *Neptune* weighs 175-200 pounds. For testing, a variably inclined surface was used. Experimentally, it managed to *start* on a 10° slope.

Another 'feature' of these motors is that once they slip, given enough speed, they will turn relatively easily. While this may be a convenience when turning the fork by hand (without power), it may be hazardous to stand below the vehicle when attempting too great a slope. Caution is recommended.

The steering motor with its 3.32RPM output and a 1:1 chain drive to the fork neck, provides more than enough torque, even when the vehicle has no forward rolling speed. Final steering is at about 20° per second.

5.2 Moving Accuracy

Synchronous motors have a starting delay which varies somewhat. This is not apparent in the steering which, due to the low gearing, has a measured accuracy within one degree. On the other hand, effects of this delay are significant in the movement of the drive motor.

Measurements were taken for straight moves forward and backward at varying lengths of time. An equation for calculating distance traveled is

$$distance = speed \times (time - delay)$$

where *speed* is 12.3 inches per second and *delay* is considered 0.12 seconds. Variation in short moves (one second) was about ±0.75 inches, and in longer moves about ±0.5 inches of the desired position. Different algorithms for moving will result in different dead-reckoning accuracies. One early method for moves required very little geometric calculation:

1. Turn the steered wheel 90°.

2. Run the drive motor for a short time to rotate the vehicle about the center point of the rear axle.

3. Return the steered wheel to 0°.

4. drive forward along the diagonal formed by the desired change in the *x* and *y* positions.

5. Again turn the steered wheel 90°.

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[7] However, this test was not optimal as it was a live load, namely Hans Moravec.

6. Rotate the vehicle to the direction it originally started.

7. Again straighten the steered wheel.

If at the second step, the intent is to rotate the vehicle a only small amount, the starting delay variation of the driving motor will more adversely affect move accuracy.

For each move employing this method, the steered wheel is scrubbed back and forth a number of times by the substantial encouragement of the steering motor.[8]

Another algorithm employs S-shaped curves (fitting splines to positions along the desired path) which allows the drive motor to run continuously while the steering motor is moved back and forth. This helps to minimize the effect of the drive motor starting delay error.

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[8]Another useful application of this ability (to rotate the front wheel in place) is to orient a sensor or manipulator attached to the fork assembly.

5.3 System Performance

The physical vehicle becomes a robot with the addition of environment mapping capabilities [7, 4], path planning [6], and navigation [1], software. The current software runs off-board on a VAX-11/780. In a number of Vision based experiments (using a binocular pair of monochrome video cameras), the vehicle made moves of about 20 inches (0.5m) at three minute intervals, to successfully navigate 32 feet (10m) through a room of obstacles. Experiments have also been run with environment maps derived from a 360° ring of 24 sonar range sensors mounted on-board.

Near-future plans include an on-board video digitizer and processor for some of these vision functions.

5.4 Summary

To facilitate autonomous mobile robot research, it was decided to build an uncomplicated mobile base. Ninety days later, a tested, working vehicle was used for vision and navigation experiments. Its operational simplicity allows it to be used for a variety of different studies by a number of researchers. Its mechanical fortitude accommodates the mounting needs of many different experimental apparatuses. By careful design and employing standard components wherever possible, this rugged, reliable vehicle was produced in a minimum of time.
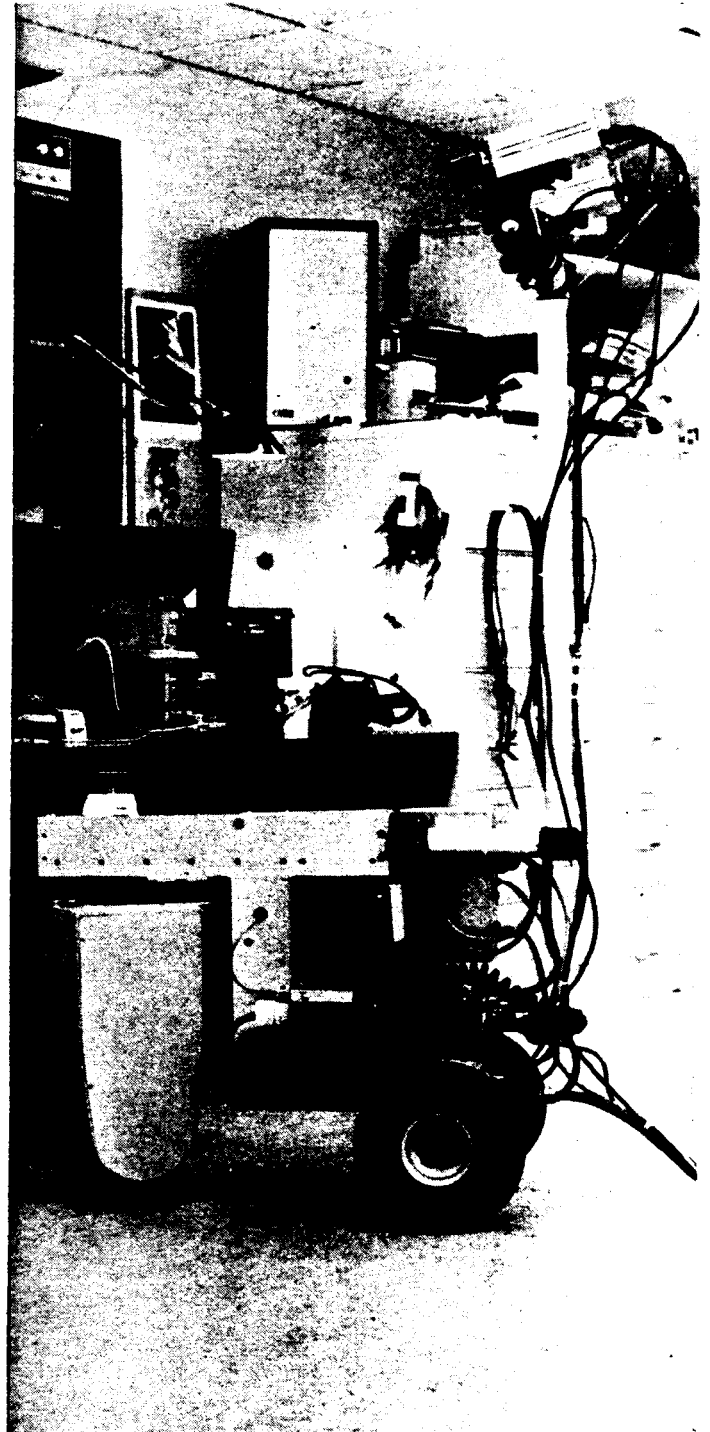
Figure 5-1: *Neptune* - Navigating in the Lab

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6. Electrical Control

Simplicity and the ability to change hardware were primary design considerations in the electrical system.

All control is binary. Logic signals from the on-board processor control solid-state relays which switch power to the motors. Some additional circuitry provides for safety:

- The system must be powered ON and then the START button pressed before the motors can be energized.
- Both windings of one motor cannot be switched on simultaneously.
- A delay prevents a motor from being instantly reversed.
- A number of STOP buttons helps prevent collisions in an emergency.
- The drive motor is used as a brake when the vehicle is not moving by applying a DC 'holding' voltage.

6.1 System Power

A latching configuration is used for turning on system power.
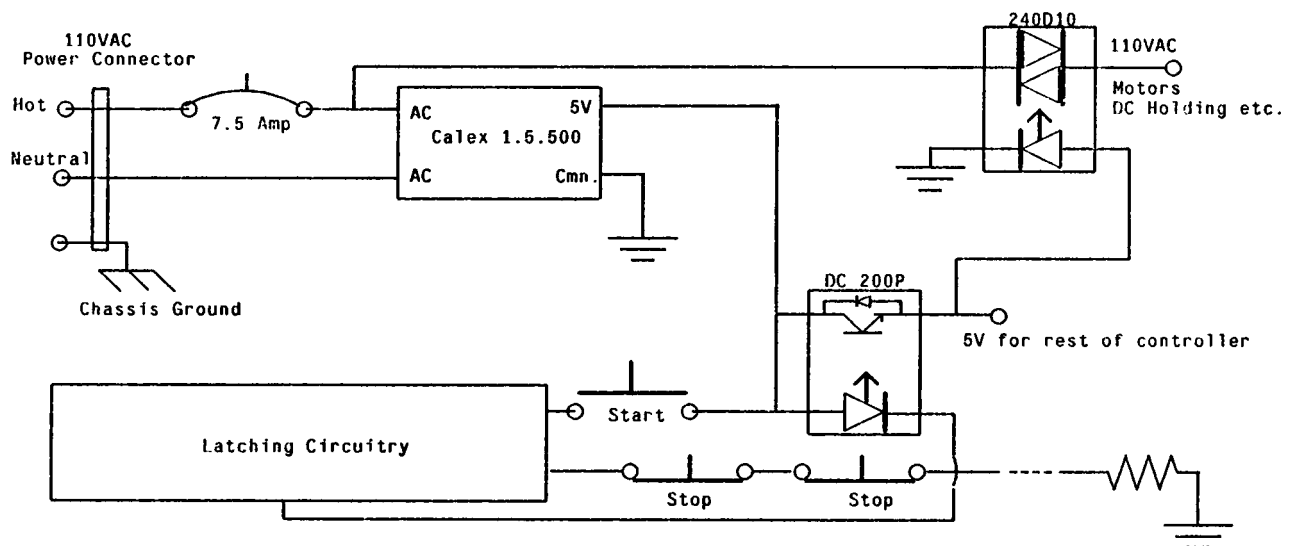
Figure 6-1: Start/Stop System

The start/stop system must have the following properties: When a stop switch is pressed, power to the controller and motors is shut off *immediately*. If the start switch and a stop are pressed simultaneously, the power stays off. The manual controller must be able to disconnect from the vehicle and yet, when connected, be able to stop the vehicle with the stop switch provided.

The figure above shows a simple outline of how this was accomplished. The inputs to the latching circuitry are the start and several stop switches. When the start switch is pressed, the output line is pulled low, thus turning the control side of the two SSR's ON. One SSR turns on the AC power for the rest of the controller and the motors. The others turns on the 5VDC for the logic in the rest of the controller.

The latching circuitry can be seen in detail in Appendix II. A simple flip flop was constructed from NOR gates. In addition, the switch inputs are gated in such a way that illegal inputs to this configuration cannot occur. The output latches high if any of the stop switches are pressed, thus turning off the control side of the SSR's. If the manual controller is connected, and the stop switch on it is pressed, it pulls an input low. The arrangement of discrete components shown with Schmidt trigger buffers is to initialize the state of the circuit when power is applied to Neptune and make sure the SSR's remain off until the start switch is pressed.

6.2 Motor switching

Several solid-state relays provide a simple interface between the logic level signals and switching AC power to the motors on and off. The requirement was a 10 amp capacity with higher peak ratings and a voltage rating able to handle the doubled voltage that can occur across the phase shifting capacitor and the motor windings. The model Opto-22 240D10 is used for directly switching the motor currents for both motors.

See Appendix II for the schematic layout of the SSRs and the motor windings.

When the drive motor is off and no current is flowing though the windings, it becomes fairly easy to turn. This is unacceptable since reliance on position is essential and the vehicle will be stopped on inclines. On the other hand, the steering motor is geared down about 20:1 so that a great deal of external force is required to rotate the fork when it is not powered.

For the drive motor, a DC current is put through the windings which holds the motors with a substantial torque. The motor manufacturer recommended a 9.5VDC supply capable of handling 4.7 Amps. A 9VDC unregulated supply, rated at 10 Amps, is used because exact voltages and regulation are not necessary for the holding torque. In a simple experiment, *Neptune* was placed on a steep 30 degree slope, and the DC current put across one of the motor windings. *Neptune* would tip over before the wheel ever gave way.

When switching motor direction by turning off one SSR and turning on another, care must be taken during this transition period because the capacitor may discharge through the two SSRs. This short circuit discharge current may destroy the SSRs. An additional resistor may be placed in series with each SSR for protection, but if the control circuit insures that one SSR is off before the other is on the resistors are unnecessary. A simple delay circuit has been incorporated into the control signal circuit to do exactly this. It is possible to do this in software by timing the output control signals but the potential is there for damage. Thus, the hardware incorporation of the delay is a major safety factor.

6.3 Digital Control Logic

All logic in the *Neptune* Electrical Control System operates on active low logic. That is, things turn on and switch with logic 0 signals. This is consistent throughout the design. The simple reason is that the digital circuit elements effectively sink more current than they can source.

The inputs to the system are the processor signals and the manual controller signals. The outputs are the motor signals and directions. In between, there is hardware to make sure that conflicting signals aren't generated (e.g., a motor told to go forward and backward at the same time), and that manual and computer control do not conflict.
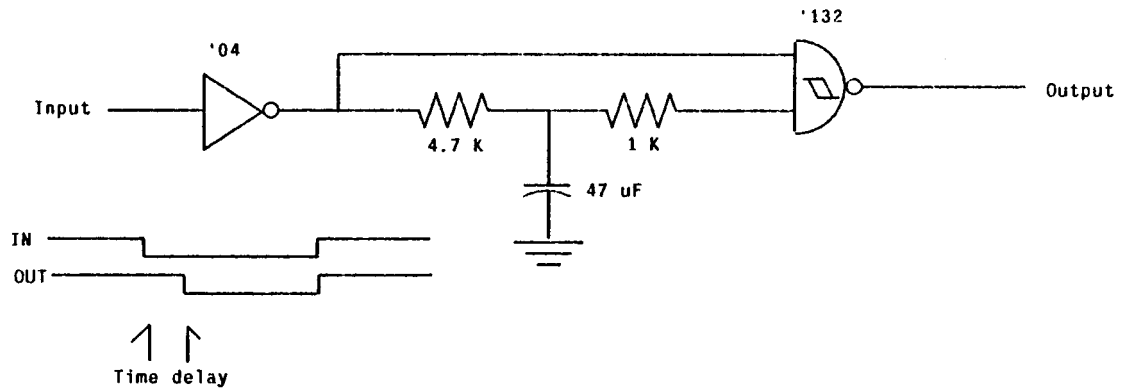
6.4 Delay Circuit

Figure 6-2: Delay Circuit

The delay circuit provides a safety factor when motor direction is changed, ensuring that one SSR is off before the other is turned on. (See the section on Motor Switching for more information on this.) The delay circuit has the following property: When an input signal drops low (active), the output signal will drop low slightly later. When the input signal goes high, the output signal also goes high (effectively at the same time).

This circuit block buffers and inverts the input signal. The inverter output fans out to a resistor-capacitor arrangement and to the input of a Schmitt trigger NAND gate. The RC arrangement delays the signal because the capacitor charges up over a finite time, and the resistor impedes the current to it. Then after some time, the capacitor charges up and the NAND input on the RC circuit side changes state. The Schmitt trigger output changes smoothly due to the hysteresis effect. When one input is low, a property of NAND logic causes the output to go high. Thus when the delay input goes high, the inverter output goes low, then one of the NAND inputs is low and it's output goes high. This simply means that when the input goes back to a high state the output also returns to a high state.

The values of R and C are common values that provide an RC value of 0.08 seconds (assuming actual values are equal to their labeled values). Originally the delay was longer with an overestimated safety factor but for smooth motions while turning the delay was reduced to the present value.

6.5 Main Control Circuitry

As described, each motor SSR control has a delay unit associated with it. The delay unit has computer or manual controller signals as its input. A simple method of switching between the manual controller and the computer so conflicting signals will not occur is obtained by using a Quad Dual Input Multiplexer. A 74C157 is used and fits the bill perfectly. The four inputs are: Drive Forward, Drive Back, Steer Left, Steer Right for each set of inputs.

Note that the manual controller has a switch to enable manual control. It pulls the select on the mux enable low thus allowing the set of four inputs from the manual controller to control the vehicle. When this switch pulls the mux enable high the computer signals control the vehicle. Passive pull-up resistors are used for bringing the signal high when something is not enabled.

The computer inputs still have the capability of turning on both SSRs to a motor in software. Through the addition of a few NAND gates, this both-on state is not allowed to occur. When it does, the motor is turned off because both signals are low.

Due to the physical construction of the switch, the manual controller cannot have both directions turned on at once. The final addition is NANDing the inputs to the drive motor to see when the DC Holding Torque should be turned on. If both directions are turned off, then the DC SSR should be turned on. One NAND gate suffices for this.

The DC holding torque is switched by a small electro-mechanical relay. The relay has logic level voltage input to a small 2N2222 transistor configuration which drives the relay coil. An attempt to find a DC SSR with the combination of TTL level control, high current handling (5AMP), and high blocking voltage (200v) was unsuccessful so a simple relay configuration was used (See Appendix II).

Camera Switching
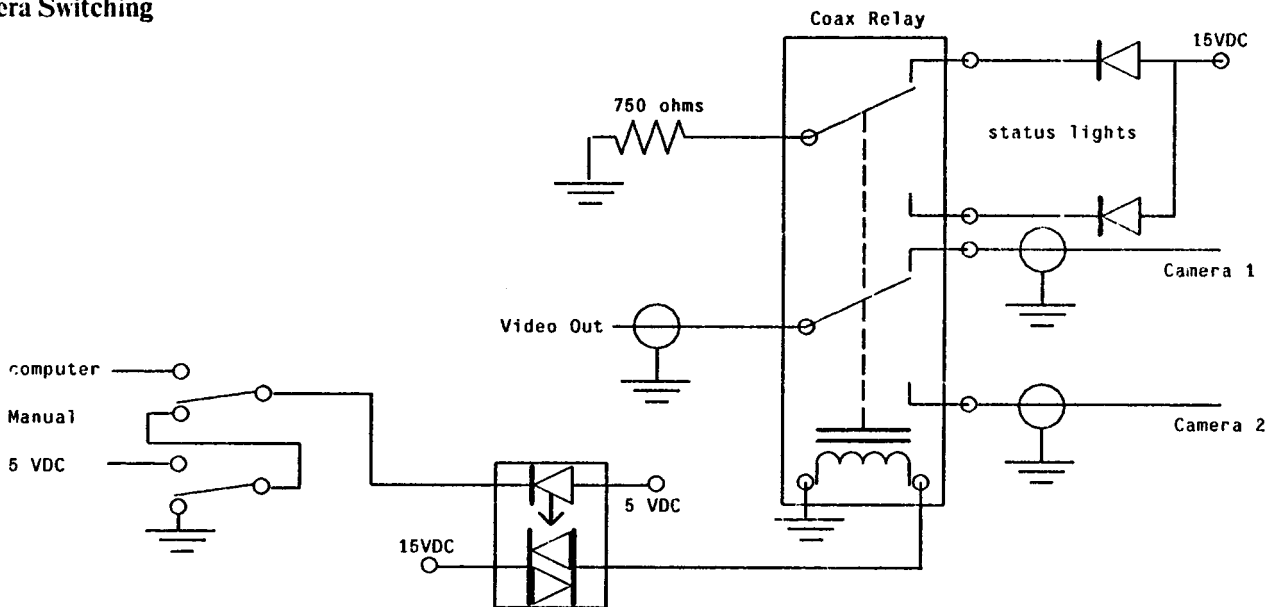
Figure 6-3:   Camera Circuitry

Two cameras are mounted above the vehicle for capturing stereo image data. Instead of running a coaxial cable for each camera, one cable and a method of switching between the two cameras was designed. A processor signal turns on the input side to a DC SSR. This SSR triggers a coax relay which switches the output line between camera 0 or camera 1. The relay is a double-pole, double throw design. The other pole is used simply to select an LED output to signal visually which camera is currently being selected. The LED's are mounted adjacent to the BNC connectors to which cameras are connected to on the rear of the control box.

In addition, a pair of switches enables manual camera switching. This makes it easy to do calibrations, inspect

camera focus etc. One switch switches from computer control to manual control and the other selects one of the two cameras. Again, the LED's indicate which camera is currently selected.

6.6 Layout

All the power supplies, circuitry, switches, etc. fit into a 12x12x4 inch box that fits on the back of *Neptune*. See the drawings in Appendix II for further layout details. Considerations for enclosures, switches, and connectors were simplicity and ruggedness.

6.7 Possible Enhancements

Because the drive motor is synchronous, *Neptune* starts with a slight lurch when the motor is enabled. Ramping up the frequency is a possibility. A simple circuit using power MOSFET's may be used to chop a DC input voltage and provide logic level control of speed. There are on the market variable frequency drives but with few exceptions, these are designed for multiple phase induction motors and are physically fairly large for Neptune to haul around.

In series with the stop switches is planned a bumper "skirt" to shut down the motors when a collision is imminent.

24

7. On-Board Computer

On board, *Neptune* carries one microcomputer system, built around a Motorola MC68000 32-bit microprocessor. The function of the microcomputer is to act as an intelligent interface between the off board computers (i.e., a VAX running vision software) and the on board hardware, chiefly the motor driver and the camera selection circuitry.

Two RS-232 lines in the umbilical are used to connect the microcomputer serially to the outside world. One of these lines connects the microcomputer to a debugging and status terminal, while the other connects it to the VAX. The microcomputer is connected to the various robot control and status lines through a parallel port.

Figure 7-1 depicts the basic microcomputer's architecture, along with the external connections.
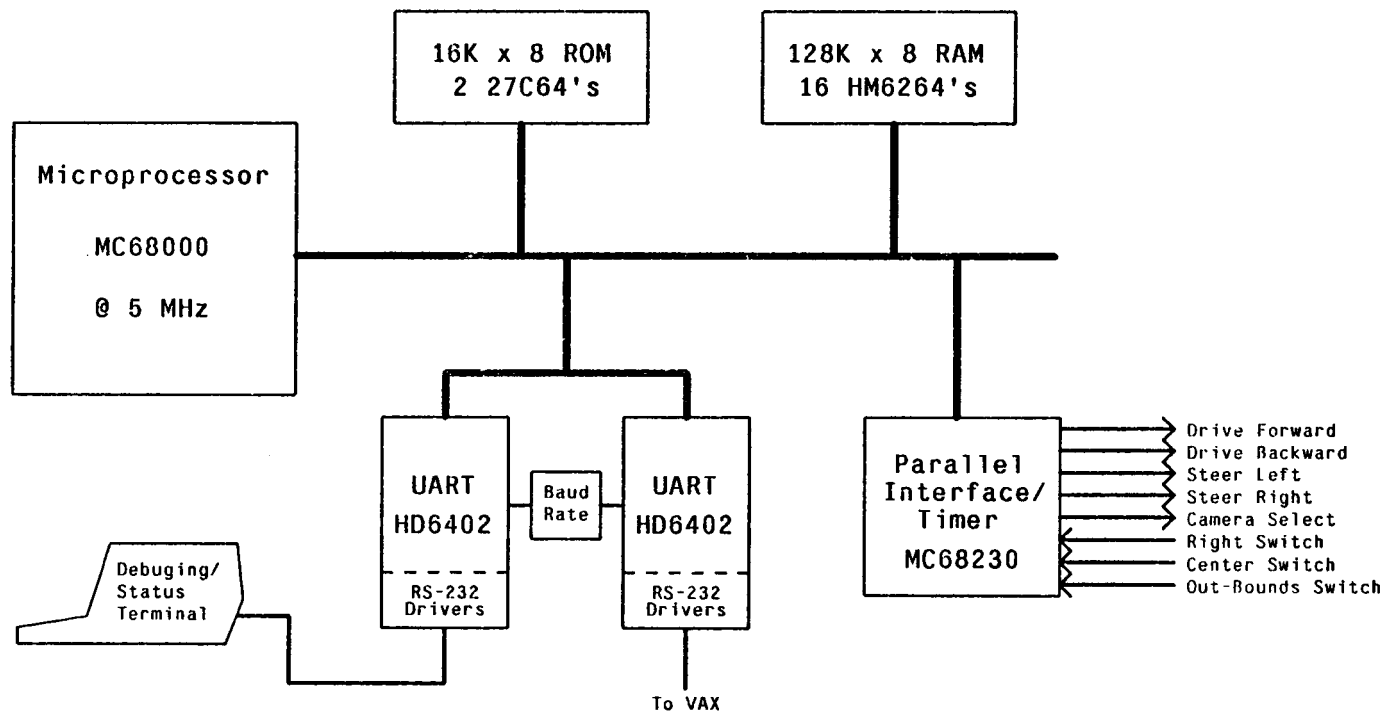
Figure 7-1: On-Board Processor Block Diagram

To allow the VAX to control the robot, the microcomputer runs a special controller program, 'Nepcon', which parses high level commands from the VAX and translates them in to robot motion and control. Appendix III contains a complete description of the 'Nepcon' program.

Physically, the microcomputer is built on one Augat Multibus prototyping board, approximately 7 by 12 inches. To minimize power consumption and possible heat problem, CMOS integrated circuitry was used where ever possible (the only non-CMOS circuits are the 68000 microprocessor, the 68230 parallel interface/timer and the RS-232 bus drivers). The microprocessor is enclosed in a 10 by 14 by 4 inch aluminum box, along with a small Calex +5, +12 and -12 volt supply.

8. Bibliography

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PhD thesis, Stanford University, September, 1980.
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Technical Report, Carnegie-Mellon University, May, 1984.

[4]   Moravec, H. P. & Elfes, A.
High Resolution Maps from Wide Angle Sonar.
In *Proceedings of IEEE-International Conference on Robotics and Automation*. IEEE, 1985.

[5]   Muir, P. F.
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Master's thesis, Carnegie-Mellon University, December, 1983.

[6]   Thorpe, C.
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In *Proceedings of AAAI-84*. AAAI, 1984.

[7]   Thorpe, C.
An Analysis of Interest Operators for FIDO.
In *Proceedings of IEEE Workshop on Computer Vision*. IEEE, April, 1984.

Appendix I

Mechanical Drawings

Appendix I

1.0

8.75

8.75

8.75

5.25

5.25

12.0

3.

.250

6.25

.125

.250

SS1800
4.6

7.5

SS400 w/ P2

SS1800

1 inch

12.00

6.00

2.125

2.125

CL

3.375

4.375

1.250 1.250

Six holes
.175 dia.
countersunk
for #8 screws

3.375

8.75

1.250

CL

1.250

3.375

3.375

Four holes
in a square
.325 dia.

One hole
Centered
.500 Dia.
Chamfer edges.

Top

Left

A

Back

D

B

Note: All measurements: +/-.015"
Or where given.

C

Note: Make one.

Right

Material: .250" Aluminum
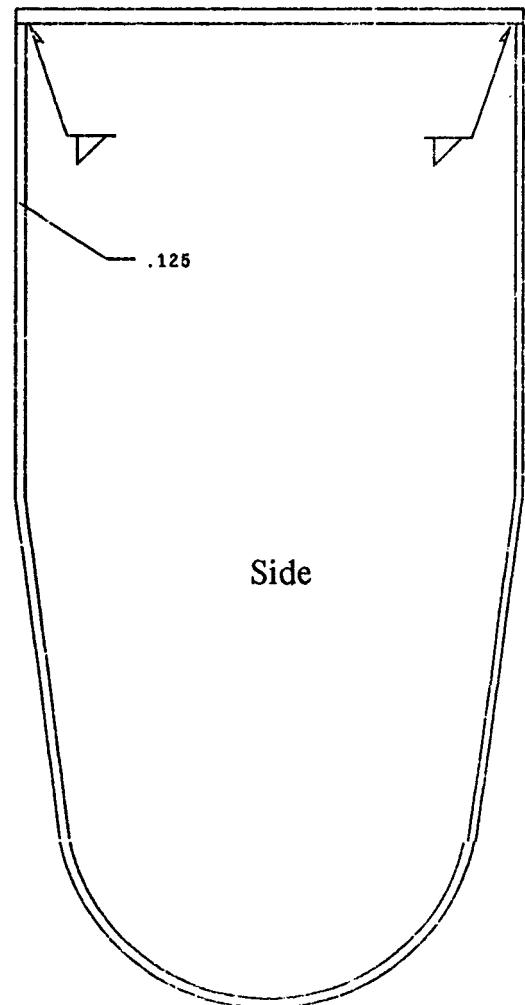6063-T5

Front

1 inch

8.500

3.375   3.375

.250

Seven Holes
About 1.000 deep
Drilled and
Tapped for #8

.425

1.000
.800

1.000

1.500

8.250

r= 1.380
   1.375

2.656

3.875

Four
holes

2.656   2.656

1.000

9.000

2.656

Ⓒ

.250

1.000   1.000

.425

8.500

One Hole
3" dia.

11.000

3 holes
.300 dia.

120°

One hole
1.000 dia.

14.000

r=1.250

120°

14.5"

r= 3.500

17.500

The taper is determined by a line from 8.500 to about 14.5 in.
which is tangent to the 3.500R arc (about .75 in).
The arc is about 165°.

Top

Left

Back

A

B

D

C

Right

Front

Note: All measurements: +/-.015"
      Or where given.

Note: Make one.

Note: Bevel perimeter on one side
      for welding.

Material: .250" Aluminum
          6063-T5

1 inch

⌂ᵢ	**Mobile Robot Lab**	Ⓒ 1984

Title: Trike Fork Right Side

File: [rover]/usr/gwp/d.tri/ForkRight.dp

Date: 7-Feb-84	Scale: NTS	Approved:
Drawn by: G.Podnar		Dwg. Fork
Checked by:		No.: 3 of 8

8.500

3.375   3.375

.250

Seven Holes
About 1.000 deep
Drilled and
Tapped for #8

1.000
.800

.500

1.500

2.500

6.250

8.250

All four
r= 2.000

1.500   1.500

3.750

8.500

9.000

.250

.250

1.000

.425

C L

14.000

3 holes
.300 dia.

120°

One hole
1.000 dia.

r=1.250

120°

14.5"

r= 3.500

17.500

The taper is determined by a line from 8.500 to about 14.5 in.
which is tangent to the 3.500R arc (about .75 in).
The arc is about 165°.

Top

Left

Back

A

B

D

C

Right

Front

Note: All measurements: +/-.015"
      Or where given.

Note: Make one.

Note: Bevel perimeter on one side
      for welding.

Note: Material: .250" Aluminum
              6063-T5

1 inch

Mobile Robot Lab   © 1984

Title: Trike Fork Left Side

File: [rover]/usr/gwp/d.tri/Forkleft.dp

Date: 8-Feb-84   Scale: NTS   Approved:
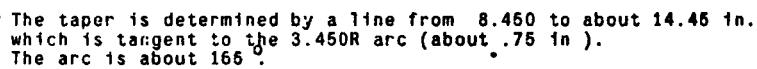
Drawn by: G.Podnar

Checked by:

Dwg. Fork
No.: 4 of 8

12.000

2.625

2.125

7.825

8.125

.375

1.000

1.500

8.250

.250

11.00

Four holes
each end.
.200 dia.

Four holes
each end.
.175 dia.
Countersunk
one side.

Four holes
each end.
.175 dia.
Countersunk
one side.

3.500

One hole
each end.
.500 dia.
Beveled
both sides.

Bend line

r=3.750

6.000

13.00

14.50

19.55 (approximate)

Gradual bend
starts here
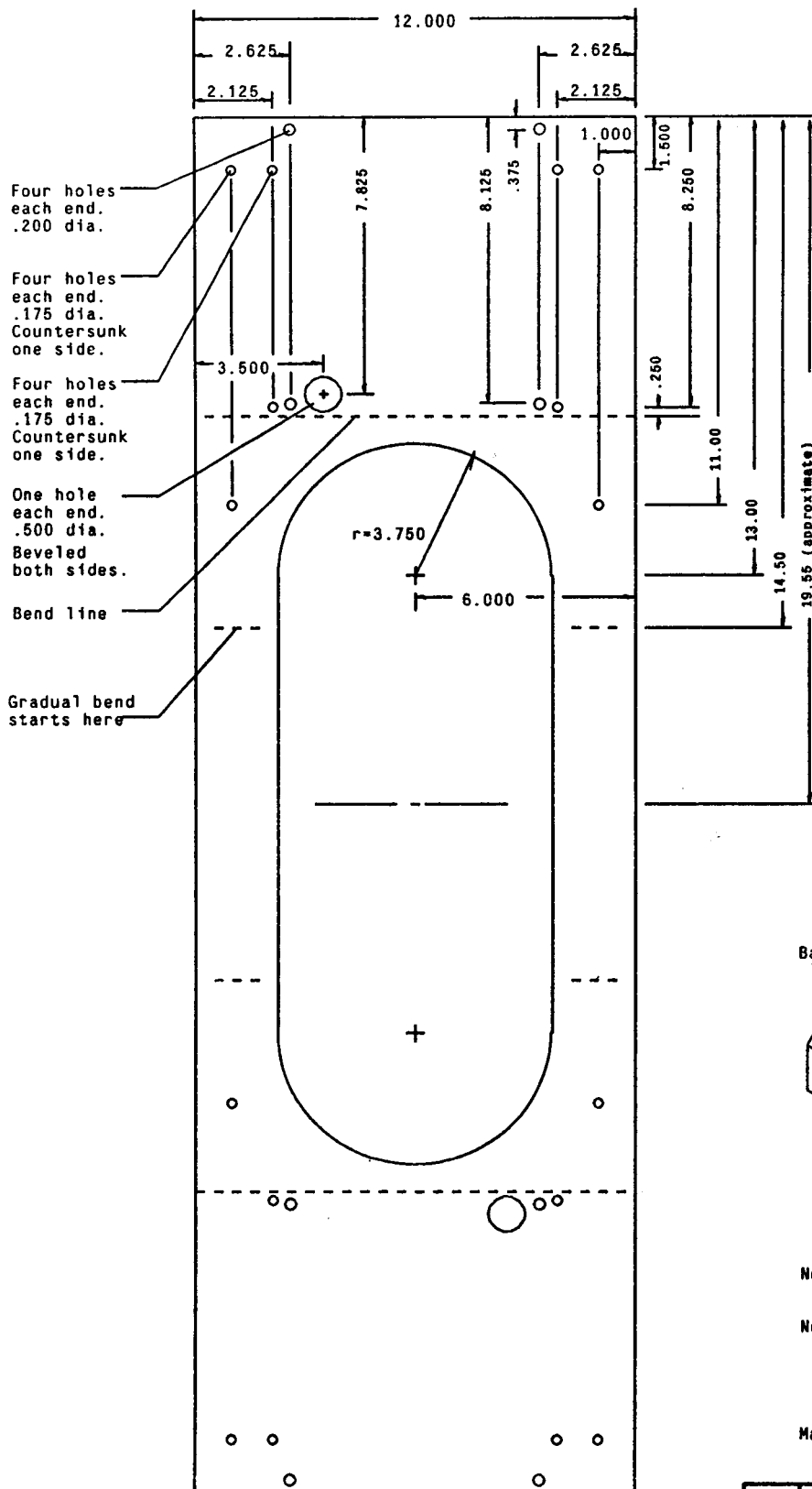
Eight in-board countersunk holes are to
mate with threaded holes in the
Left and Right side plates.
The pieces will be screwed together
before welding to help a neat job.

Eight out-board countersunk holes are
for brackets to hold side cover plates.

This piece forms the front and back
of the fork. It will be welded with
the Left and Right side plates and the
Top plate. The fit of the bends is
important for strength. If necessary
this piece may be made in two parts
with a split halfway (see *).

*

Top

Left

Back

A

B

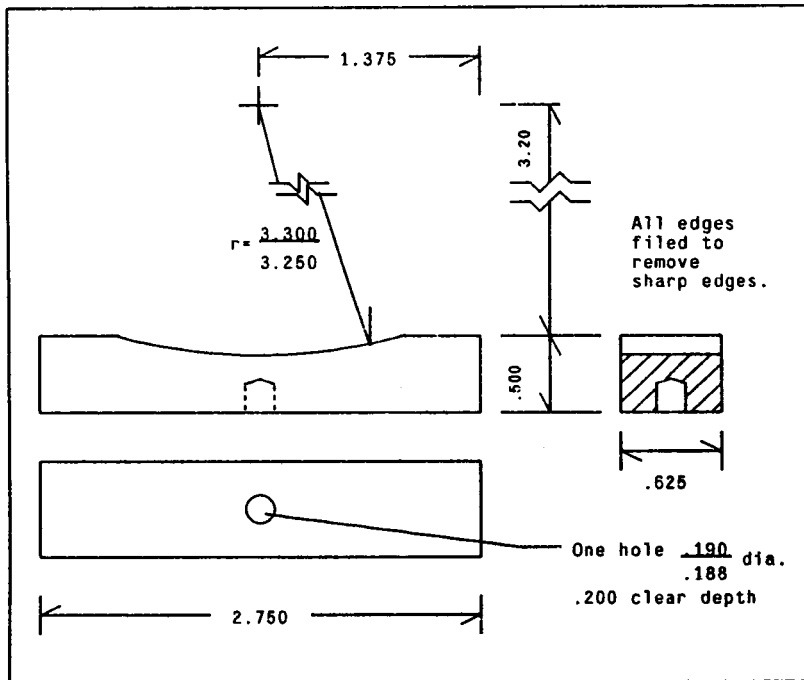D

C

Right

Front

Note: All measurements: +/-.015"
      Or where given.

Note: Make one.

1 inch

Material: .125" Aluminum
          6063-T5

Top

Back A Top left

D B

C

Right Front

.250

.250

Front
(cutaway)

.125

Side

Fillet welds all the way around the side
plates on the out-board side.

Fillet welds along the inside corners where
the top piece meets the front and back.
Note that the central part of these welds
are accomplished by reaching inside from
the rounded end.

The pieces will be screwed together
before welding to help a neat job.

Material:
Aluminum 6061

⌐fi	Mobile Robot Lab	© 1984
Title: Trike Fork Welds		
File: [rover]/usr/gwp/d.tri/forkweld.dp		
Date: 5-Feb-84	Scale: NTS	Approved:
Drawn by: C.Podnar		Dwg. Fork
Checked by:		No.: 6 of 8

8.400

4.200

1.450

.200

8.450

10.95

Two holes
.180" dia.

.525

13.950

Two holes
.180" dia.

⊄

14.45"

17.400

r= 3.450

The taper is determined by a line from 8.450 to about 14.45 in.
which is tangent to the 3.450R arc (about .75 in).
The arc is about 165°.

Cover Brackets

.500

.500

.750

1.000

.250 x 45°

1.935

Both holes
drilled and
tapped for
#8 screws.

Material: Aluminum
Note: Make 10

one inch

Top

Left

Back

A

B

D

C

Right

Front

Note: All measurements: +/-.015"
      Or where given.

Note: Make two.

Material: .0625" Aluminum

1 inch

Title: Trike Fork Side Cover

File: [rover]/usr/gwp/d.tri/ForkCov.dp

Date: 18-Feb-84 | Scale: NTS | Approved:

Drawn by: G.Podnar

Checked by:

Dwg. Fork
No.: of

1.000

.500

2.550

1.355

Two sets of
two holes each.
Drilled and
tapped for #4.

3.625

7.188

6.188

3.375

8.043

7.043

6.043

.250

.250

Four Holes
in four
corners.
Drilled
and tapped
for #8.

.750

8.250

7.250

5.175

4.925

2.300

3.188

3.043

.750
1.150

Two holes.
Drilled and
tapped for #4.

1.750

1.125

One cutout
r=.500

.500

2.188

1.188

Two sets of 16 holes each.
Drilled and tapped for #4.

2.043

1.043

.188

Note: All measurements: +/-.010"
      Or where given.

Note: Make one.

Material: .125" Aluminum
         6061

1 inch

⋔	Mobile Robot Lab	© 1984
Title: Trike Drive Motor Resistor Base		
File: [rover]/usr/gwp/d.tri/ForkRes.dp		
Date: 20-Feb-84	Scale: NTS	Approved:
Drawn by: G.Podnar	Dwg. Fork No.:	
Checked by:		of

1.375

3.20

r= 3.300
   3.250

All edges
filed to
remove
sharp edges.

.500

.625

2.750

One hole .190 dia.
          .188
.200 clear depth

$\frac{5}{16}$ Hex Cap Screw, 2" long, fine thread

With a reduced diameter of . 1875
                              .1840

for a length of ..200

.1875
.1840

.200

2.00

1.375

1.000   1.000

.625

.625

Two holes
.425" dia.

2.750

One hole
Drilled and tapped
for $\frac{5}{16}$ fine thread

Assembled

$\frac{5}{16}$ Hex nut
for locking
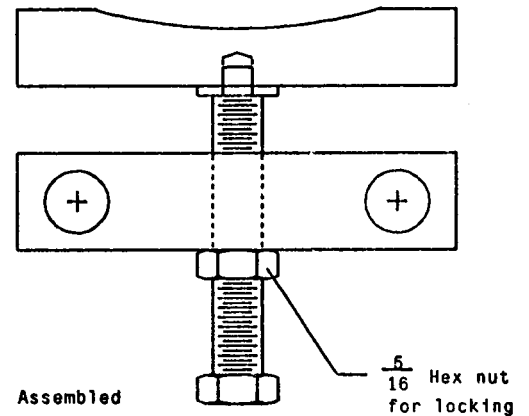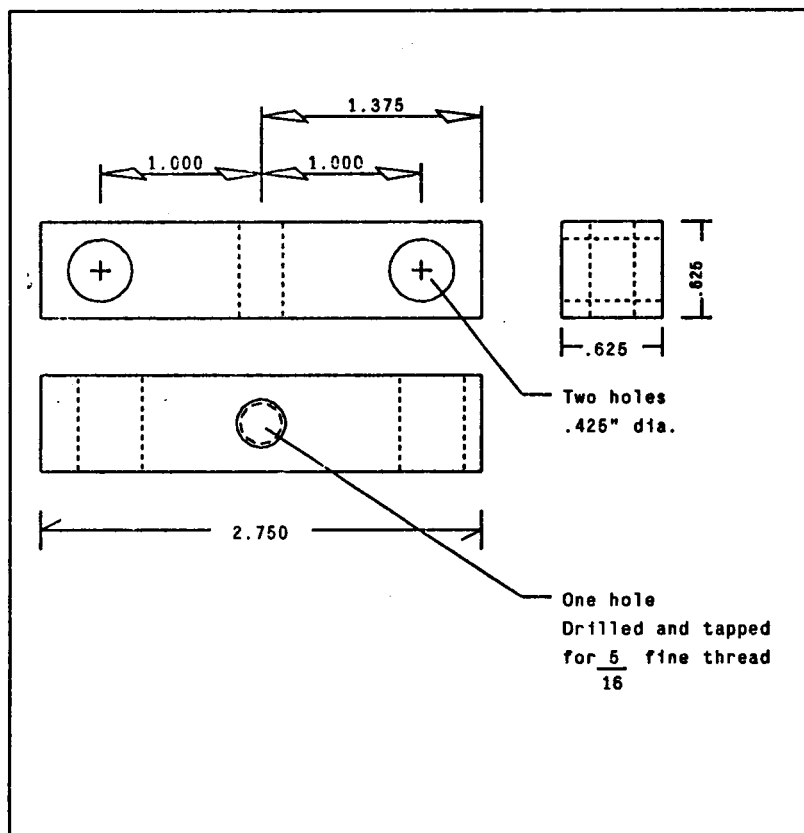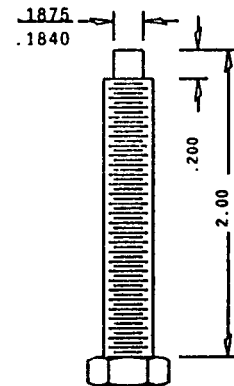
Materials:
One 5/16" steel hex cap screw, fully threaded.
One 5/16" steel hex nut.
Other parts - mild steel.

Note: Make one set.

1 inch

.0375
.0300

.200 ID
.190

.500

Smooth parallel surfaces
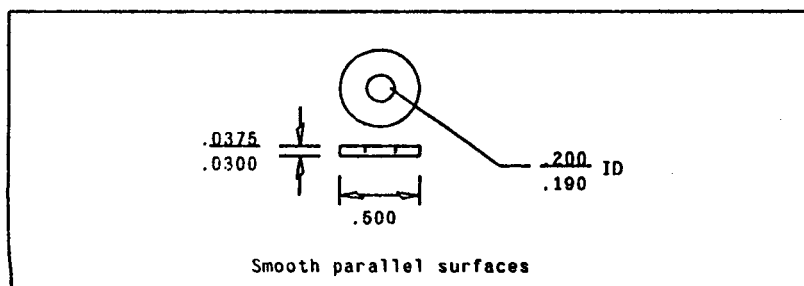
⌂ Mobile Robot Lab	© 1984
Title: Trike Motor Support A	
For Adjusting Chain Tension	
File: [rover]/usr/gwp/d.tri/ForkSupA.dp	
Date: 17-Feb-84 Scale: NTS Approved:	
Drawn by: G.Podnar	Dwg. Fork
Checked by:	No.: of

875

r = 3.300
3.250

3.20

All edges
filed to
remove
sharp edges.

2.376

3.500

One hole
1.0" dia.

.600

One hole
Drilled and tapped
for 3/8" coarse thread

1.750

.250
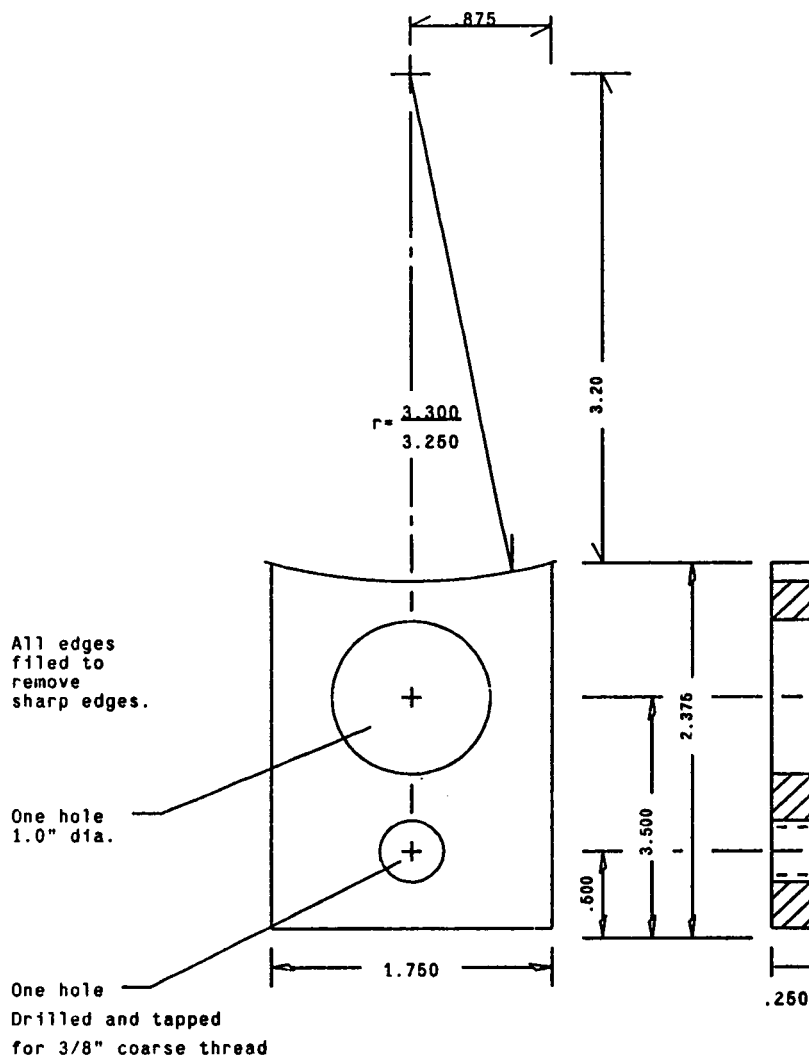
Materials: Mild steel.
Note: Measurements +/-.050 or as noted.
Note: Make one.
Supply one 3/8" x 1" Hex Cap Screw and washer.

	Mobile Robot Lab	© 1984
Title: Trike Motor Support B		
For Supporting Back End of Motor		
File: [rover]/usr/gwp/d.tri/ForkSupB.dp		
Date: 17-Feb-84	Scale: NTS	Approved:
Drawn by: G.Podnar		Dwg.
Checked by:		No.:

Fork
of

1 inch

Hole bored through shaft
for passing wires.

.50" diameter.
Concent. +/-.050

To prevent abrasion,
file or bevel sharp
edges at each end.
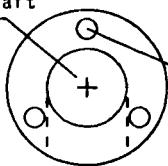
See Detail for
hole pattern and
size.

.500

$\frac{1}{32}$ x 45° Chamfer.

.375
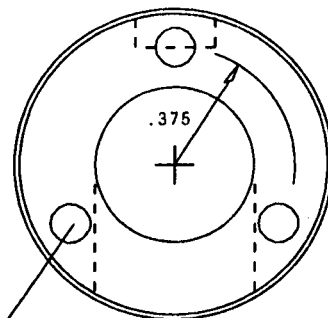
HOLE PATTERN DETAIL

Three holes located 120° apart.
Drilled to depth of about 0.5"
and tapped for #8 screws.

Hole bored
.50" deep
in side of
shaft for
passing
wires.

.50" dia.

To prevent
abrasion,
file or bevel
sharp edges
inside & out.

Keyseat .250 x .125
Length: 3"min. - 4"max.
Centererd 4" from end as shown.
Keyseat ends need not be neat.

8.750

8.000

2.000

1.600

2.000

1.600

Note 1: Groove for retaining ring.
        ANSI standard for 1" shaft.

Note 2: All measurements: +/-.010"
        Or where given.

Note 3: Have Shaft made by
        Thompson Industries, Inc.
        Manhasset, NY 11030
        (516)883-8000

Note 4: Make One.

See
Note 1

.625

.250

4.000

FRONT

.875
.860

SIDE (cutaway)

BACK

$\frac{1}{16}$ x 45° Chamfer.

$\frac{1}{32}$ x 45° Chamfer.

Material: 60 Case hardened steel.
          1" shafting
          Class "L" dia. tolerance.

.500

Mobile Robot Lab

©
1984
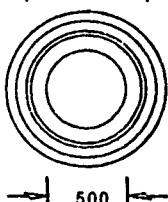
Title: Trike Fork Neck Shaft

File: [rover]/usr/gwp/d.tri/ForkShaft.dp

Date: 30-Jan-84 | Scale: NTS | Approved:

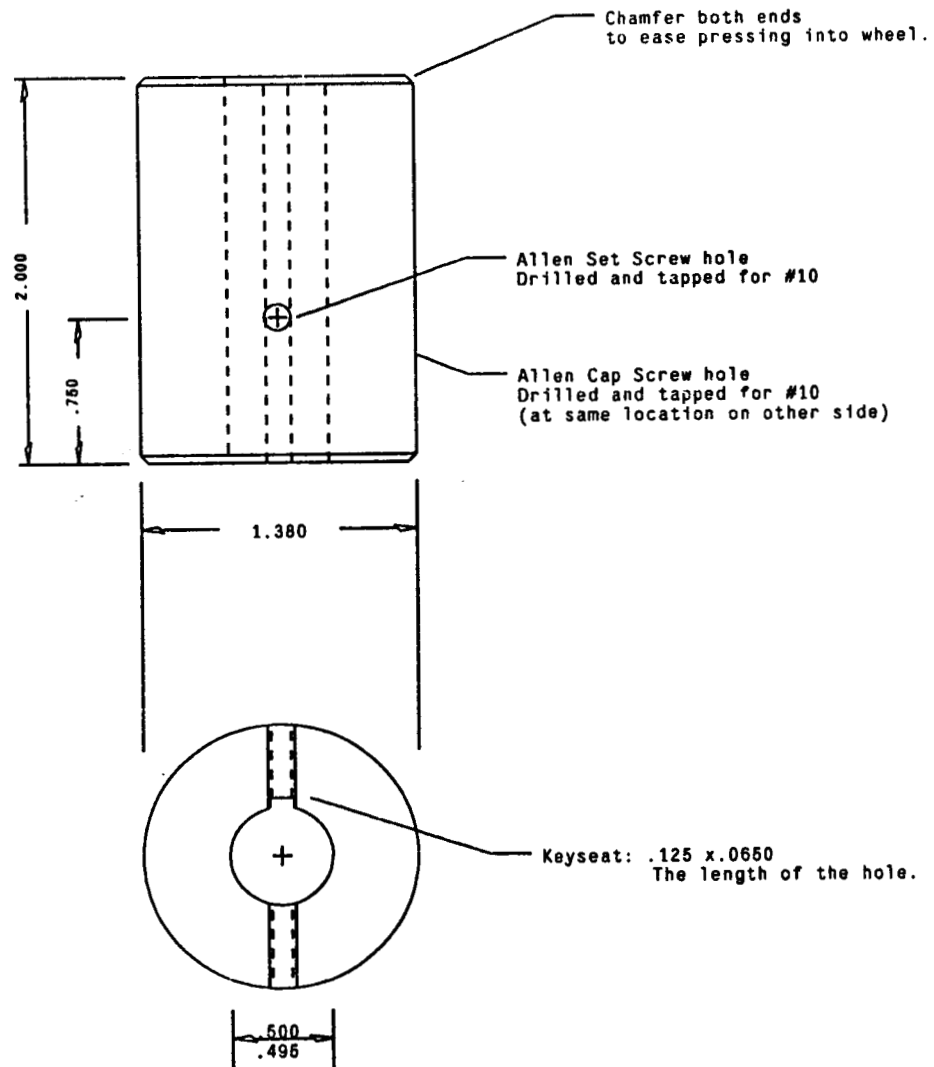Drawn by: G.Podnar | Dwg.
Checked by: | No.:

1 inch

5.00"

1.250   1.250

1.250

1.250

Four holes
in a square
.325 dia.

One hole
Centered

$\dfrac{.880}{.875}$ dia.

.250

$\dfrac{1}{16}$ x45° Chamfer.
One side.
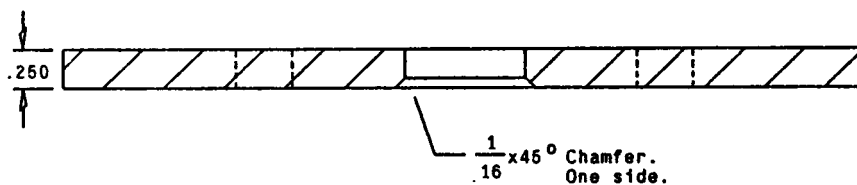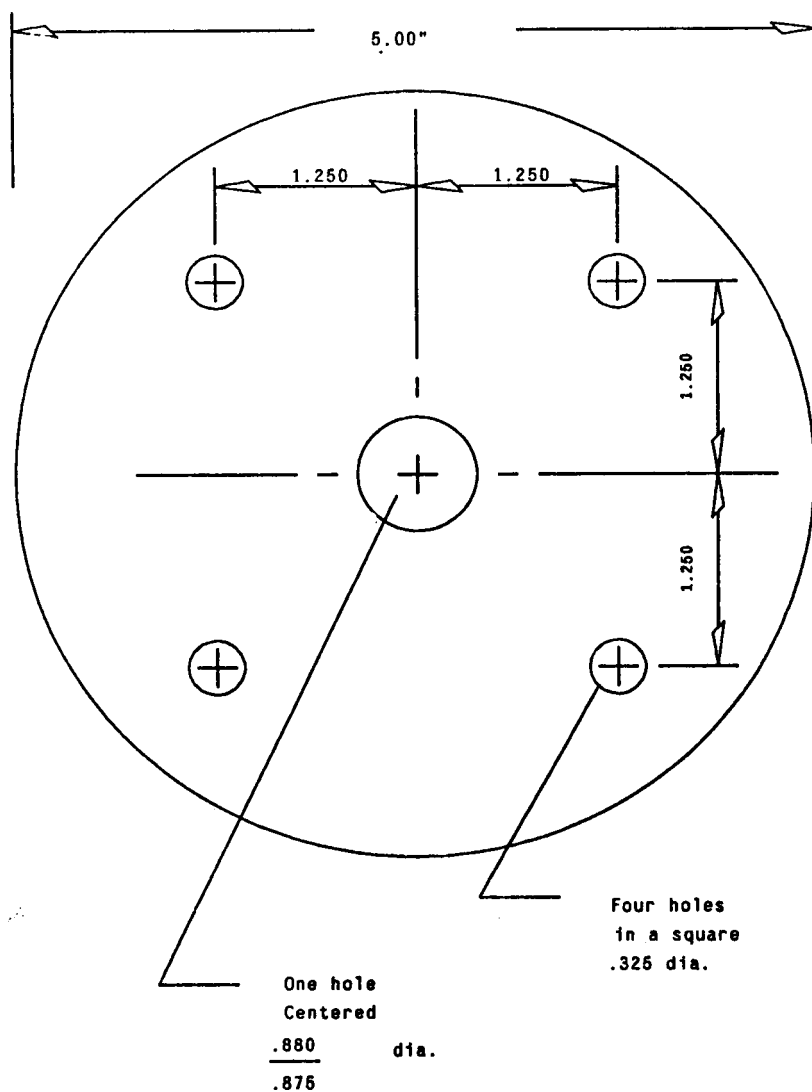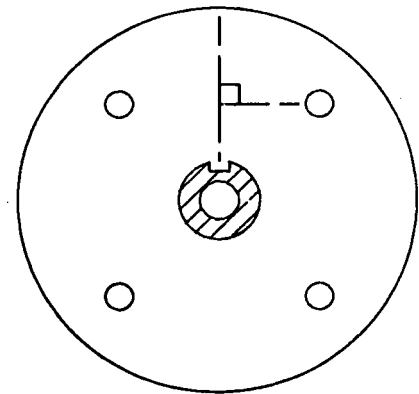
Use Fork Shaft.
Square keyway with flange holes.
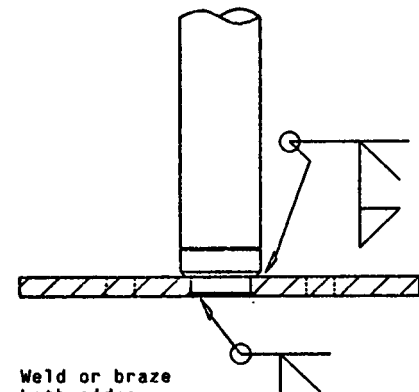
Weld or braze
both sides.
Bevel welds
all around.
A fillet around the top of
at least .125 x.125.

Weld strength: 30,000 lbs./in.^{2} min.

Bottom finished by grinding flat.

Note: All measurements: +/-.015"
      Or where given.

Note: Make one.

Material: .250" Mild Steel

1 inch

Mobile Robot Lab	© 1984
Title: Trike Fork Flange	

File: [rover]/usr/gwp/d.tri/ForkFlange.dp	
Date: 18-Feb-84	Scale: NTS	Approved:
Drawn by: G.Podnar .	Dwg. No.: Fork
Checked by:	of

4.000
3.825

.375

— One Hole, .500 Dia.

— Three holes located 120 °apart.
Drilled and countersunk for #8.
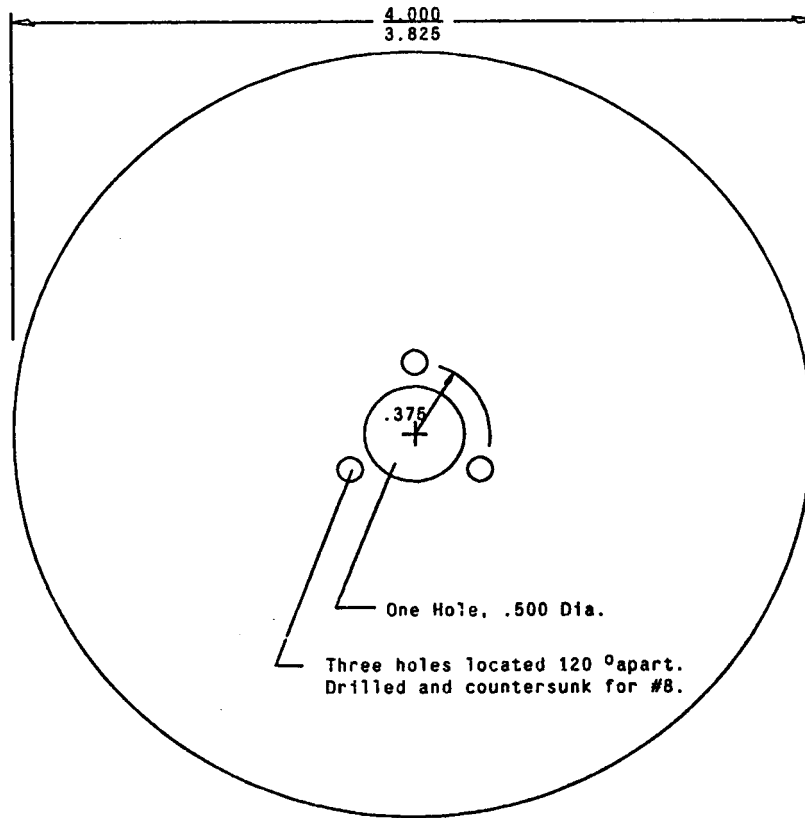
Note: All measurements: +/-.010"
Or where given.

Note: Make Two.

Material: Aluminum .125" 6061

Mobile Robot Lab	© 1984

Title: Trike Fork Neck Shaft Cap Plate

File: [rover]/usr/gwp/d.tri/ForkCap.dp

Date: 30-Jan-84	Scale: NTS	Approved:
Drawn by: G.Podnar		Dwg.
Checked by:		No.:

1 inch

.625" UNC thread

.650
.500

21.85
21.75

.625" UNC thread

.650
.500

.625

Note 1: Have Shaft made by
Thompson Industries, Inc.
Manhasset, NY 11030
(516)883-8000

Note 2: Make One.

Material: 60 Case hardened steel.
.625" shafting
Class "L" dia. tolerance.

1 inch

Mobile Robot Lab © 1984

Title: Trike Rear Axel Shaft

File: [rover]/usr/gwp/d.tri/RearAxel.dp

Date: 1-Feb-84 | Scale: NTS | Approved:

Drawn by: G.Podnar | Dwg.

Checked by: | No.:

Chamfer both ends
to ease pressing into wheel.

Allen Set Screw hole
Drilled and tapped for #10

Allen Cap Screw hole
Drilled and tapped for #10
(at same location on other side)

2.000

.750

1.380

Keyseat: .125 x.0650
The length of the hole.

.500
.495

Note 1: Measurements +/-.010" or as indicated.

Note 2: Make One.

Material: Mild steel.

1 inch

	Mobile Robot Lab	© 1984
Title: Trike Drive Wheel Hub		
File: [rover]/usr/gwp/d.tri/WheelHub.dp		
Date: 2-Feb-84	Scale: NTS	Approved:
Drawn by: G.Podnar		Dwg. No.:
Checked by:		

$\frac{1}{32} \times 45^{\circ}$ Chamfer.

11.000
10.900

2.600
2.100

2.600
2.100

5.550
5.450

1.600
1.400

Note 1: Have Shaft made by
        Thompson Industries, Inc.
        Manhasset, NY 11030
        (516)883-8000

Note 2: Make One.

Material: 60 Case hardened steel.
          0.5" shafting
          Class "L" dia. tolerance.

Keyseat: .128 x .0625
Ends need not be neat.

.500

$\frac{1}{32} \times 45^{\circ}$ Chamfer.

1 inch

	Mobile Robot Lab	© 1984
Title: Trike Fork Axel Shaft		
File: [rover]/usr/gwp/d.tri/ForkAxel.dp		
Date: 31-Jan-84	Scale: NTS	Approved:
Drawn by: G.Podnar		Dwg.
Checked by:		No.:

Measurements for bevels
are given to edge of
opening (bottom).
Bevel is made at 45 degrees.
(May be filed.)

Top

Top

Bottom

7.750

3.875   3.875

45°   45°

$r=\dfrac{3.375}{3.300}$

$r=\dfrac{3.625}{3.550}$

$r=\dfrac{2.625}{2.550}$

$r=\dfrac{4.375}{4.300}$

3.375

3.375

5.375

5.375   4.625

.500

Four holes
.200 dia.
Countersunk
for #8

Two holes
.200 dia.

2.125   2.125

$r=\dfrac{7.750}{7.700}$

Top View

Material: Aluminum $\dfrac{3}{16}$" thick.

Note: Make one.

1 inch
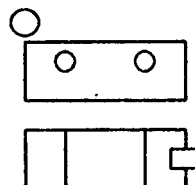
Mobile Robot Lab   © 1984

Title: Trike Fork Limit Switch Control Plate

File: [rover]/usr/gwp/d.tri/ForkLimit.dp

| Date: 10-Feb-84 | Scale: NTS | Approved: |

Drawn by: G.Podnar

Dwg. Fork

Checked by:

No.: of

4.00"

1.000

.500 1.500

2.000

1.500 .500

4.00"

3.000

Six holes.
Drilled and tapped
for #6.

Four holes.

.250

.375

.125

.250

.250

Material: Aluminum 6061
       .1875 (or .250) thick.

Note: Make one.

.150x.400
Two Holes

.250

.400   .250 .250

Two Holes
.150x.650

.375

.250

.500

.650

.125

1.250
1.200

.125

.625
.600

1.750
1.650
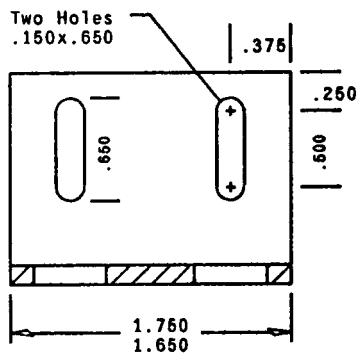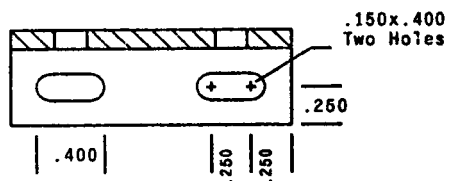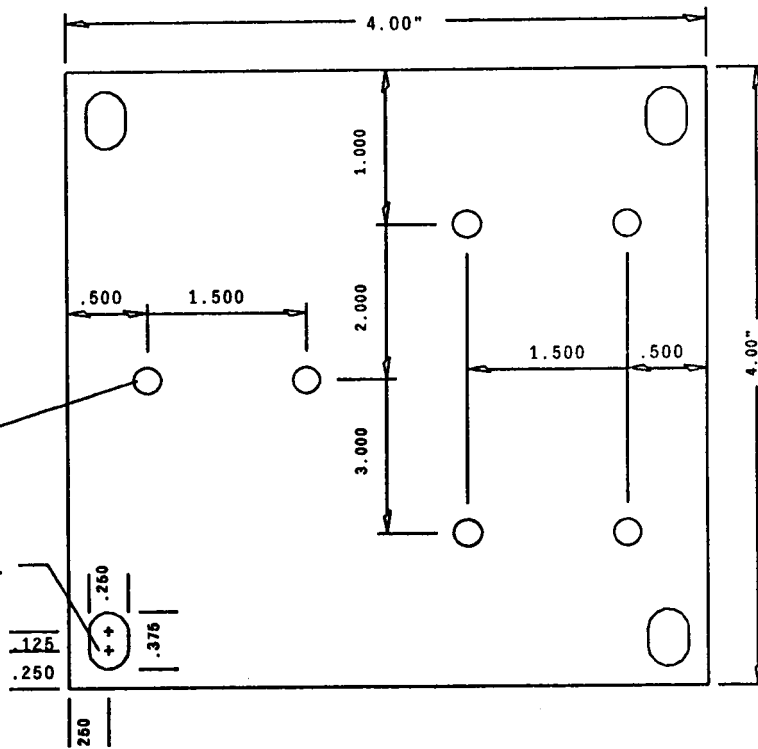
Material: Aluminum 6061
Note: Make four.

1.500

.125   .250

.250

Two Holes. Drilled
and tapped for #6.

.125
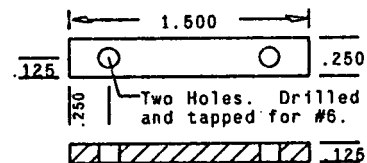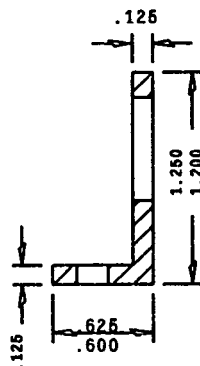
Material: Mild Steel
Note: Make four.

Supply:

8 - #6x1" Allen head
8 - #6x.260 Round head Phillips
16 - #6 Washers
16 - #6 Lockwashers

4 - #8x.500 Brass
4 - #8 Washers
4 - #8 Lockwashers

Measurements: +/-.010

|_ 1 inch _|
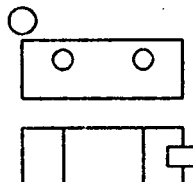
Mobile Robot Lab

© 1984

Title: Trike Fork Limit Switch Brackets

File: [rover]/usr/gwp/d.tri/ForkLB.dp

Date: 10-Feb-84 | Scale: NTS | Approved:

Drawn by: G.Podnar | Dwg. Fork

Checked by: | No.:   of

24"
19"

Turning Length 42" ('curb to curb')

25"

22.5
32.5

12"
22.5

SS1800

SS400-P2

1 inch

23.0

Right

Top

Left

Bottom

Top

Back

A

D

+

B

Left

C

Right

Front

Material:
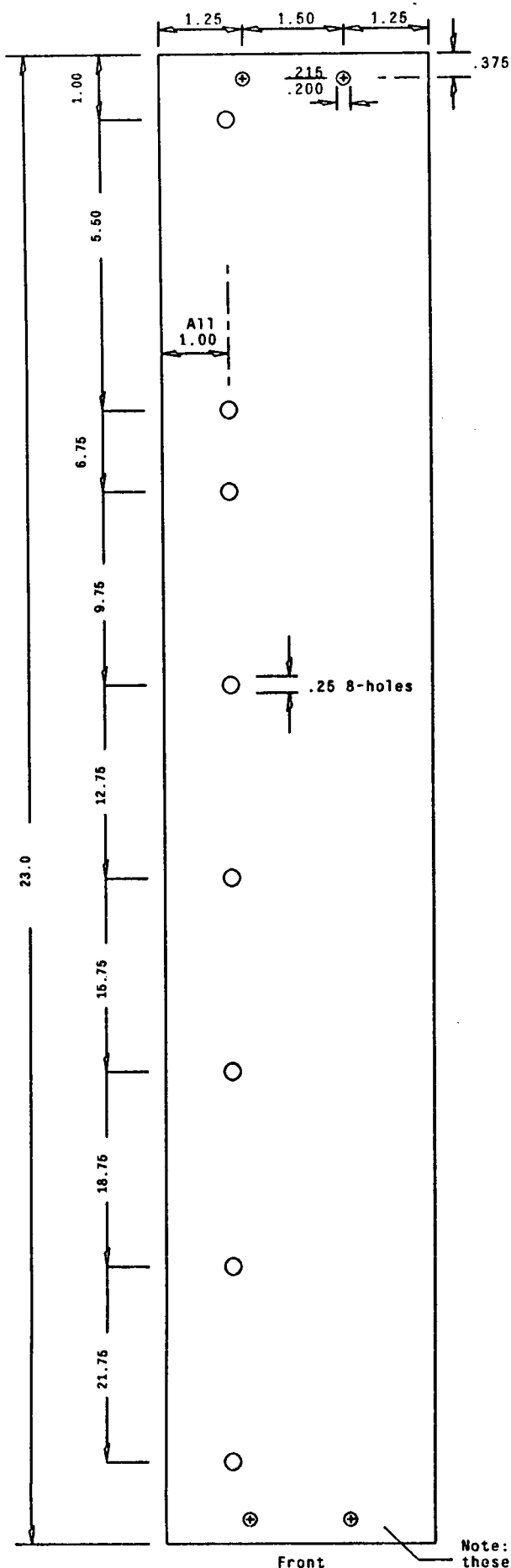
4" Square Aluminum
Tubing. .125" wall.
6063-T5

1 inch

Note: Make one.

For Details see Drawings:
Trike FrameA1 - Right
Trike FrameA2 - Top
Trike FrameA3 - Left
Trike FrameA4 - Bottom

Part A

| | Mobile Robot Lab | ©
1984 |
|---|---|---|
| Title: Trike FrameA | | |
| File: [rover]/usr/gwp/d.tri/FrameA.dp | | |
| Date: 26-Jan-84 | Scale: NTS | Approved: |
| Drawn by: G.Podnar | | Dwg.
No.: Frame
1 of 10 |
| Checked by: | | |

Note: Same hole pattern
on all four sides
and both ends.

1.25   1.50   1.25

.375

1.00

.215
.200

5.50

All
1.00

6.75

9.75

.25 8-holes

12.75

Top

Back

A

D   B   Left

C

Right   Front

15.75

Material:
4" Square Aluminum
Tubing.   .125" wall.
6063-T5

Right

18.75

Note: Detail of Frame Part A.

Note: All measurements: +/-.015"
       Except overall length: +/-.100"
       Or where given.

21.76

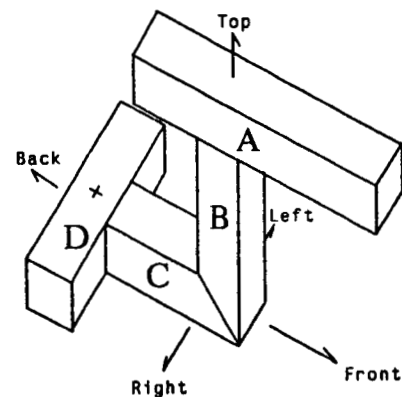23.0

1 inch
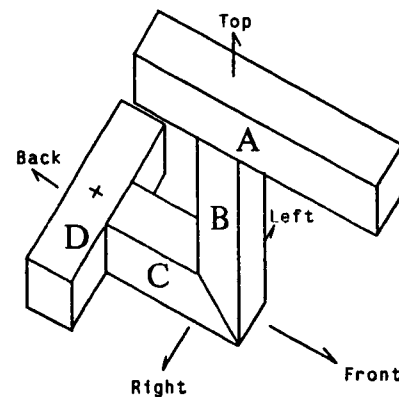
Mobile Robot Lab   © 1984

Title: Trike FrameA1 - Right

File: [rover]/usr/gwp/d.tri/FrameA1.dp

Date: 26-Jan-84 | Scale: NTS | Approved:

Drawn by: G.Podnar

Checked by:

Dwg.
No.: Frame
2 of 10

Front

Note: See other end for
these hole placements.

1.25   1.50   1.25

.215
.200   .375

Note: Same hole pattern
      on all four sides
      and both ends.

8.25

1.25

1.25

r=1.375

23.0   10.25

1 large hole on Top
and Bottom. 2.75 dia.
With four small holes
spaced as shown.
Drilled and tapped
for #10 screws.

1.25   1.25

2.00   2.00

Top

2.00   2.00

120°

1.25
1-hole

Note: Same hole pattern on
      both Top and Bottom.

120°

r=1.50   .375 3-holes

4.50

Front

Note: See other end for
      these hole placements.

Top

Back

A

B

Left

D

C

Right   Front

Material:
4" Square Aluminum
Tubing. .125" wall.
6063-T5
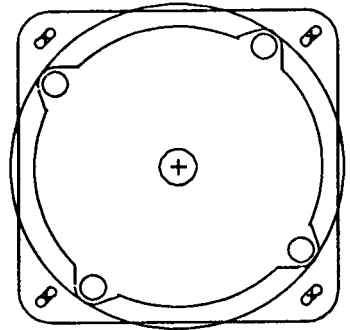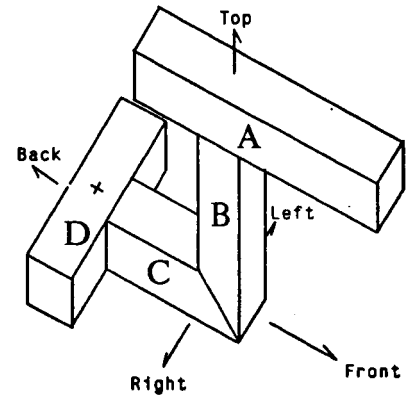
Note: Detail of Frame Part A

Note: All measurements: +/-.015"
      Except overall length: +/-.100"
      Or where given.

1 inch

1.25   1.50   1.25

Note: Same hole pattern
on all four sides
and both ends.

.375

1.00

.215
.200

5.50

All
1.00

6.75

9.75

8-holes .25

12.75

15.75

Left

18.75

21.75

23.0

Top

Back

A

D   B   Left

C

Right   Front

Material:
4" Square Aluminum
Tubing.   .125" wall.
6063-T5

Note: Detail of Frame Part A.

Note: All measurements: +/-.015"
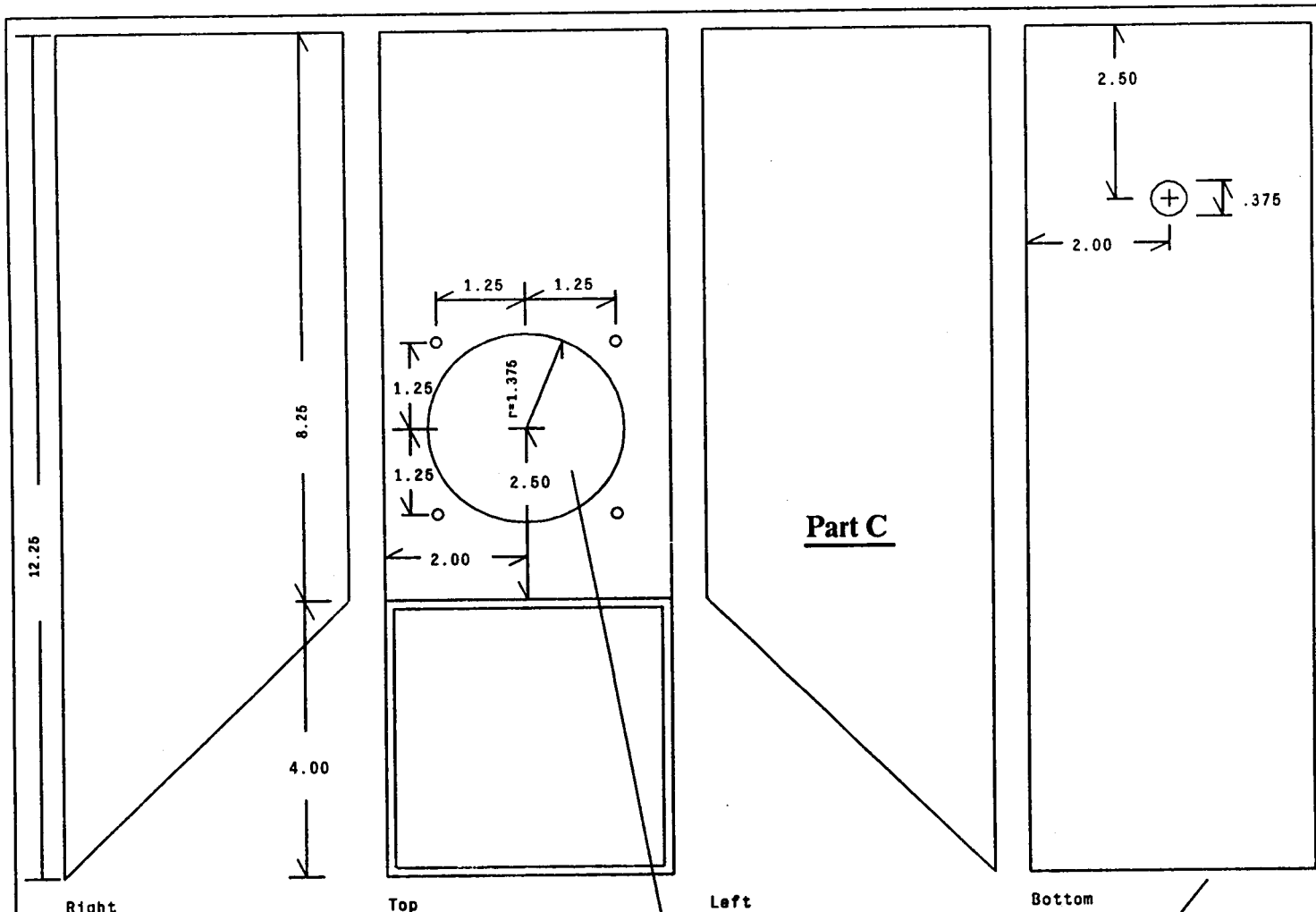   Except overall length: +/-.100"
      Or where given.

1 inch

Front

Note: See other end for
these hole placements.

Note: Same hole pattern
on all four sides
and both ends.

2-cutouts

r=.40

1.00

1.375

r= 1.80
1.75

4-holes

r= .215
.200
4-holes

Two lines marked to
indicate alignment
for welding of Part B.

r=1.375

1 large hole on Bottom
and Top. 2.75 dia.
With four small holes
spaced as shown.
Drilled and tapped
for #10 screws.

SS400-P2 Motor for reference

Top

Back

A

D

B

Left

C

Right

Front

Material:
4" Square Aluminum
Tubing.   .125" wall.
6063-T5

Bottom

120°

120°

1-hole

r=1.50

.375 3-holes

Note: Same hole pattern on
both Top and Bottom.

Note: Detail of Frame Part A.

Note: All measurements: +/-.015"
Except overall length: +/-.100"
Or where given.

1 inch

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Title: Trike FrameA4 - Bottom

File: [rover]/usr/gwp/d.tri/FrameA4.dp

Revised: 5-Feb-84 gp

Date: 26-Jan-84

Scale: NTS

Approved:

Drawn by: G.Podnar

Dwg.
No.:

Frame

Checked by:

5   of 10

Note: See other end for
these hole placements.

Front

Part B

11.25

15.25

2.50

1.25

2.00
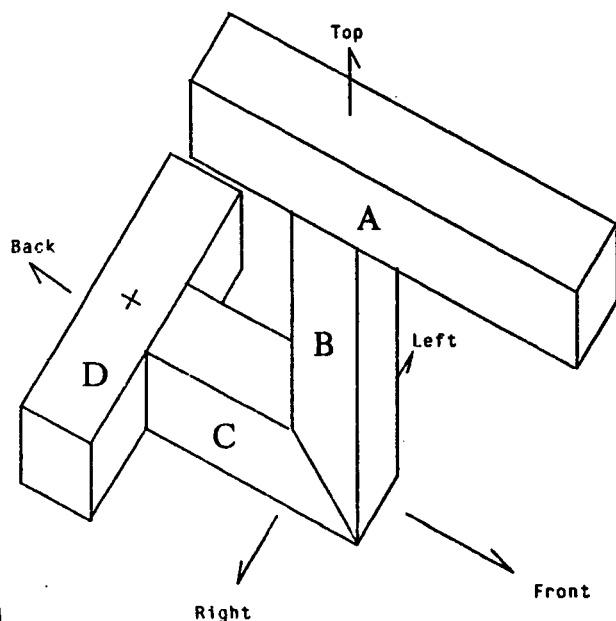
1.25

r=1.375

1.25   1.25

4.00

Right

Front

Left

Back

One large hole on Front
2.75 dia. With 4 small holes
spaced as shown, drilled
and tapped for #10 screws.

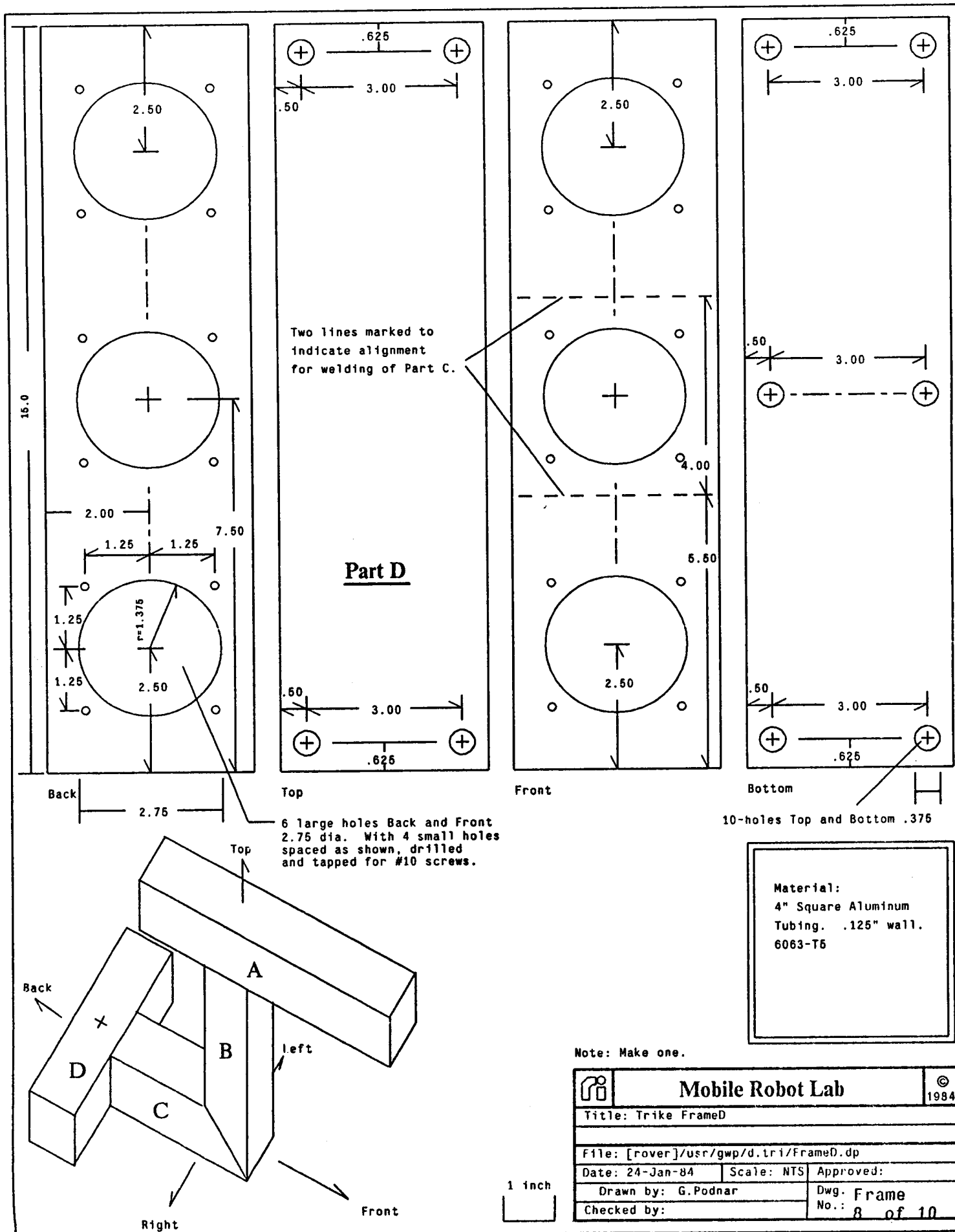Chamfer edges at both ends
for welding to Part A and
Part C.

Top

A

Back

+

B

D

Left

C

Right

Front

Material:
4" Square Aluminum
Tubing. .125" wall.
6063-T6

Note: Make one.

1 inch

Mobile Robot Lab	© 1984
Title: Trike FrameB	

File: [rover]/usr/gwp/d.tri/FrameB.dp		
Date: 26-Jan-84	Scale: NTS	Approved:
Drawn by: G.Podnar		Dwg. No.: Frame
Checked by:		6 of 10

Part C

12.25

8.25

4.00

Right

1.25   1.25

1.25

r=1.375

1.25

2.50

2.00

Top

Left

2.50

.375

2.00

Bottom

One large hole on Top
2.75 dia. With 4 small holes
spaced as shown, drilled
and tapped for #10 screws.

Top

Back

+

A

B

Left

D

C

Right

Front

Chamfer edges at both ends
for welding with Part B and
Part D.
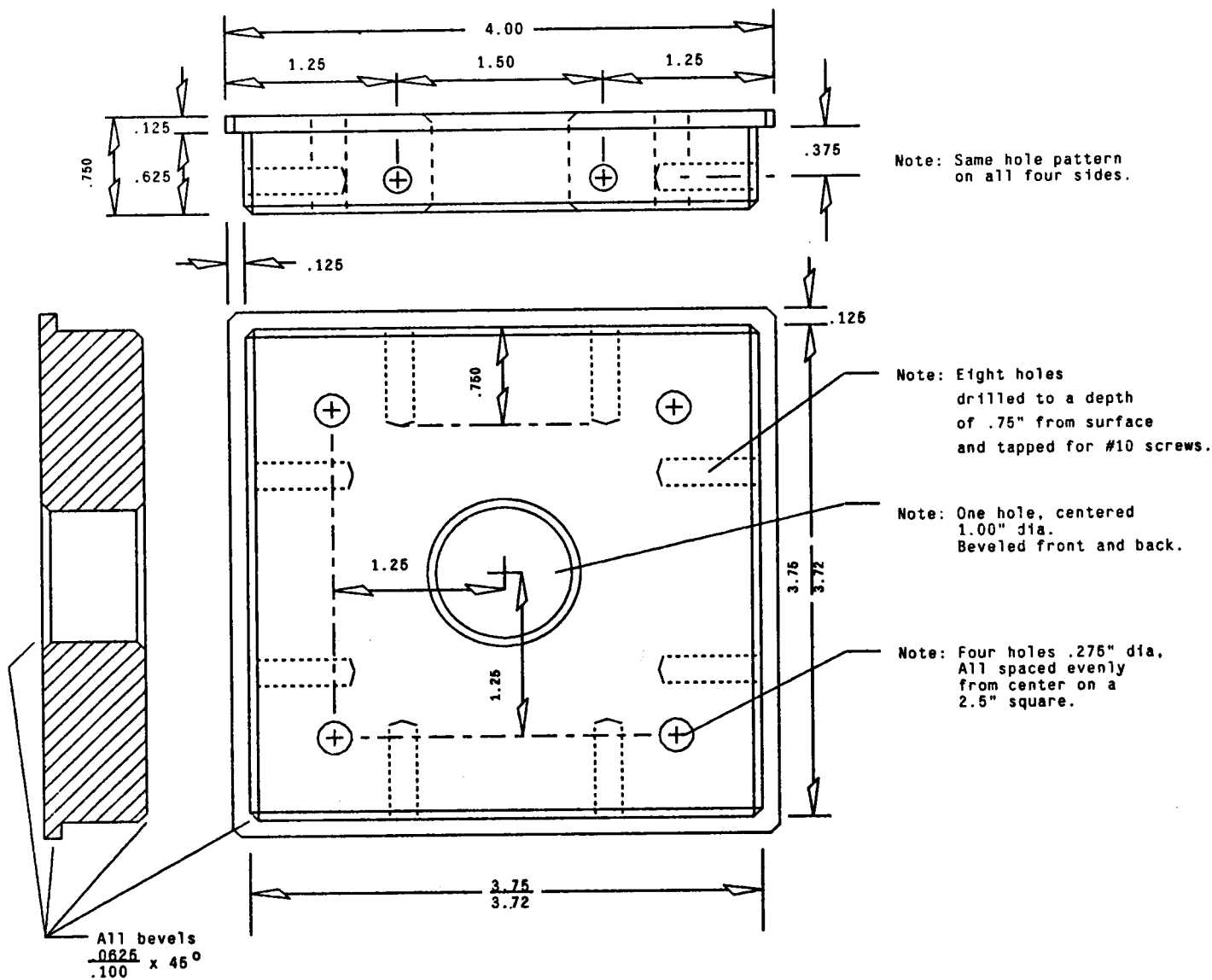
Material:
4" Square Aluminum
Tubing. .125" wall.
6063-T5

Note: Make one.

1 inch

.625

3.00

.50

.625

3.00

2.50

.50

3.00

Two lines marked to
indicate alignment
for welding of Part C.

Part D

15.0

2.00

1.25   1.25

7.50

1.25

r=1.375

1.25

2.50

4.00

5.50

2.50

.50

3.00

Back

2.75

Top

.50

3.00

.625

Front

.50

.625

Bottom

10-holes Top and Bottom .375

6 large holes Back and Front
2.75 dia. With 4 small holes
spaced as shown, drilled
and tapped for #10 screws.

Top

Back

A

D

B

Left

C

Right

Front

Material:
4" Square Aluminum
Tubing. .125" wall.
6063-T5

Note: Make one.

1 inch

![Mobile Robot Lab logo]	**Mobile Robot Lab**	©1984

Title: Trike FrameD

File: [rover]/usr/gwp/d.tri/FrameD.dp		
Date: 24-Jan-84	Scale: NTS	Approved:
Drawn by: G.Podnar		Dwg. No.: Frame
Checked by:		8 of 10

4.00

1.25   1.50   1.25

.125

.750   .625   .375

.125

.125

Note: Same hole pattern
on all four sides.

.750

3.75
3.72

1.25

1.25

Note: Eight holes
drilled to a depth
of .75" from surface
and tapped for #10 screws.

Note: One hole, centered
1.00" dia.
Beveled front and back.

Note: Four holes .275" dia,
All spaced evenly
from center on a
2.5" square.

3.75
3.72

All bevels
.0625
------ x 45°
.100

Material: Aluminum

Note: All measurements: +/-.010"
Or where given.

Note: Make Two.

1 inch

3.75
3.72

1.875   1.875

1.00

.625

.325   1.50   1.50

3.00

Two holes .375" dia.
Drilled Through

3.76
3.72

All bevels
.0625
.100 x 45°

RPB 5/8   for reference.

Material: Aluminum

Note: All measurements: +/-.010"
      Or where given.

Note: Make Two.

Title: Trike Frame "D" End Caps

File: [rover]/usr/gwp/d.tri/FrameCapD.dp

Date: 27-Jan-84 | Scale: NTS | Approved:
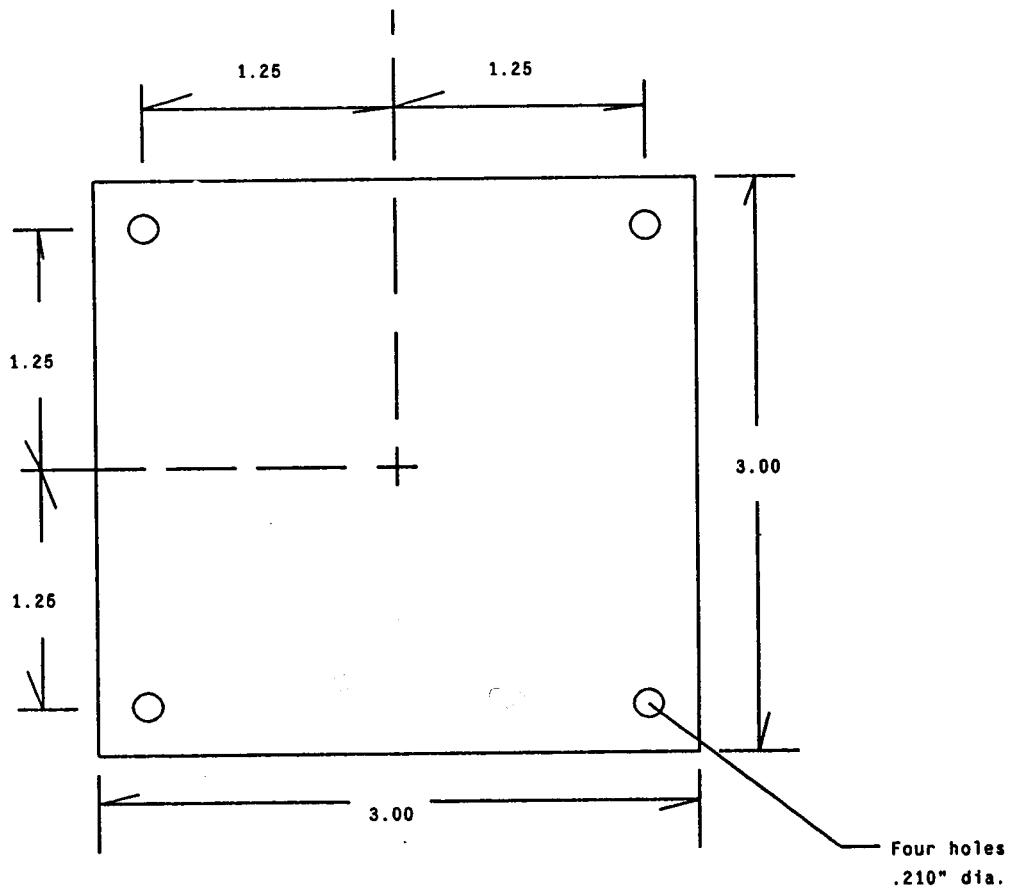
Drawn by: G.Podnar | Dwg. Frame

Checked by: | No.: 10 of 10

1 inch

Top

Back

Right

Front

Top

Back

Left

D

A

B

C

Right

Front
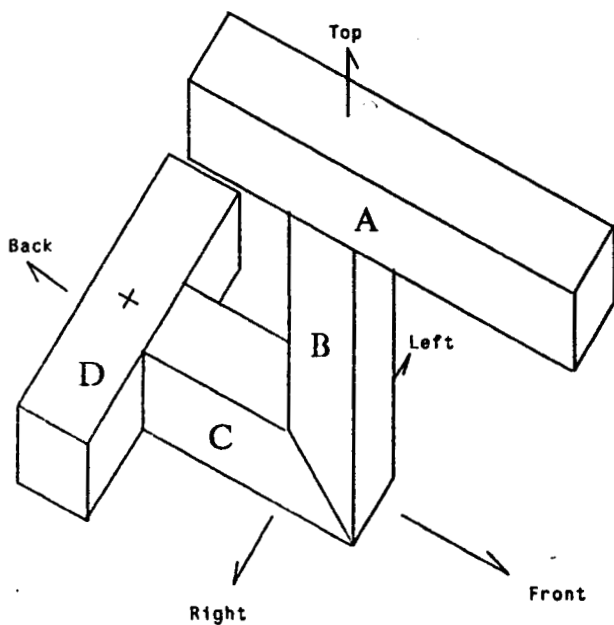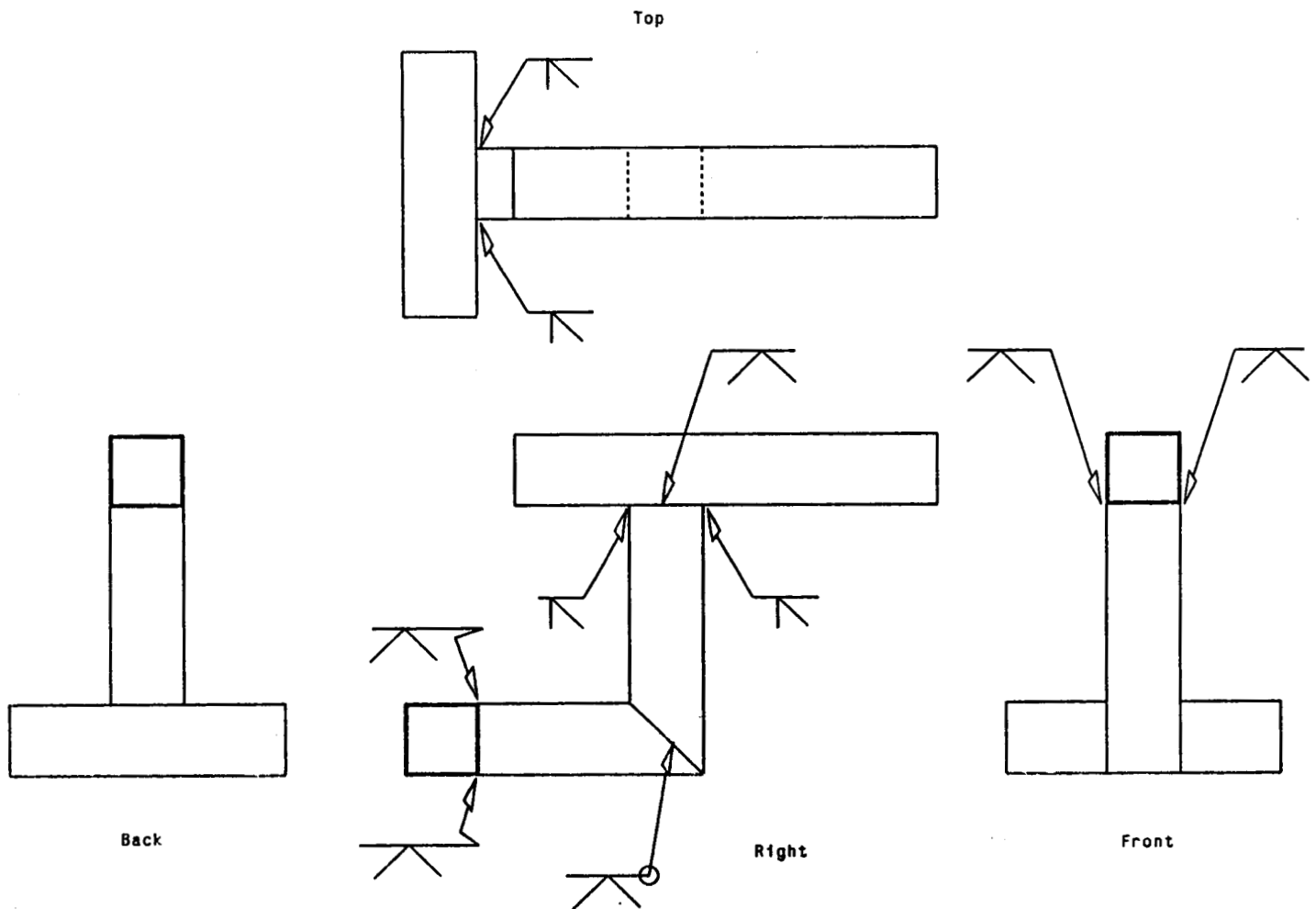
Material:
4" Square Aluminum
Tubing. .126" wall.
6063-T5

1 inch
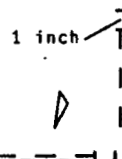
Mobile Robot Lab		© 1984
Title: Trike Frame Welds		
File: [rover]/usr/gwp/d.tri/FrameWeld.dp		
Date: 15-Feb-64	Scale: NTS	Approved:
Drawn by: G.Podnar		Dwg. No.: Frame
Checked by:		of

1.25   1.25

1.25

1.25

3.00

3.00

Four holes
.210" dia.

Material: .0625" Aluminum

1 inch

Note: Make ten.

 Mobile Robot Lab   © 1984

Title: Trike Frame Covers	
File: [rover]/usr/gwp/d.tri/FrameCov.dp	
Date: 17-Feb-84 Scale: NTS	Approved:
Drawn by: G.Podnar	Dwg. Frame
Checked by:	No.: of

3.650

1.825

1.625   1.625

.750

.500

.250   .312

Two Holes.
Drilled and tapped
for #10-32

r=.275 (May be filed or ground).
.225

.375
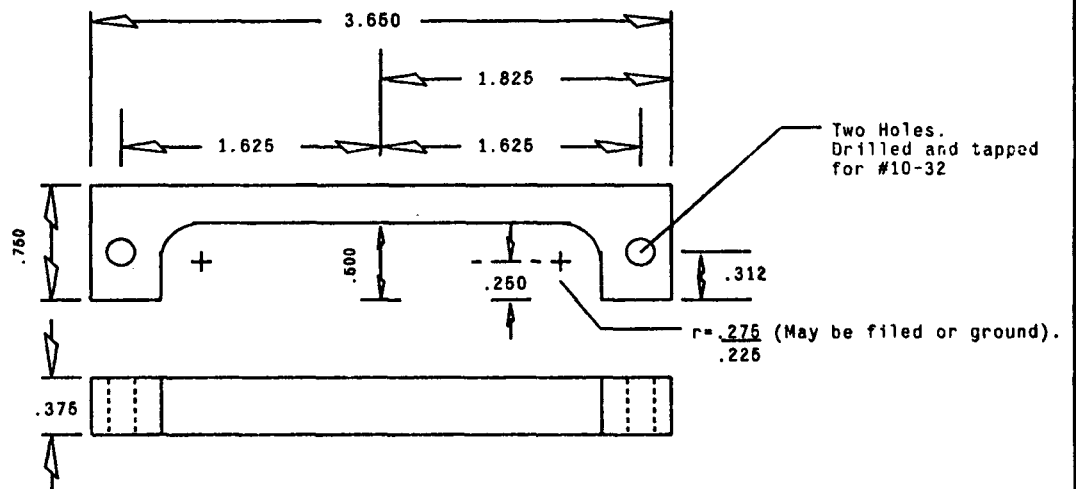
Note: All measurements: +/-.015"
      Except Hole spacing: +/-.010"
      Or where given.

Note: Make two.

Material: Mild Steel

Supply: 4 each: 10-32 Allen Cap Screws
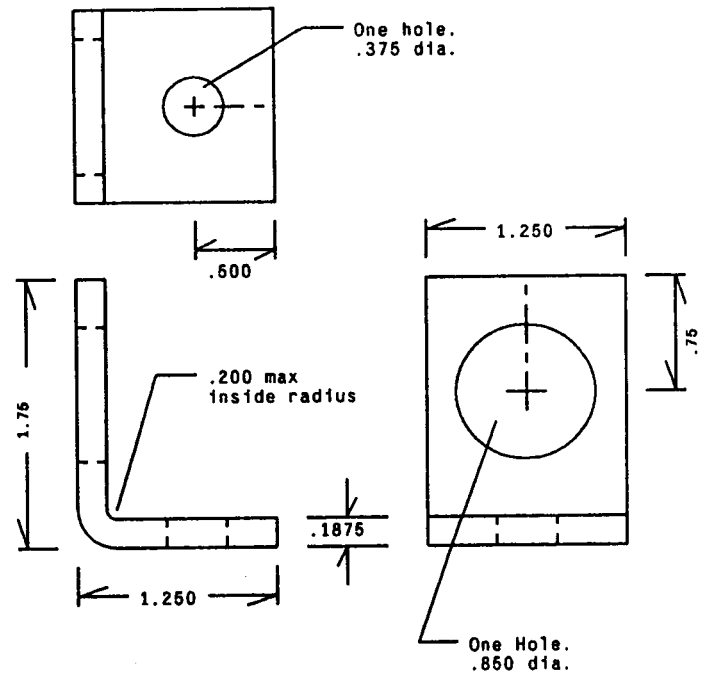   Washers
                Lock Washers

1 inch

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Title: Trike Frame Steering Motor Support.

File: [rover]/usr/gwp/d.tri/FrameSupA.dp

Date: 23-Feb-84 | Scale: NTS | Approved:

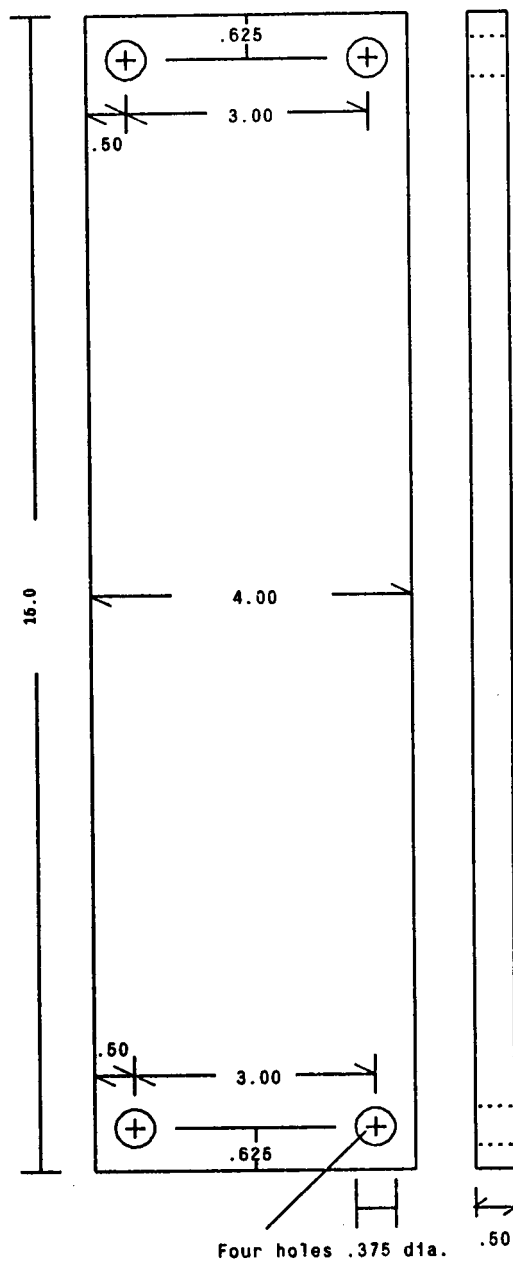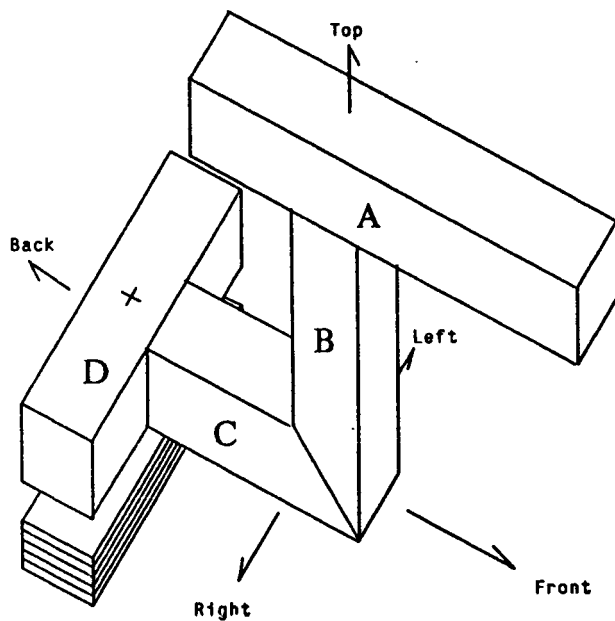Drawn by: G.Podnar | Dwg. Frame

Checked by: | No.:   of

Note: See other end for
these hole placements.

Hitch Tongue

.750

.375

3.00

3.00

3.00

.375

.250

Four Holes
.375 dia.

Hitch Bracket

One hole.
.375 dia.

.500

1.250

.75

1.75

.200 max
inside radius

.1875

1.250

One Hole.
.850 dia.
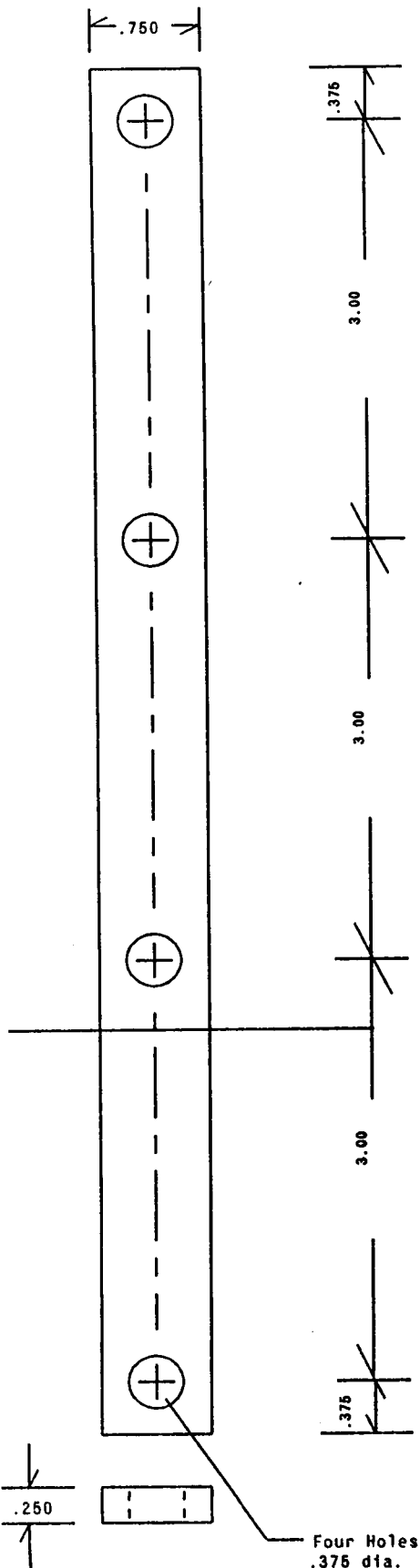
Material: Mild Steel

Note: Make one of each.

1 inch

| | Mobile Robot Lab | ©
1984 |
|---|---|---|
| Title: Trike Frame Hitch | | |
| | | |
| File: [rover]/usr/gwp/d.tri/FrameHitch.dp | | |
| Date: 27-Feb-84 | Scale: NTS | Approved: |
| Drawn by: G.Podnar | | Dwg. Frame |
| Checked by: | | No.: of |

.625

3.00

.50

16.0

4.00

.50

3.00

.625

Four holes .375 dia.

.50

Top

Back

A

B

Left

D

C

Right

Front

Material: Mild Steel
Note: Make five.
Measurements: +/-.020

1 inch

Appendix II

Electrical Drawings

Appendix II

S-AC-1
Opto-22 240D10

S-AC-2
Opto-22 240D10

110 AC

Steering Motor
Superior Electric
Slo-Syn SS400

D-DC-1
Opto-22 DC200P

DC
Acopian Model #U9Y1000
9VDC Unregulated (10A @5)

D-AC-1
Opto-22 240D10

110 AC

D-AC-2
Opto-22 240D10

Drive Motor
Superior Electric
Slo-syn SS1800
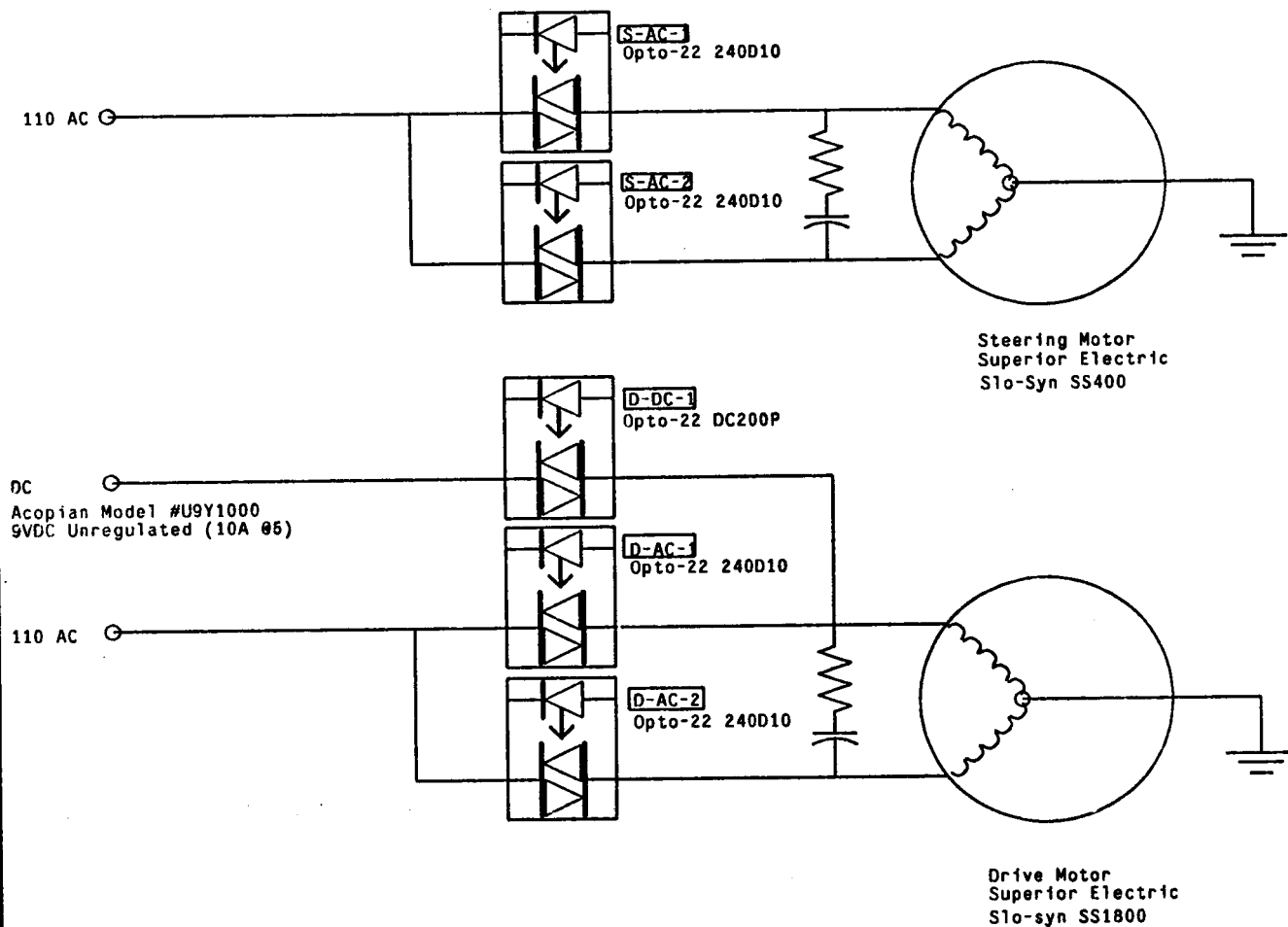
Holding Torque Requirements

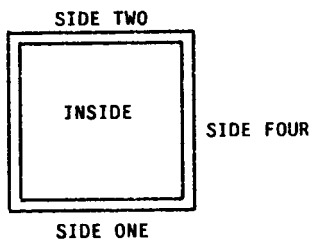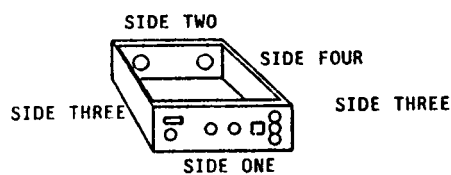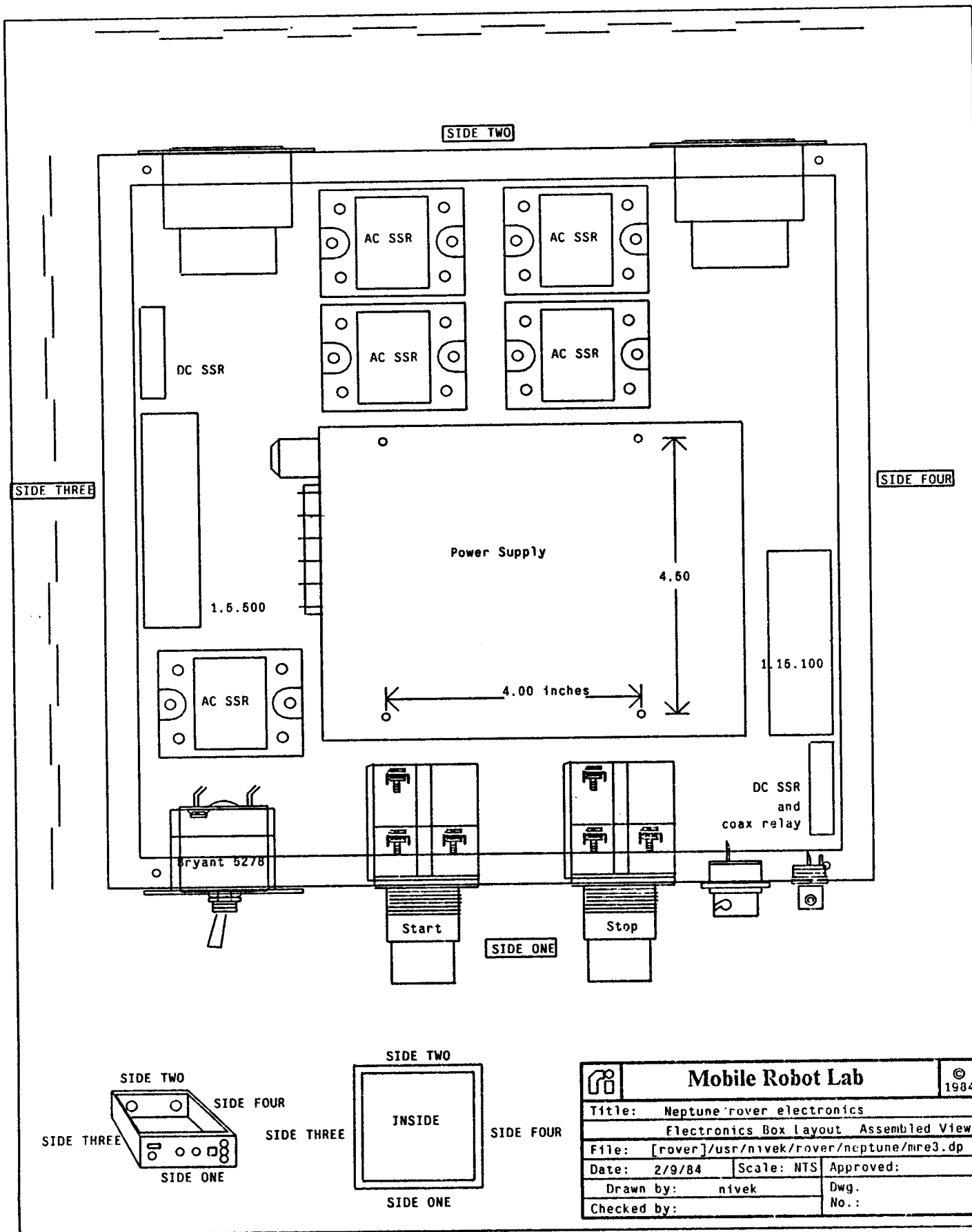|	VDC	Current	Torque	Residual H-T
Slo-Syn SS400	30 VDC	0.60 A	500 oz-in	9 oz-in
Slo-syn SS1800	9.5 VDC	4.7 A	2200 oz-in	20 oz-in

Note: The gearing on the Steering motor will be high enough that
    DC holding torque won't be necessary and little or no
    external forces on the wheel itself are expected.

110VAC
Power Connector

240D10   110VAC
Motors
DC Holding etc.

Hot

7.5 Amp

AC   Calex 1.5.500   5V

Neutral

AC   Cmn.

Chassis Ground

DC 200P

5V for rest of controller

Start
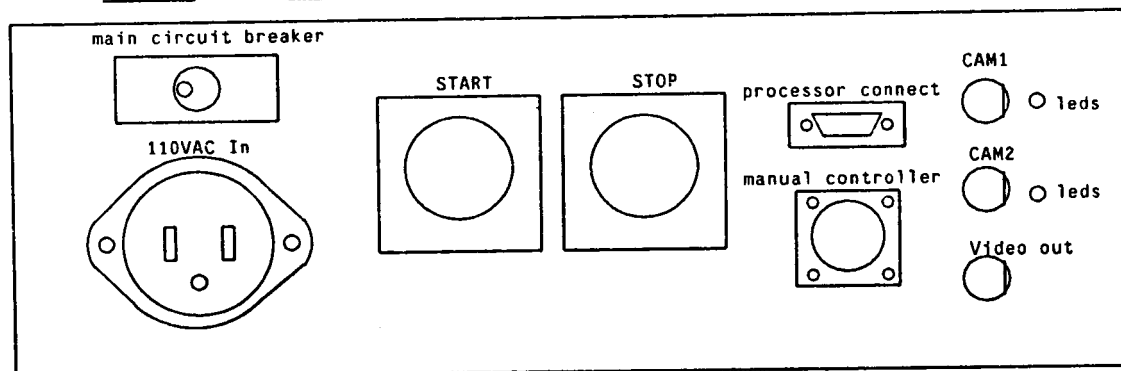
8
10
11
13
3
1   0
5
4
9
12
2
6

1   2   3   4   2
3
1

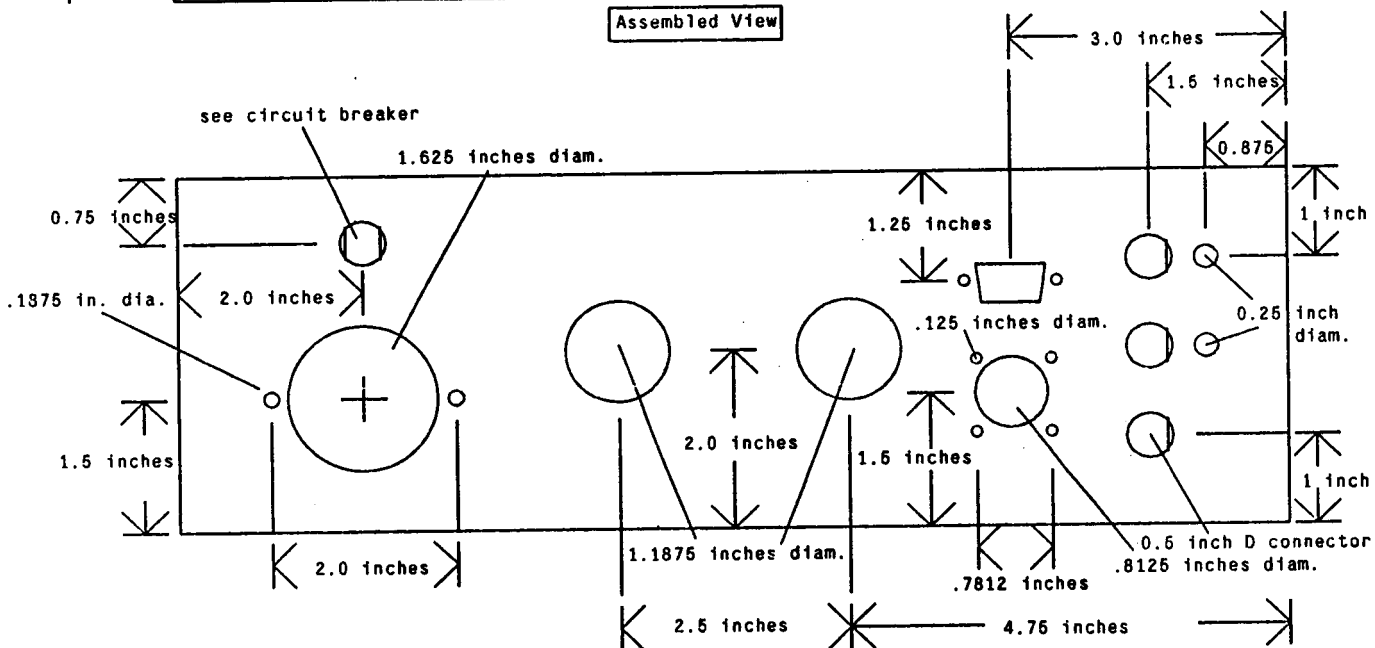Stop   Stop

Additional Panic Buttons are in series with the one shown

Title:
Emergency Start/Stop system
File: [rover]/usr/nivek/rover/neptune/mre2.dp
Date: 3/6/84   Scale: NTS   Approved:
Drawn by: nivek   Dwg.
Checked by: No.:

AC SSR

AC SSR

DC SSR

AC SSR

AC SSR

1.5.500

Power Supply

4.50

1.15.100

AC SSR

4.00 inches

DC SSR
and
coax relay

Bryant 5278

Start

Stop

SIDE TWO

SIDE FOUR

SIDE THREE

SIDE ONE

SIDE TWO

INSIDE

SIDE THREE

SIDE FOUR

SIDE ONE

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|---|---|---|
| Title: | Neptune rover electronics | |
| | Electronics Box Layout   Assembled View | |
| File: | [rover]/usr/nivek/rover/neptune/mre3.dp | |
| Date: | 2/9/84 | Scale: NTS | Approved: |
| Drawn by: | nivek | Dwg. |
| Checked by: | | No.: |

main circuit breaker

START   STOP   processor connect   CAM1 ○ leds

110VAC In

manual controller   CAM2 ○ leds

Video out

Assembled View

3.0 inches

1.5 inches

0.875

see circuit breaker

1.625 inches diam.

0.75 inches

1.25 inches

1 inch

.1875 in. dia.

2.0 inches

0.25 inch diam.

.125 inches diam.

1.5 inches

2.0 inches

1.5 inches

1 inch

2.0 inches

1.1875 inches diam.

0.5 inch D connector
.8125 inches diam.

.7812 inches

2.5 inches   4.75 inches

Cutout Diagram

SIDE TWO

SIDE THREE   SIDE FOUR

SIDE ONE

View from this side

SIDE TWO

SIDE THREE   SIDE FOUR

SIDE ONE

one inch

Mobile Robot Lab		© 1984
Title:	Neptune rover electronics	
	Electrical Box Sides . SIDE ONE	
File: [rover]/usr/nivek/rover/neptune/mre4.dp		
Date: 2/9/84	Scale: NTS	Approved:
Drawn by: nivek		Dwg. No.:
Checked by:		
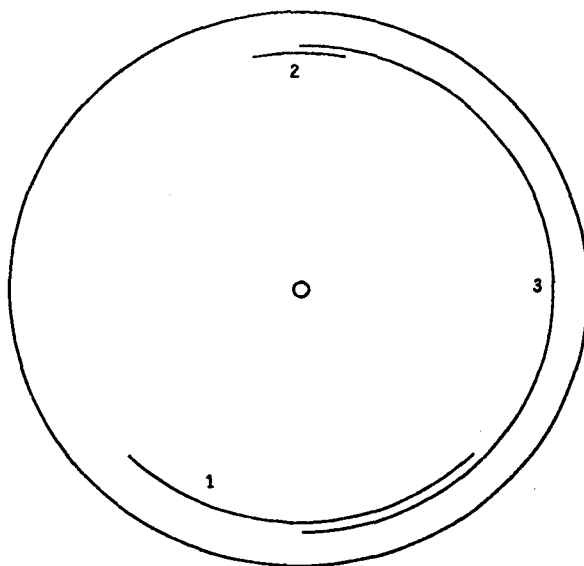
1	2	3		
0	0	0	Legal states	Legal states are NOT(1 AND 2)
0	0	1		
0	1	0		
0	1	1		
1	0	0		
1	0	1		
1	1	0	Illegal states	Switches 1 and 2 cannot be on at the same time
1	1	1		

0.20 inches w/ clearance

2.02 inches dia. cutout

2.50 inch dia. bolt circle

2"

2"

2"

2"

The holes are for mounting these connectors

View from this side

SIDE TWO

SIDE TWO

SIDE FOUR

SIDE THREE

SIDE ONE

SIDE THREE

INSIDE

SIDE FOUR

SIDE ONE
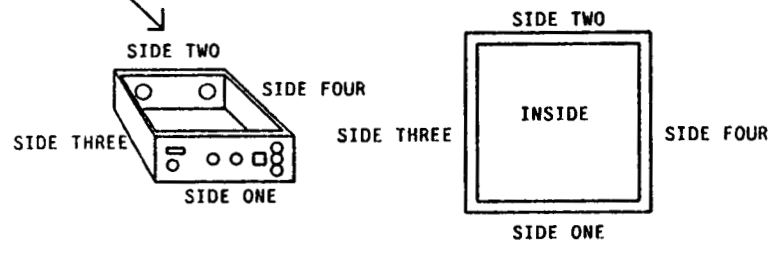
⌐╥⌐	**Mobile Robot Lab**	© 1984
Title:	Neptune rover electronics	
	Electronics Box Layout SIDE TWO	
File:	[rover]/usr/nivek/rover/neptune/mre6.dp	
Date: 2/9/84	Scale: NTS	Approved:
Drawn by: nivek	Dwg. No.:	
Checked by:		

SIDE TWO

3.625 inches   3.625 inches

1.875 inches   1.875 inches   1.50 inches

⊕   ⊕   ⊕   ⊕

1 inch

1.875 inches

⊕ ———— ⊕   ⊕ ———— ⊕

1.375 inches

⊕ ———————— ⊕

SIDE THREE   SIDE FOUR

4.00 inches   4.50

1.875 inches

⊕   ⊕

1 inch

⊕   ⊕ ————————— ⊕

3.00 inches

SIDE ONE

The box bottom is 12 inches square
All holes are for 8-32 screws with clearance.
The inner square is the 1/2 inch lip around the top.

View from the top

SIDE TWO
SIDE FOUR
SIDE THREE
SIDE ONE

SIDE TWO

SIDE THREE   INSIDE   SIDE FOUR

SIDE ONE

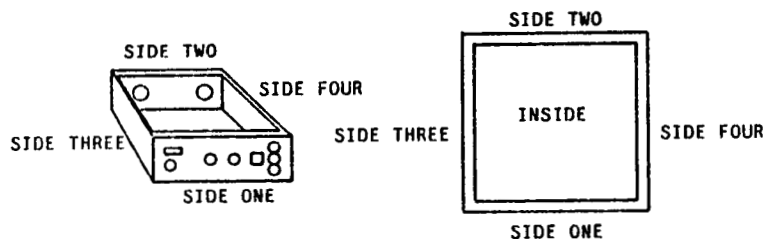| ⋔	**Mobile Robot Lab**	© 1984
Title:	Neptune rover electronics	
	Electronics Box layout Inside Bottom	
File:	[rover]/usr/nivek/rover/neptune/mre7.dp	
Date: 2/9/84	Scale: NTS	Approved:
Drawn by: nivek		Dwg.
Checked by:		No.:

0.5 inches   0.5 inches

0.5 inches   0.5 inches

SIDE THREE

one inch   one inch

0.5 inches   0.6 inches

0.5 inches   0.6 inches

SIDE FOUR

Holes are for 10-32 Screws with clearance

SIDE TWO

SIDE TWO
              SIDE FOUR
                              INSIDE
SIDE THREE   SIDE THREE   SIDE FOUR

SIDE ONE

SIDE ONE

Mobile Robot Lab		© 1984
Title: Neptune Rover Electronics		
Electronic box sides THREE and FOUR		
File: [Rover]/usr/nivek/rover/neptune/mre8.dp		
Date: 3/5/84	Scale: NTS	Approved:
Drawn by: nivek		Dwg. No.:
Checked by:		
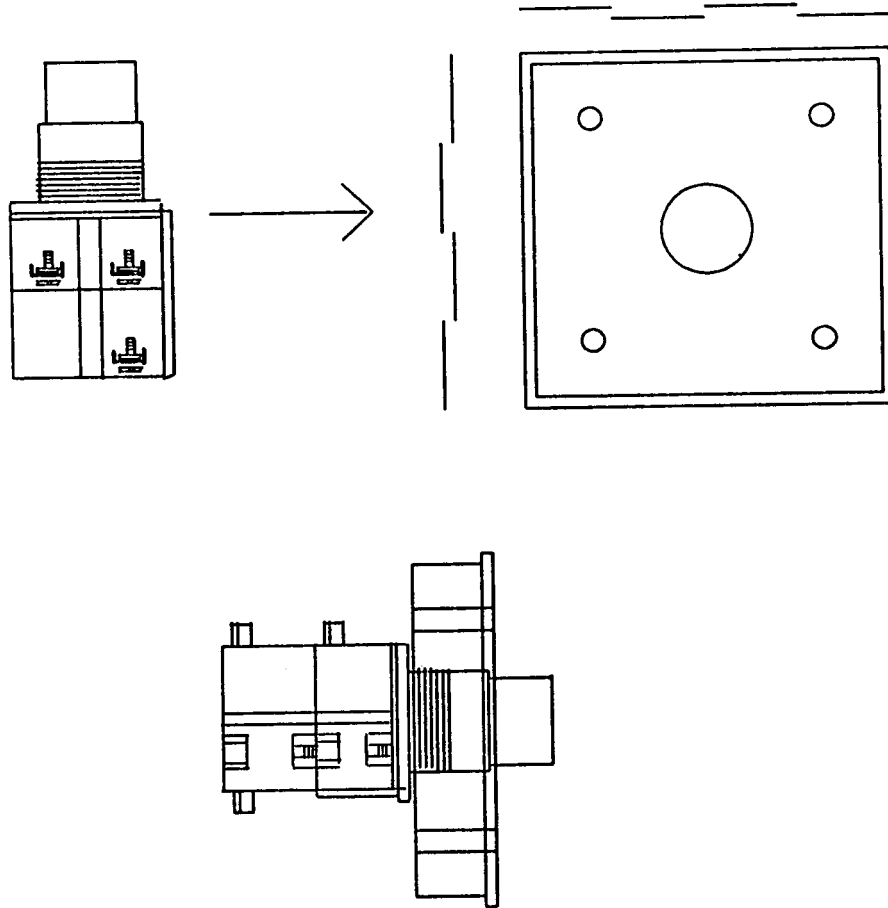
Center hole in plate to be threaded for the switch.
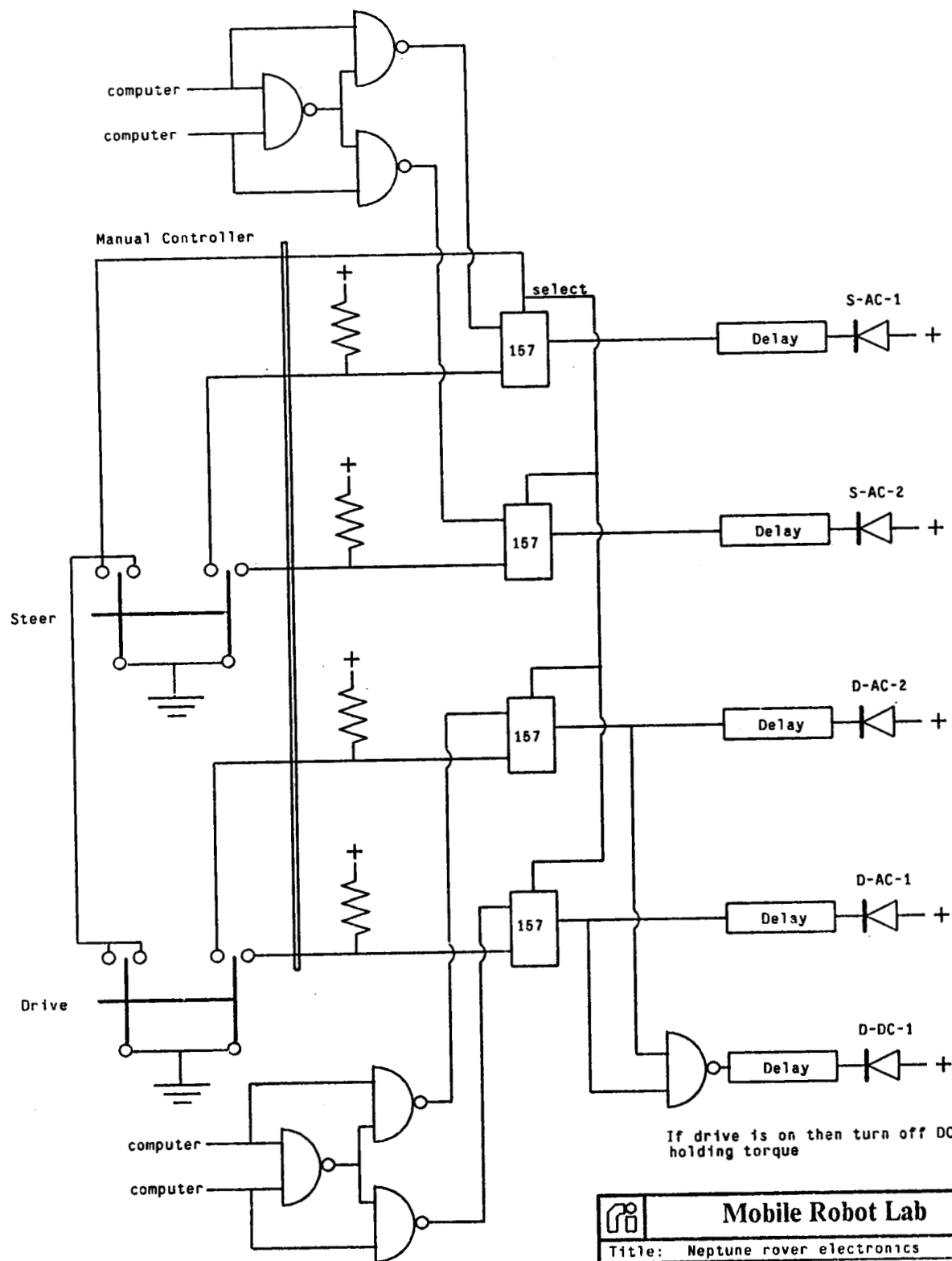Not sure about threading diameters.

'04   132

Input ———▷o———   4.7 K   1 K   ⊐o——— Output

                              ═══ 100 uF

                              ⏚

IN ‾‾‾‾‾‾‾‾_____/‾‾‾‾‾‾‾‾

OUT ‾‾‾‾‾‾‾‾‾‾‾_____/‾‾‾‾‾‾‾‾‾‾‾

              ⇑ ⇑

              Time delay

This symbol will refer to this circuit in other drawings.

┌─────────────────┐
│   Delay   │
└─────────────────┘

computer

computer

Manual Controller

select

157

S-AC-1

Delay

157

S-AC-2

Delay

Steer

157

D-AC-2

Delay

157

D-AC-1

Delay

Drive

D-DC-1

Delay

If drive is on then turn off DC
holding torque

computer

computer

When either of the manual controller switches are moved in
either direction the Select line on the Mux inputs is pulled
low, thus disabling computer control.

	Mobile Robot Lab	© 1984
Title: Neptune rover electronics		
Circuit diagrams		
File: [rover]/usr/nivek/rover/neptune/mre11.dp		
Date: 3/7/84	Scale: NTS	Approved:
Drawn by: nivek		Dwg. No.:
Checked by:		

Coax Relay

750 ohms

status lights

15VDC

Video Out

Camera 1

Camera 2

computer

Manual

5 VDC

5 VDC

15VDC

Sync

Sync

Appendix III

On-Board Processor Software

A simple controller for the Neptune rover.

This program parses commands from the VAX or the debugging terminal and translates them in to robot motion and control. On start up, the debugging terminal is queried for the source of commands: either the VAX, or the debugging terminal for manual control. When an entire command has been parsed, the commands are executed. At the end of execution, a '!' is sent to the terminal, and also to the VAX, if it is originating commands. If there was a problem with the parse, a '?' is sent and nothing is done.
Commands are in the form:

        [subcommand subcommand subcommand ...]

Subcommands are either a single character or a movement command enclosed in parenthesis.
The single character subcommands are:

        C : Center steering motor
        0 : Select camera zero (left)
        1 : Select camera one (right)

The movement subcommand is of the form:

        (motion, duration)

where motion is one or two characters:

        N : Do nothing
        C : Center steering
        L : Steer left
        R : Steer right
        F : Drive forward
        B : Drive backwards

and duration is a decimal number representing the number of 1/60ths of a second to run this particular motion. The N command is mutually exclusive of everything else, the C, L and R commands are mutually exclusive, as are the F and B commands. If you specify two or more mutually exclusive commands, the parser will return an error.
In all commands, upper and lower case is identical and spaces, carriage returns and line feeds are ignored.
If the out-of-bounds limit switch is triggered during movement, all steering in the out-of-bounds direction is inhibited, but execution continues.
Here's an example command:

        [0 C (LF, 60) (CF, 120) (RB, 60) (B, 120)]

This command would be completely parsed, and then the following actions would occur: The left camera will be selected, the steering motor will be centered, the robot will move forward steering left for one second, forward steering to the center position for two seconds, backwards steering right for one second, and backwards for two seconds. After all of this had been performed, a '!' would be sent to the terminal, and the VAX, if it were issuing commands.
While running, a ↑K typed at the terminal will immediately abort the current command and turn off all of the motors.