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California Department of Transportation

COMPLETION REPORT FOR THE AUTOMATED STENCILLING PROJECT: PREFABRICATED TARGET LAYER

Preliminary Draft of M.S. Thesis by Ian Broverman
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Committee Chair

University of California, Irvine
1994

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ABSTRACT OF THE THESIS

Design of a Prefabricated Target Layer for Automated Surveying

by

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This thesis describes the design and construction of an automated prefabricated target laying device to be used for the installation of aerial survey markings on the shoulders of motor vehicle lanes. The goal of this work has been to produce a machine that operates on simple principles, could be installed on a maintenancevehicle, and would be easy to operate. In the design of the system, a structured design methodology was used, which broke the design process into several steps; developing functional specifications, strawman concepts, feasability studies, system and component specifications, prototyping, integration with support systems, and field testing.

The prototype system used targets made out of 110 pound card stock and Screenrite semigloss black ink. They were stored in a paper tray and the top sheet was separated with a two stage suction system. The targets were positioned with a pick and place manipulator, made from two air cylinders. They were pressed to the ground with an end effector plate that would allow for sloped shoulders. The targets were glued down with a mastic, which was dispensed from three snuffer valves. The mastic was pressurized with a ram-mount pump. The target and mastic prototype were tested with an environmental exposure test and a wind loading test. The overall system was

actuated pneumatically, using air-actuated spring-return solenoids to control flow. The system was controlled with a Z-world brand control board, using digital logic.

Chapter 1: Introduction

1.1 Problem Description

The purpose of this thesis is to automate and improve the installation of abbreviated premarks on a roadway for surveying. The abbreviated premark is an experimental marking currently being tested by the California Department of Transportation (Caltrans) to increase the level of accuracy in their photogrammetric survey mappings. (See Fig. 1.1.1) This marking increases photogrammetric accuracy by making the Edge of Travelled Way (ETW) lines more visible in aerial photographs. They are placed every 50′ along the ETW lines in both the road's shoulders and median dividing strip.

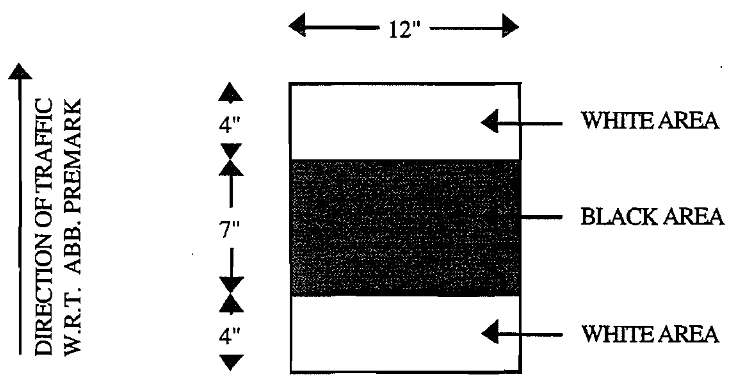


Figure 1.1.1: Abbreviated Premark Target

Currently, these premarks are applied by hand. Crew members spray paint a large black mark, then use a stencil to spray paint the white lines on top of the black, after the black has dried. The workers must exit the vehicle for this operation.

The major improvement to the system that this thesis offers is the reduction of risk for the crew members. Exposure to traffic is a great risk for pedestrian crew members; the danger of employees being injured or killed by vehicles in normal traffic patterns is great.

There are two other motivating factors for the development of an automated system. The first is the need for reduced cycle times. Previously, photogrammetric surveying crews only needed to paint a control point marker every 500′ down the length of a roadway. With the use of abbreviated premarks spaced every 50′ in the shoulders and median, 20 to 40 times more markings would be needed to survey highways. Stated another way, approximately 422 abbreviated premarks per mile are required. Clearly, a quick system of marking the highways is needed.

The last motivating factor is the need for a more temporary system of markings. Since these markings are to be used for only one run of aerial photographs, and since the photographs are normally taken within a few weeks of premarking the roadway, the abbreviated premarks are not needed after about two months. Present methods of applying premarks involve painting on the shoulders, which only get light amounts of traffic, and hence, wear. As a result, the premarks may last years past their intended usefulness. While this is not a serious problem for markings that appear once every 500′ in a roadway, markings that line both sides of the roadway every 50′ may be a distraction to drivers. It is therefore desirable to have these new markings start to degrade soon after they are photographed. The PTL system addresses this issue by using degradable paper, rather than paint, for its targets.

1.2 California's Use of Photogrammetry

Although a thorough knowledge of photogrammetry is not necessary in the development of a system to install abbreviated premarks, some introduction to photogrammetry is useful in that it gives insight into why certain tolerances and specifications have to be met.

Photogrammetry is defined by the American Society for Photogrammetry and Remote Sensing as "the art, science, and technology of obtaining reliable information about physical objects and the environment through the processes of recording, measuring, and interpreting photographic images and patterns of radiant energy and other phenomena" [McCormac, Stafford, 1991]. The science of acquiring analytical data such as land surveying from the direct measurements of aerial photographs falls under this broad definition, and is more specifically known as *metric photogrammetry*.

The aerial photographs used in photogrammetry can be taken on either a vertical or oblique angle. Vertical photographs are taken with the camera's optical axis perpendicular to the ground, which minimizes the amount of depth distortion in the photo. Oblique photographs are taken at angles other than 90°, and any measurements taken from these photos must use geometric methods to compensate for the depth distortion. For land surveys, the camera axis should be as close to vertical as possible.

Accurate measurements of elevation in photogrammetry can be made by using *stereography*. A stereographic effect is achieved by taking two photos of the same object from two different locations that are a set distance apart. The change in perspective allows for measurement of depth. This effect can be seen by the human eye by training one eye on each photo.

The scale of a photographic survey is defined by a ratio between the focal length of the camera, f, and the average distance between the camera's lens and the ground pictured in the photo, h . In *engineering scale,* scale is expressed as

$$S_{ENG} = \frac{h}{f}$$

which is in terms of feet per inch.

The Surveys Section of Caltrans' Geometronics Branch is responsible for California's photogrammetric mapping. Caltrans uses 50 scale photogrammetric mapping to make maps of their roadways. Fifty scale means the maps have a scale of 1" = 50', and are made from aerial photos which are taken at approximately 1"=250' scale.

California currently uses ground surveying crews to survey sites. These crews paint and surveying X-shaped control points on the ground to add measured reference points to the photos. Most likely it will be these crews that put the abbreviated premarks on the roadways. These crews mark about 600 miles of roadway per year for photogrammetric mapping. This accounts for 8000 X-premarks/year and, if use of the abbreviated premarks is fully implemented, 240,000 abbreviated premarks/year.

Photogrammetric mapping in California is supplemented with 600 to 800 miles of manual cross sections per year to obtain pavement elevations. There are about 80 survey crews working for the state highway department, and each crew averages 40 days per year obtaining pavement elevations. It generally takes a four person survey crew between five to seven days to accomplish one mile of cross sections. This represents considerable exposure of surveyors to traffic, and causes delays to the public due to shoulder and lane closure. If photogrammetric methods can be made more efficient, fewer manual cross section will be needed, significantly reducing the traffic exposure of crews.

1.3 Design Process

A structured process of design was followed in the development of the Prefabricated Target Laying system (PTL) presented in this thesis. The phases of this process were specification generation, strawman conceptual brainstorming, feasibility testing of concepts, design prototyping, and field testing.

Phase 1 - Functional Specifications

The first step in this thesis project was to establish functional specifications. The functional specifications build an understanding between the designer and the surveyor as to what would be needed from an automated system.

After several interviews with the surveyors, a set of functional specifications (5) was made that outlined their needs for placement, coloring, permanence, etc. for the abbreviated premarks. These and other specifications can be found in Chapter 2.

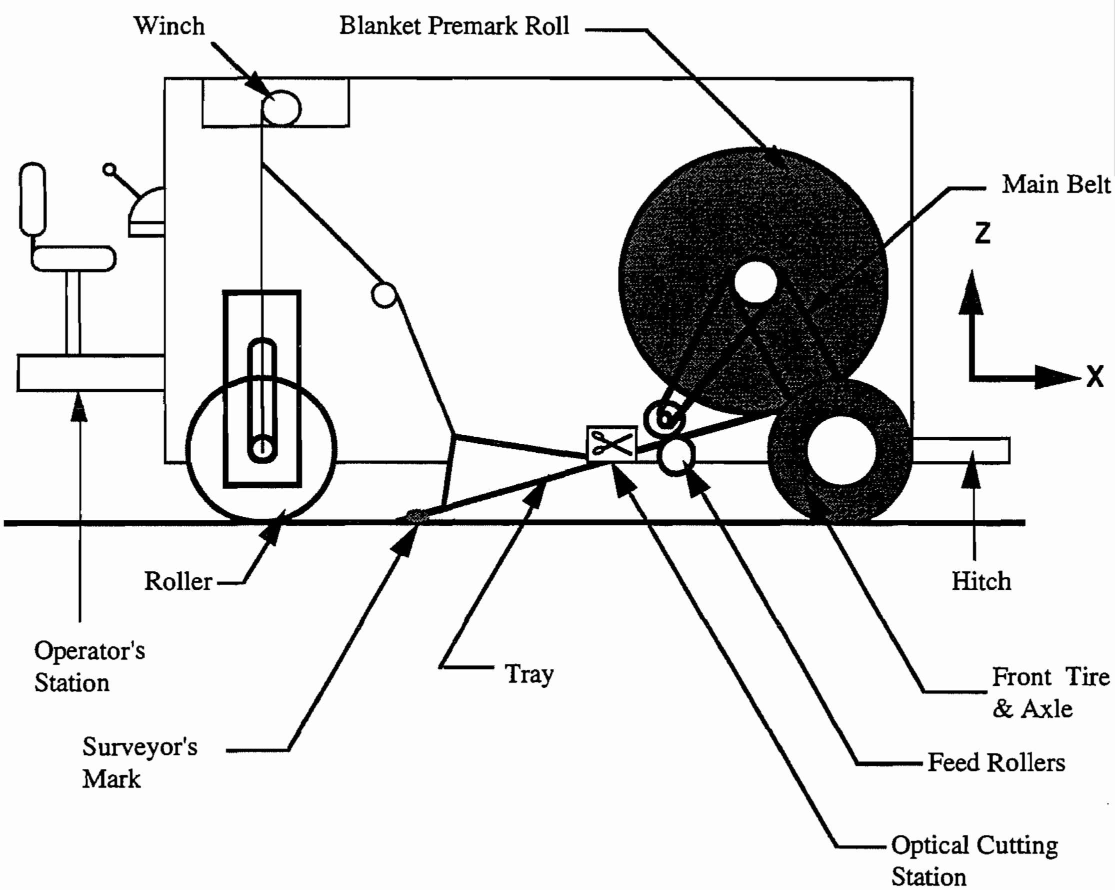
Phase 2 - Strawman Concepts

Strawman concepts are rough, conceptual designs of what the final process may be like. They are generated through a combination of brainstorming and preliminary research. In the case of this particular thesis work, the strawman consisted of a description of the basic operating principle, an operational procedure that the mechanism may use, and rough sketches of the design. Several of these conceptual designs are produced, most of which will be eliminated as options for a final design. The choice for a final design will initially be narrowed down by feasibility, which is determined in Phase 3, then will be further narrowed down by the basis of which of the working design ideas is the better idea.

Originally, four strawman concepts were presented for the making of abbreviated premark. (6) All of these concepts involved painting the markings on the roadway. The idea for a non-paint system for abbreviated premarks was developed from a strawman for a similar project, the automation of the application of the "X" shaped marks mentioned earlier in the photogrammetry overview.

The strawman for the PTL system bears no resemblance to the final product. (See Fig. 1.2.1) The original idea featured a continuous roll of soft plastic targets which would be cut to size at the site, then crushed down into the surface of the shoulder. This original design was overly complex, and stood little chance of actually working correctly, as shown. But as stated earlier, the strawman concepts were not presented to give polished designs, just rough ideas. The only thing that this strawman was meant to convey was the use of some method other than paint for making photogrammetry targets.

NOTE: Back tire of trailer and suspension are not shown.



OPERATION:

1.) Sweeper on front of truck prepares area for premark. (not shown)
2.) When trailer is close to SURVEYOR'S MARK, operator lowers ROLLER and TRAY with WINCH
3.) When SURVEYOR'S MARK is located at end of TRAY, operator signals driver to move foreward, and engages MAIN BELT on FRONT TIRE & AXLE.
4.) BLANKET PREMARK ROLL turns, and FEED ROLLERS send the premark down through the TRAY and onto the road surface.
5.) ROLLER imbeds soft plastic premark into road surface
6.) When trigger mark signals OPTICAL CUTTING STATION that the edge of the target is reached, premark is separated from roll with a cutter contained in the station. The MAIN BELT will automatically disengage, and the BLANKET PREMARK ROLL is stopped from turning.
7.) After the ROLLER has completely rolled over the premark, the operator lifts the TRAY and ROLLER with the WINCH, and the unit moves to the next surveyed location.

Figure 1.2.1: Strawman Concept for PTL

Phase 3 - Feasibility Studies

The feasibility study is the method of determining if the overall design concept will work. Research and/or tests are performed to see if the design could produce something that has potential to being the desired output. Exact performance to specifications is not necessary at this point; fine tuning of the system will occur later. This phase is only done to prove whether or not a design could work.

Feasibility study for the PTL consisted of the development and testing of several prefabricated targets. Targets were tested for their ability to withstand natural environmental conditions, and induced wind loading. The tests performed and results are contained in Chapter 3.

Phase 4 - System & Component Specifications

After the design concept has been proved feasible, and the decision has been made to pursue the concept further, the system itself must be defined. To do that, one must generate specifications for the system and its operation. The designer must now familiarize his/herself as to what options are available for the design; what techniques could be used, what's available on the market, what would be most efficient, etc. An outline is then prepared that bounds the composition and operation of the design. Components and subsystems are identified at this time, and component specifications are then prepared.

The system and component specifications are in Chapter 2, after the functional specifications.

Phase 5 - Prototyping

The prototyping phase is the phase where the majority of the design work takes place. In the prototype phase, a working model is designed, built, and documented with detailed drawings. Further redesign may be done at a later date, but these changes would be considered "fine tuning".

Design prototyping information is contained in Chapter 4.

Phase 6 - Integration with Support Systems and Field Testing

In the final phase, issues such as mounting to the truck and power supply are fully explored and built. Any adjustments to make the mechanism "roadworthy" would be done at this time. Note that this thesis does not include a Phase 6 step.

Chapter 2: Specification Phases

All of the parameters used to specify the PTL system are contained in this chapter. The first set presented are the functional specifications, which define what the surveyors need from a system that places abbreviated premarks to a roadway. The second set are the system specifications, which were produced in order to give some guidelines for the design of the PTL machine. The last sets are the individual subsystem specifications, which were used for selecting components for the subsystem, and to aid in the design.

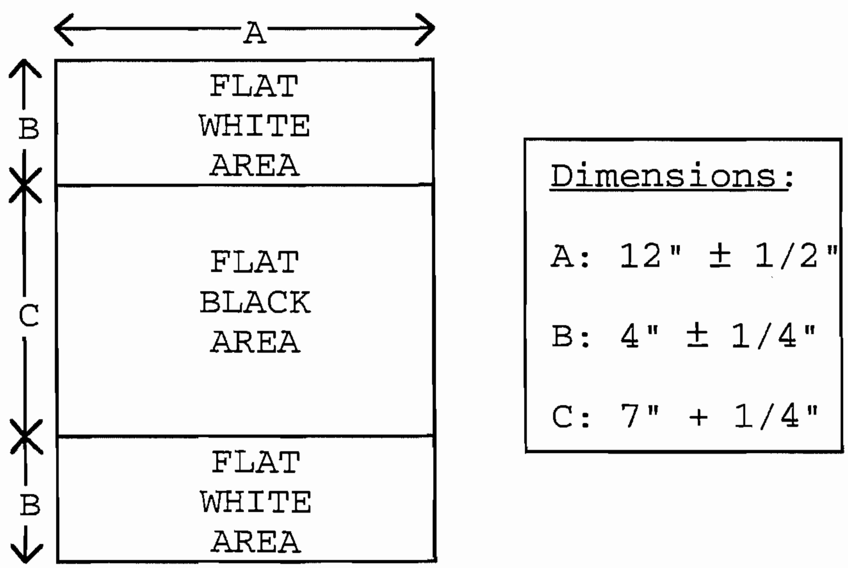


Figure 2.1.1: Detail Drawing of Abbreviated Premark

2.1 Functional Specifications

2.1.1 Appearance of Abbreviated Premarks

The dimensioned drawing for the appearance of the abbreviated premark is given in figure 2.1.1. The mark consists of two white stripes separated by a black field. Due to the nature of the application, the tolerances are not very strict. The most important dimensional feature in the appearance is that there must be at least seven inches separation between the two white stripes. If the lines were less than seven inches apart, the brightness of the white lines may provide an undesirable spreading of light over the black area, obscuring the black area. This effect is called halation.

To reduce the amount of light reflected back into the photograph, the coloring in both the black and white areas should be as flat (non-reflective) as possible. The edge definition of the white areas is also important. All of the edges of the white areas of the target must be crisp and well - defined. The highest possible contrast between black and white areas should be achieved. There should be little to no blending of black and white areas. Also, the edges of the white areas must not waver more than 1/4".

2.1.2 Durability and Longevity of the Abbreviated Premarks

In a worst-case situation, the targets would have to stay on the road for ten weeks. Under normal circumstances, a premarked area is photographed two to three weeks after the targets are laid. Ideally, the targets should start to degrade after twelve weeks, and break down quickly afterwards. It is not desirable to leave these marks every 50' along the roadside, as they may distract drivers.

The abbreviated premarks should survive the following environments:

- TEMPERATURE: -20° to 120°F
- WEATHER: Local weather conditions.

(Parameters must be specified by the local transit authority)

- LIGHT FASTNESS: 10 weeks of UV radiation.
- TRAFFIC: Normal shoulder use .

(Parameters must be specified by the local transit authority)

- WIND LOADING: Gusts up to 40 miles per hour while adhesive is wet.

2.1.3 Environmental Compatibility of Abbreviated Premarks

All materials used in targets must comply with all environmental codes enforced in the state of California.

2.1.4 Placement and Orientation of Abbreviated Premarks

Premarks are to be placed according to the following specifications:

- Marks are spaced every 50' ± 10% apart along roadway (See Fig. 2.1.2).
- Marks must be oriented along ETW (Edge of Traveled Way) line. It is preferable to locate the marks entirely on the asphalt concrete (AC) shoulder, with the left side of the mark touching the ETW line, or to have the marks centered on the ETW line. Locating the marks entirely on the Portland Cement Concrete (PCC) road surface is acceptable, but not preferable (See Fig. 2.1.3).
- For divided roadways, marks will be placed on both the inside and outside ETWs. (See Fig. 2.1.2)
- For roadways with no non-traffic area separating lanes of traffic that travel in opposite directions, marks will be placed only on outer ETWs.
- Marks should be oriented perpendicular to ETW line (±5°).

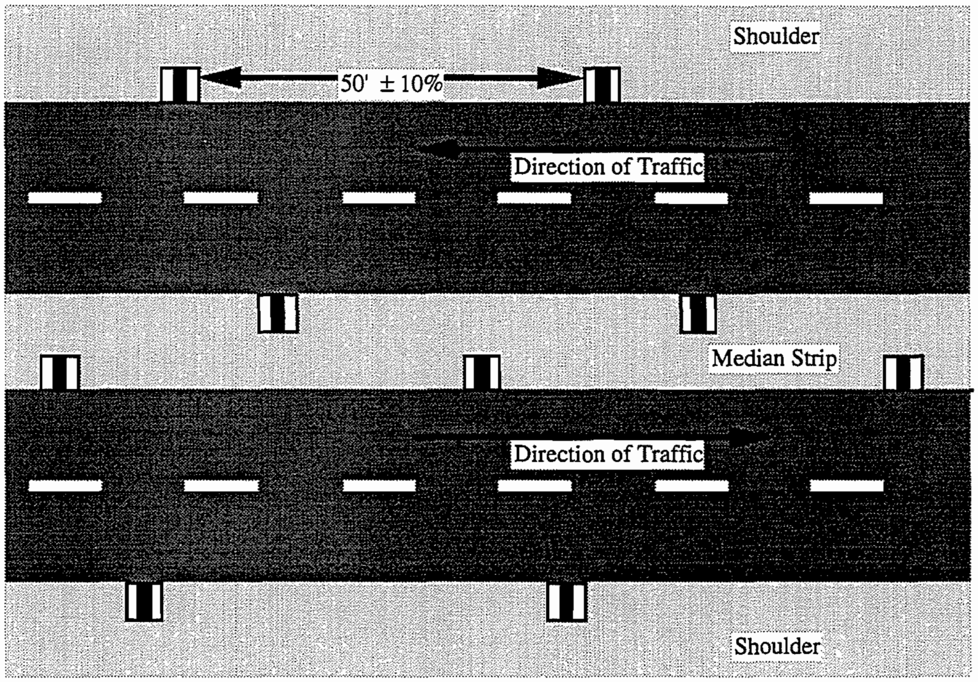


Figure 2.1.2 Location and Ideal Orientation of Abbreviated Premark for a Divided Roadway

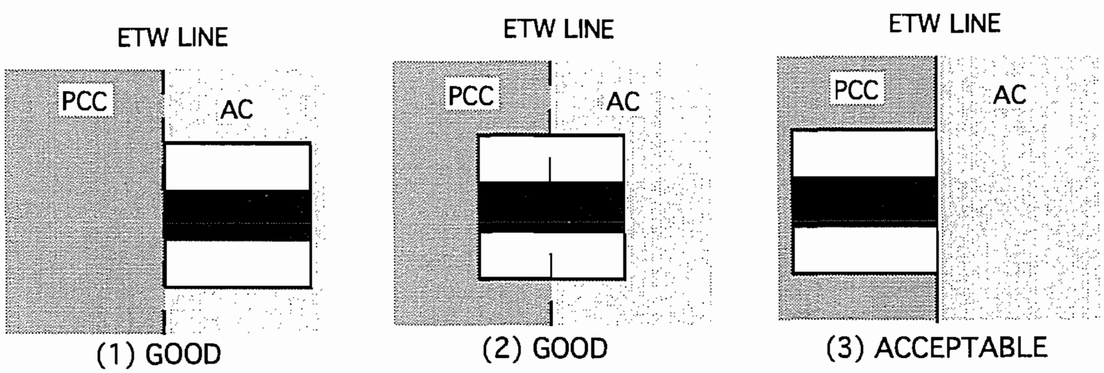


Figure 2.1.3 Options for Orientation of Abbreviated Premark

2.2 System Specifications

2.2.1 General Operation Requirements

- Only one operator (ideally the driver of the vehicle) will be needed to run the system.
- Operator will remain in cab during target laying operation.
- Reloading may require operator to exit cab of truck.
- Truck is stationary for application of target to road surface.
- Targets are positioned by sight.
- Machine cycle time should be approximately 10 seconds or less.
- User Control interface should be logical and easy to follow.

2.2.2 General Machine Requirements

- All subsystems are to be as simple as possible.
- Standard commercially available parts are to be used wherever possible. Using commercially available parts keeps costs down, and speeds fabrication and replacement.
- Use "fail-safe" design methods whenever possible. Anticipate where failure can occur, and design so that any foreseen failure mode would not be catastrophic.
- Machine will be able to withstand normal abuses from being mounted to a vehicle.
- Machine will operate reliably while on an active roadway. (i.e. some traffic lanes will be active with normal traffic)
- System will operate off of 24 volt DC power.
- System will operate off of a supply of 100 psi of air.

2.2.3 Mounting of System to Vehicle

2.2.3 Mounting Requirements

- Unit will not exceed legal width limits while traveling to/from site.
- Unit will be at least 10″ above pavement when vehicle is traveling to/from work site.
- Unit will be approximately 3″ above pavement when traveling between premarking locations.
- An automated pavement cleaning operation will be on the truck to prepare the road surface for premarking.

2.2.4 Maintenance

The system should be reliable, requiring a minimum amount of maintenance. Minor maintenance activities may be performed by the operator when the vehicle is on a side street, or other low traffic area. Major maintenance should be performed by a qualified mechanic. Maintenance schedules and inspection procedures are to be developed where needed. (See Appendix B for preliminary inspection procedures)

2.2.5 List of Subsystems

- Paper Separation and Holding Subsystem :

    The separation function of this system refers to the separation of a single target from a stack. The holding function is the grasping of the target throughout the operation.

- ″Pick and Place″ Subsystem :

This system is responsible for taking the target from the point of target separation to the point of installation. It also provides the application force that secures the target to the pavement.

- Adhesive Delivery Subsystem:

  The adhesive subsystem includes all items associated with a total gluing system. These include glue pumping, plumbing, glue dispensing, and glue placement.

- Control Subsystem:

  The control subsystem consists of electronic and pneumatic controls. This subsystem actuates all of the previous subsystems, and allows the operator to use the PTL system.

2.3 Subsystem Specifications

2.3.1 Paper Separation and Holding

- Subsystem will be a vacuum-based system.
- Separation unit will reliably take one, and only one, target from the top of a stack of prefabricated targets.
- The subsystem will provide adequate suction to hold the target throughout the motion of the entire process.
- When the target is installed, disengagement will release the target.

2.3.2 "Pick and Place" Subsystem

- Subsystem will be driven by air cylinders.
- Subsystem will be able to reliably and repeatably move the end effector from the separation point to the placement point.
- Mechanism will be given clearance tolerances, so that it will not interfere with itself, its mounting, or the vehicle that it is mounted on at any point.

• Mechanism will be able to "find" the top of the stack of premarks, noting that the height of the stack changes as the stack is depleted.

• Mechanism will be able to 'find" the road within an inch tolerance.

• End effector must accommodate sloped roadways.

• Mechanism should operate in only one plane.

• Exposed air cylinder rods should not be more than 14".

• Necessary application forces are to be determined experimentally.

2.3.3 Adhesive Subsystem

• Must dispense glue in an effective pattern for affixing premarks. Pattern will be determined experimentally.

• System must not experience major difficulties from dried adhesive.

• Components of the PTL should not be in danger of coming in contact with fresh glue.

• Nozzles will be air-actuated.

• When no air is supplied to nozzles, they will be in "off" position. This will be done as a fail-safe.

• Glue dispensed that is not covered by the target should be minimized.

2.3.4 Control Subsystem

2.3.4.1 Pneumatic Controls:

• Reliable air-actuated spring return solenoid valves will be used wherever possible.

• The valves should be chosen and connected so that they are in "fail-safe" positions where possible.

2.3.4.2 Electronic Controls:

- A Z-World control system will be used as an electronic controller. The Z-World has been chosen because it will most likely be used for controlling other systems on the truck.
- Control of the system will be binary.
- Inputs will be taken from mechanical switches.
- All outputs will be air-actuated solenoids.
- The system will be operated by a hand-held or similar small controller.
- Each PTL operation will be started with the push of one button.
- Fail-safes in the coding such as emergency stops will be included.

Chapter 3: Feasibility Testing Phase

At the time of this writing, the standard method used to apply photogrammetry markings to a roadway was to paint them by hand. The idea of using prefabricated markings on the pavement for aerial surveying was new, so it needed to be proven that it could work. If it did, research could begin on a full application system.

To prove that the idea is feasible, prototype markings had to be developed that could survive normal roadway conditions. Various materials and methods were tested for the prototype markers. The prototype markers were put under two tests:

- An **Environmental Exposure Test**
- An **Induced Wind Loading Test**

These tests needed to do the following things:

- Show if prefabricated markings could be made which would survive normal weather conditions, and remain attached to the pavement.
- Show if markings could be attached rigidly enough to survive the strong gusts of wind created by passing trucks.
- Find a good design for the prefabricated mark, using field tests.

A description of the most current prototype, as well as reports on the two tests are contained in this chapter.

3.1 The Prototype Prefabricated Abbreviated Premark

There were three variables in material selection for the prefabricated marks; what would the base material be? How would the black and white striped pattern be rendered? And how would the mark be attached to the pavement? A more detailed description of the requirements for these materials follows, along with descriptions of the materials used for the final prototype.

3.1.1 Base Material - 110# Card Stock Paper

The requirements for the base material were that it would be relatively inexpensive, relatively easy to handle in a mechanical process, able to have the premark pattern applied to it, would survive normal weather conditions for several weeks, and then would start to degrade. Using paper fills all of those requirements very well, so all testing was done with different types of paper. Of the papers considered and tested, one hundred and ten pound card stock was chosen as the best performer. Not only did this paper fulfill all of the above requirements, but it also had the advantage that the flat, white surface color could be used as part of the marking, so no printed coating would be needed for white areas.

3.1.2 Marking Material - Screen Rite Black Ink

The requirements for the marking materials were that they could be used to create the abbreviated premark pattern, would not lose appearance quality when exposed to weather over long periods of time, and would remain secured to the base material.

For the prototypes, the striped pattern was made by applying black ink to the paper in the appropriate area. The same ink was used in all testing; #110 Screen Rite semi-gloss poster ink. (See Appendix C for the MSDS sheets) An interview with an industrial printing expert led to the choice to test this ink. The tests showed that the ink worked well. No other marking materials were tested. The Screen Rite series of inks are recommended for printing on outdoor signs and billboards [Calcom, 1993]. Inks used on this type of media have to survive hostile weather without bleeding, and do not fade under the exposure of UV radiation from the sun.

3.1.3 Attachment to Pavement - H. B. Fuller Mastic

After testing several methods of adhesion, H. B. Fuller's SC-664 mastic adhesive was found to work the best. (See Appendix C for the MSDS sheets) This product lists concrete as one of the substances that it will bond to. It also lists drywall, a product which has similar surface properties to paper. Mastic is a cold tar, so it does not need to be heated in order to be extruded. It can be extruded through a small diameter nozzle to leave fairly uniform beads. This material is sometimes referred to commercially as caulk, and it requires a ram type plunger similar to that of a caulking gun to extrude the material.

3.2 The Environmental Exposure Test

Purpose of Test

The overall goal of this test was to determine if it was plausible to use prefabricated targets. In addition to this, the following was to be determined from this study:

1. To find a base material for the prefabricated targets that would survive environmental conditions.
2. To find a white-black-white pattern rendering procedure that would survive environmental conditions.
3. To find a good adhesive for holding the targets to the pavement.

For the PTL idea to be proved plausible, it needed to be shown that inexpensive, degradable targets could be attached to the pavement for a long period of time (approx. 4-6 weeks), and still retain their sharpness during that time. In order for an adhesive to be judged 'good', it not only had to hold the targets down to the pavement for that period of time, but it would also be relatively easy to apply by mechanical means.

Test Description

Targets were applied by hand to a test site road surface. Hand application resulted in targets applied with light, non-uniform pressure. It was expected that targets would not perform as well as those that were applied with a controlled, uniform, heavy force. If the targets could survive with only hand application, it would be assumed that an automated applicator would then also work.

The site used in this test was the test road facility of the AHMCT program at the University of California, Davis campus. It exhibited all of the properties of a normal roadway, with the exception of traffic (Operational highways could not be used due to the inherent risk of working next to high speed traffic). Targets were attached to the surface of this road, then periodically observed. These targets were attached with various adhesive types, with various gluing patterns, and under various gluing conditions. (dirty surface, incomplete coverage, etc.) All of these properties were noted in journals, as well as written on the faces of the targets. During observation, such properties as adhesive holding strength and target degradation were noted.

Adhesives Tested

The following types of adhesive were tested:

- White Glue
- Spray Cement

- Brush - On Contact Cement
- "Crack and Peel" Adhesive Backed Paper
- Mastic Sealant

Results

Both the spray cement and the adhesive backed paper failed almost immediately. The white glue, the contact cement and the mastic held the targets in place for a period of one month under normal Sacramento Valley springtime weather conditions. (fairly strong sun, light rains, constant winds) All of the targets made with 110 lb. paper and Screen Rite black ink retained a high degree of sharpness during this period, and showed no signs of fading due to UV radiation.

Analysis

Of the three adhesives that performed well in this test, it is believed that the mastic would be the best for an automated system. Mastic can be extruded into thick beads which can be flattened to cover a wide surface area with an evenly applied force. The contact cement dries very quickly, and could clog a mechanical applicator between application sites. The cement would require some sort of brush or squeegee to spread the glue, which would make clean-up operations more difficult. The white glue would require either a similar spreading brush, or a multi-nozzle system to spread the glue. Because white glue is less viscous than the mastic, its bead size is much smaller, and any delivery system designed for white glue would require more nozzles than for mastic; perhaps three times as many.

Conclusions

The test showed that it is possible to produce cheap, lightweight targets that could adhere to the pavement for long periods of time. Further testing would be needed to ensure the targets could survive all California weather conditions. Paper made from 110 lb. card stock, Screen Rite black ink, and SC-664 mastic all performed well in this test, and are recommended for use in further tests.

3.3 Wind Loading Testing of Adhesives

Purpose of Test

Strong gusts of wind generated by passing trucks have been found to blow targets off of the pavement in previous studies. This problem occurred while the glue was still drying. Their tests involved applying targets by hand, and it was expected that greater and more uniform application pressures would alleviate that problem. As winds generated by passing trucks are a normal operating hazard, no system could be considered viable until it was proved that it could operate successfully under this condition. In addition to the feasibility motivation of this study, tests for adequate gluing procedures needed to be made. Specifically, tests were necessary to determine:

1. Whether paper targets held with wet mastic would stay on the pavement when short blasts of high velocity air are applied.
2. An application force that would be able to flatten the beads of mastic out so that the target is fully adhered to the pavement.
3. An easily appliable gluing pattern that would provide for adequate coverage.

To test the performance of the targets under actual wind loads from passing trucks would have been a severe safety risk to the experimenters since it would expose them to high speed traffic. If precautions were taken to allow the experimenters work safely, it would have interfered with traffic, and would have corrupted the data. For these reasons, a simulation was needed.

Test Description

In order to simulate the wind blast, wind was created by the High Speed Wind Tunnel (Fig 3.3.1) in the U. C. Davis Wind Tunnel Laboratory. Winds created by this machine were approximately 45 mph at the exit. Since the wind tunnel controls could not create the short blasts of air needed to simulate a passing

Figure 3.3.1: High Speed Wind Tunnel

truck, an air flap was added to the end of the tunnel, as shown in figure 3.3.2. The targets were glued down near the end of the tunnel in an area that was just below the air flow out of the tunnel. When a blast was desired, the air flap was lowered to divert the air stream onto the target (See Fig. 3.3.3).

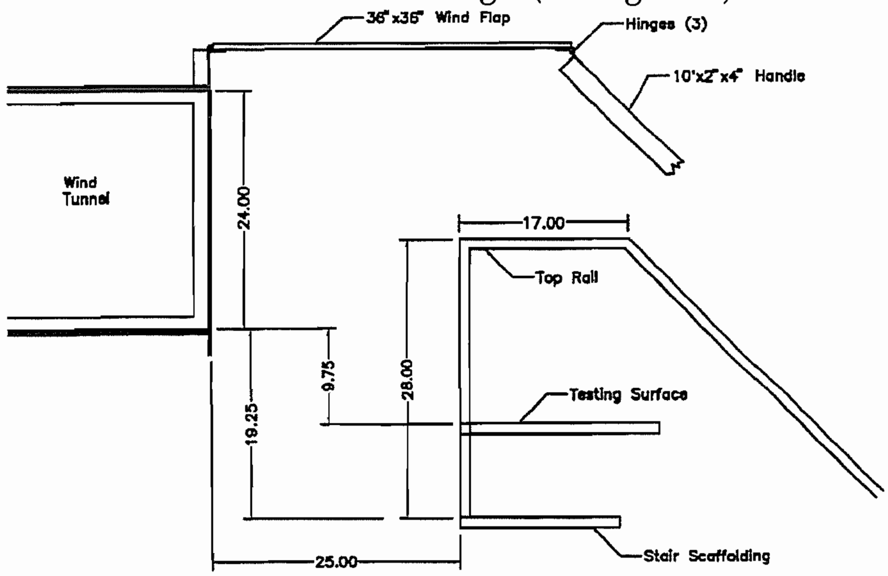


Figure 3.3.2: Air Flap in Non-Diverting Position

The targets used for the experiment were blank; they did not include the black marking stripe. Using blank targets saved set-up time, since at this point, all targets were made by hand. The targets were glued to tar paper to simulate the road surface. The smooth side of the tar paper was used, as it was believed that

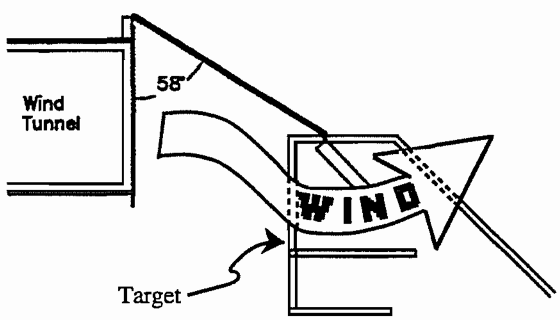


Figure 3.3.3: Air Flap in Diverting Position

this would be an extremely good approximation of actual road surface conditions. Mastic was applied to the targets, which were then pressed onto the paper with a 12x15" Formica application board. There were eight 1"D holes drilled into the board to represent the locations of suction cups that would be on the final application plate. Free weights were stacked on the board to achieve the desired application pressure. (Fig. 3.3.4)

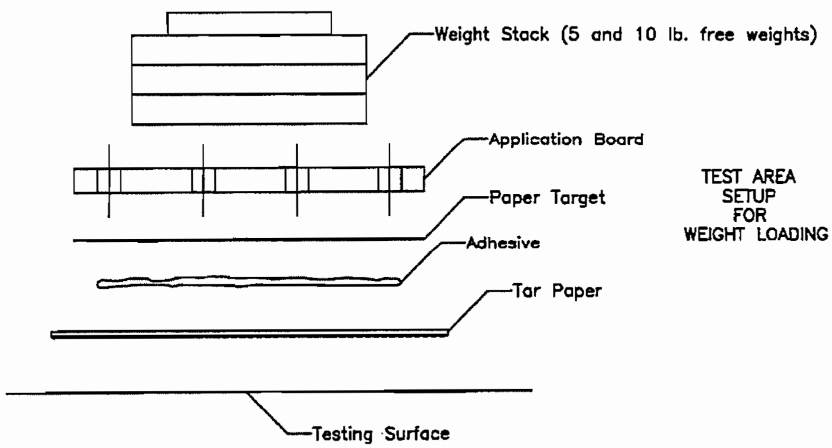


Figure 3.3.4: Loading of Glued Target

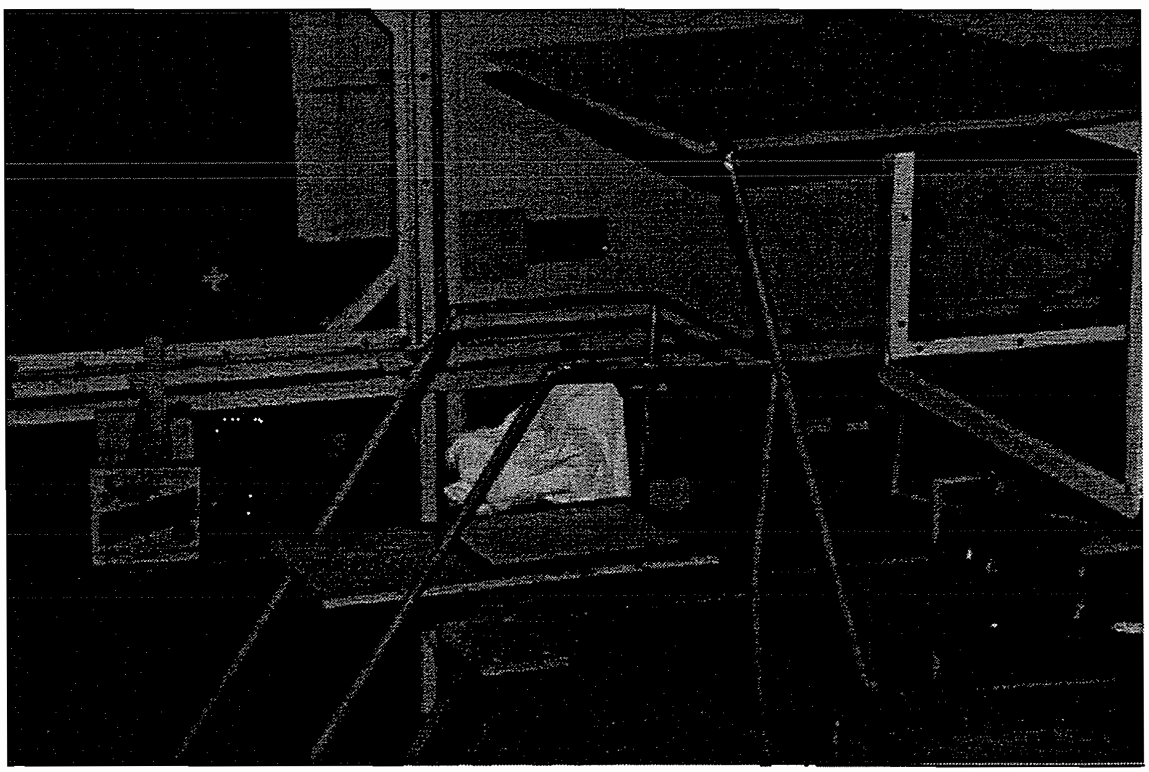


Figure 3.3.5: Non-Diverting Position in Testing

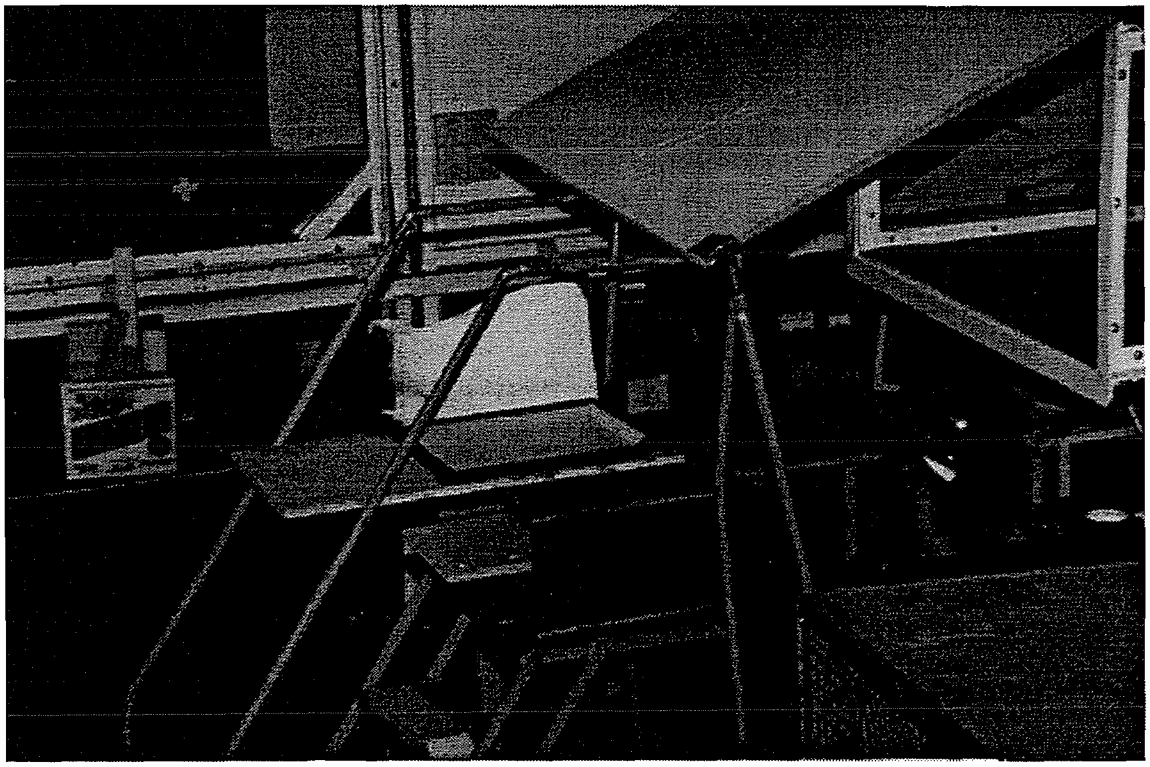


Figure 3.3.6: Diverting Position in Testing

Apparatus Used

- High speed **Wind Tunnel.**
- **Wind Flap** to divert wind onto target.
- 2"x4" beam **Handle** to pull down wind flap.
- **Hinges, C-Clamps, and Misc. Hardware** needed to attach flap.
- Wind Tunnel Lab's **Stair Scaffold,** to be used to hold up Test Plate.
- Swatches of **Tar Paper** to simulate road surface.
- **Tape** used in normal wind tunnel operations to hold down tar paper to scaffold.
- 12"x15" 100# **Paper Targets**; black markings not necessary.
- 12"x15" **Application Board,** with holes drilled in locations planned for future suction cup placement. (Weight of board is approximately 3.5 lbs.)

- **Free Weights**; five 10 lb. plates, and one 5 lb. plate. (Standard weight lifter's weights)
- **Mastic sealant** and **caulking gun.**

Test Procedure

1) Set up wind tunnel & apparatus as shown in figure 3.3.1.
2) With wind tunnel off, tape down tar paper to test plate (top step) of scaffold. The smooth side of the tar paper will be face up. (i.e. the rough, sandy surface that is normally face up for roofing applications will be taped face down. It is believed that the smooth back side of the paper better approximates road surface conditions)
3) Lift flap out of the wind tunnel exhaust's path. (Non-diverting position)
4) Turn on wind tunnel and bring up to full speed.
5) Apply glue to either the tar paper or the target in the desired configuration.
6) Lightly place target on tar paper, so that the glue is completely blanketed by the target.
7) Place application board on target, so that the target is completely covered by it.
8) Quickly stack the weights on the center of the application board, until the desired loading weight is achieved. PLACE THE WEIGHTS ONTO THE STACK. DO NOT DROP THE WEIGHTS ONTO THE BOARD OR WEIGHT STACK.
9) Remove the weight stack immediately after it is assembled.
10) Remove application board.
11) Using the 2"x4" Handle, pull down the flap until it contacts the upper rail of the scaffolding. After contact, return the flap to the non-diverting position.

12) Shut off wind tunnel.

13) Record observations on success of test.

14) Remove target & tar paper, and ready apparatus for another test.

Results

Success of SC664 Mastic

The mastic held up very well under blasting wind loads in this experiment. While not every condition could be checked in this experiment (various temperatures, etc.) the targets did hold up well at 74°F, 28.51 in. Hg barometer.

Necessary Application Force

Most tests showed no signs of loosening off of the tar paper after 10 or more blasts. At application forces below 20 pounds, however, the target began to fail after 5 blasts. It is believed that this test started to fail because the bead diameter used on the target was large, and 20 pounds was not enough to fully compress the bead. Since the bead was not compressed, there was a gap between the target and the pavement, allowing the wind to blow under the target and directly onto the bead.

Gluing Pattern

A pattern using 3 beads of mastic was used for all tests, with the bead diameter varied. The 3-bead pattern seems to be a good choice for gluing, both from the standpoint of how well it holds the targets, and of how easy it is to apply.

The most critical bead is the one along the upper edge. (edge that is first contacted by the wind) It is critical to have the upper edge well sealed onto the pavement. In the test, the mastic was placed approximately 1" away from all edges. This distance can be decreased in future designs.

Beads from 1/4" to 1/2" were tried, with both showing good results, so long as the bead is completely compressed. For the final design, a 1/4" bead should be used, to ensure complete compression, and to save on material costs.

Conclusions

The SC664 Mastic worked well as the adhesive material for the paper targets. The best conditions for application were found to be:

- Apply with at least 40 lbs force against pavement.
- Use 3-bead pattern with 1/4" bead, and locate beads near target edges.

Because the prefabricated markings have shown to be able to survive all normal conditions that they would face in their use, the overall conclusion is that the Prefabricated Target Layer would be a feasible system.

Chapter 4: Design Protoyping Phase

4.1 Description of Operation

The working prototype of the PTL is shown in figure 4.1.1. The main apparatus can be seen mounted otn the test frame connected onto the BAND cylinder, which moves the MULT cylinder and end effector. When put into operation, the BAND cylinder would be mounted to a smaller frame, which would then be mounted to a truck. The unit would be

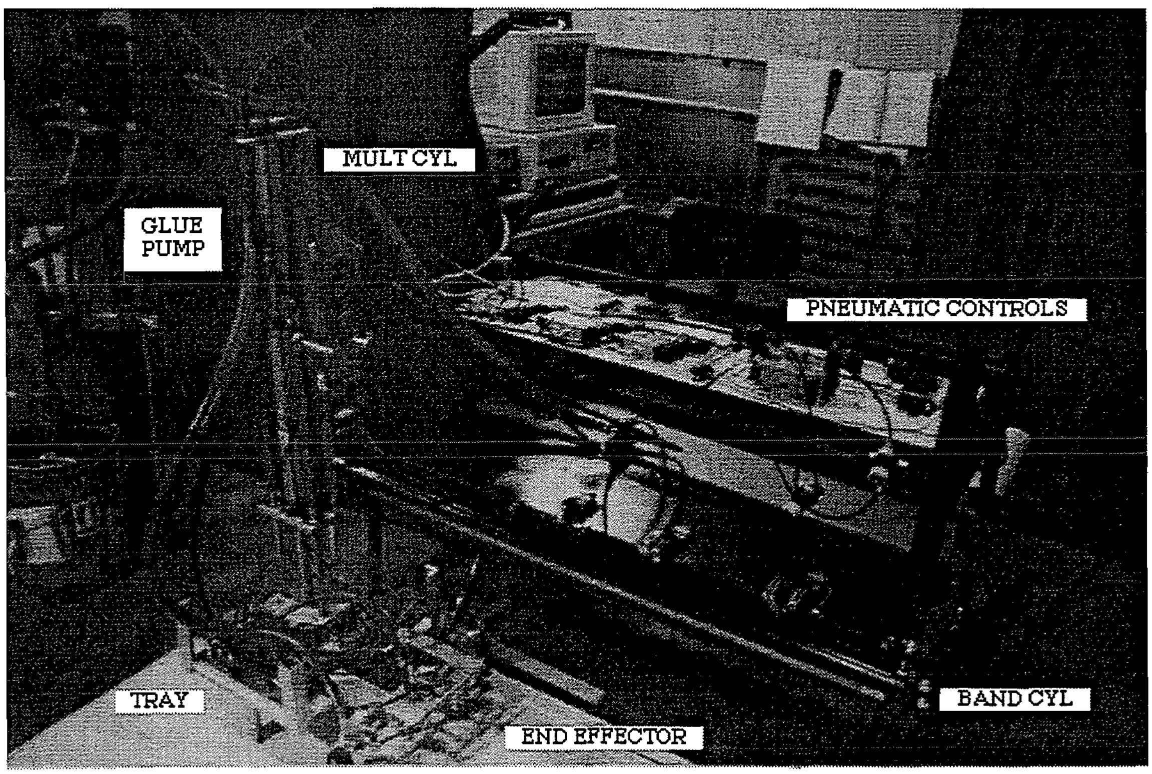


Figure 4.1.1: Prototype for PTL System

mounted so that the lowest part would be an average of one foot from the pavement when the vehicle is traveling. In order for the unit sit that high, andstill be able to reach the ground, (exposed air cylinder rods could not exceed 14") the paper tray was made to be removable. The one foot clearance could then be achieved by fully retracting the MULT cylinder. The glue pump would be installed in a convenient storage area on the truck, such as on a flat bed. The pneumatic control switches would be mounted relatively close to the installation unit.

The standard operation for the system would be as follows:

When the truck arrives at the location to be premarked, the driver will position the mechanism by driving the truck to a point where a target is desired, laying a target, then driving the truck 50′ to the next site. The positioning of the machine to achieve this longitudinal spacing would be done by using either the odometer of the vehicle, or by some other linear positioning means. The positioning of the machine perpendicular to the roadway would be done by the placement of the truck by the driver. Relying on the driver for the positioning of the truck is not unreasonable; past projects such as the longitudinal crack sealing machine use the driver to position the mechanism [Velinsky, 1993].

Once the operator has arrived at the point where the mark is desired, the truck is put into parking gear. (When the PTL system is installed onto a truck, the controls would be wired in such a way that it will only operate when the vehicle has its parking gear on. Movement of the vehicle while the end effector is in contact with the ground could seriously damage the machine.)

Once the truck is parked, the operator presses the "LAY TARGET" button on the hand-held controller. This starts the operation shown in figure 4.1.2. In the first frame, the PTL is shown in the "ONSITE TRAVEL" position. The horizontal air cylinder (referred to as MULT) is pressurized at this time, so that the end effector does not bounce or rattle while the truck is traveling. While in this position, the paper separation system is activated, and the top sheet is grabbed. In frame 2,

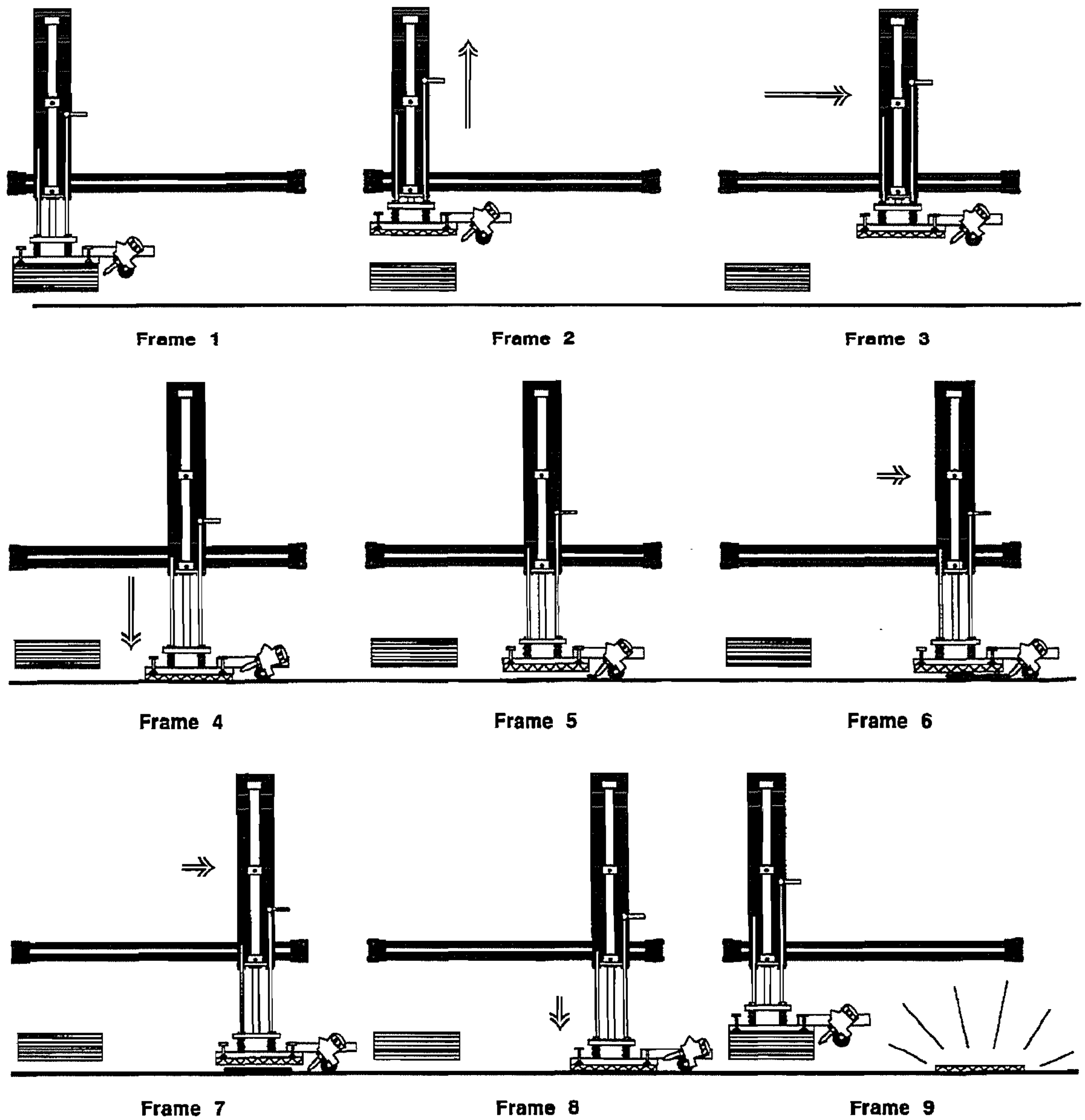


Figure 4.1.2: Simplified Operation of the PTL

the end effector has been lifted straight up to ensure that neither the end effector nor the target will interfere with the walls of the paper tray when horizontal motion starts. Frames 3 & 4 show the end effector being moved away from the paper tray, and then being pressed to the pavement surface. The end effector is pressed to the pavement so that the target can be fully secured before gluing. Gluing is started when the end effector reaches a switch in the position shown in frame 5, and is stopped when the end effector reaches the point in frame 6. The end effector continues to move laterally, until the end stop is encountered in frame 7. In frame 8, the target is pressed onto the fresh glue, and the suction holding the target to the end effector is shut off. The mechanism then returns to the "ONSITE TRAVEL" position. The operation would then be complete; the driver could then move on to the next site.

As noted earlier, the design of this system was broken down into several subsystems. The subsystems developed during the design prototyping phase were the separation and holding subsystem, the "pick and place" actuator subsystem, the adhesive delivery subsystem, and the control subsystem. (The target itself and the frame and mounting concerns can also be considered subsystems) The remainder of this chapter is devoted to explaining these four subsystems.

4.2 Paper Separation Subsystem

The separation of a sheet of paper from the top of a stack has long been a problem in paper handling industries. In order to avoid problems such as "paper jams" in this system, eight different paper handling processes were considered in a literature search [Wu, 1993]. Several of these ideas were eliminated because they could not handle the thick 110# paper that the system uses. The rest were evaluated based on their ability to perform in a hostile environment (mounted to a vehicle) and on their simplicity. It was judged that the most common handling methods would be overly complex for this system, and would most likely fail on the road.

The conventional method of picking up one sheet of 110# paper off of a stack requires blowing on the side of the stack with high pressure air, causing the upper sheets to rise. The top sheet would then be grabbed out of the air by suction cups. This method was considered, but not used, because it was felt that it would be difficult to calibrate such a system when it is installed on a moving vehicle.

Instead, a similar system was used. Picking up the top sheets with the suction cups alone would fail, since the paper is porous. It was found through experimentation that grasping plain white 100# paper with suction would either lift the top 4 - 7 sheets off of the stack, or would not be able to lift any sheets at all, depending on the strength of the vacuum.

Fortunately, the black stripe on the target provides a non porous surface to grab. When the paper needed to be separated, a vacuum pump dedicated to the four suction cups over the black stripe (VAC7) came on, and those four cups grabbed the stripe. The end effector then traveled straight up, and the top sheet was separated. (See Fig. 4.2.1)

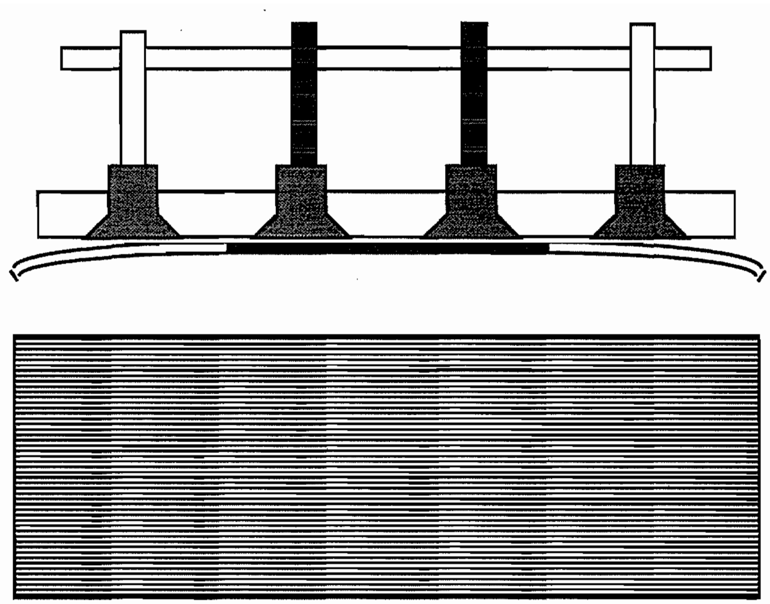


Figure 4.2.1 Separation by Grasping Black Stripe

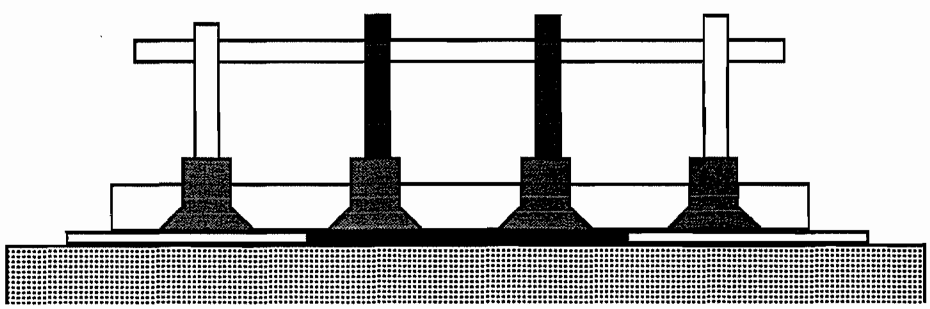


Figure 4.2.2 Pressing to Road to Grip White Areas

This separated sheet was not, however, held by the end effector in a manner that would be satisfactory for the rest of the process. The outer white edges were free to bend, and would do so because of gravity or wind. If the target were to be held only by the black stripe during operation, the target edges could drag through the fresh glue as it is applied, or the paper could crinkle and fold during application.

It was for this reason that a second vacuum pump (VAC8) and four more suction cups were included to grip the white areas. Sometime after separation, the target would be pressed against a flat surface (See Fig 4.2.2) (in the current design, the road surface is used; See Fig. 4.1.2, Frame 4) so that the white vacuum pump can grab the corners of the sheet. The corners needed to be held so that the target didn't drag while glue was put down. After the target was applied, the vacuum pumps were shut off, and the end effector was lifted away from the target. The glue bond was strong enough to hold the target down when the suction cups were pulled off; overcoming the force of the vacuum still remaining in the lines.

4.3 The "Pick & Place" System

The PTL's "pick & place" system is a 2 D.O.F. system which takes the target from the paper tray to the application point. It is comprised of two prismatic joints which move in a plane that is approximately parallel to the truck's grill, and perpendicular to the road surface. Both joints are air cylinders; one which moves in the horizontal direction, and one in the vertical. They operate in conjunction with one another in the manner described in the first section of this chapter.

Thirteen design ideas were explored before settling on this particular "pick-and-place" machine. The two-cylinder concept was selected for its simplicity, which would make the system more reliable and more easily maintainable. A description of the components follows.

Horizontal Cylinder

A rodless band cylinder, referred to as BAND in this system, was used for the horizontal motion (See Fig 4.3.1). This type of air cylinder was used as a cheap, reliable alternative to a linear slide. While a band cylinder does not have the positional control of a linear slide (the band cylinder has only two repeatable positions, located at the end stops), it does have the advantage of being a much

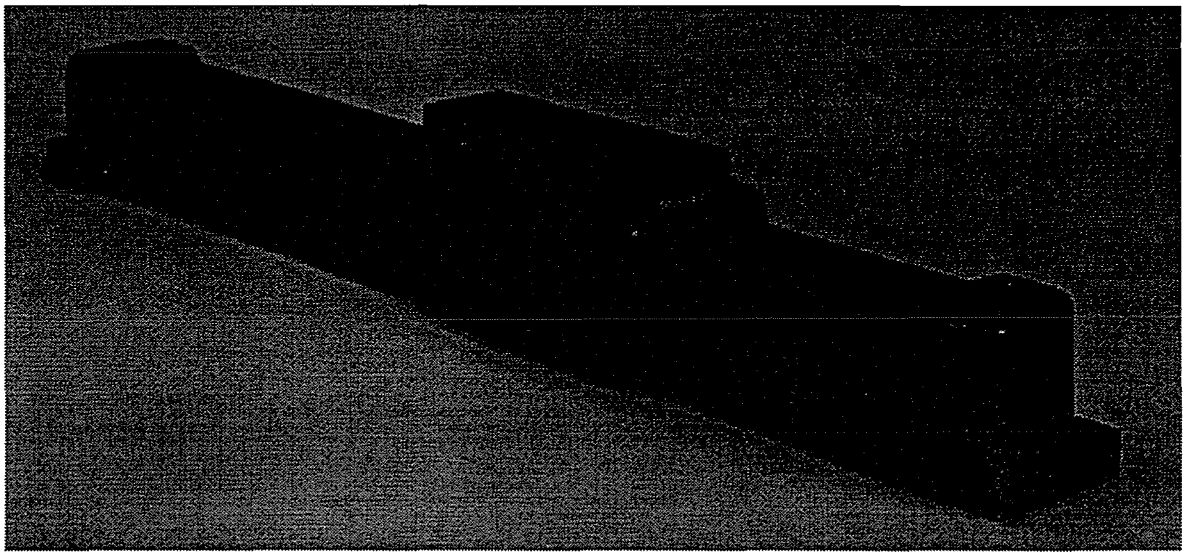
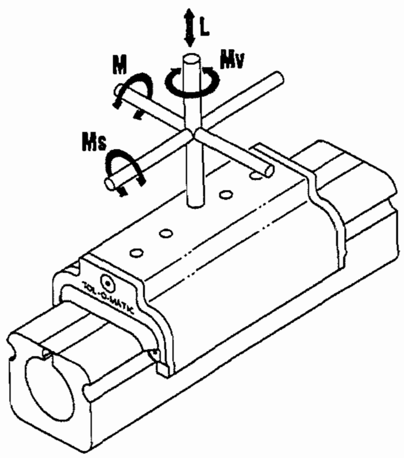


Figure 4.3.1 Manufacturer's Picture of Band Cylinder

simpler device which does not require calibration, and would have less chance of malfunctioning. The band cylinder selected was a Tol-O-Matic Model BC100-150, with a 40" stroke. This particular band cylinder also features a patented sealing band system, which encloses its working parts and makes it much more suitable for hostile environments encountered in highway maintenance. It also costs only about a tenth of what a driven linear slide would have.

The BC100-150 model was chosen for its side load moment capacity. (See Fig. 4.3.2) The major force that the cylinder had to withstand was a moment **Ms** created when the end effector was pressing the target to the pavement.



Bore Size	Maximum Bending Moment			Max.Load
(Inches)	M	Ms	Mv	L
BC100-150	500	275	200	180
1-1/2"	In/Lbs.	In/Lbs.	In/Lbs.	Lbs.

Figure 4.3.2 Manufacturer's Loading Specifications

Estimation of the moment **Ms** was made as follows: From the wind tunnel test, it was decided that 50 lbs. force would be sufficient to apply the targets. As a safety factor, this force was doubled for the selection of the band cylinder. The moment arm was assumed to be 1.5" from the center of the vertical cylinder's rod to the surface of the band cylinder's carrier bracket. (The actual moment arm turned out to be 1.375") This made for an estimated 150 in/lbs of torque, 125 in/lbs less than what the cylinder could handle. This estimation was made with a simple force balance [Beer, Johnston, 1984]. Further information on this cylinder may be found in [Tol-O-Matic, 1993].

Vertical Cylinder

The vertical positioning cylinder used was a "Multi-Position Cylinder", referred to as MULT in this system. (See Fig. 4.3.3) This unit is a construction of two air cylinders placed end-to-end, with the rod of the top cylinder pushing the piston of the bottom cylinder, to allow the system to hold three repeatable positions. (See Fig. 4.3.4) The first position is held when both rods are retracted. In the second, the top (shown on the right in the manufacturer's illustration) rod is fully extended, and the bottom (left) piston is held against its end with a positive air pressure. In the third position, both rods are extended. Note that the bottom cylinder has a longer travel than the top.

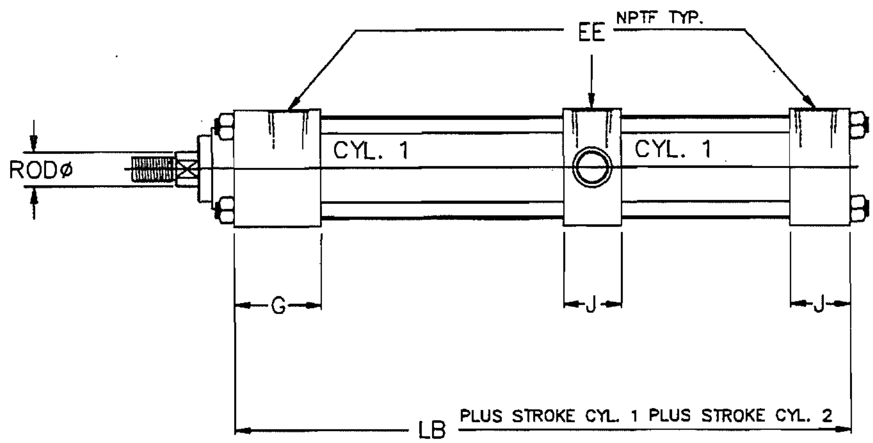


Figure 4.3.3 Manufacturer's Picture of Multiposition Cylinder

The first position is needed when the truck is traveling to and from the site; MULT is fully retracted to allow for maximum ground clearance. This position is also used to ensure that the end effector will be above the lip of the paper tray, and will not cause interference with it when traveling to or from the tray.

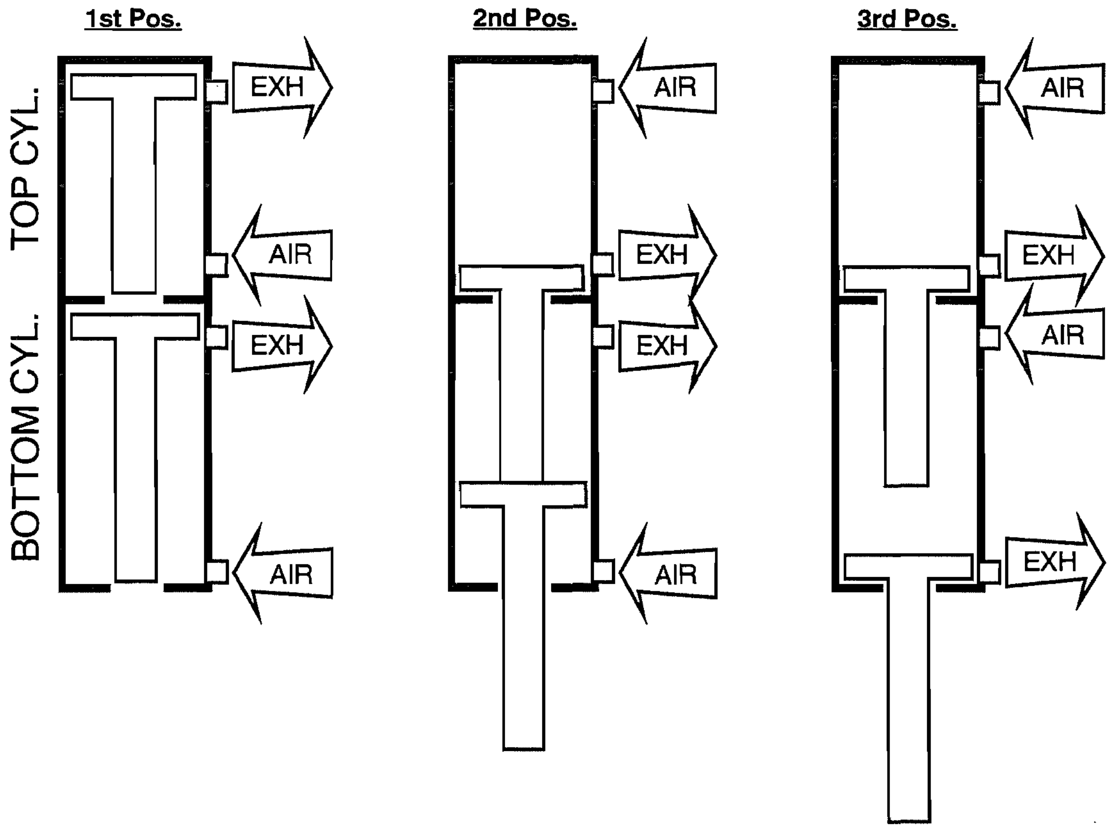


Fig. 4.3.4: Three Positions of MULT

The second position allows the end effector to hover a set distance above the ground while applying glue. The main benefit of using this cylinder assembly is having this middle "hard stop". In order to reliably stop the travel of an air cylinder, some mechanical stop must be encountered. Trying to control the position of a cylinder with air had in the past proved unreliable, due to leakage and compression of air.

The third position is the application position, and is used whenever the end effector needs to be pressed against the ground. Note that in operation, the end effector's travel should be stopped by the pavement in this position, and not the cylinder's end stop.

The top cylinder for this system has a travel length of 11", and the bottom cylinder has a travel of 13". The unit was designed to be mounted to the truck to allow the end effector 12" of travel. This allows the entire unit to retract 1 foot from the ground for traveling, and to hover 1" above the pavement during gluing. The additional inch of travel capability was added as a factor of safety.

The MULT cylinder did not control rotation, however. Two additional stainless steel rails were installed in parallel to the MULT rod. These kept the end effector from spinning around the center of the rod. More information on the cylinder can be found in the catalog [Numatics, ND]

End Effector

Three functions were built into the system's end effector; a vacuum/suction separation and holding system, (discussed in the previous section), a three nozzle glue delivery system, (discussed in next section), and a surface for delivery of application force, which would to press the targets onto the pavement. In this section, this third function, as well as mounting and assembly concerns for the other two systems are discussed.

The base component of the end effector is a 11.5" x 14.5" x 1/2" aluminum plate, which is the surface that pushes the target down to compress the glue. The face of this plate are slightly smaller than the surface of the targets (12" x 15"). When the plate is brought in contact with the targets, the plate is centered with the targets, so the paper extends 1/4" past the lip of the plate in all directions. The

1/4" extra paper provides an overflow area for the glue. If there is excess adhesive, the paper lip will keep the glue from flowing around the paper edge, and back onto the end effector. (See Fig. 4.3.5) Loose glue in a mechanical system could cause any number of problems; it is best to ensure that no glue gets onto the mechanism. Aside from the glue contamination control feature, the smaller plate dimensions also allow for a great deal of clearance between the plate and the tray walls.

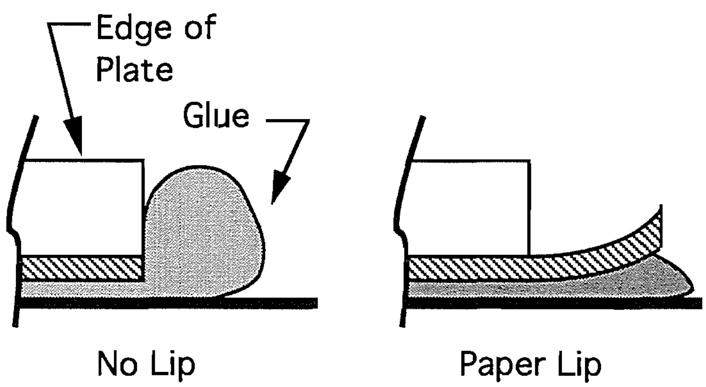


Figure 4.3.5: Paper Lip Used for Glue Control

Attached to the plate is a "spring board" composed of a coupler plate and four coupler springs on rods, that was used for angular compensation. (See Fig. 4.3.6) The end effector needed to be capable of pressing onto road surfaces that do not lie in the "ideal plane"; the plane that is perfectly perpendicular to the MULT cylinder's rod. In normal roadway construction, the travel lanes are usually made with a 2% grade, sloping down in the lateral direction. The shoulders are usually made with a 5% grade. Since the truck will be in the traveling lane while the PTL is applying in the shoulder, this 3% grade must be compensated for. In addition to the 3% grade difference, complex roadway geometry and degradation of the shoulder surface could provide for even larger angular differences. For this reason, the end effector must be able to accommodate rotation in the X and Y directions.

Tilting compensation is achieved by attaching the rod from MULT to the center of a coupler plate. The coupler plate is free to slide along the shafts of four 3.5″ steel bare shank bolts. The coupler plate is held against the heads of these bolts by four coupler springs. When the ground is encountered, the springs compress, allowing the bottom plate to tilt.

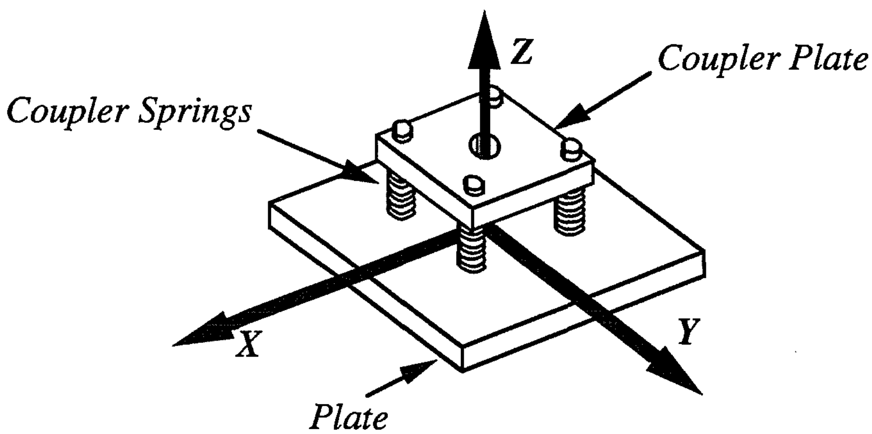


Figure 4.3.6: End Effector's Compensation for Sloped Roadways

Sharp bumps were not considered in the designing of the end effector, however. For this application, the road surface under the 12″ x 15″ is considered to be roughly flat enough that a rigid plate can be used to evenly press down a target. Since there's a tolerance of 10 feet in spacing, it is assumed that the driver can avoid these bumps by choosing a nearby application location.

The end effector also carries the suction cups for the separation system. The suction cups pass through eight 1.5″ diameter holes to be able to reach the paper. These suction cups are mounted to two vacuum support beams. (See Fig. 4.3.7)

By mounting to the support beam rather than the bottom plate, the machining and assembly were made much easier. This design also simplifies the adjustment of the height of the suction cups when necessary.

The vacuum pumps and manifolds are mounted directly to the bottom plate as well. The suction system is most efficient when the volume of the connecting

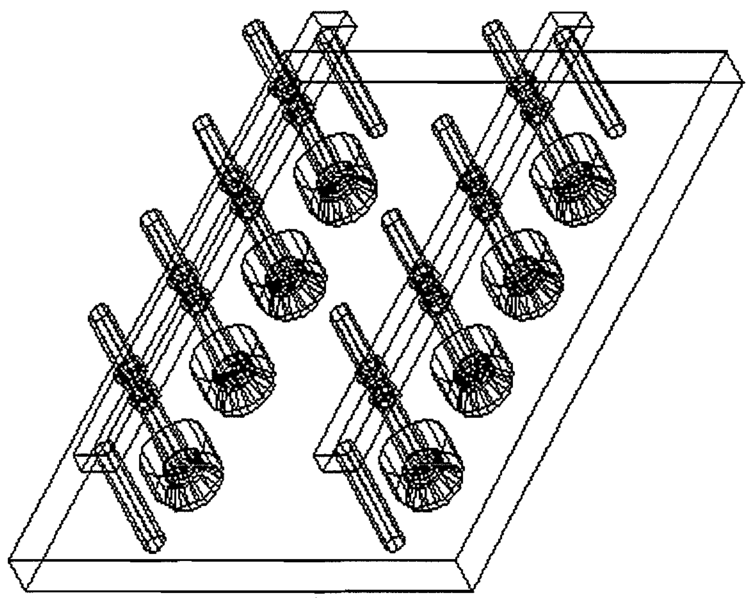


Figure 4.3.7: Mounting of Vacuum Cups to Offset Beams

tubing and manifolds are minimized, since everything that is in line needs to be pumped down when the suction cups contact the surface. For this reason, the connecting tubing used had a smaller ID than in other places in the PTL system, and it was used sparingly. The three glue delivery nozzles were mounted on an arm that extended off of the side of the bottom plate. (See fig 4.3.8) This arm subassembly was designed to keep the tips of the nozzles as close to the ground as possible. The nozzles are bolted tight to an aluminum axle, which runs on the ground with two neoprene wheels. The axle is attached to a rotating shaft by two spacers. Torsional springs on the rotating shaft ensure that the axle is pressed to the ground. This assembly is mounted to the bottom plate by two arm extensions.

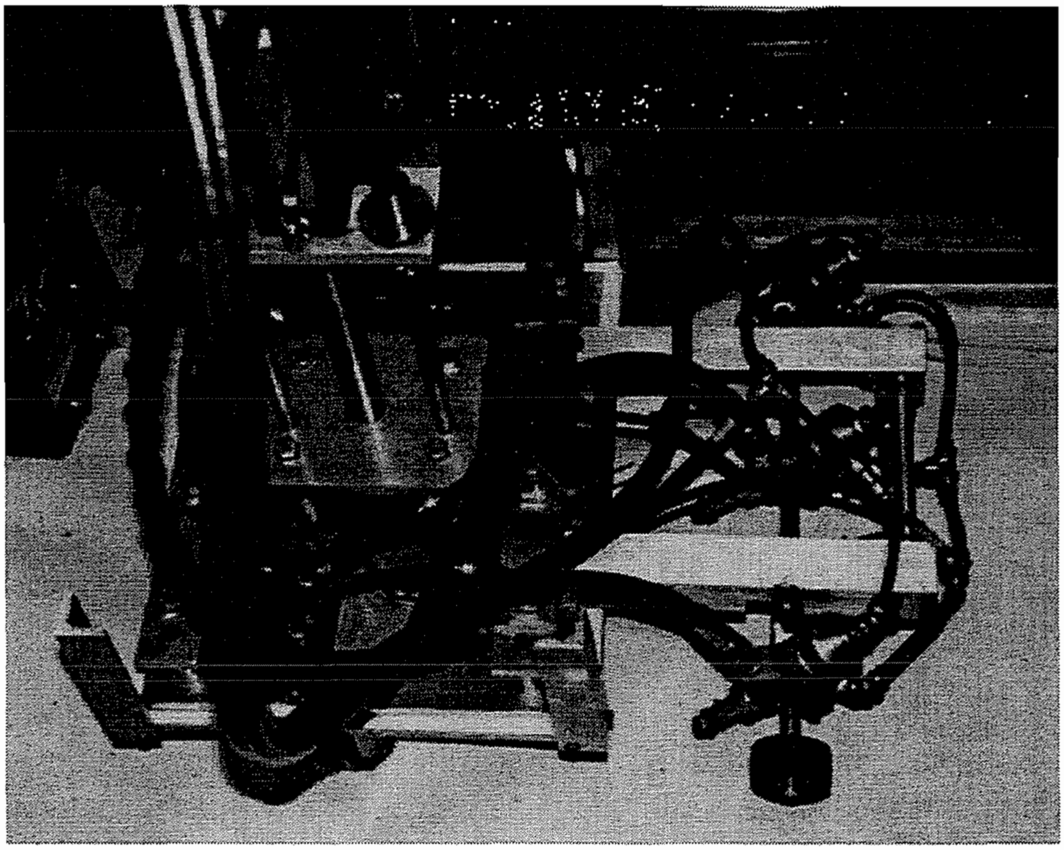


Figure 4.3.8: Mounting of Glue Nozzles to End Effector

When the MULT cylinder lowers the end effector to the gluing position, the wheels come into contact with the pavement. As the BAND cylinder moves, the wheels roll along the ground, the torsional springs holding the nozzles close to a set distance above the ground. Because the axle is rigidly attached to the rotating shaft, there may be instances where only one wheel is contacting the surface. It is believed that this will not significantly interfere with the gluing. When the

MULT cylinder presses the end effector to the ground, the torsional springs give some more, allowing the axle assembly to "fold up" in between the extension arms, like the closing of a pocket knife.

4.4 Adhesive Delivery Subsystem

The operation of the glue system is very simple. A ram mount pump is used to keep pressure in the glue lines while the PTL was in service. When the adhesive

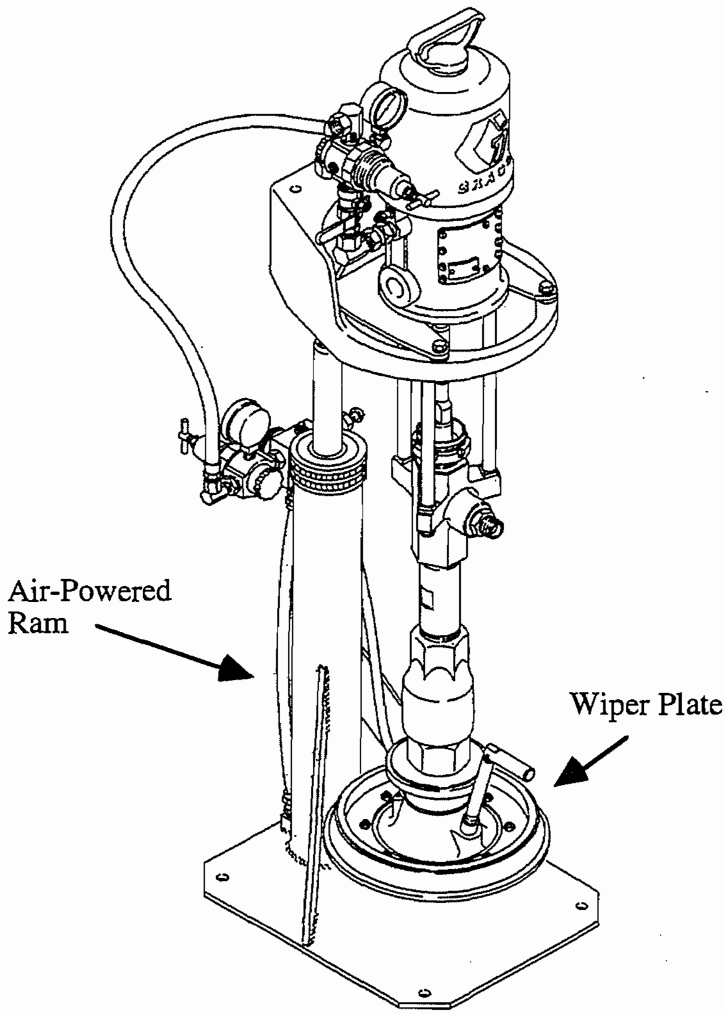


Figure 4.4.1: Ram-Mounted Pump (Model 231-111 Shown)

needs to be dispensed, air-actuated valves in the nozzles open, and the adhesive extrudes out of the nozzles. When the supply of air ceases to the nozzles, they close, and gluing stopped.

Glue delivery for this system was provided by a Graco 34:1 Ratio Senator Pump, Model #231-112, Series B. (See Fig. 4.4.1) This pump has a maximum fluid working pressure of 3400 psi. In order to pump material, air is supplied to an air-powered ram on the pump. This ram forces a circular wiper plate into a 5-gallon bucket. An orifice in the wiper plate allows the material to flow into the hoses. This operation is similar to the way a syringe forces fluid to flow into a needle, or how a hand-held caulking gun extrudes caulk. More information on this pump can be found in [Graco, 1990].

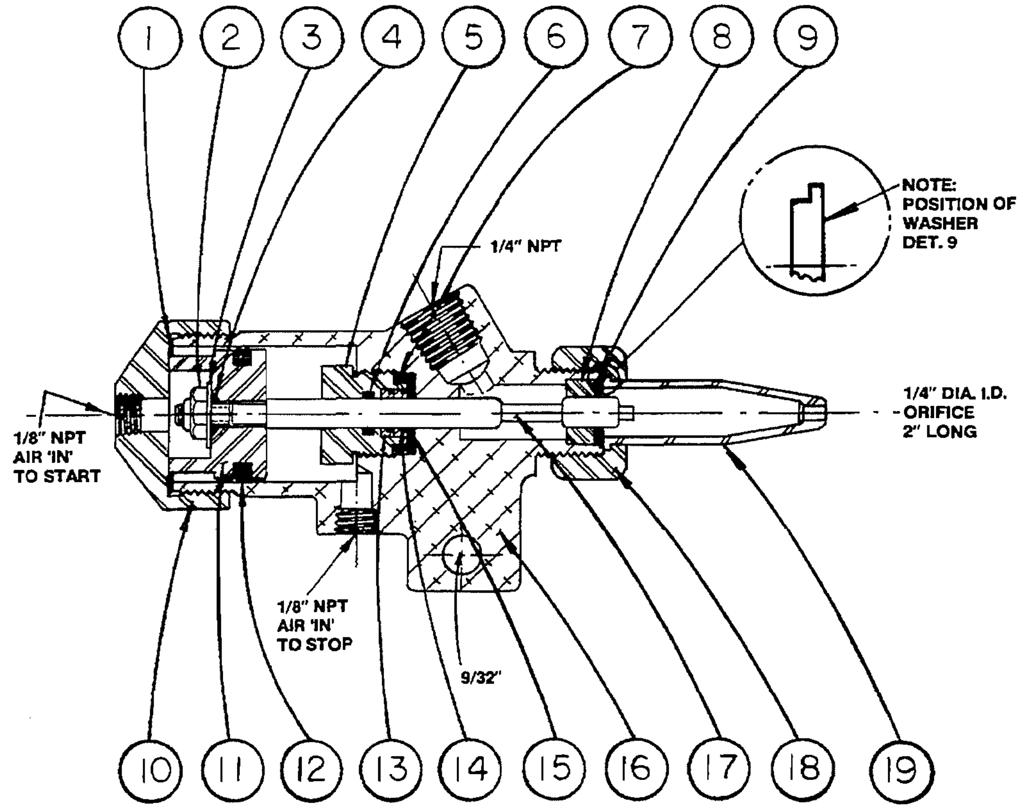


Figure 4.4.2: Automatic Snuffer Valve (Graco)

Glue beads are laid out by extruding through three nozzles attached to the end effector of the mechanism while the BAND cylinder is in motion. Snuffer valves located directly behind the nozzles are switched on and off with a single solenoid (See Fig. 4.4.2). The snuffer valves are designed to prevent "stringing" of the glue by sucking in the glue in the tips when the valves are shut off. If this is not done, strings of glue would stretch out from the ends of the beads to the nozzle tips, and these strings would stretch out like cheese on a slice of pizza taken from a pie. Currently, the PTL still experiences some stringing problems, which may be attributable to the nozzle size.

4.5 Control System

The PTL system was regulated by a pneumatic circuit, and controlled by a single board miniature control computer. The entire system can be run on 24VDC and a 100 psi supply of air.

Pneumatic Controls

The pneumatic circuitry consisted mainly of air-actuated spring return solenoid valves which controlled supply and exhaust to the air cylinders, the vacuum pumps, and the glue delivery. The solenoids used for the control of the air cylinders and the glue were all from the Norgren 200 line. These solenoids were selected because they proved to be highly reliable in previous Caltrans/AHMCT projects. The Vaccon light duty vacuum pumps had built in solenoid switches. All switches for the project ran off of 24 volt coils. The PTL was designed to be powered by 24V so that it may be easily integrated with a proposed stenciling trailer.

The most complex element in the pneumatic design was the operation of the MULT cylinder. When the cylinder is held in the gluing position (Position 2; see fig. 4.1.4), and when it is moving from the fully retracted position to the gluing position, the re must be enough pressure in the bottom cylinder to keep the two rods pressed together. If there isn't enough pressure under the bottom plunger, the weight of the end effector will pull the bottom rod down prematurely.

Figures 4.5.1 through 4.5.3 show how two 5-port / 2-position valves and one 3-port / 2-position valve were used to control MULT's operation. The cylinder is held in the retracted position by keeping MULT5 on. When dropping the cylinder down to the gluing position, both MULT3 and MULT5 are activated. The two solenoids are left on to hold the cylinder in place. This may seem like a counter-intuitive way to move to this position, since air is supplied to both the upper port of the top cylinder and the bottom port of the lower. On paper, it seems that this would end up in a stalemate. In actuality, the weight of the end effector and pressure losses in the system cause the end effector to drop to position 2. To press the end effector to the pavement, the top port of the bottom cylinder is supplied air by turning on MULT4. The whole cylinder is then retracted by switching on MULT5.

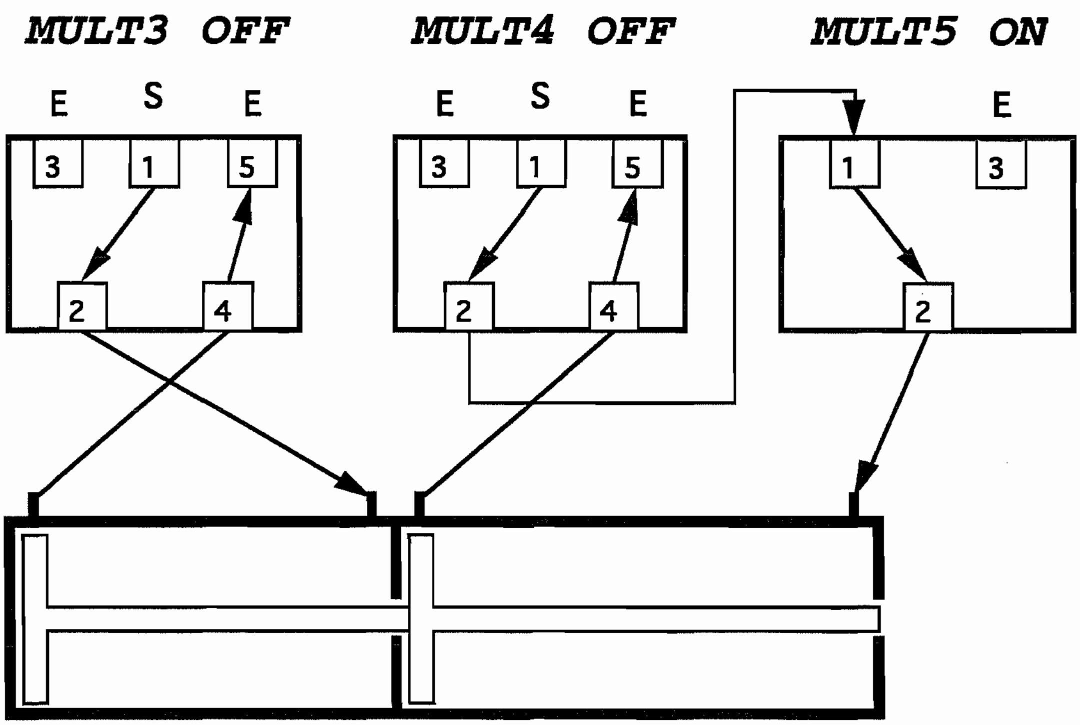


Figure 4.5.1: Valve Configuration to Put MULT in Position 1

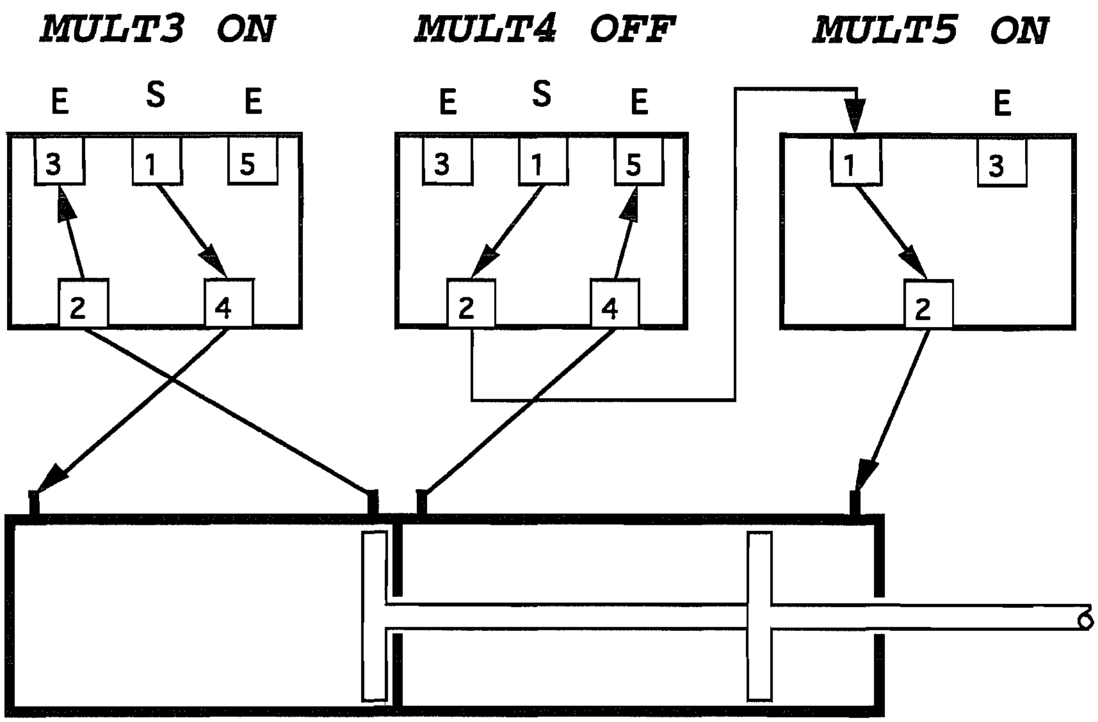


Figure 4.5.2: Valve Configuration to Put MULT in Position 2

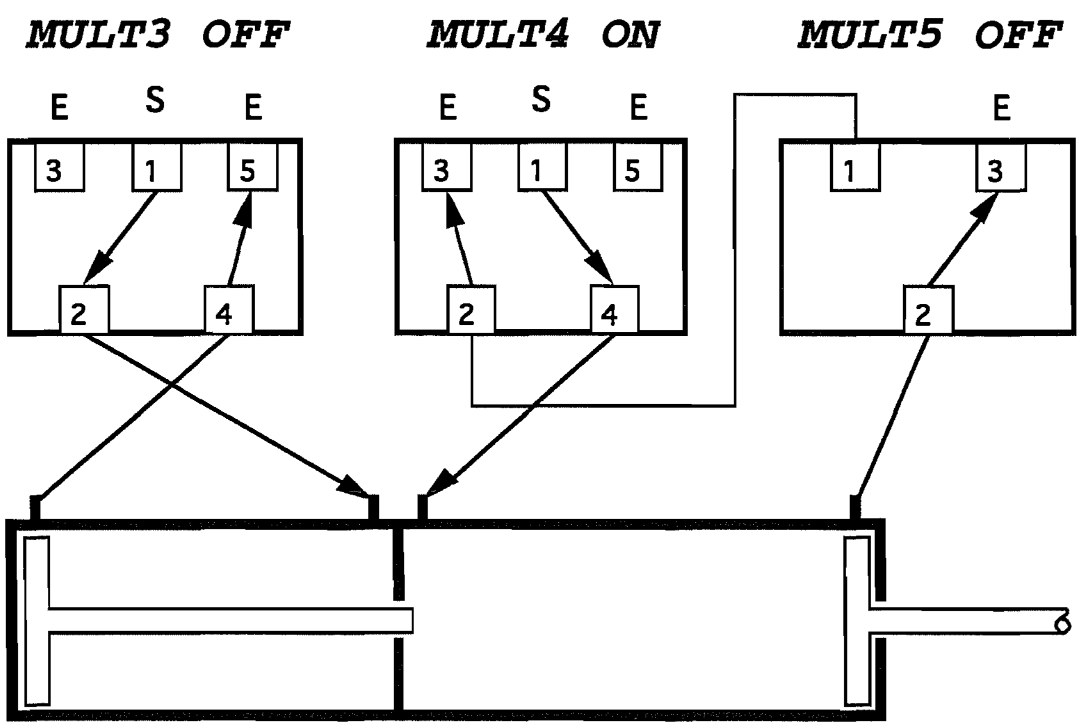


Figure 4.5.3: Valve Configuration to Put MULT in Position 3

This operation of solenoids and cylinders has been tested and found to work very well for a prototype system. One small change should be made for a commercial system, however. The system should be changed so that MULT goes into its fully retracted position when all of the solenoids are off. This is a safety feature that will keep the machine from damaging itself in the event of an electrical failure. If power is lost, the springs in the solenoids would push the internal spool back to its 'normal' position. Therefore, the system should be designed so that the machine is put into a 'safe' position when all of the solenoids are in their normal positions. The safe position for the PTL would be:

- MULT fully retracted.
- BAND stopped and held in its last position.
- Glue off.
- Vacuum off.

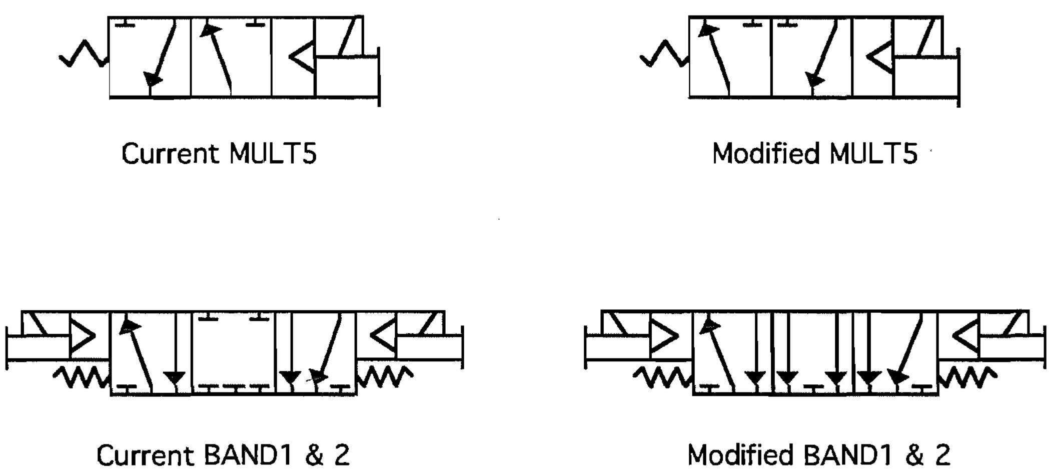


Figure 4.5.4: Suggested Valve Replacements

To achieve this, a special solenoid would have to be made to replace MULT5, with a reversed spool configuration, as shown in figure 4.5.4. This solenoid would have to be specially made at the factory. Also, it is recommended that the

5-Port / 3-Position All Ports Blocked in Center solenoid used for BAND1 & BAND2 (BAND1 & BAND2 each control one of the two solenoid coils on this unit) be replaced with a 5-Port / 3-Position Cylinder Ports Exhausted unit. It was found in operation that the 'ports blocked' model did not adequately stop the BAND cylinder, due to back pressures in the cylinder. It is believed that this can be remedied by immediately exhausting the cylinder, and relying on friction to keep the carrier bracket from moving.

Electronic Controls

The overall operation of the device and the interface with the user were taken care of with a compact controller package. A 'Little Giant' single board computer was the brain of the PTL. This controller sits on a very small (5.6" x 4.8") board, which was placed in a hand-held controller box, along with a keyboard display module (KDM). The KDM features a LCD display and 24 programmable keys. The entire unit was programmed in a specially tailored language, Dynamic C.

Besides the keys on the keypad, the controller observed 6 digital inputs from the PTL system, and controlled 8 digital outputs. Inputs were all read from mechanical switches. The following is a list of those switches, and what they corresponded to:

1MULT	MULT cylinder is fully retracted. (Position 1)
2MULT	MULT cylinder is in gluing position. (Position 2)
1BAND	BAND cylinder is over paper tray.
2BAND	BAND cylinder is in 'start glue' position.
3BAND	BAND cylinder is in 'stop glue' position.

4BAND	BAND cylinder is in 'application' position.

Each of the digital outputs controlled a solenoid switch. The following is a list of what these switches did when turned on:

BAND1	Moves BAND away from tray.
BAND2	Moves BAND towards tray.
MULT3 + MULT5	Moves MULT to gluing position.
MULT4	Moves MULT to application position.
MULT5	Moves MULT to retracted position.
GLUE6	Turns glue on.
VAC7	Turns on black vacuum (separation) system.
VAC8	Turns on white vacuum (holding) system.

Two testing devices were built to aid development of the control system. These devices were a switch box that directly controlled the solenoid valves, and an LED box that would show digital output from the controlling computer. The use of these two devices allowed the development of the pneumatic system and the control code to be done simultaneously. The ability to isolate the pneumatics from the electrical controls was also a great aid in troubleshooting. The code for this operation can be found in Appendix D.

Chapter 5: Conclusions and Recommendations

This thesis reports on the development of an automated machine for the placement of experimental abbreviated premarks for photogrammetric surveys. The system developed uses paper targets with the appropriate surveying markings printed on them. The paper targets are lifted off from a stack and are glued to the road's shoulder with a pick and place mechanism that is based on two prismatic joints. A detailed description of how this system would be used in the field is presented. The descriptions of the development of the paper target and the application machine are also presented. Testing information is included which shows that the paper targets would be viable under normal operational conditions.

The design of the PTL was broken down into independent subsystems wherever possible. The system was subdivided to allow for simultaneous development of different subsystems, which could be assembled and tested as parts were procured. An additional advantage of this subsystem design was that it made troubleshooting much easier; subsystems could be easily isolated to find and correct problems.

Note that the current PTL machine is a prototype, and has never been tested on the road. A few factors need to be worked out before the system can be deemed roadworthy. First, a mounting frame must be developed and built that will mount the PTL to a maintenance vehicle used in surveying. Second, an intensive testing program must be developed to test the machine's ability to lay targets on road surfaces under various testing conditions. Any shortcomings of the system under actual duty use would then be discovered, and be resolved. Even after these steps are taken, however, the PTL would only be a roadworthy prototype. Additional optimization of the working system may be needed in order to develop a production model of the PTL.

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APPENDIX A

MATERIAL COSTS

Table A.1: Total Materials Purchased for PTL Prototype

SUPPLIER	P.O. #	QTY	DESCRIPTION	QUOTED	PAID AMT.
ABC Supply	242		Misc. Aluminum		<$150
	303		Misc. Aluminum & Steel		<$100
	187		11.75"x14.75"x0.5" Plate	$36.00	
			6.25"x5.25"x0.5"Plate	$15.78	
			4" Bare Shank Bolts	$0.51	$52.29
Air Concepts & Controls	1386	1	Light Duty Vacuum Pump	$65.00	$65.00
	71	10	1 1/8" Suction Cups		
		1	Light Duty Vacuum Pump		
		2	Regulator-Coalescer		
		2	Manifold		
		10	1/4" OD Connector Elbows		
		10	1/4" OD Connectors		<$500
	163	1	Multi-Pos. Cylinder (MULT)	$324.90	$324.90
	185	1	Numatics Flow Control Valve	$15.55	$15.55
	207	1	Light Duty Vacuum Pump	$65.00	
		2	3/8" Pipe Plugs	$1.64	$66.64
	213	1	24V Coil for Vacuum Pump	$51.48	$51.48
	221	5	Numatics Flow Control Valve	$100.06	$100.06
Bay Pneumatics, Inc.	2310	1	Tol-O-Matic Cylinder (BAND)	$577.88	
		1	Support Bracket for BAND	$32.40	$654.53
	139	1	Norg. Solenoid; 5-port/3-pos.	$105.86	$105.86
	184	1	Foot Mount Set for BAND	$13.26	
		1	Norg. Solenoid; 3-port/2-pos.	$50.90	
		2	Norg. Solenoid; 5-port/2-pos.	$105.70	
		1	X-tra 24V coil for Norg.	$6.30	$188.93
	239	1	Norg. End Plate Kit	$25.70	$25.70
	251	1	Norg. Solenoid; 3-port/2-pos.	$50.90	$54.59
	302	1	Norg. Solenoid; 5-port/2-pos.	$52.85	$52.85
Calcom Graphics	947	5 Gal	Black Ink; Screenrite #111	$92.55	$92.55
Cal Hose & Fitting	304		Misc. Air & Glue Fittings		$199.88
	261		Misc. Air & Glue Fittings		$301.47
	241		Misc. Manifold Fittings		$198.95
	332		Misc. Fittings		<$100
McMaster-Carr	260	7	Adjustable Roller Switch	$159.11	$159.11
	138	1	Mini Limit Switch	$22.73	
		1	Hex Stock	$10.47	
		2	Solid Neoprene Wheels	$11.36	
		2	Damper Crank Arms	$7.60	$55.94

APPENDIX A

MATERIAL COSTS

Table A.1: Total Materials Purchased for PTL Prototype (Cont.)

SUPPLIER	P.O.	QTY	DESCRIPTION	QUOTED	PAID AMT.
Newark Elect.	425	1	Power Supply: 24V, 2A	$113.51	$113.51
Spec Springs	136		Misc Springs	$74.63	$74.63
Sutherland & Associates	2312	1	Ram Mount Pump - 5 Gal. Cap.	$3,670.00	
		1	Hi-Pressure Hose Assy	$156.05	
		3	Automatic Snuffer Valves	$942.90	$4,758.00
	229		Misc. Pneumatic Components		<$500
Z-World Cont.	Stock	1	Control Board & Keypad	≈$350	$350.00

Two estimates, a low and a high, have been prepared from the information in Table A.1.

Low Estimate of Total Cost: $8,062

High Estimate of Total Cost $9,412

A brief explanation of the information in Table A.1 follows:

Supplier: The table groups parts for the PTL by the supplier that they were purchased from. Miscellaneous small parts (bolts, scrap metal, tie-downs, etc.) used in the PTL do not show up in this table, as they were taken from stock. These costs are balanced by the included costs of leftover small components from the PTL prototype. Most of the leftover items consist of small air fittings ordered from Cal Hose & Fittings. The control board & keypad from Z-World Controllers was also taken from stock; and since it was such a significant cost, an estimate of its price was made.

P. O. Number: The parts are further subdivided by the number of the U. C. Davis purchase order that they were ordered from. Further information on these parts can be found by accessing these P.O.s. The full P. O. number code is obtained by adding the prefix DOV-302N- to the number listed.

Description: An identifying description of the equipment ordered. More detailed information can be found by referencing the purchase orders and cross-referencing the manufacturer's catalog numbers.

Quoted: This is the cost quoted at the time of placing the order.

Paid Amount: The actual amount of payment sent for the received purchase order. Values preceded with a "less than" sign signify that the purchase order was to be filled to an amount not exceeding the amount shown. These 'ceiling priced' purchase orders rarely were filled to the full amount. Hence, two estimates were prepared, showing a low amount and a high.

APPENDIX B

SUGGESTED INSPECTION & OPERATION PROCEDURES

Proper care lengthens the life of any machine. The following are suggested inspection techniques and operational procedures to be used with the PTL system:

"Pre-Op" Inspection

The pre-operational (pre-op) inspection is a routine inspection that is done each time a unit is taken out for service. The pre-op inspection for a vehicle carrying a PTL unit would include a checklist for the following items:

- Line air pressure, taken from gauge
- System voltage
- Log number of targets taken
- Refill glue if necessary
- Inspection of the glue pump as per the manufacturer's recommendations
- Visual inspection of all glue lines and nozzles for leakage, pressure bubbles, etc.
- Visual inspection of mechanical system for cracks, wear, etc.
- Testing of glue system
- Testing of entire system

The first two checks are done to make sure that the system is getting constant electrical power and at least 100 psi of air. Both the generator and the air compressor should be switched on during the pre-op inspection after the inspector has determined that it is safe to do so. They should be left on for the entire operation, and should only be turned off when the vehicle is returned to the garage at the end of a run of targets. Regular maintenance inspections of the generator and compressor should be scheduled on an annual basis.

Before the vehicle leaves the garage, the operator should make sure that there are enough targets and glue on board to complete the amount of roadway that is intended to be premarked. It should only be necessary to add glue to the system while it is in the garage, and glue should be added as per the manufacturer's instructions for the glue pump. A full 5-gallon pail of glue should cover at least two miles worth of targets (210 targets). The operator should also bring on board at least *twice* the number of targets needed for a run, as a factor of safety. The operator should log in approximately how many targets were taken initially, how many were laid on the road, and approximately how many were returned after the run.

The glue pump should also be subjected to a regular maintenance schedule. The pump should be turned on during the pre-op inspection, and may be left on until the end of a target run. After the pump is pressurized, the operator should visually inspect the glue lines for pressure bubbles, which may be caused by failure of the hoses, and the glue fittings for leaks. Any problems found should be corrected before further use. The operator should then remove the caps from the glue nozzles and test the system by pressing the "GLUE TEST" button on the hand held controller. This will cause all three nozzles to fire simultaneously, excreting a small amount of adhesive from each one. Repeat this test until even flow is achieved. The nozzle caps should be left off until the truck is returned to the garage.

Finally, the operator lays a target in the garage. The procedure is the same as it would be in the field, except that the target is placed on tar paper. If any problems are encountered, they should be corrected before taking the unit onto the road.

Travel To and From the Site

When the vehicle travels to the worksite the paper tray is removed and the end effector is fully raised to allow for maximum ground clearance. When the mechanism is in this configuration, the lowest point on the system (frame and hoses included) should be at least one foot above a "normal" road surface; where "normal" implies that the road surface is completely flat. Having the system raised to this height during travel will reduce the possibility of damage from such obstacles as curbs, speed bumps, road debris, etc.

The primary restraint used to hold the end effector in the fully raised position will be the control system, which is enacted by depressing a button labeled "OFFSITE TRAVEL". A secondary restraining system composed of straps such as bungee cords should be attached to the end effector, to hold it in place of an electrical or pneumatic failure.

APPENDIX B

SUGGESTED INSPECTION & OPERATION PROCEDURES

Right before the truck arrives at the site, the operator should stop at some nearby lightly trafficked area, such as a parking lot, and complete the necessary procedure to prepare the PTL for operation. This involves filling the paper tray, getting out of the truck, attaching the tray to the applicator and securing it in place, removing the secondary restraints from the end effector, then entering the truck and pushing the "ONSITE TRAVEL" button, which will drop the end effector to the top of the paper stack and holding it there with positive pressure.

Any time the paper tray may need refilling in the middle of a run, the truck should be taken to a similar lightly trafficked area. Note that this will not have to be done often, as the tray will accommodate at least 3 miles worth of targets when full. To refill the tray, the "OFFSITE TRAVEL" button is pushed, the tray is then removed, refilled, and replaced. The operation is completed by pressing the "ONSITE TRAVEL" button.

At the end of a run, the truck is taken off of the site, and the "OFFSITE TRAVEL" button is hit. The driver then comes out and removes the tray and secures the end effector with the secondary restraining system. The vehicle is then ready for the trip back to the garage.

Onsite Operation

When the truck arrives at the site, the driver will position the mechanism by driving the truck to a point where a target is desired, laying a target, then driving the truck 50′ to the next site. The positioning of the machine parallel to the roadway would be done by using either the odometer of the vehicle, or by some other linear positioning means implemented by Caltrans. The positioning of the machine perpendicular to the roadway would be done by the placement of the truck by the driver. Relying on the driver for the positioning of the truck is not unreasonable; past projects such as the longitudinal crack sealing machine use the driver to position the mechanism [Velinsky, 1993].

Once the operator has arrived at the point where the mark is desired, the truck is put into parking gear. It is recommended that when the PTL is hooked up to the light duty vehicle of Caltrans' choice, that the controls be wired in such a way so that the mechanism will only lay targets when the vehicle is parked. Movement of the vehicle while the end effector is in contact with the ground could seriously damage the machine.

Once the truck is parked, the operator presses the "LAY TARGET" button on the hand-held controller. This starts the operation shown in fig. 4.1.2 of the main document. In the first frame, the PTL is shown in the "ONSITE TRAVEL" position. The horizontal air cylinder (MULT) is pressurized at this time, so that the end effector does not bounce or rattle while the truck is traveling. While in this position, the paper separation system is activated, and the top sheet is grabbed. In frame 2, the end effector has been lifted straight up to ensure that neither the end effector nor the target will interfere with the walls of the paper tray when horizontal motion starts.

Frames 3 & 4 show the end effector being moved away from the paper tray, and then being pressed to the pavement surface. The end effector is pressed to the pavement so that the target can be fully secured before gluing. Gluing is started when the end effector reaches a switch in the position shown in frame 5, and is stopped when the end effector reaches the point in frame 6. The end effector continues to move laterally, until the end stop is encountered in frame 7. In frame 8, the target is pressed onto the fresh glue, and the suction holding the target to the end effector is shut off. The mechanism then returns to the "ONSITE TRAVEL" position.

APPENDIX C

MATERIAL SAFETY DATA SHEETS

ECONOMY SEMI-GLOSS POSTER INK

TRIANGLE SCREEN RITE

for Calcom.

37

DESCRIPTION
Screen Rite Poster Ink is formulated primarily for printing billboards but can be used on other paper or card substrates. It is an economical, semi-gloss poster ink that features flexibility and adhesion. The ink will perform well on hand or mechanical equipment. End uses include posters, P.O.P. displays, greeting cards, store signs, banners, etc.

SUBSTRATES
Paper, cardboard, wood, foamcore, etc.

SCREEN FABRIC/STENCILS
110 to 260 monofilament polyester or 10XX to 14XX multifilament polyester. All types of stencils, including paper, are suitable.

THINNERS/MODIFICATION/ WASH-UP
Thinning Use mineral spirits as a thinner; xylol as a fast thinner.
Modification Use L322 Extender Base or RM 9002 Binding Varnish for adjustment of color or viscosity.
Wash-Up Mineral spirits or xylol.

DRYING TIME
Will air dry in 20 to 30 minutes; less than one minute in a jet dryer.

CAUTION
Always test ink on substrate prior to production run. Allow 24 to 96 hours after test printing to evaluate suitability of ink for intended application.

PACKAGING
Available in five gallon containers.

COLOR RANGE
100 Vermillion
102 Fire Red
104 Bright Red
106 Carmine
111 Black
112 White
114 Brown
124 Orange
127 Cerise
128 Magenta
130 Primrose Yellow
132 Lemon Yellow
134 Chrome Yellow
142 Emerald Green
148 Dark Green
150 Blue Green
152 Light Blue
156 Brilliant Blue
158 Dark Blue
162 Purple

MODIFICATION
L322 Extender Base
RM 9002 Binder Varnish

WASH-UP
Mineral Spirits
Xylol

DAYLIGHT FLUORESCENT POSTER INK

DAYGLO® COLOR CORP.

SUPER 66
S66 SERIES

DESCRIPTION
Super 66 daylight fluorescent inks provide excellent printability and visual impact. They exhibit exceptional mileage, drying speed and color strength. Super 66 colors are transparent and must be printed on white backgrounds; they have a flat finish.

SUBSTRATES
Paper and cardboard POP displays, billboards, posters, banners, greeting cards, packaging materials, etc.

CAUTION
Always test ink on substrate prior to production run. Allow 24 to 96 hours after test printing to evaluate suitability of ink for intended application.

SCREEN FABRICS/STENCILS
All fabrics are suitable. However, drying time and opacity are affected by the mesh count. A 195 mesh will give greater opacity but may take longer to dry than a 280 mesh. All types of stencils are suitable.

THINNERS/WASH-UP
Thinners If necessary, use mineral spirits as a thinner or kerosene as a retarder.
Wash-Up Mineral spirits or xylol.

DRYING TIME
Dries by evaporation: air dries in 15 to 20 minutes; in seconds in a jet dryer.

PACKAGING
Available in quarts, gallons, five gallons.

STANDARD COLOR RANGE
S66-11 Aurora Pink
S66-12 Neon Red
S66-13 Rocket Red
S66-14 Fire Orange
S66-15 Blaze Orange
S66-16 Arc Yellow
S66-17 Saturn Yellow
S66-18 Signal Green
S66-19 Horizon Blue

APPENDIX C

MATERIAL SAFETY DATA SHEETS

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* 03.25.86 *

MATERIAL SAFETY DATA SHEET

for coatings,resins and related materials

SECTION I

MANUFACTURER:
TRIANGLE COATINGS, INC.
1930 FAIRWAY DRIVE
SAN LEANDRO, CA. 94577

EMERGENCY TELEPHONE:
(415)895-8000 DAY
(415)284-9031 NIGHT

TRADE NAME ___ PROCESS WHITE
PRODUCT CLASS ___ MODIFIED ROSIN ESTER
MFR.CODE ___ CP112

SECTION II HAZARDOUS INGREDIENTS

ingredient	cas no.	%	exposure limits	v.p.
1) XYLENE	133-20-7	30.0	100	5.0
2) MINERAL SPIRITS	64741-41-9	25.0	100	5.0
3)				
4)				
5)				
6)				
7)				
8)				

SECTION III PHYSICAL DATA

BOILING RANGE	280-405`F
EVAPORATION RATE	XX_SLOWER ___FASTER THAN ETHER
VAPOR DENSITY	XX_HEAVIER ___LIGHTER THAN AIR
% VOLATILE BY VOLUME	78.0 %
WEIGHT PER GALLON	9.39
VOLATILE ORGANIC COMPOUND	5.36 LBS/GAL (643.2 GR/LITER)

TRIANGLE COATINGS, INC.
MFR.CODE __ CP112

SECTION VII SPILL OR LEAK PROCEDURE

STEPS TO BE TAKEN IN CASE MATERIAL IS RELEASED OR SPILLED:
REMOVE ALL SOURCES OF IGNITION (FLAMES HOT SURFACES, AND ELECTRICAL, STATIC, OR FRICTIONAL SPARKS). AVOID BREATHING VAPORS. VENTILATE AREA. REMOVE WITH INERT ABSORBENT USING NON-SPARKING TOOLS.

WASTE DISPOSAL METHOD: DISPOSE OF IN ACCORDANCE WITH ALL LOCAL, STATE AND FEDERAL REGULATIONS. DO NOT INCINERATE CLOSED CONTAINERS.

SECTION VIII SPECIAL PROTECTION INFORMATION

RESPIRATORY PROTECTION: NIOSH APPROVED RESPIRATOR

VENTILATION: LOCAL EXHAUST-ADEQUATE VOLUME AND PATTERN TO AVOID VAPOR LIMITS BELOW TLV.

PROTECTIVE GLOVES: REQUIRED FOR PROLONGED USE.

EYE PROTECTION: USE SAFETY EYEWEAR.

OTHER PROTECTIVE EQUIP.: N/A

SECTION IX SPECIAL PRECAUTIONS

PRECAUTIONS TO BE TAKEN IN HANDLING AND STORAGE:
DO NOT STORE ABOVE 120'F
GROUND ALL CONTAINERS

OTHER PRECAUTIONS: DO NOT TAKE INTERNALLY

**-

APPENDIX C

MATERIAL SAFETY DATA SHEETS

09/02/93

Attn: Safety Director
UNIVERSITY OF CALIFORNIA DAVIS
804 9TH STREET
#204
DAVIS CA 95616

SUBJECT: Material Safety Data Sheet

PRODUCT REFERENCE: SC-0664

Dear Customer:

Enclosed are Material Safety Data Sheets (MSDS) for H. B. Fuller Company products. We have reviewed our products, conducted a hazard determination, and prepared an MSDS in compliance with the requirements of the Occupational Safety and Health Administration (OSHA) Hazard Communication Standard, 29 CFR 1910.1200 and Canada's Workplace Hazardous Materials Information System (WHMIS). Our MSDS also provide information on any toxic chemical subject to the reporting requirements of section 313 of Title III of the Superfund Amendments and Reauthorization Act of 1986 (SARA).

If this product, or any component of it, is considered to be hazardous or carcinogenic under the OSHA Hazard Communication Standard or the WHMIS regulations, information is provided in Section 2: COMPOSITION/INFORMATION ON INGREDIENTS or in Section 3: HAZARDS IDENTIFICATION.

If you have any questions, please contact your Sales Representative.

Sincerely yours,

H. B. Fuller Company

Industrial Hygiene Section

SC-0664
Date Printed: 09/02/93

MATERIAL SAFETY DATA SHEET

SECTION 1: CHEMICAL PRODUCT AND COMPANY IDENTIFICATION

COMPANY INFORMATION

H.B. Fuller Company
1200 Wolters Boulevard
Vadnais Heights, MN 55110
Phone: 612-481-3300
Fax: 612-481-3309

MSDS INFORMATION

Preparation Date: 08/15/93
Supersedes: 06/23/93
Prepared By: Industrial Hygiene
Phone Number: 612-481-3300

Medical Emergency Phone Number: 1-800-228-5635 ext 018
Transport Emergency Phone Number (CHEMTREC): 1-800-424-9300

PRODUCT INFORMATION

Product Name/Number: SC-0664
Product Description (product use): Solvent based adhesive

SECTION 2: COMPOSITION/INFORMATION ON INGREDIENTS

This Material Safety Data Sheet is prepared to comply with the United States Occupational Safety and Health Administration (OSHA) Hazard Communication Standard (29 CFR 1910.1200) and the Canadian Workplace Hazardous Materials Information System (WHMIS). Unlisted ingredients are not 'hazardous' per the OSHA standard and/or are not found on the WHMIS ingredient disclosure list.

Chemical/CAS Number	Percent	OSHA PEL	ACGIH TLV
Cyclohexane (110-82-7)	1-5%	300 ppm	300 ppm
LD50: 12,705 mg/kg (oral, rat) LC50: No data found			
Vapor pressure in mm Hg @ 20 C: 80			
Heptane (142-82-5)	5-10%	400 ppm	400 ppm
LD50: No data found LC50: 38 gm/M3/4h (mouse)			
Vapor pressure, in mm Hg @ 20 C: 36			
OSHA, ACGIH STEL: 500 ppm			
N-hexane (110-54-3)	10-30%	50 ppm	50 ppm
other isomers		500 ppm	500 ppm
LD50: 28,710 mg/kg (oral, rat) LC50: 48,000 ppm/4h (rat)			
Vapor pressure, in mm Hg @ 20 C: 120			
OSHA, ACGIH STEL: 1000 ppm (for isomers)			
Toluene (108-88-3)	0.1-1.0%	100 ppm	50 ppm
LD50: 5000 mg/kg (oral, rat) LC50: 7524 ppm/4h (rat)			
Vapor pressure, in mm Hg @ 20 C: 24			
OSHA, ACGIH STEL: 150 ppm			
(Skin)			

See Section 16 for additional information.

SC-0664
Date Printed: 09/02/93

SECTION 3: HAZARDS IDENTIFICATION

EMERGENCY OVERVIEW

Flammable
Eye irritant
Contact will dry and defat the skin
Vapors harmful
Harmful if swallowed
May cause adverse reproductive effects, based on tests with laboratory animals.
Possible cancer hazard. Contains a material which may cause cancer.

POTENTIAL HEALTH EFFECTS

Eyes: Contact with the product or high vapor levels will cause irritation.

Skin: Liquid contact will dry and defat the skin. Prolonged or repeated contact may cause irritation and sensitization.

Inhalation: Overexposure to vapors in poorly ventilated areas will cause irritation of the nose, throat and respiratory tract and may cause dizziness, headaches, nausea or unconsciousness.

Ingestion: Harmful if swallowed.

Chronic: When the product is in its final form and is abraded or disturbed, dusting may occur and crystalline silica may be released into the air. Long-term overexposure to crystalline silica may cause permanent lung damage and reduced pulmonary function.
Long-term overexposure to solvents may cause liver and kidney damage.
n-Hexane has been demonstrated to cause peripheral nerve damage in overexposed workers. Symptoms include loss of feeling and weakness in the hands and feet and loss of manual dexterity.
Overexposure to toluene may cause female and male reproductive disorders, based on tests with laboratory animals. Current exposure guidelines are expected to protect from these effects.

REGULATED CARCINOGEN STATUS:

Crystalline silica is listed as a potential carcinogen by NTP and IARC.

Existing Health Conditions Affected by Exposure: No known effects on other illnesses.

SECTION 4: FIRST AID MEASURES

If in eye: Flush immediately with large amounts of water for at least 15 minutes. Call a physician.

If on skin: Wash affected area with soap and water. Launder contaminated clothing before reuse.

If vapors inhaled: Remove from exposure. Restore breathing if necessary. Keep warm and quiet. Call a physician.

If ingested: If person can swallow, give one glass of water or milk. Do not induce vomiting. Get immediate medical attention. Never give anything by mouth to an unconscious person.

SECTION 5: FIRE FIGHTING MEASURES

Flash Point/Method: Less than 0 degrees F TCC, Less than -18 degrees C

Upper Explosive Limit/Lower Explosive Limit: Not established

Autoignition Temperature: Not established

Appropriate Extinguishers: Use water spray, foam, dry chemical or carbon dioxide.

Special Fire Fighting Procedures: Persons exposed to products of combustion should wear self-contained breathing apparatus and full protective equipment.

Unusual Fire and Explosion Hazards: There is the possibility of pressure buildup in closed containers when heated. Water spray may be used to cool the containers.

Hazardous Combustion Product: Incomplete combustion can yield low molecular weight hydrocarbons, carbon monoxide

SECTION 6: ACCIDENTAL RELEASE MEASURES

Spill or Leak Procedures: Remove all sources of ignition. Ventilate area. Avoid breathing vapors. Dike and contain spill with inert absorbent and transfer to container for disposal. Use non-sparking tools. Keep spill out of sewers.

SECTION 7: HANDLING AND STORAGE

HANDLING INFORMATION

Keep away from heat, sparks and flame
Avoid breathing vapors
Use only with adequate ventilation
Avoid contact with eyes, skin and clothing
Wash thoroughly after handling
Keep container closed
Emptied container retains vapor and product residue
Observe all labeled precautions until container is cleaned
DO NOT CUT OR WELD ON OR NEAR THIS CONTAINER

STORAGE INFORMATION

Consult the Technical Data Sheet for specific storage instructions.

SECTION 8: EXPOSURE CONTROLS/PERSONAL PROTECTION

Eye Protection: Wear safety glasses to reduce the potential for eye contact; chemical safety goggles are appropriate if splashing is likely. Have eye washes available where eye contact can occur.

Skin Protection: Prevent contact by using rubber gloves and appropriate protective clothing. Launder contaminated clothing before reuse.

Respiratory Protection: Use NIOSH/MSHA approved equipment - organic vapor respirators when airborne exposure limits are exceeded.

Ventilation: Local exhaust ventilation preferred. Provide ventilation to control contaminant levels below airborne exposure limits.

SECTION 9: PHYSICAL AND CHEMICAL PROPERTIES

Physical State:	Liquid
Color:	Light Cream
Odor:	Pungent, solvent
Odor Threshold:	Not established
Weight per Gallon:	9.2 lbs.
Specific Gravity:	1.1
% Solids by Weight:	68.6
pH:	Not applicable
Boiling Range:	Greater than 156 F (69 C)
Vapor Pressure:	Not established
Vapor Density:	Not established
Evaporation Rate:	Not established
Water/Oil Partition Coefficient:	Not established
VOC:	347 g VOC/liter of material (VOC theoretically determined using EPA Publication 450/3-84-019)
VOC, less water:	347 g VOC/liter of material, less water and exempt solvents (VOC theoretically determined using EPA Publication 450/3-84-019.)

SECTION 10: STABILITY AND REACTIVITY DATA

Stability: Stable

Incompatibility: Not established

Hazardous Decomposition: Not established

Hazardous Polymerization: Will not occur

SC-0664
Date Printed: 09/02/93

SECTION 11: TOXICOLOGICAL INFORMATION

No data available

SECTION 12: ECOLOGICAL INFORMATION

No data available

SECTION 13: DISPOSAL CONSIDERATIONS

This product meets the definition of hazardous waste under the U.S. EPA Hazardous Waste Regulations 40 CFR 261. It is ignitable waste class D001. Disposal via incineration is recommended. Consult your state, local, or provincial authorities for more restrictive requirements.

SECTION 14: TRANSPORTATION INFORMATION

UNITED STATES DEPARTMENT OF TRANSPORTATION (DOT)

DOT Proper Shipping Name:	Adhesives
DOT Hazard Class/I.D. Code:	3, UN-1133
DOT Label:	FLAMMABLE LIQUID
DOT Packaging Group:	II

SECTION 15: REGULATORY INFORMATION

FEDERAL

Toxic Substances Control Act (TSCA)

Section 8(b) - Inventory Status

All components of this product are registered under the regulations of the Toxic Substances Control Act.

SARA TITLE III

Section 313: This product contains the following toxic chemical(s) subject to the reporting requirements of section 313 of Title III of the Superfund Amendments and Reauthorization Act of 1986 (SARA) and 40 CFR part 372:

Chemical Name	CAS Number	Percent
Cyclohexane	110-82-7	1-5%

STATE REGULATIONS

California Proposition 65: Proposition 65, The Safe Drinking Water and Toxic Enforcement Act of 1986:

This product contains chemical(s) known to the state of California to cause cancer or reproductive damage.
<0.0094% Benzene 71-43-2
listed February 27, 1987
<0.0001% Cadmium (7440-43-9) and cadmium compounds
listed October 1, 1987
0.1-1.0% Crystalline silica
listed October 1, 1988
<0.0013% Lead (7439-92-1)
listed February 27, 1987
0.1-1.0% Toluene 108-88-3
listed January 1, 1991

WHMIS IDENTIFICATION/OTHER INTERNATIONAL REGULATIONS

B2, D2A, D2B

SECTION 16: ADDITIONAL INFORMATION

Drums of this material should be grounded when pouring.

This product contains the following substance(s) identified by OSHA, WHMIS, or the ACGIH as hazardous. During normal use, the material will not present an exposure risk. Once the product has reached its final state and is abraded or disturbed, dusting and exposure may occur.

Calcium carbonate (1317-65-3)
Exposure limit total dust 15 mg/M3 (OSHA) 10 mg/M3 (ACGIH)
Exposure limit respirable dust 5 mg/M3 (OSHA)
LD50: No data found LC50: No data found

Kaolin (1332-58-7)
Exposure limit total dust 10 mg/M3 (OSHA) 10 mg/M3 (ACGIH)
Exposure limit respirable dust 5 mg/M3 (OSHA) 2 mg/M3 (ACGIH)
LD50: No data found LC50: No data found

Silica-crystalline (14808-60-7)
Exposure limit respirable dust 0.1 mg/M3 (OSHA) 0.1 mg/M3 (ACGIH)
LD50: No data found LC50: No data found

Talc-containing no asbetos fibers (14807-96-6)
Exposure limit total dust 15 mg/M3 (OSHA) 10 mg/M3 (ACGIH)
Exposure limit respirable dust 2 mg/M3 (OSHA) 2 mg/M3 (ACGIH)
LD50: No data found LC50: No data found

HMIS RATING

Health-2 Flammability-3 Reactivity-0

See SECTION 8: EXPOSURE CONTROLS/PERSONAL PROTECTION for personal protective equipment recommendations.

The information and recommendations set forth herein are believed to be accurate. Because some of the information is derived from information provided to the H.B. Fuller Company from its suppliers, and because the H.B. Fuller Company has no control over the conditions of handling and use, the H.B. Fuller Company makes no warranty, express or implied, regarding the accuracy of the data or the results to be obtained from the use thereof. The information is supplied solely for your information and consideration, and the H.B. Fuller Company assumes no responsibility from use or reliance thereon. It is the responsibility of the user of H.B. Fuller Company products to comply with all applicable federal, state and local laws and regulations.

APPENDIX C

MATERIAL SAFETY DATA SHEETS

H.B. Fuller Company

SOLVENT BASED PRODUCTS SB-0664

Product Number

Technical Information

DESCRIPTION

This is a fast drying, quality construction mastic that develops tough, flexible bonds resistant to heat, moisture, and aging. It is designed to bond wood, concrete, cement asbestos board, gypsum board, and metals such as steel and aluminum.

TYPICAL PHYSICAL PROPERTIES and GENERAL INFORMATION

RAW MATERIAL BASE	SBR
FLASH POINT (T C C)	Less than 0 DEGREES F
SOLIDS	68.6 %
COLOR	Light Cream
TYPE-SPINDLE/SPEED/TEMPERATURE . .	RVF 7/20/77F
VISCOSITY	95,000 cP (mPa.s)
WEIGHT PER GALLON	9.2 POUNDS
VOC AS IS - THEORETICAL METHOD . .	347 GRAM/LITER
VOC LESS WATER & EXEMPT-THEO. METH.	347 GRAM/LITER
SCAQMD PHOTOCHEMICALLY REACTIVE . .	No

SOLVENT BLEND

Hexane, Heptane, Ethanol

CLEAN-UP SOLVENT

Toluene, Methyl Ethyl Ketone, Chlorothane

DRYING TIME

One to 10 minutes to skin over. Twelve to 36 hours to dry all the way through. It depends on bead size, type of substrates, and ambient conditions.

COVERAGE

375 lineal ft/gal (based on 1/4" bead).

BONDING RANGE

Bond Wet or Semiwet

(continued)

ADEQUATE TESTS: The information contained in this bulletin we believe is correct to the best of our knowledge and tests. The recommendations and suggestions herein are made without guarantee or representation as to results. We recommend that adequate tests be made in your laboratory or plant to determine if this product meets all of your requirements.

ALL SALES OF THIS PRODUCT ARE SUBJECT TO THE H.B. FULLER LIMITED WARRANTY SHOWN ON THE REVERSE SIDE.

APPENDIX C

MATERIAL SAFETY DATA SHEETS

EQUIPMENT SUGGESTIONS

Extrusion Equipment

5 GALLON PAIL DISPENSING SYSTEM

1. Pump - 24 to 1 ratio pump divorced design. 2 cu.in./cycle with 4 1/4" air motor. Ball type check valves-double acting.
2. Primer - Gravity type with plate type follower plate.

55 GALLON DRUM DISPENSING SYSTEM

1. Pump - 24 to 1 ratio pump divorced design. 2 cu.in./cycle with 4 1/4" air motor. Ball type check valves-double acting.
2. Primer - Elevator with plate type follow plate.

PERFORMANCE CHARACTERISTICS

Certified by the American Plywood Association (APA) for compliance to Spec. AFG-01.

Meets ASTM C-557 performance spec. (adhesive for fastening Gypsum Wallboard to Wood Framing).

	Cross Lap Tensile Strength (FTM-33)	Shear Strengths (FTM-35)
24 hours	25 psi	52 psi
7 days	154 psi	292 psi
21 days	263 psi	327 psi

DIRECTIONS FOR USE

1. Clean all surfaces thoroughly. Make sure the surfaces are free of any oil residue.

2. Apply a bead, usually 1/4" wide, to one surface.

3. Combine the substrates with sufficient pressure to insure 100% contact.

4. Seperate the surfaces and allow the excessive solvent to escape.

5. Re-combine the substrates with sufficient pressure to insure 100% contact.

STORAGE & HANDLING

(continued)

LIMITED WARRANTY
ADHESIVES, SEALANTS AND COATINGS DIVISION
H.B. FULLER COMPANY

H.B. FULLER COMPANY ("Fuller") warrants, for a Warranty Period of one year (or the period specified on the applicable Technical Data Sheet, whichever is less) from the date of shipment from Fuller to the Initial Purchaser, that this Fuller product was manufactured in accordance with Fuller's specifications in effect on the date of manufacture. These specifications are available upon request. This Warranty does not cover test data, or any defects, damages or other harms caused to any extent or in any way by failure to follow applicable Fuller instructions, if any, or abuse or misuse of the product. For any valid claim presented under the Warranty, Fuller will replace the product, or at its option, refund the purchase price.

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APPENDIX C

MATERIAL SAFETY DATA SHEETS

The shelf life of this product is 6 (six) months when stored at 60-80 degrees F in the original sealed container. If stored below 60 degrees F, the product should be conditioned in its unopened container at room temperature for at least 24 hours before usage.

CAUTION

Extrememly flammable. Vapors may cause flash fires. Do not use near heat, sparks, or flames. Vapors harmful. Use in a well-ventilated area. Avoid prolonged skin contact and breathing of vapors and contact with eyes. Harmful if swallowed. Consult container label and Material Safety Data Sheet for additional cautionary information before using.

8/16/93

APPENDIX D

PTLcontrol.c

```
/*-----------------------------------------------------------------*
 |  PTLcontrol.c                                                   |
 |                                                                 |
 |  This program uses the Z-World little giant to control the      |
 |  functions of the Prefabricated Target Layer                    |
 *-----------------------------------------------------------------*/

#include <stdio.h>

#define KEYPAD_SIZE 24      /* set param for pendant  */
#define LK_LINES 4          /* see p.28 in KDM Manual */
#define LK_COLS 20
#define LK_BLINK 1
#define ON 1
#define OFF 0

main()
{
  int keypad;
  int read_j10;
  int lk_kxget();
  int hv_wr();

  Initialize_Keypad();
/*  Test_Inputs(); */
  Home();
  Lay_Target();
  Home();
}

/*******************************************************************
*  Input Bit Assignment:                                 Bus: J10   *
*                                                                   *
*    ()      ()      ()      ()      ()      ()      ()      ()     *
*                    4BAND   3BAND   2BAND   1BAND   2MULT   1MULT  *
*                                                            [MSB]  *
*******************************************************************/

/*******************************************************************
*  Output Bit Assignment:                                Bus: HV_WR *
*                                                                   *
*    ()      ()      ()      ()      ()      ()      ()      ()     *
*    VAC8    VAC7    GLUE6   MULT5   MULT4   MULT3   BAND2   BAND1  *
*                                                            [MSB]  *
*******************************************************************/
```

```
/*-------------------------------------------------------------------*
 |  Initialize_Keypad()                                              |
 *-------------------------------------------------------------------*/

Initialize_Keypad()
{
  int index;

  ser_init_s0((char)4, (char)8);    /* initialize serial port  */
              /* as per param. on page 53   */
  lk_kxinit();
  lk_init();
  lk_init_keypad();
/*******ClearBuf(Input, 100);
  ClearBuf(Output, 100);**************************************/
  hv_wr((char)0xff);             /* turn off the drivers    */
  hv_enb();                      /* enable the driver ports */
  outport(0x41, (char)0xf);      /* initialize the parallel port  */
  outport(0x40, (char)1);        /* turn on the solenoid drivers */
}

/*-------------------------------------------------------------------*
 |  Test_Inputs();                                                   |
 *-------------------------------------------------------------------*/

Test_Inputs()
{
  int keypad;
  int read_me;

  lk_printf("INPUT TEST SEQUENCE \n");
  keypad=0;
  outport(0x41, 0x4f);
  while (keypad != 4)
  {
    keypad=lk_kxget(0);
    read_me=~inport(0x40);
    printf(" INPUT CODE (dec): %d, (hex): %x \n",read_me,read_me);

    hv_wr(read_me);     /* output = input */
  }
}

/*-------------------------------------------------------------------*
 |  Home();                                                          |
 *-------------------------------------------------------------------*/

Home()
{
  int read_me;
```

```
  int switchcheck;
  int action;
  long wait;

  lk_printf("HOMING....\n");
  printf("Homing started  \n");
  outport(0x41, 0x4f);

  action=0;
  switchcheck=0x0;
  hv_wr(0x0f);

  while (switchcheck == 0x0)         /* wait for 1MULT to trigger    */
  {
    read_me=inport(0x40);
    switchcheck=((~(read_me)) & 0x1);
    action=0x10;
    hv_wr(action);                           /* ON> MULT5              */
    printf("....5... Lifting end effector \n");
  }
  switchcheck = 0x0;

  while (switchcheck == 0x0)    /* wait for 1BAND to trigger          */
  {
    read_me=inport(0x40);
    switchcheck=((~(read_me)) & 0x4);
    action=0x12;
    hv_wr(action);                       /* ON> BAND2 MULT5            */
    printf(".2..5... Moving starboard \n");
  }
  switchcheck = 0x0;
  for (wait=0; wait<10000; ++wait)
  {
    action=0x15;
    hv_wr(action);
  }
}

/*------------------------------------------------------------------*
 |  Lay_Target()                                                     |
 *------------------------------------------------------------------*/

LayTarget()
{
  int read_me;
  int keypad;
  int switchcheck;
  int action;
  long wait;
```

```
switchcheck=0x0;

while (switchcheck == 0x0)        /* wait for 1MULT to trigger     */
{
  read_me=inport(0x40);
  switchcheck=((~(read_me)) & 0x1);
  action=0x52;
  hv_wr(action);                           /* ON> MULT5             */
  printf(".2..5.7. Lifting end effector again\n");
}
switchcheck = 0x0;

while (switchcheck == 0x0)        /* wait for 2BAND to trigger     */
{
  read_me=inport(0x40);
  switchcheck=((~(read_me)) & 0x8);
  action=0x51;
  hv_wr(action);                  /* ON> BAND1 MULT5 VAC7          */
  printf("1...5.7. Moving horizontally to glue start \n");
}
switchcheck = 0x0;

for (wait=0; wait<1000; ++wait)                      /* QUICKSTOP */
{
  action=52;
  hv_wr(action);                           /* ON> BAND2 MULT5 VAC7 */
}

while (switchcheck == 0x0)        /* wait for 2MULT to trigger     */
{
  read_me=inport(0x40);
  switchcheck=((~(read_me)) & 0x2);
  action=0x54;
  hv_wr(action);                  /* ON> MULT3 MULT5 VAC7          */
  printf("..3.5.7. Moving vertically to glue start \n");
}
switchcheck = 0x0;

printf("...4..78 Secondary vacuum coming online \n");
for (wait=0; wait<1000; ++wait)                  /* POUND ON VAC8 */
{
  action=c8;
  hv_wr(action);                           /* ON> MULT4 VAC7 VAC8 */
}

printf("..3.5.78 Raising back to hover \n");
for (wait=0; wait<1000; ++wait)   /* return to start glue position */
{
  action=d4;
  hv_wr(action);    /* ON> MULT4 VAC7 VAC8 */
```

```
    }

    while (switchcheck == 0x0)        /* wait for 3BAND to trigger     */
    {
      read_me=inport(0x40);
      switchcheck=((~(read_me)) & 0x10);
      action=0xf5;
      hv_wr(action);          /* ON> BAND1 MULT3 MULT5 GLUE6 VAC7 VAC8  */
      printf("1.3.5678 Glueing \n");
    }
    switchcheck = 0x0;

    while (switchcheck == 0x0)        /* wait for 4BAND to trigger     */
    {
      read_me=inport(0x40);
      switchcheck=((~(read_me)) & 0x20);
      action=0xd5;
      hv_wr(action);                /* ON> BAND1 MULT3 MULT5 VAC7 VAC8  */
      printf("1.3.5.78 Glueing \n");
    }
    switchcheck = 0x0;

    printf("1..4..78 Applying target \n");
    for (wait=0; wait<1000; ++wait)                      /* POUND ON VAC8 */
    {
      action=c9;
      hv_wr(action);                          /* ON> BAND1 MULT4 VAC7 VAC8 */
    }
  }
```

APPENDIX E

Detail Drawings of PTL

Prefabricated Target Layer
Drawing Log Sheet

Subassembly #	Subassembly Name
PTL-00-XXXXX	General Assembly; Working views, etc.
PTL-01-XXXXX	Paper Tray
PTL-02-XXXXX	Manipulator & End Effector
PTL-03-XXXXX	Control Systems
PTL-04-XXXXX	Adhesive System
PTL-05-XXXXX	Target
PTL-06-XXXXX	Frame & Mounting
PTL-07-XXXXX	Unassigned
PTL-99-XXXXX	Testing Equipment

Drawing Files

Drawing #	Title	Description	Page
XXX-00-0000X	Explanation of Drawing # System		91
PTL-00-0002A	PTL on Truck - Application Position	Application Design Idea	92
PTL-00-0003A	PTL on Truck - Pick-Up Position	Application Design Idea	93
PTL-00-0012A	PTL - Application Position	Application Design Idea	94
PTL-00-0020A	PTL Operation	Application Design Idea	95
PTL-01-0100A	PTL Hanging Paper Tray Assembly	Tray Assembly	96
PTL-01-0101B	Tray-Bottom Plate	For Tray Assembly	97
PTL-01-0102B	Tray-Corner Angle	For Tray Assembly	98
PTL-01-0106B	Tray-Port Horizontal Support	For Tray Assembly	99
PTL-01-0108B	Tray-Port Vertical Support	For Tray Assembly	100
PTL-01-0110B	Tray-Starboard Vertical Support	For Tray Assembly	101
PTL-01-0111B	Tray-F/A Vertical Support	For Tray Assembly	102
PTL-01-0121B	Tray-Fore/Aft Wall	For Tray Assembly	103
PTL-01-0123B	Tray-Port Walls	For Tray Assembly	104
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PTL-02-0002B	End effector Assembly	End Effector Design Idea	107

APPENDIX E

Detail Drawings of PTL

Drawing #	Title	Description	Page
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PTL-02-0101B	Arm Shaft	For Contact Axle Sub Assm	109
PTL-02-0102B	Wheel Shaft	For Contact Axle Sub Assm	110
PTL-02-0103B	Arm Spacer	For Contact Axle Sub Assm	111
PTL-02-0104B	Arm Extension Right	For Contact Axle Sub Assm	112
PTL-02-0105B	Arm Extension Left	For Contact Axle Sub Assm	113
PTL-02-0106B	Bearing Block	For Contact Axle Sub Assm	114
PTL-02-0107B	Extension Support Block	For Contact Axle Sub Assm	115
PTL-02-0108B	Limit Pin	For Contact Axle Sub Assm	116
PTL-02-0109B	Nozzle Mount	For Contact Axle Sub Assm	117
PTL-02-0200A	Vacuum Support Sub Assm	For Manip. & End Eff. Assy	118
PTL-02-0201B	Vacuum support Tube	For Vacuum Support Sub Assm	119
PTL-02-0202B	Vacuum Support Rod	For Vacuum Support Sub Assm	120
PTL-02-0203B	Vacuum Support Beam	For Vacuum Support Sub Assm	121
PTL-02-0300A	Coupler Sub Assm	For Manip. & End Eff. Assy	122
PTL-02-0301B	Plate	For Coupler Sub Assm	123
PTL-02-0302B	Coupler Plate	For Coupler Sub Assm	124
PTL-02-0303B	Coupler Bolts	For Coupler Sub Assm	125
PTL-02-0400A	Non-Rotating Sub Assm	For Manip. & End Eff. Assy	126
PTL-02-0401B	MULT Cyl Support	For Non-Rotating Sub Assm	127
PTL-02-0402B	MULT Cyl Bracket	For Non-Rotating Sub Assm	128
PTL-02-0403B	Non-Rotating Guide Rods	For Non-Rotating Sub Assm	129
PTL-02-0500B	Band Cylinder (BAND)	For Manip. & End Eff. Assy	130
PTL-02-0600B	Multi-Position Cylinder (MULT)	For Manip. & End Eff. Assy	131
PTL-03-0100E	Pneumatic System	Glue System Not Shown	132
PTL-03-0101E	Pneumatic System for MULT Cyl.	Three Positions Shown	133
PTL-03-0200E	Output Wiring Diagram (w/ Pneu.)		134
PTL-03-0250B	Switch Mounting Bracket	For Control Input Switches	135
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PTL-06-0100A	Slide-On Tray Mount	Hanging Tray Design Idea (NU)	137
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PTL-99-0001B	Wind Tunnel Test - Tunnel Set-Up		139
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PTL-99-0701B	Band Support	For Test Frame	141

APPENDIX E

Detail Drawings of PTL

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Detail Drawings of PTL

ABC-02-1234X

(1) (2) (3) (4)

(1) DESIGN NAME

FNG - Free Nozzle Gantry
PMS - Premark Mechanized Stencil
PTL - Prefabricated Target Layer
LFN - Linear Free Nozzle

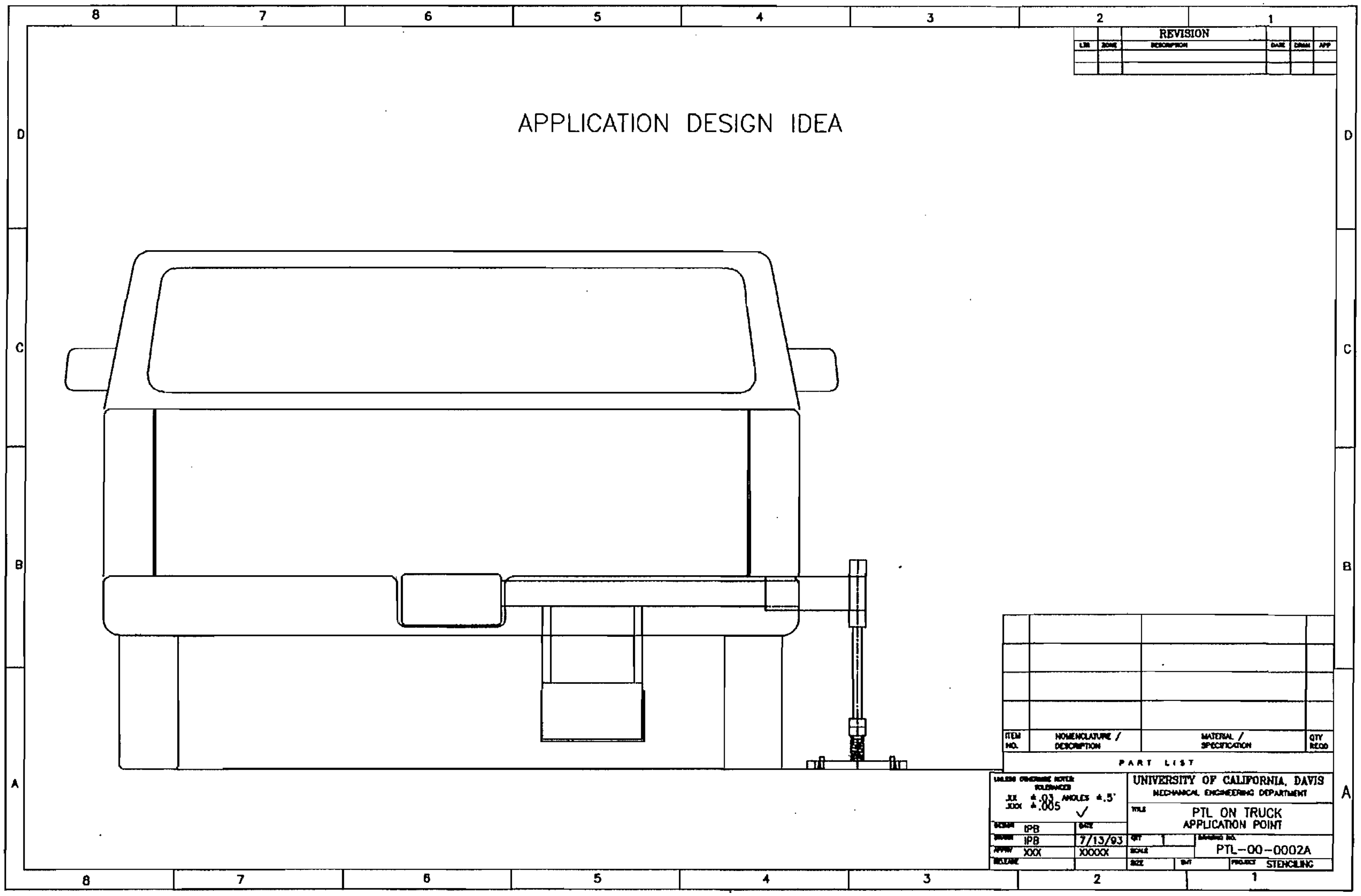
(2) SUBASSEMBLY NUMBER

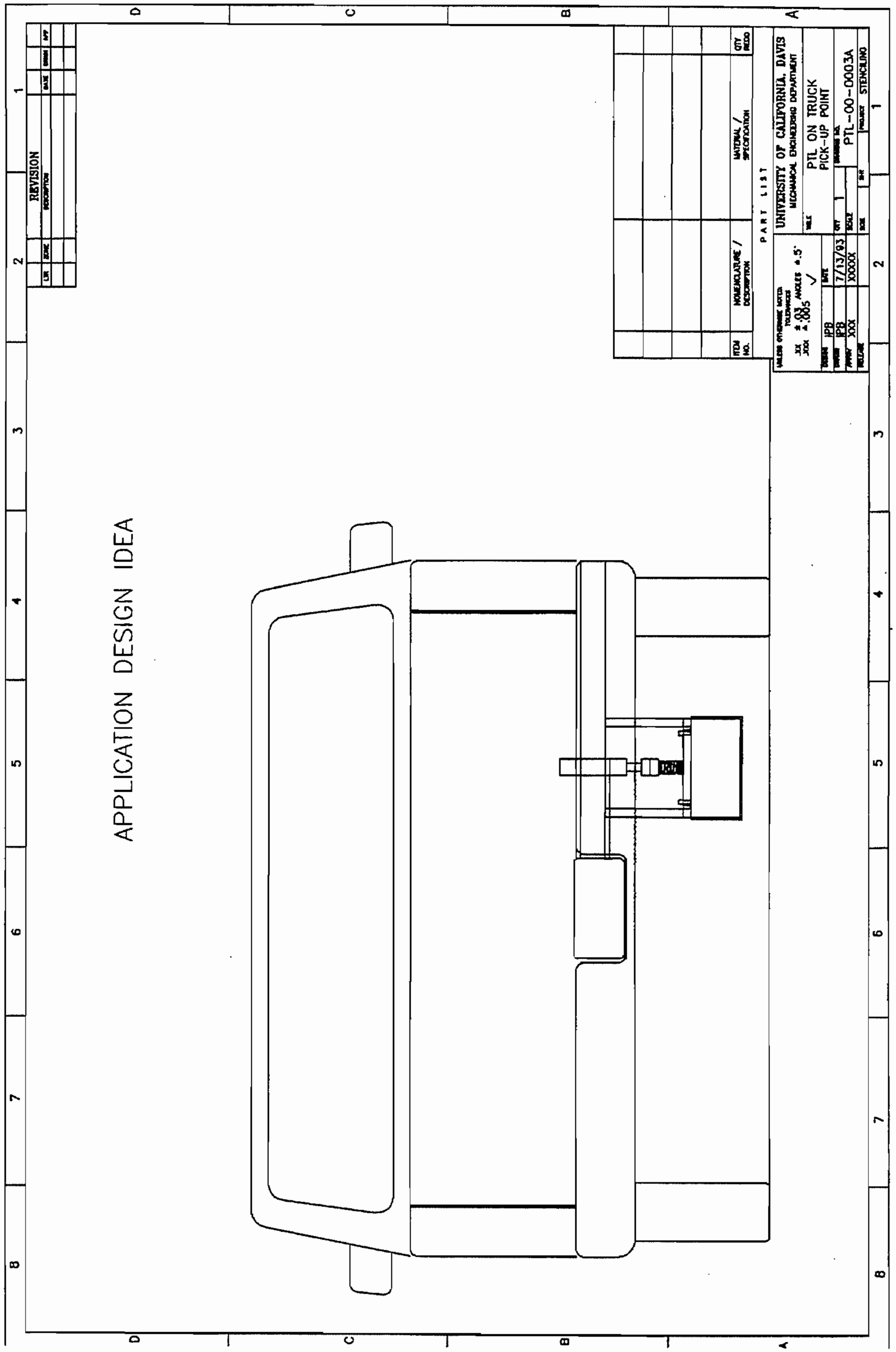
(3) PART NUMBER

(4) DRAWING TYPE

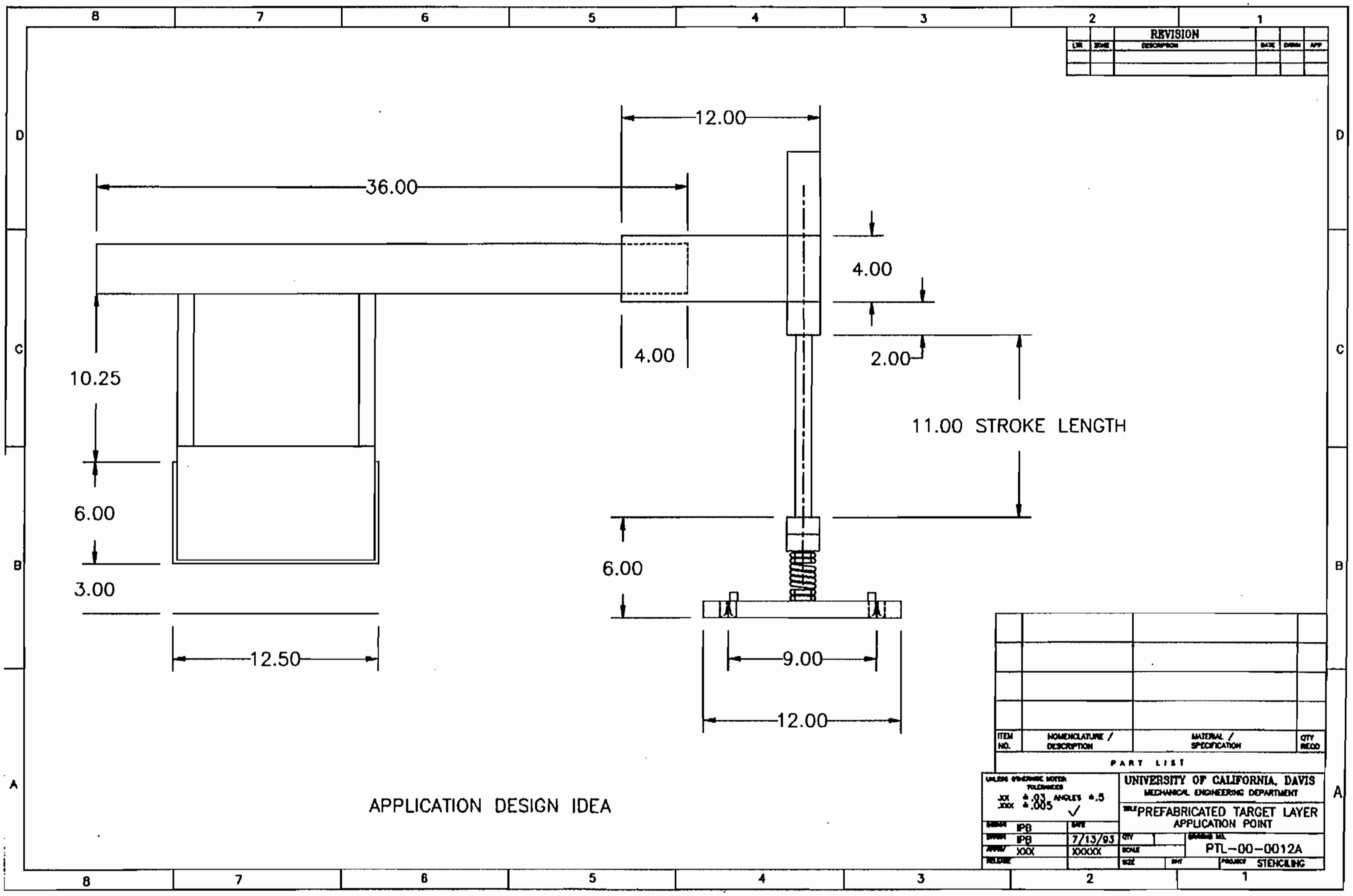
A - Assembly Drawing
B - Basic Drawing (Dims, Tols, Mat'ls, etc.)
C - Conceptual Drawing
E - Electrical/Circuit Diagram
G - Graphs & Charts
N - Non-Proprietary: Drawings for Publication
P - Piping Diagram
R - Revision Note Log Sheet
S - Shop Process / Machining Specifications
T - Technical Data
X - Special

XXX-00-0000X


REVISION
APPLICATION DESIGN IDEA
ITEM NO.
NOMENCLATURE / DESCRIPTION
MATERIAL / SPECIFICATION
QTY REQD
PART LIST
.XX ±.03 ANGLES ±.5°
.XXX ±.005
IPB
IPB
7/13/93
XXX
XXXXX
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
PTL ON TRUCK
APPLICATION POINT
PTL-00-0002A
STENCILING

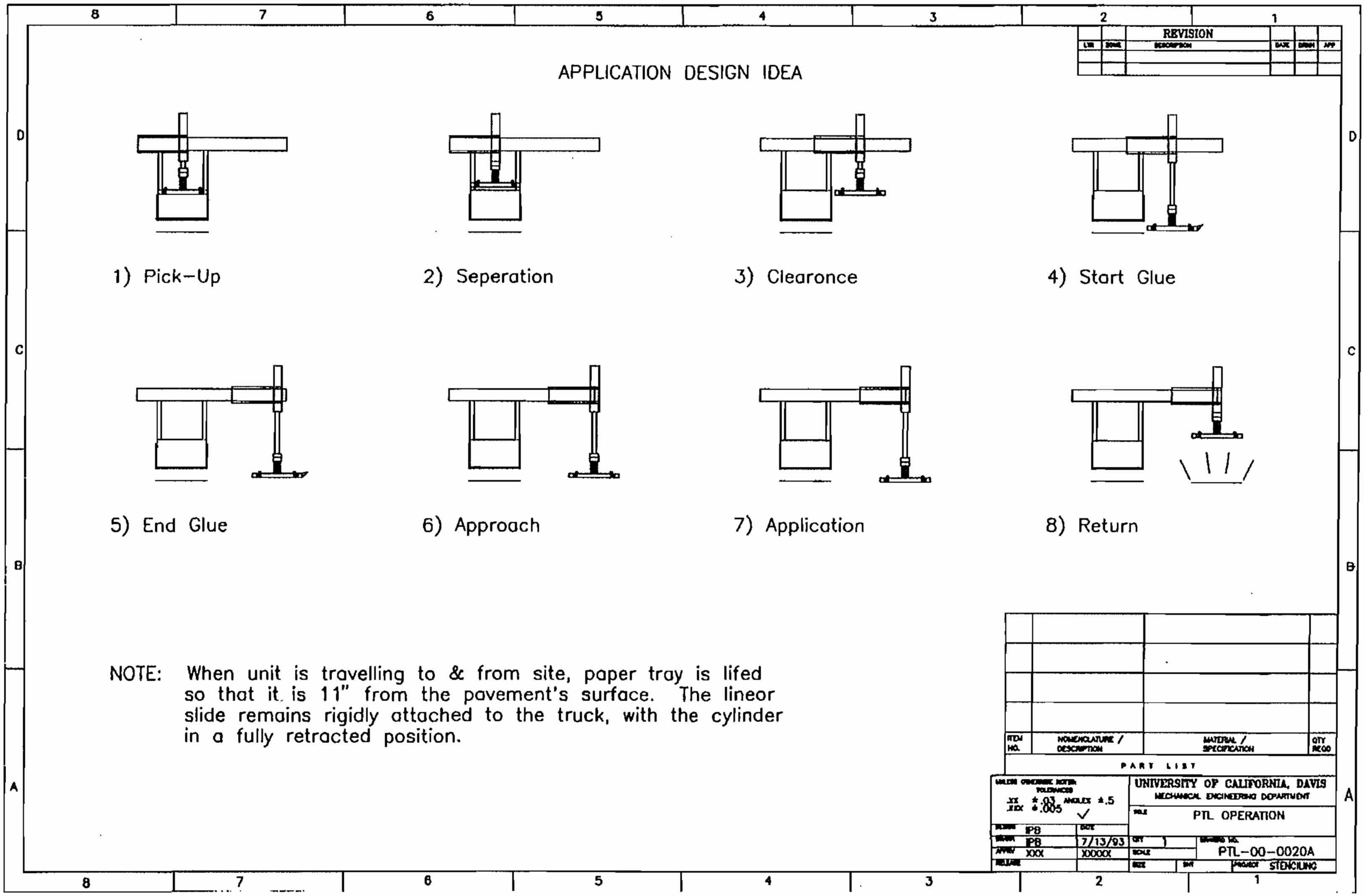


APPLICATION DESIGN IDEA
REVISION
PART LIST
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
PTL ON TRUCK
PICK-UP POINT
PTL-00-0003A
7/13/93
JPB

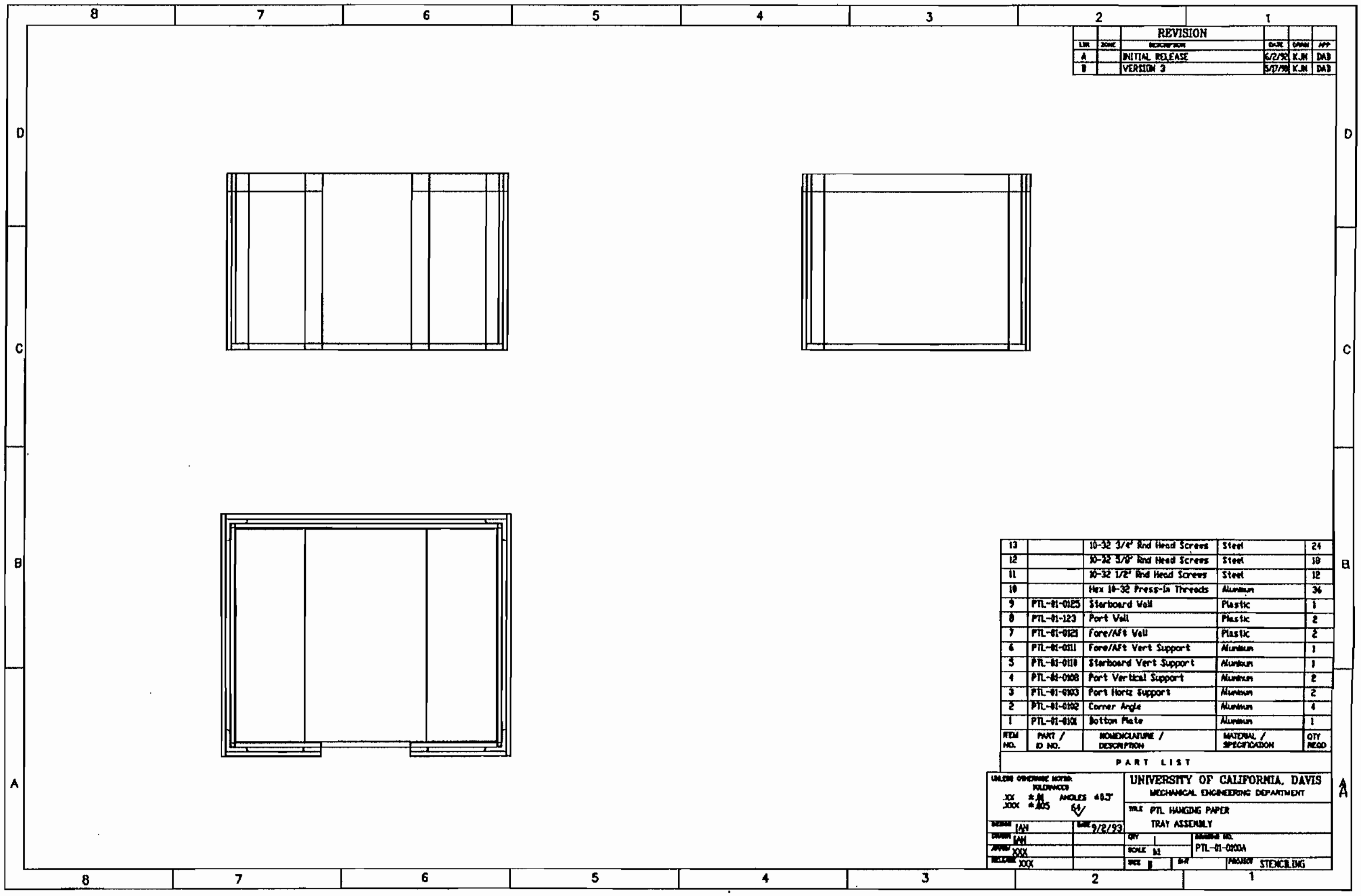

REVISION
12.00
36.00
4.00
4.00
2.00
10.25
11.00 STROKE LENGTH
6.00
6.00
3.00
12.50
9.00
12.00
APPLICATION DESIGN IDEA
PART LIST
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
PREFABRICATED TARGET LAYER APPLICATION POINT
IPB
IPB 7/13/93
XXX XXXXX
PTL-00-0012A
STENCILING

APPENDIX E

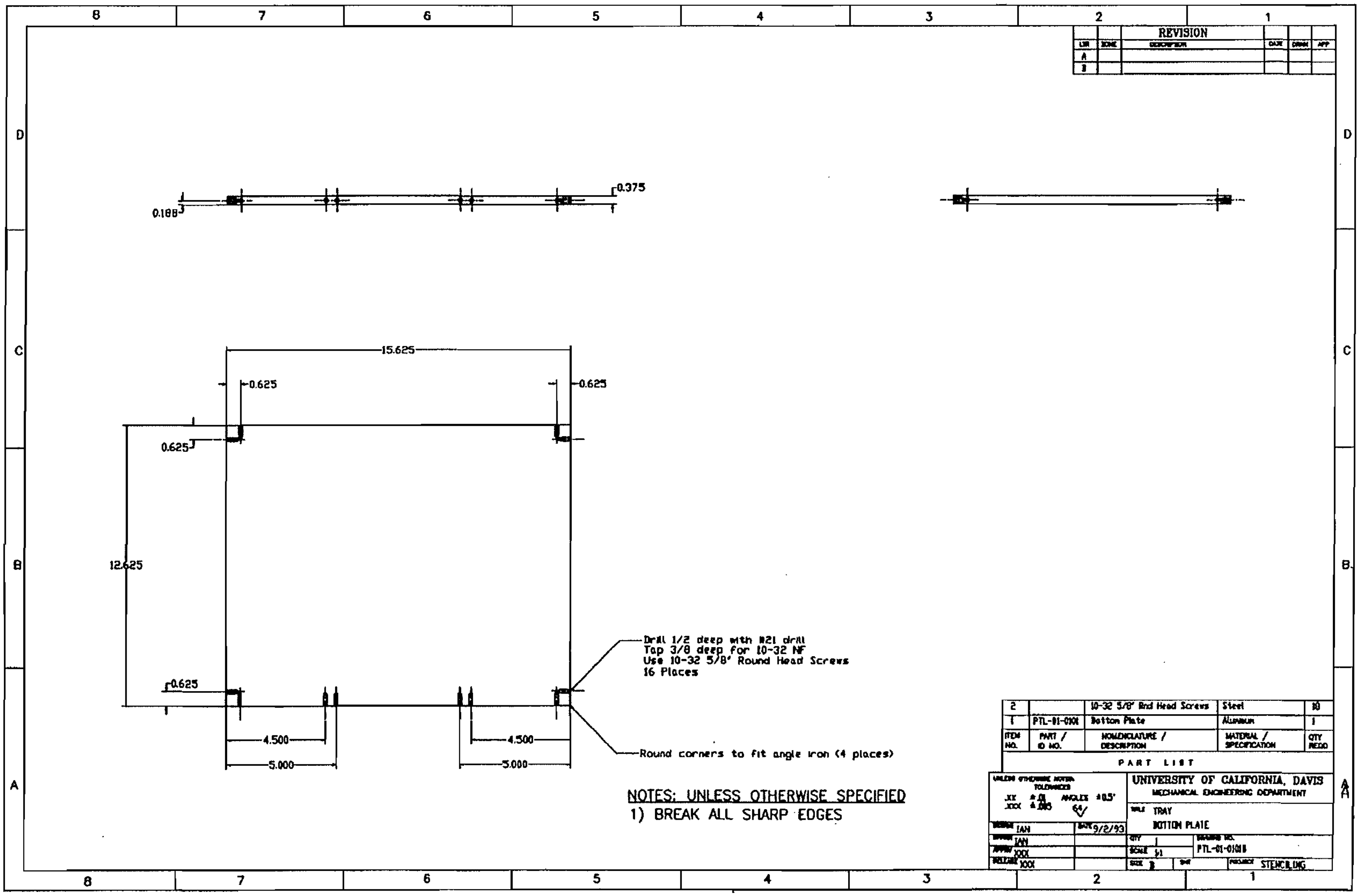
Detail Drawings of PTL

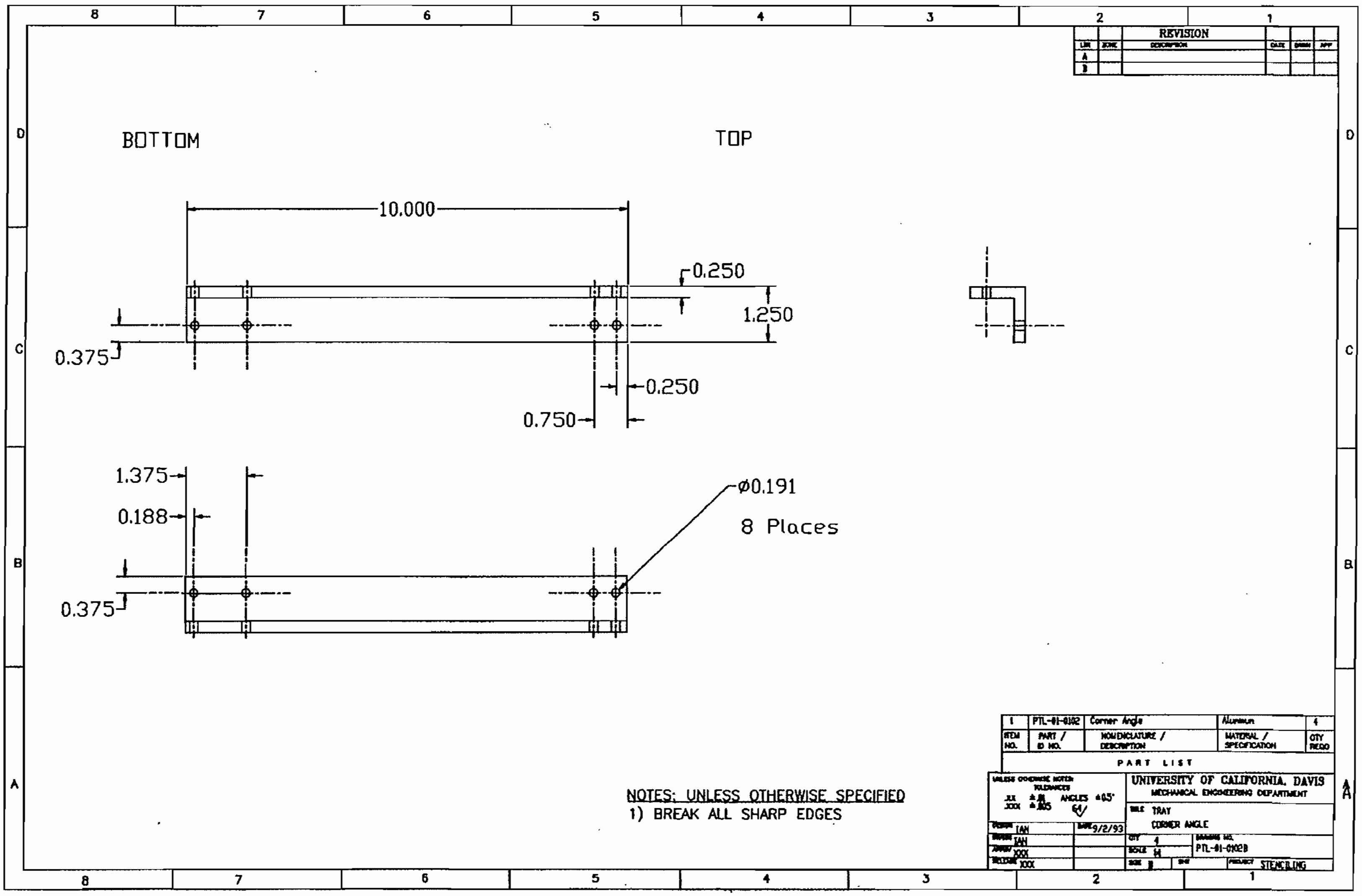


APPENDIX E
Detail Drawings of PTL



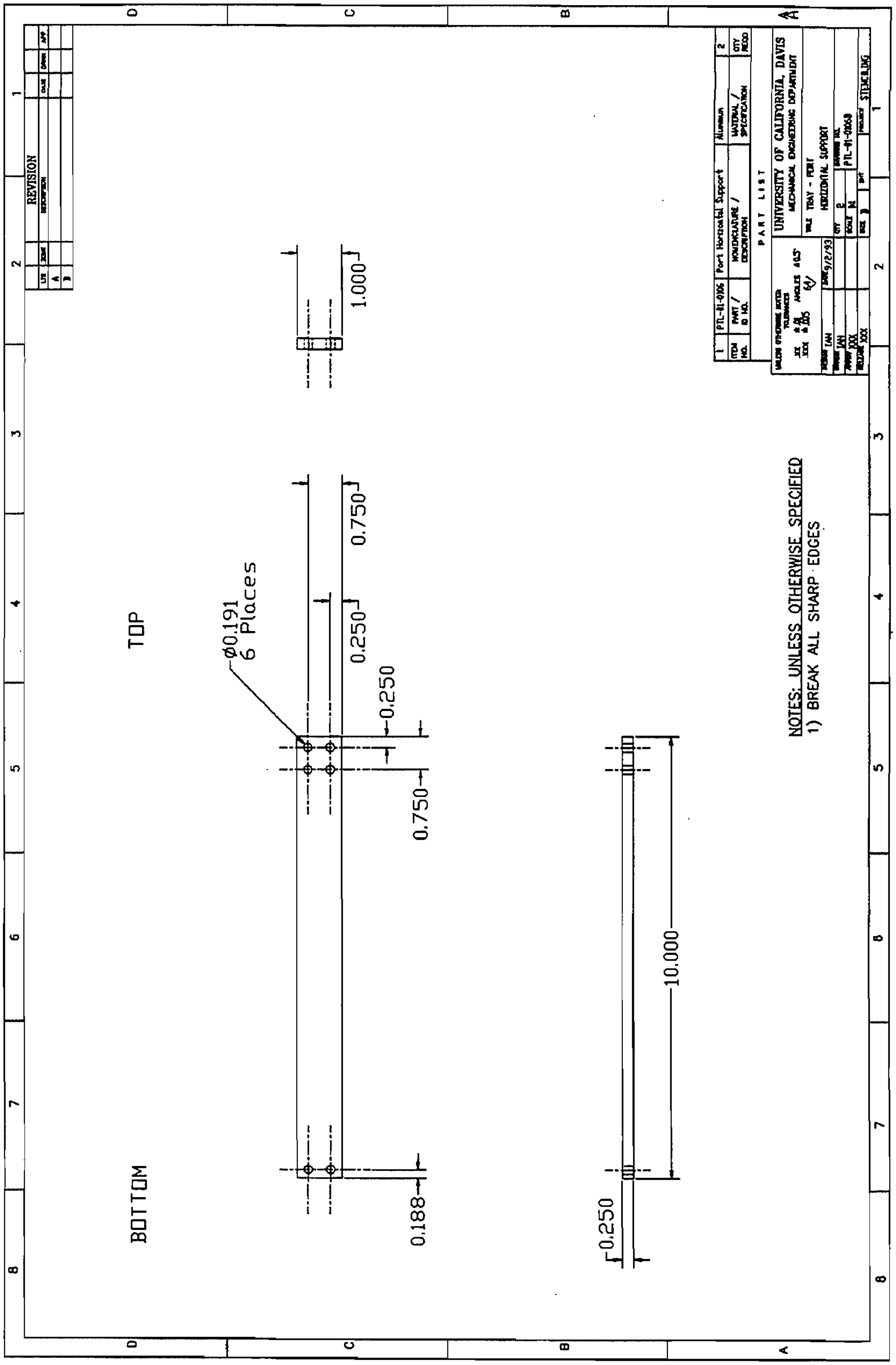
APPENDIX E
Detail Drawings of PTL




REVISION
BOTTOM
TOP
10.000
0.250
1.250
0.375
0.250
0.750
1.375
0.188
⌀0.191
8 Places
0.375
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
PART LIST
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
TRAY
CORNER ANGLE
9/2/93
STENCILING

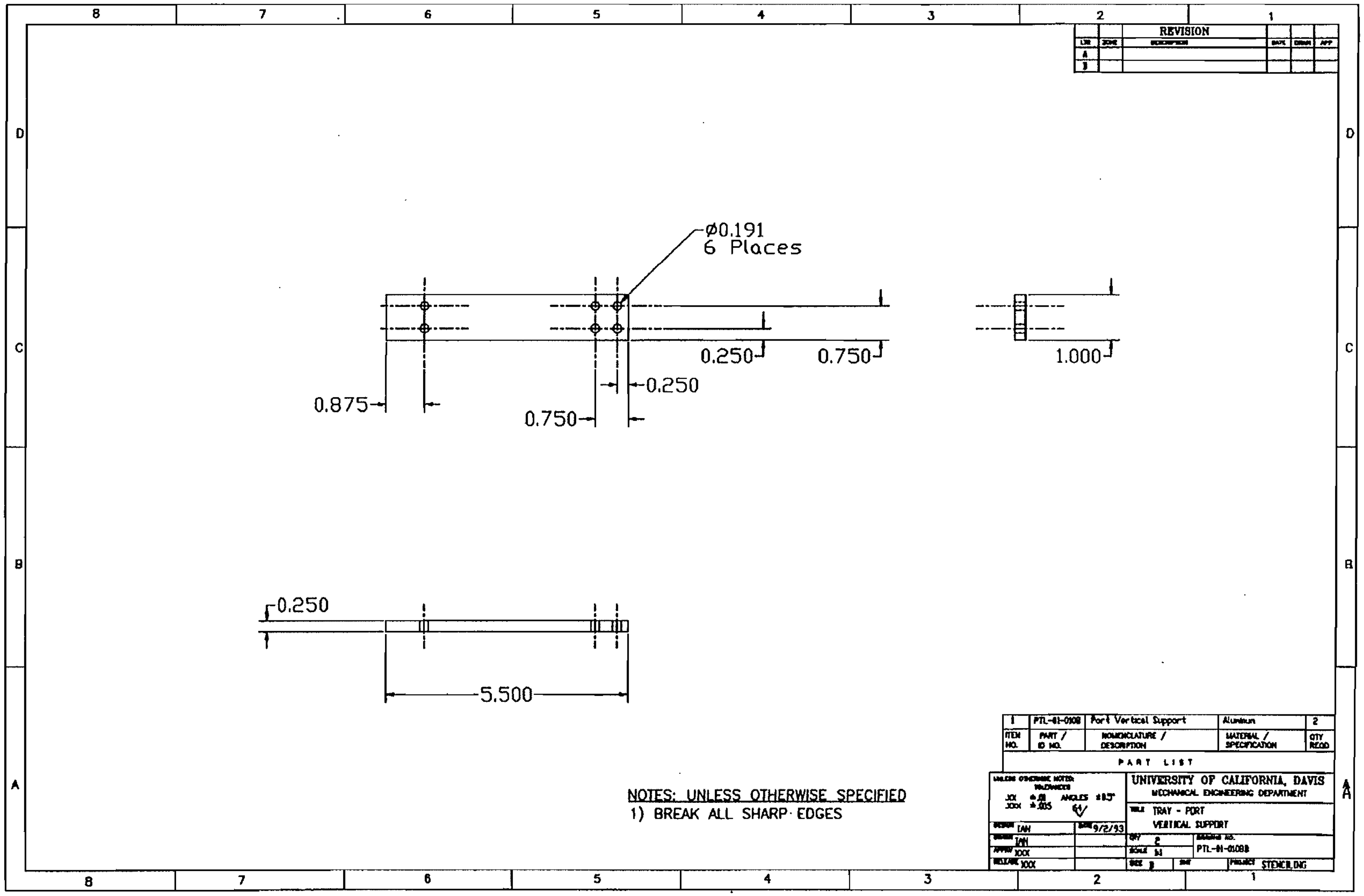
APPENDIX E

Detail Drawings of PTL

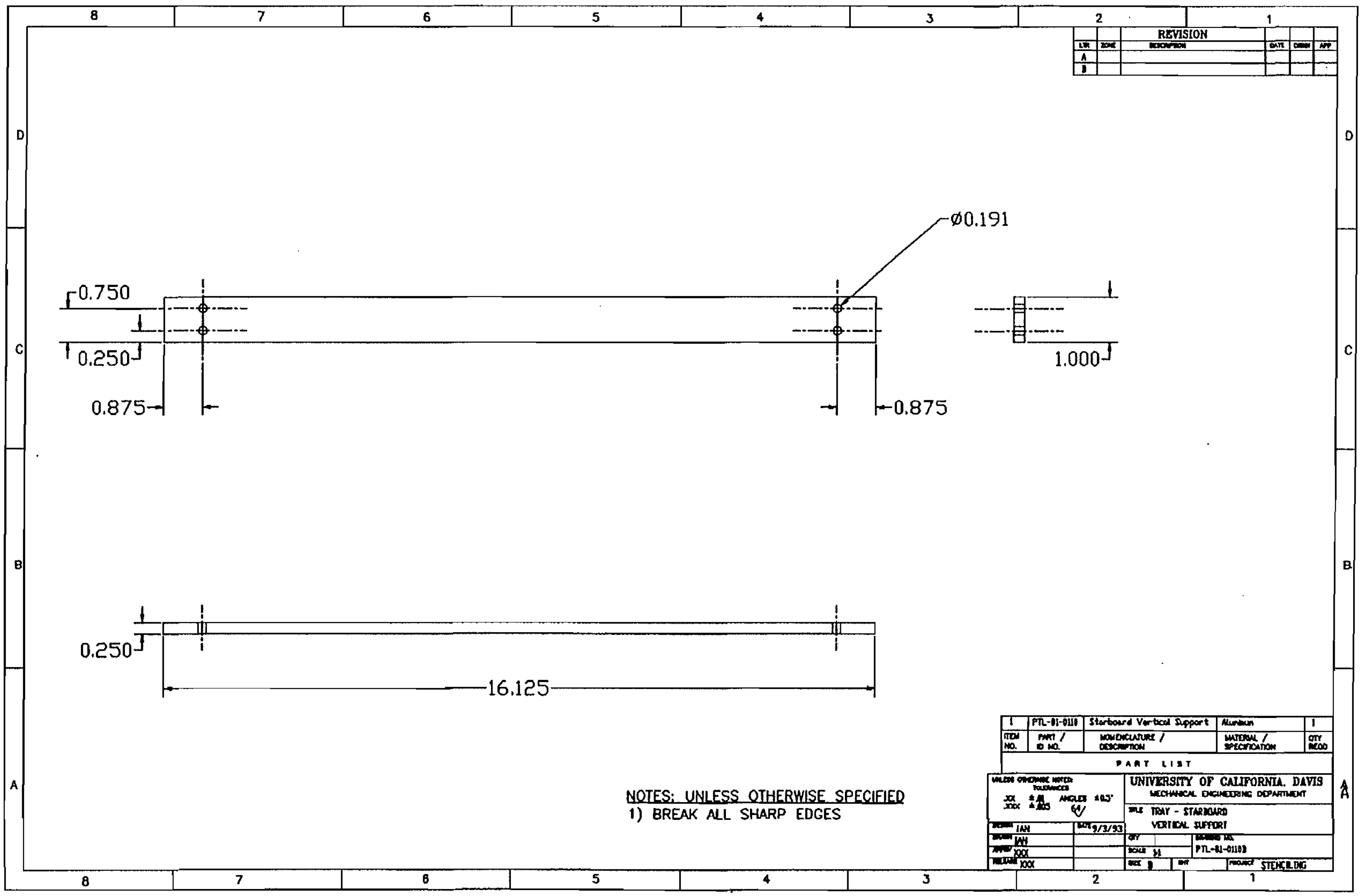


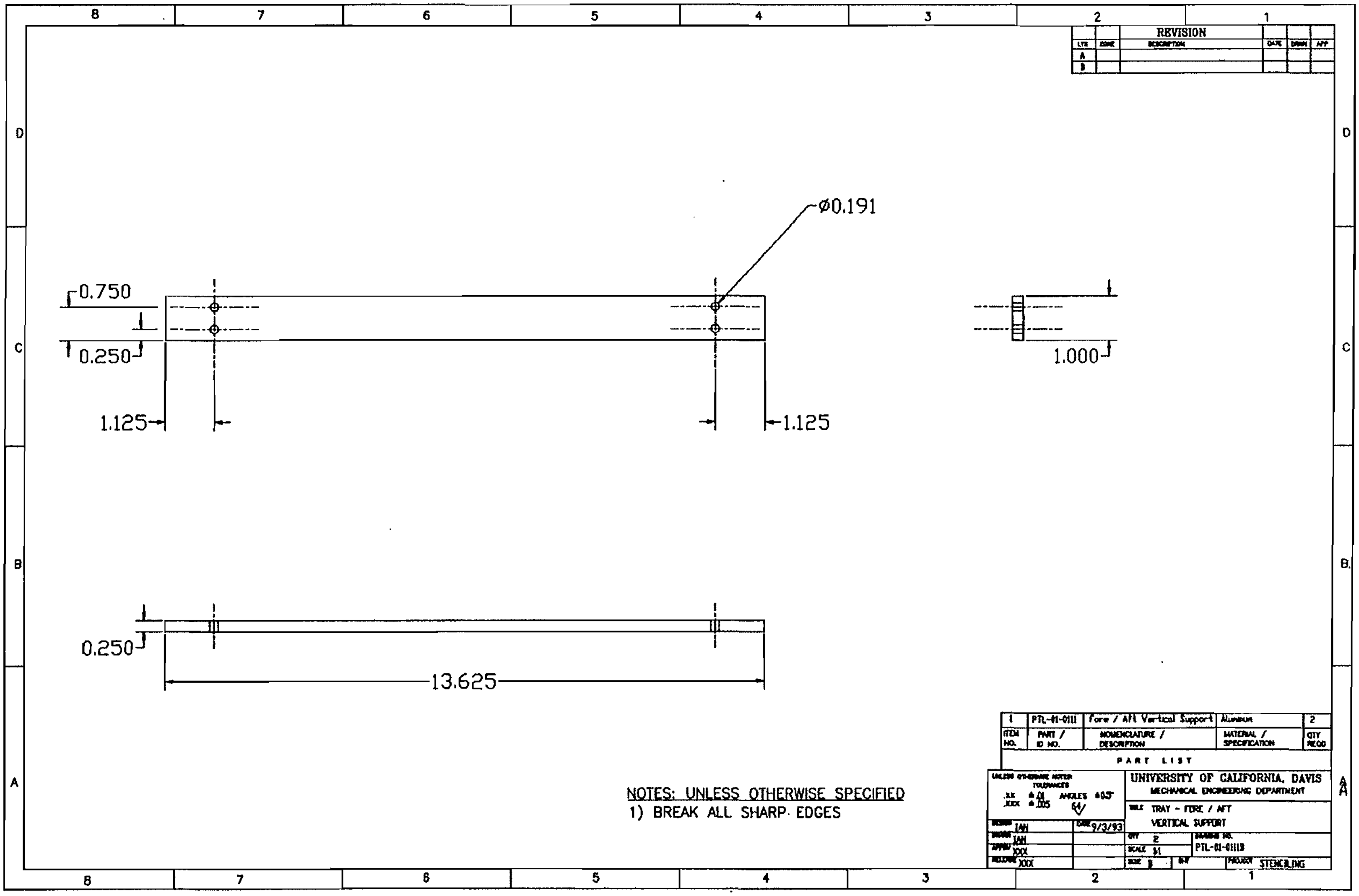
APPENDIX E

Detail Drawings of PTL



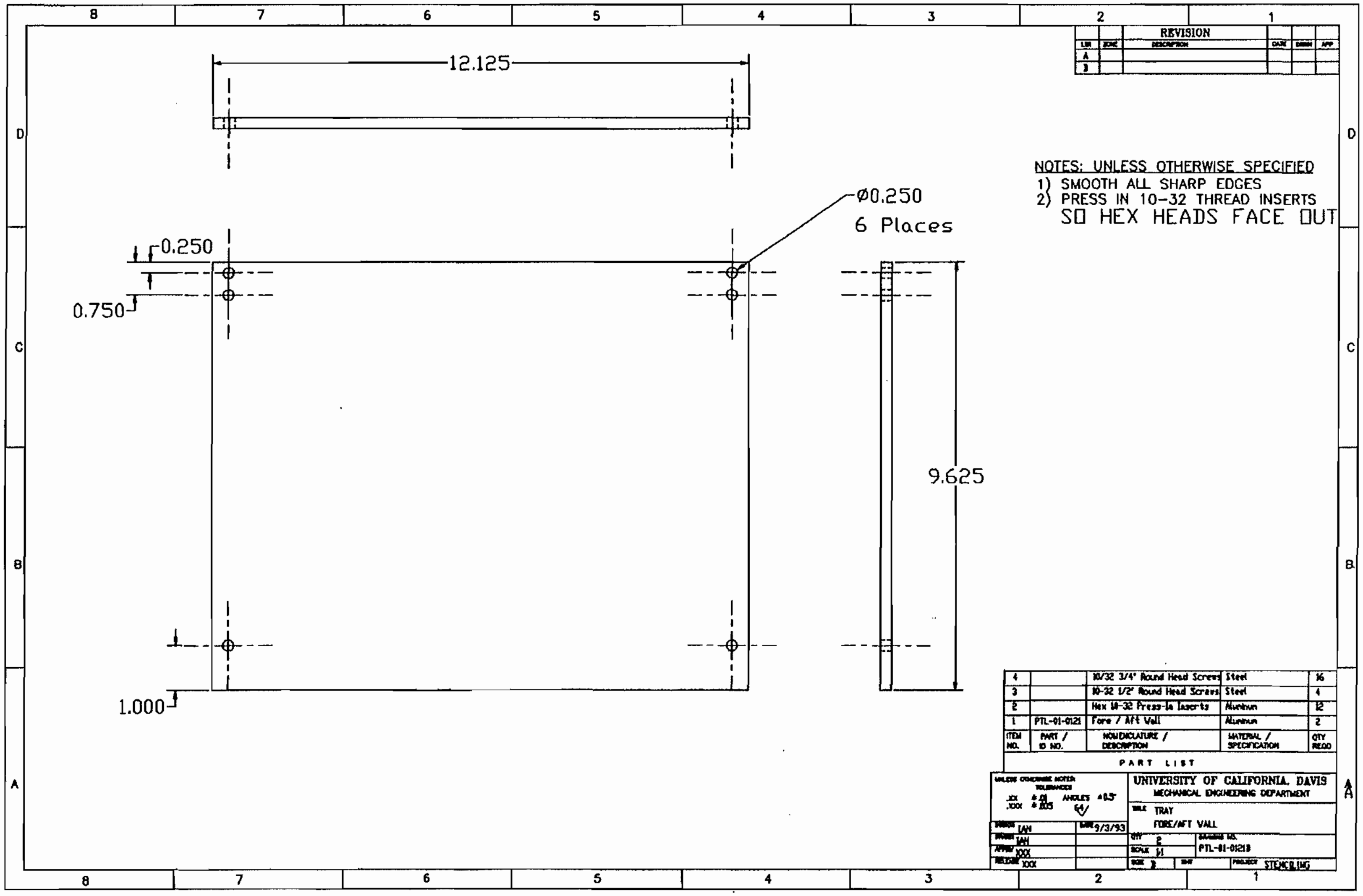
Detail Drawings of PTL

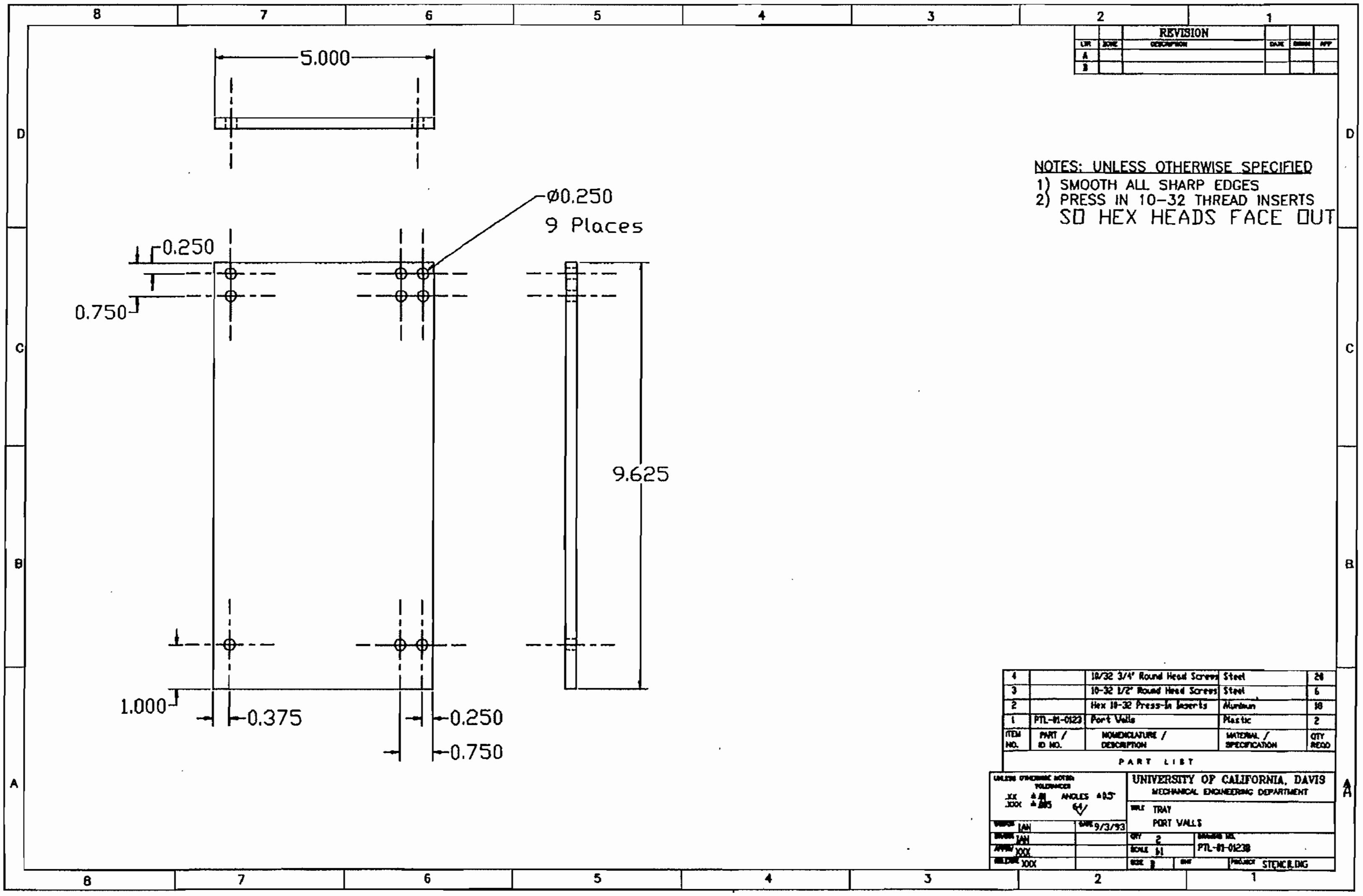



REVISION
Ø0.191
0.750
0.250
1.125
1.125
1.000
0.250
13.625
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
Fore / Aft Vertical Support
PART LIST
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
TRAY - FORE / AFT
VERTICAL SUPPORT
9/3/93
STENCILING

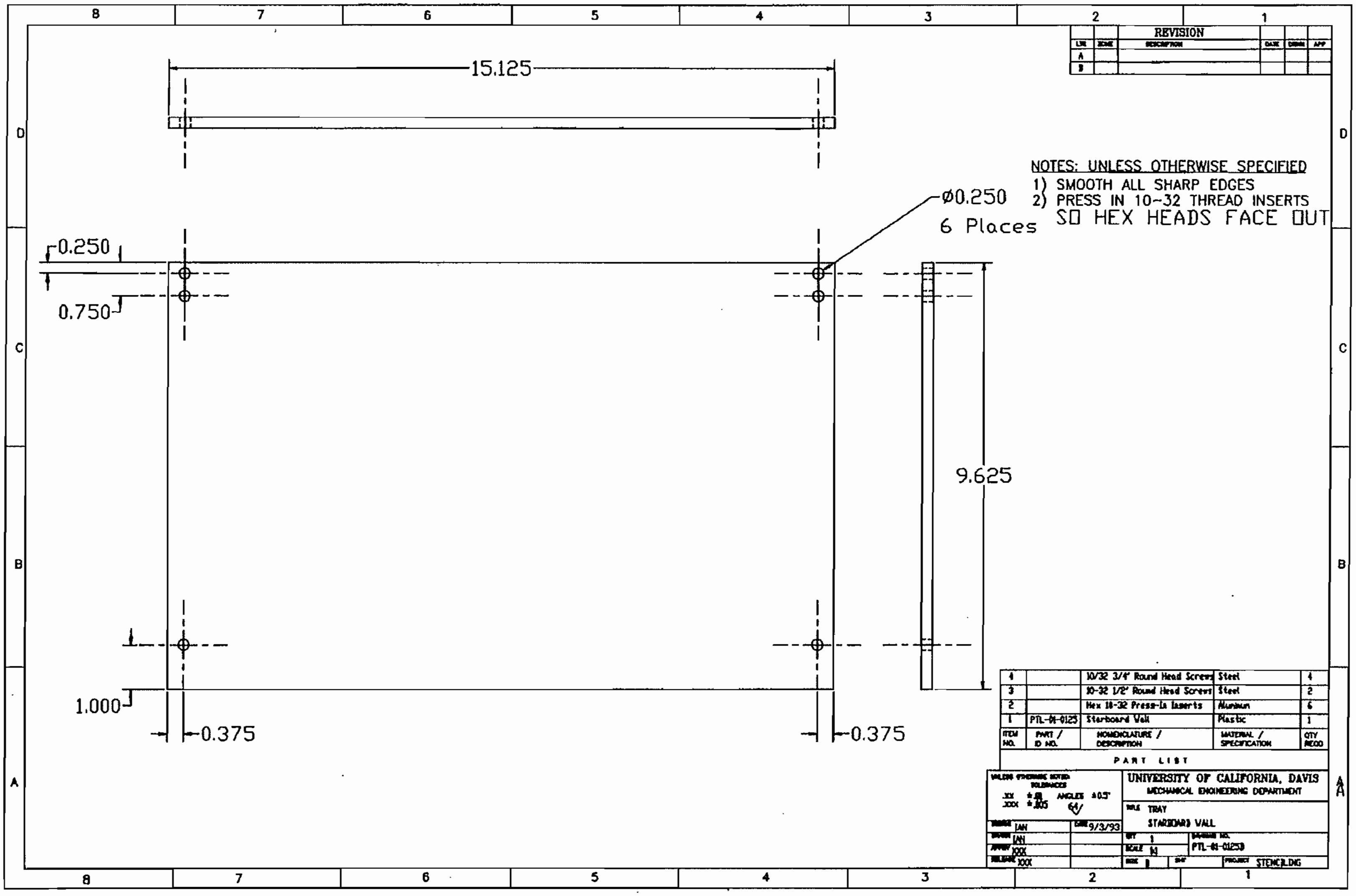
APPENDIX E

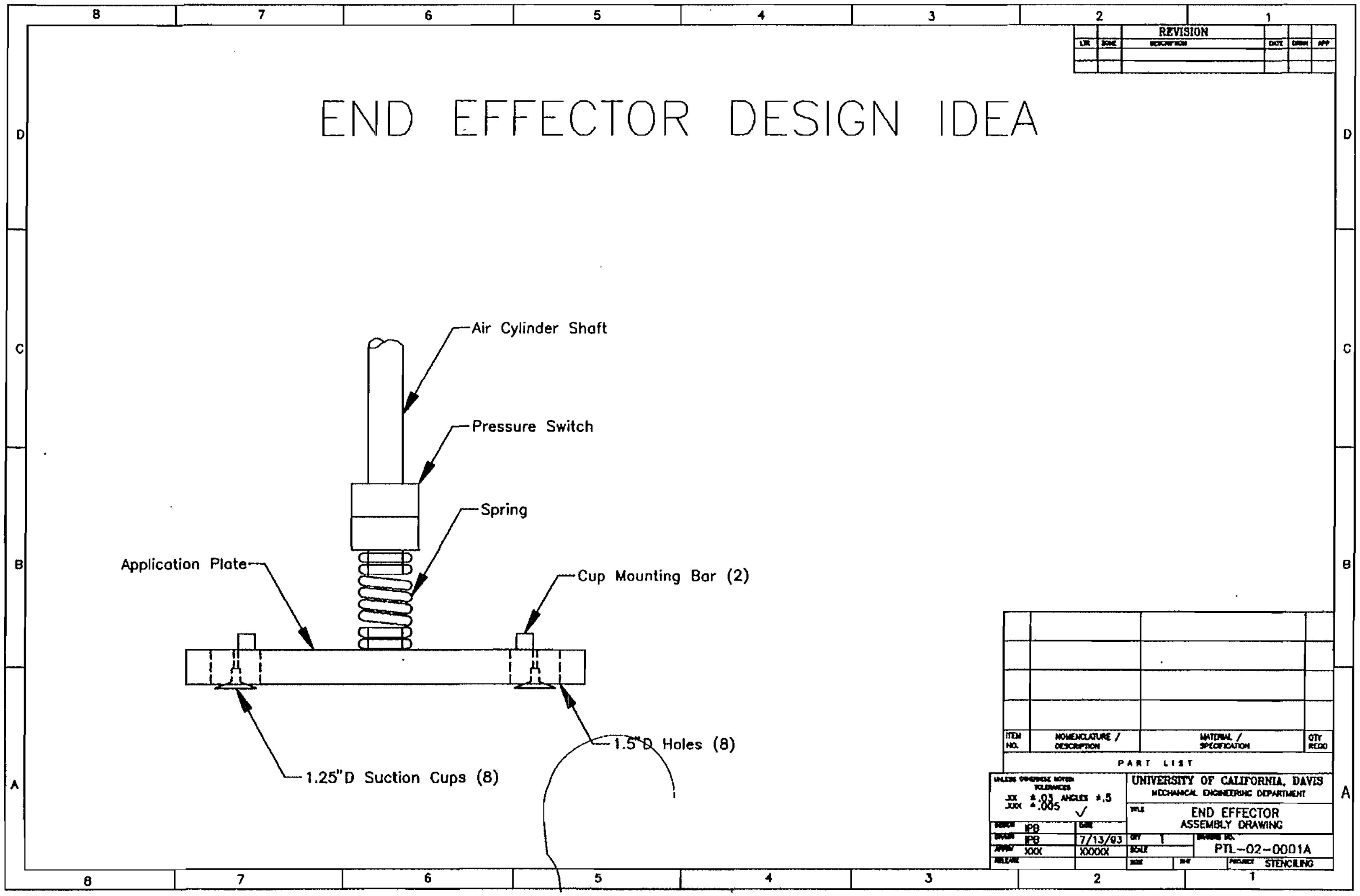
Detail Drawings of PTL




5.000
Ø0.250
9 Places
0.250
0.750
9.625
1.000
0.375
0.250
0.750
NOTES: UNLESS OTHERWISE SPECIFIED
1) SMOOTH ALL SHARP EDGES
2) PRESS IN 10-32 THREAD INSERTS
SO HEX HEADS FACE OUT
REVISION
4 10/32 3/4" Round Head Screws Steel 24
3 10-32 1/2" Round Head Screws Steel 6
2 Hex 10-32 Press-In Inserts Aluminum 18
1 PTL-01-0123 Port Walls Plastic 2
ITEM NO. PART / ID NO. NOMENCLATURE / DESCRIPTION MATERIAL / SPECIFICATION QTY REQD
PART LIST
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
TRAY
PORT WALLS
IAN 9/3/93
IAN
XXX
XXX
2
1:1
PTL-01-01238
STENCIL.DWG

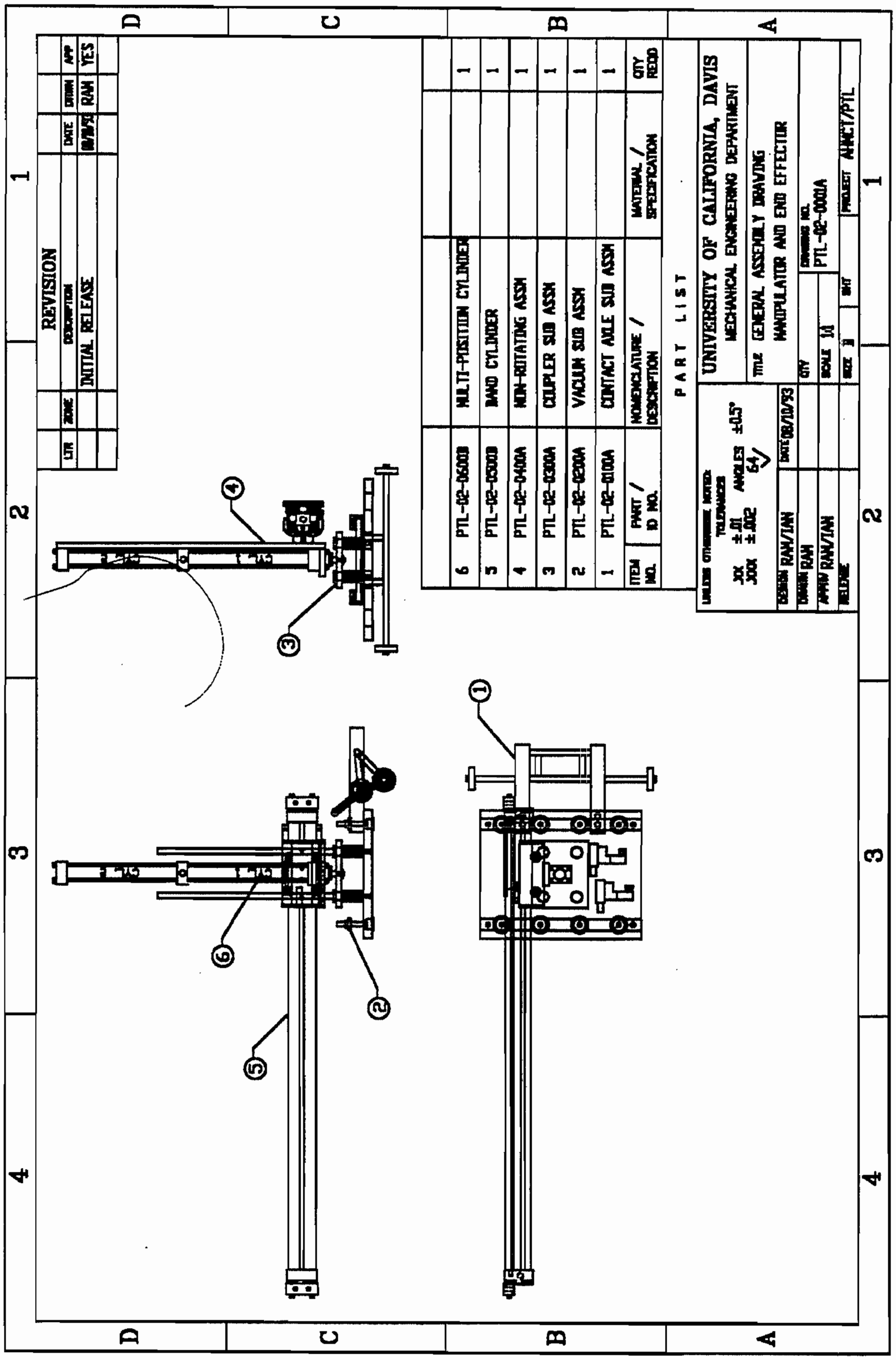
APPENDIX E
Detail Drawings of PTL



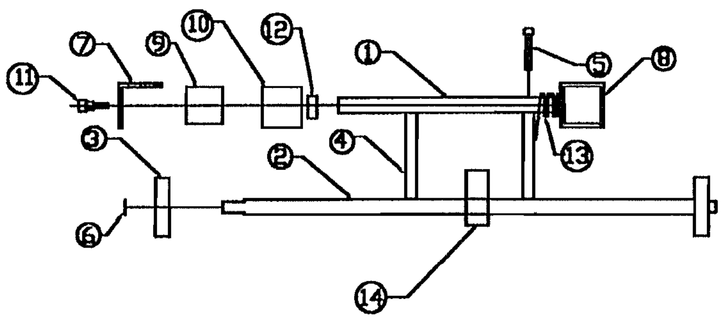

END EFFECTOR DESIGN IDEA
REVISION
Air Cylinder Shaft
Pressure Switch
Spring
Application Plate
Cup Mounting Bar (2)
1.5"D Holes (8)
1.25"D Suction Cups (8)
ITEM NO.
NOMENCLATURE / DESCRIPTION
MATERIAL / SPECIFICATION
QTY REQD
PART LIST
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
END EFFECTOR
ASSEMBLY DRAWING
.XX ±.03 ANGLES ±.5
.XXX ±.005
IPB
IPB
7/13/03
XXX
XXXXX
PTL-02-0001A
STENCILING

APPENDIX E

Detail Drawings of PTL



REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
		INITIAL RELEASE	[illegible]	RAM	YES



ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
14	PTL-02-0109B	NOZZLE MOUNT	6061-T6 ALUMINUM	3
13		TORSION SPRING	STEEL	1L/1R
12		MMC/LIMIT SWITCH		1
11	PTL-02-0108B	LIMIT PIN	STEEL	2
10	PTL-02-0107B	EXTENSION SUPPORT BLOCK	6061-T6 ALUMINUM	2
9	PTL-02-0106B	BEARING BLOCK	6061-T6 ALUMINUM	2
8	PTL-02-0105B	ARM EXTENSION LT	6061-T6 ALUMINUM	1
7	PTL-02-0104B	ARM EXTENSION RT	6061-T6 ALUMINUM	1
6		3/8" OUTSIDE SNAP RING	STEEL	2
5		10-32 X 3/4" SHCS	STEEL	4
4	PTL-02-0103B	ARM SPACER	6061-T6 ALUMINUM	2
3		MMC/WHEELS	SOLID NEOPRENE	2
2	PTL-02-0102B	WHEEL SHAFT	6061-T6 ALUMINUM	1
1	PTL-02-0101B	ARM SHAFT	6061-T6 ALUMINUM	1

PART LIST

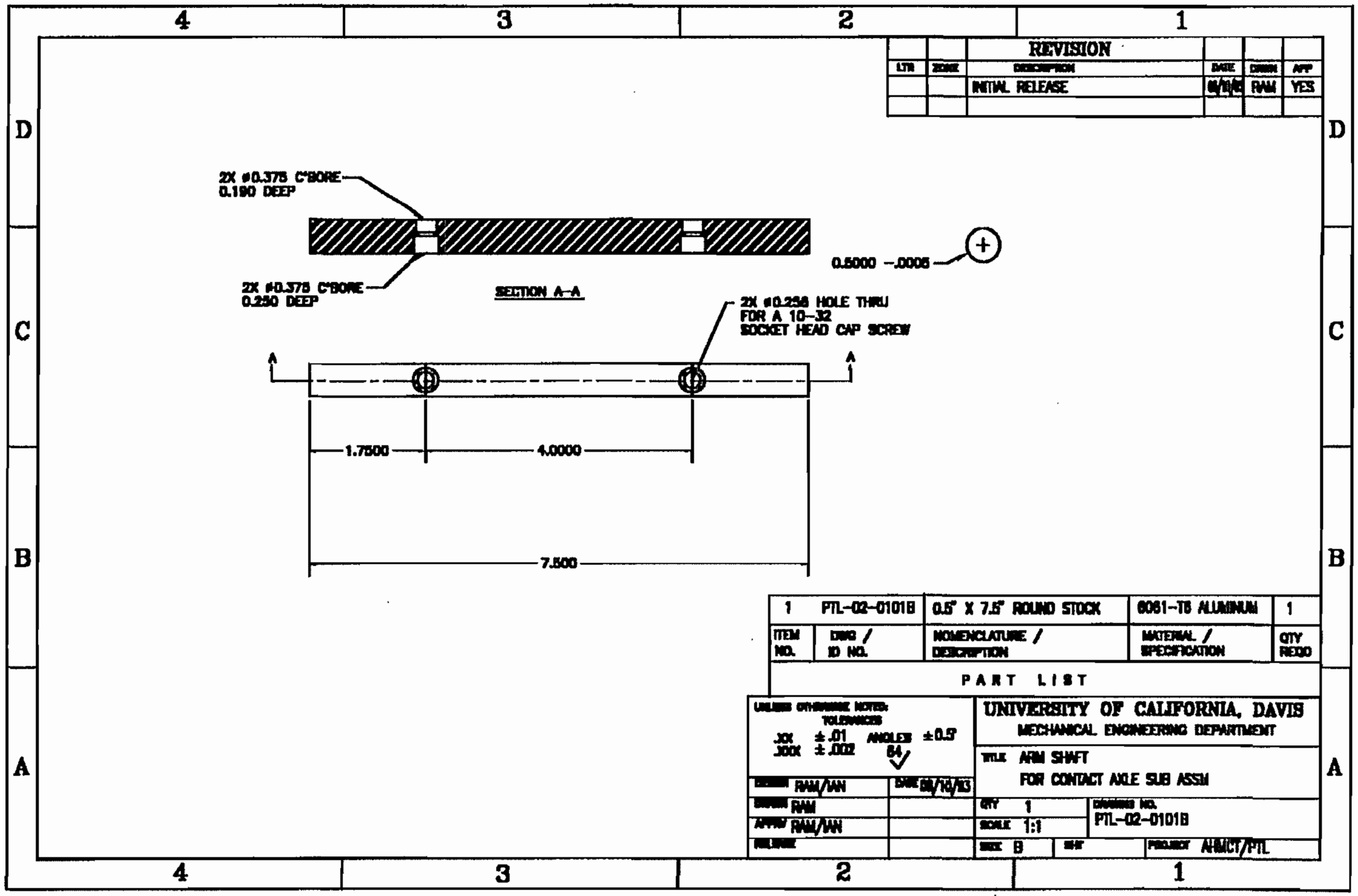
UNLESS OTHERWISE NOTED: TOLERANCES
.XX ±.01 ANGLES ±0.5°
.XXX ±.002
64✓

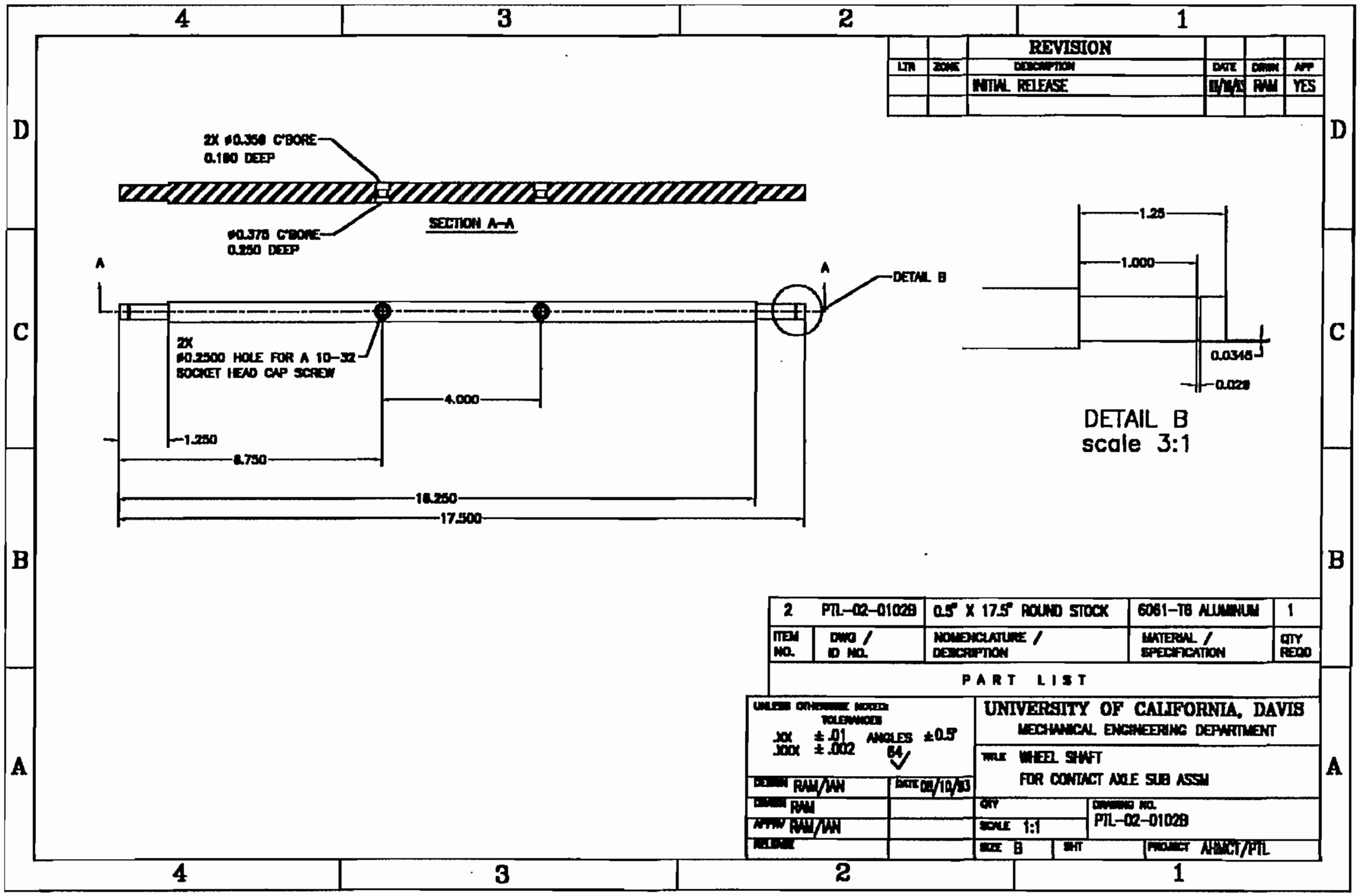
DESIGN RAM/IAN DATE 08/10/93
DRAWN RAM
APPRV RAM/IAN
RELEASE

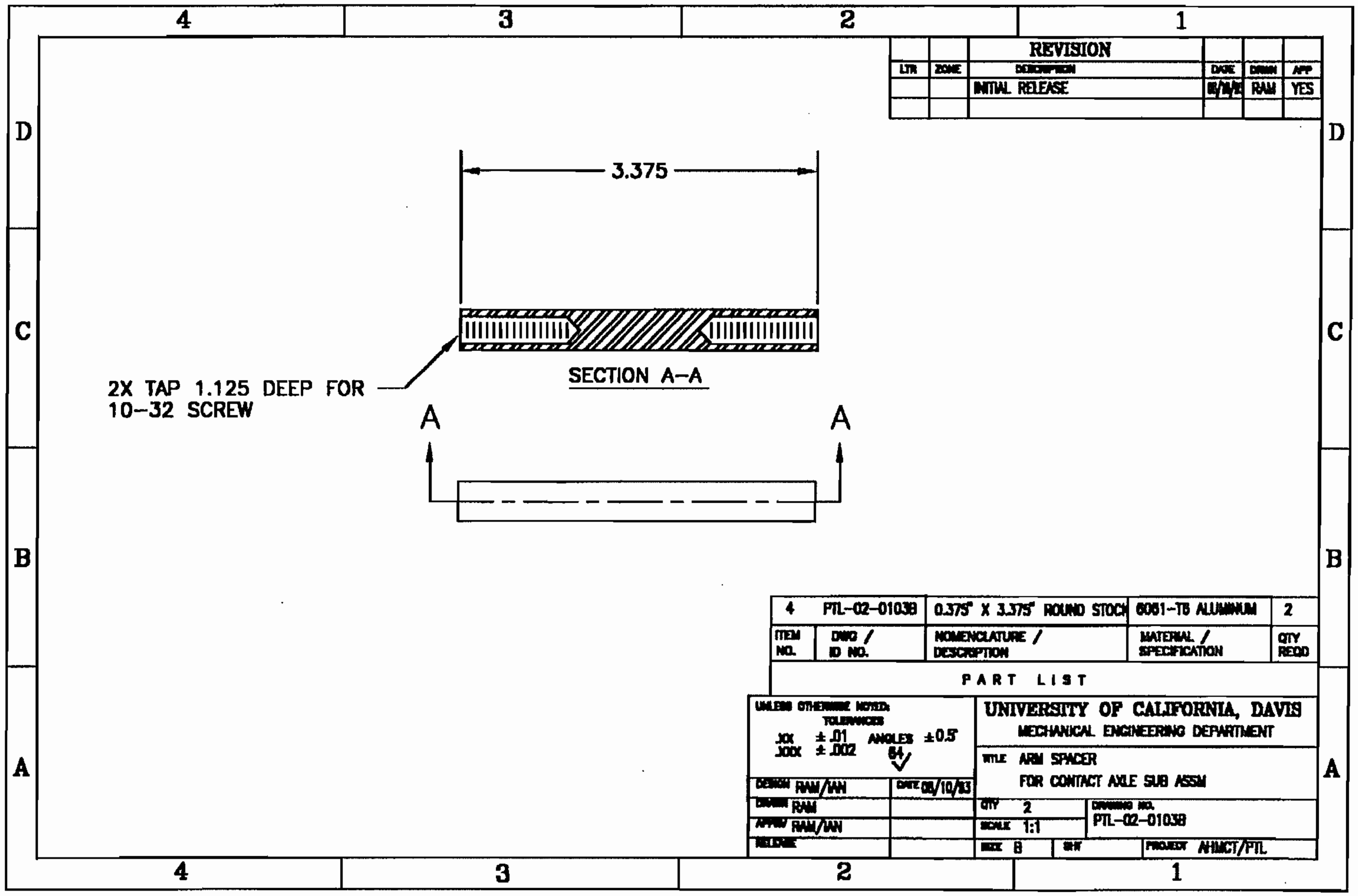
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT

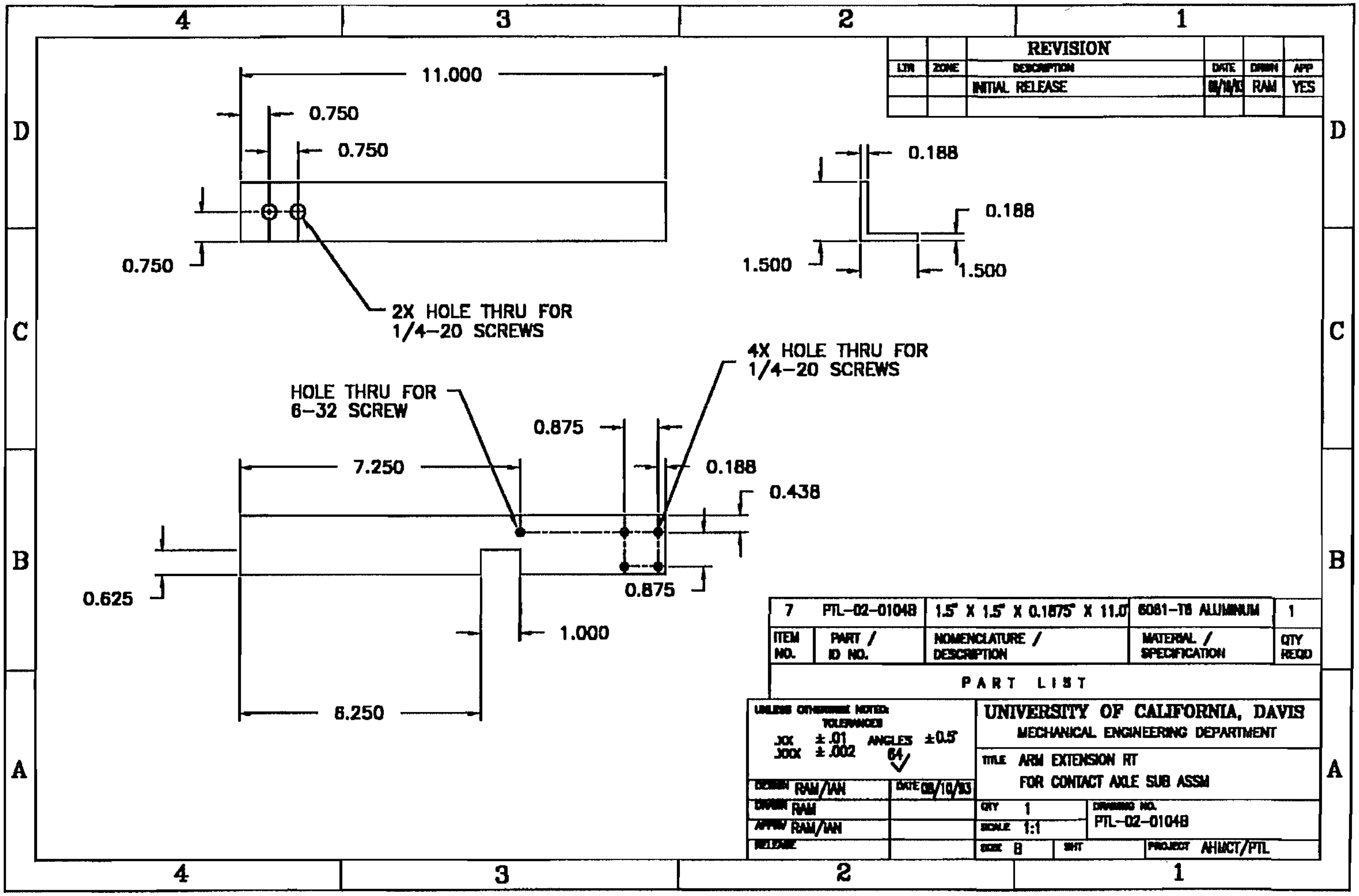
TITLE CONTACT AXLE SUB-ASSM
FOR MANIPULATOR & END EFFECTOR

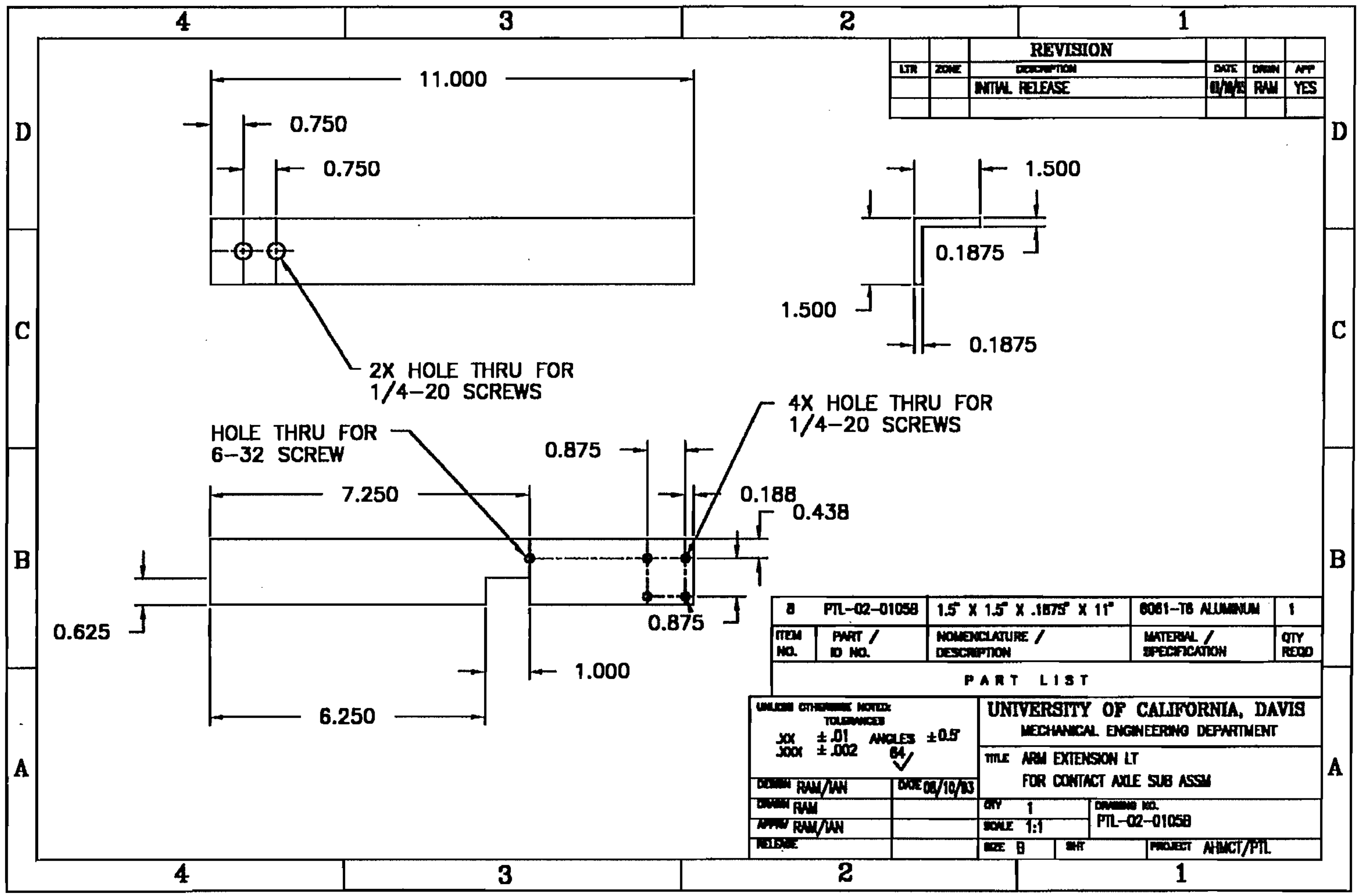
QTY
SCALE 1:1
DRAWING NO. PTL-02-0100A
SIZE B
SHT
PROJECT AHMCT/PTL

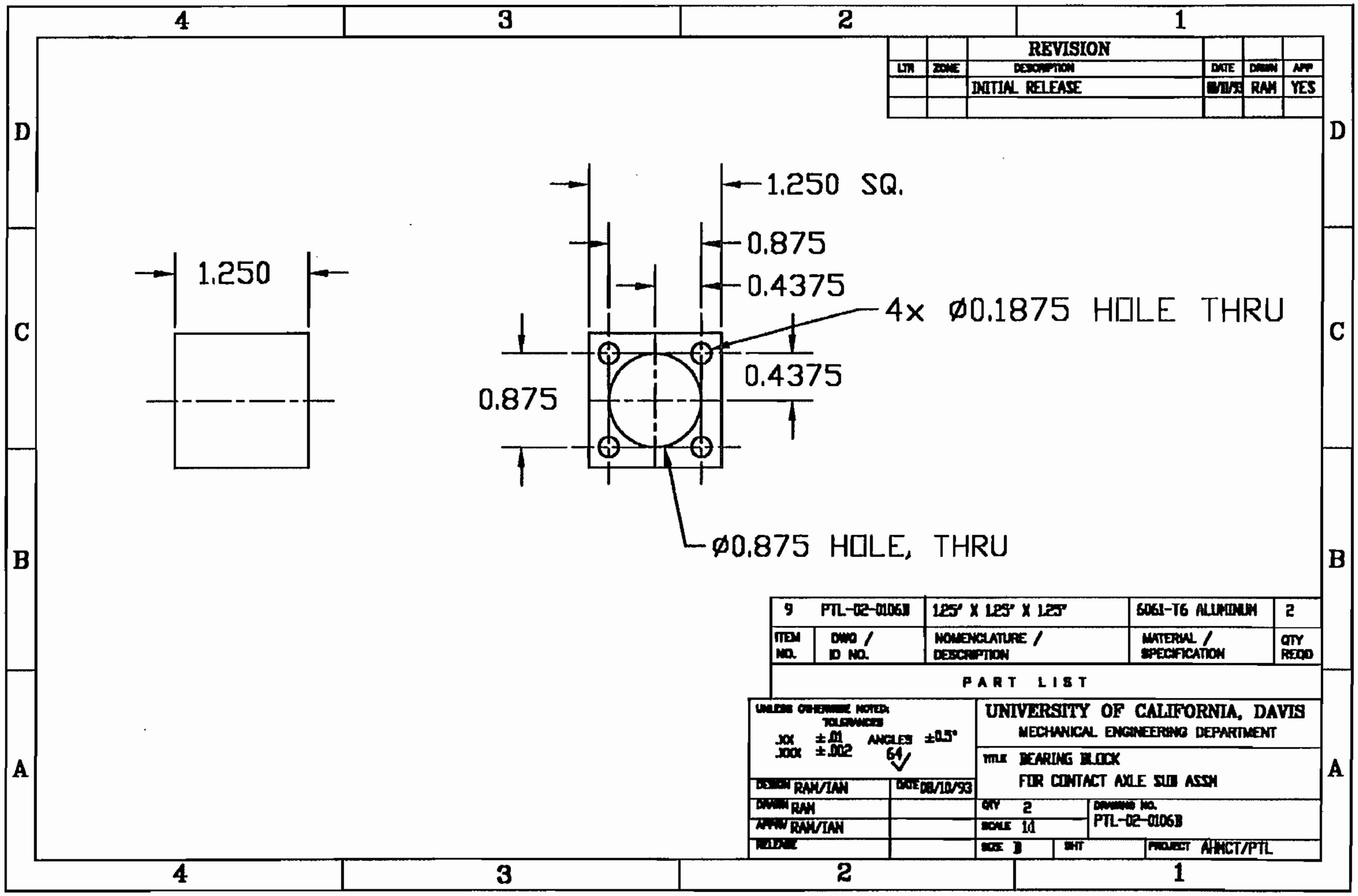

REVISION
INITIAL RELEASE
RAM
YES
2X ø0.375 C'BORE
0.190 DEEP
2X ø0.375 C'BORE
0.250 DEEP
SECTION A–A
0.5000 –.0005
2X ø0.256 HOLE THRU
FOR A 10–32
SOCKET HEAD CAP SCREW
1.7500
4.0000
7.500
1
PTL–02–0101B
0.5" X 7.5" ROUND STOCK
6061–T6 ALUMINUM
1
ITEM NO.
DWG / ID NO.
NOMENCLATURE / DESCRIPTION
MATERIAL / SPECIFICATION
QTY REQD
PART LIST
TOLERANCES
.XX ± .01
.XXX ± .002
ANGLES ± 0.5°
64
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
ARM SHAFT
FOR CONTACT AXLE SUB ASSM
RAM/IAN
RAM
RAM/IAN
QTY 1
SCALE 1:1
B
PTL–02–0101B
AHMCT/PTL

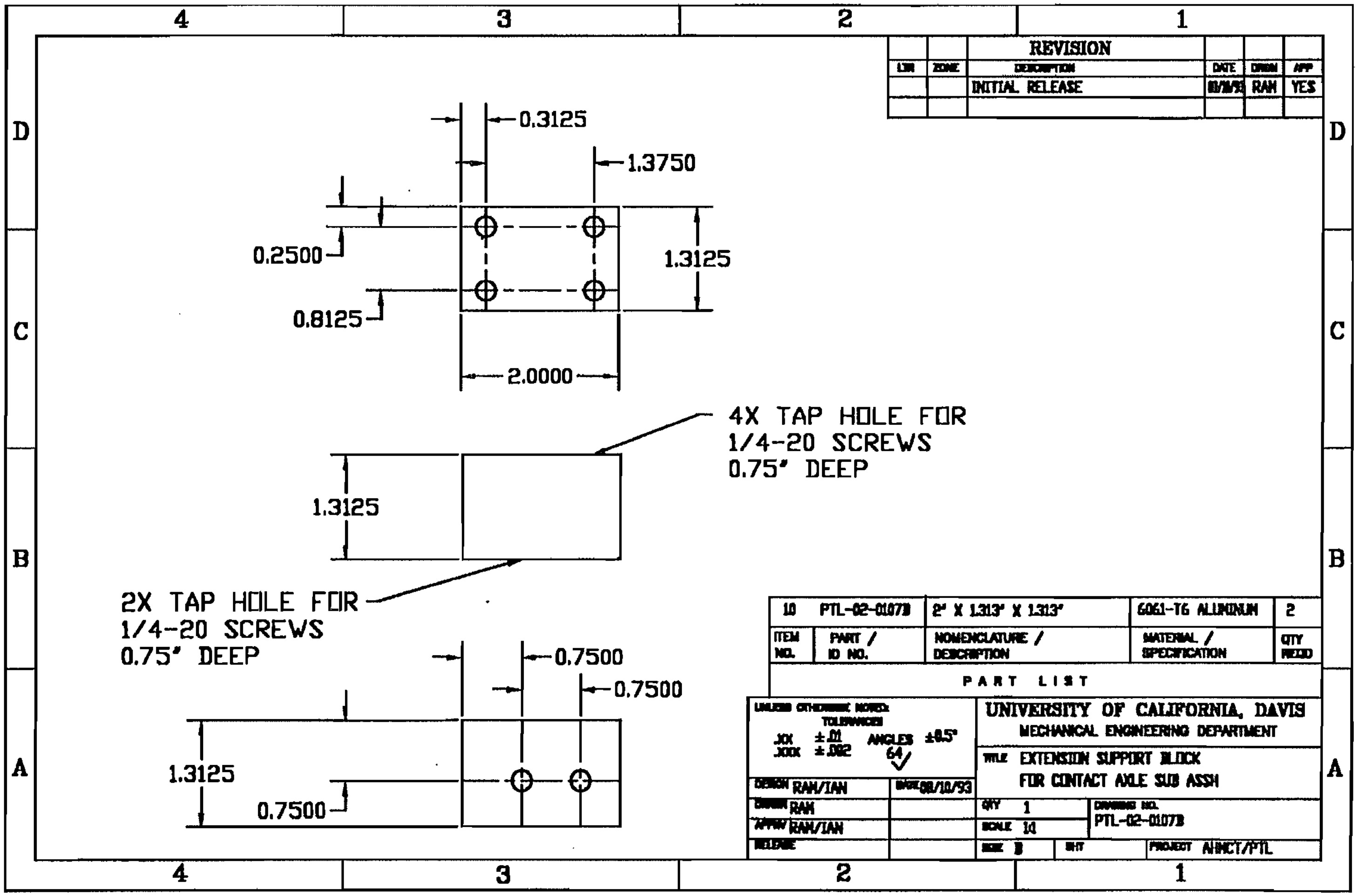

REVISION
LTR ZONE DESCRIPTION DATE DRWN APP
INITIAL RELEASE RAM YES
2X ø0.359 C'BORE 0.190 DEEP
ø0.375 C'BORE 0.250 DEEP
SECTION A–A
DETAIL B
2X ø0.2500 HOLE FOR A 10–32 SOCKET HEAD CAP SCREW
4.000
1.250
8.750
16.250
17.500
1.25
1.000
0.0345
0.020
DETAIL B
scale 3:1
2 PTL–02–0102B 0.5" X 17.5" ROUND STOCK 6061–T6 ALUMINUM 1
ITEM NO. DWG / ID NO. NOMENCLATURE / DESCRIPTION MATERIAL / SPECIFICATION QTY REQD
PART LIST
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
TITLE WHEEL SHAFT
FOR CONTACT AXLE SUB ASSM
.XX ± .01
.XXX ± .002
ANGLES ±0.5°
DESIGN RAM/IAN
DRAWN RAM
APPRV RAM/IAN
DATE 08/10/03
SCALE 1:1
DRAWING NO. PTL–02–0102B
SIZE B
PROJECT AHMCT/PTL

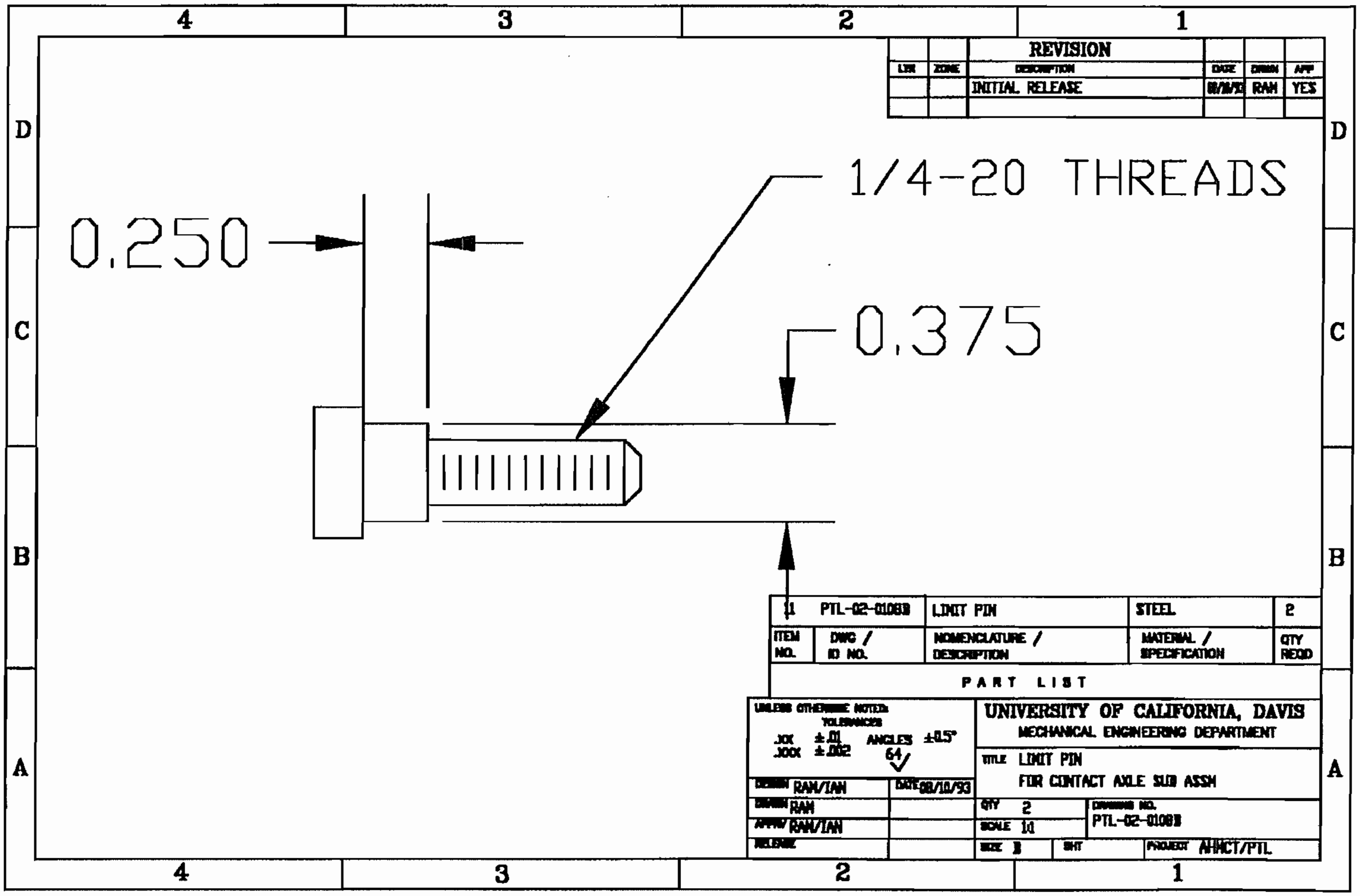

REVISION
LTR
ZONE
APP
INITIAL RELEASE
RAM
YES
3.375
2X TAP 1.125 DEEP FOR
10-32 SCREW
SECTION A-A
A
A
4
PTL-02-0103B
0.375" X 3.375" ROUND STOCK
6061-T6 ALUMINUM
2
ITEM NO.
DWG / ID NO.
NOMENCLATURE / DESCRIPTION
MATERIAL / SPECIFICATION
QTY REQD
PART LIST
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
.XX ± .01
.XXX ± .002
ANGLES ±0.5°
64
TITLE ARM SPACER
FOR CONTACT AXLE SUB ASSM
RAM/IAN
08/10/93
RAM
RAM/IAN
QTY 2
SCALE 1:1
PTL-02-0103B
B
PROJECT AHMCT/PTL

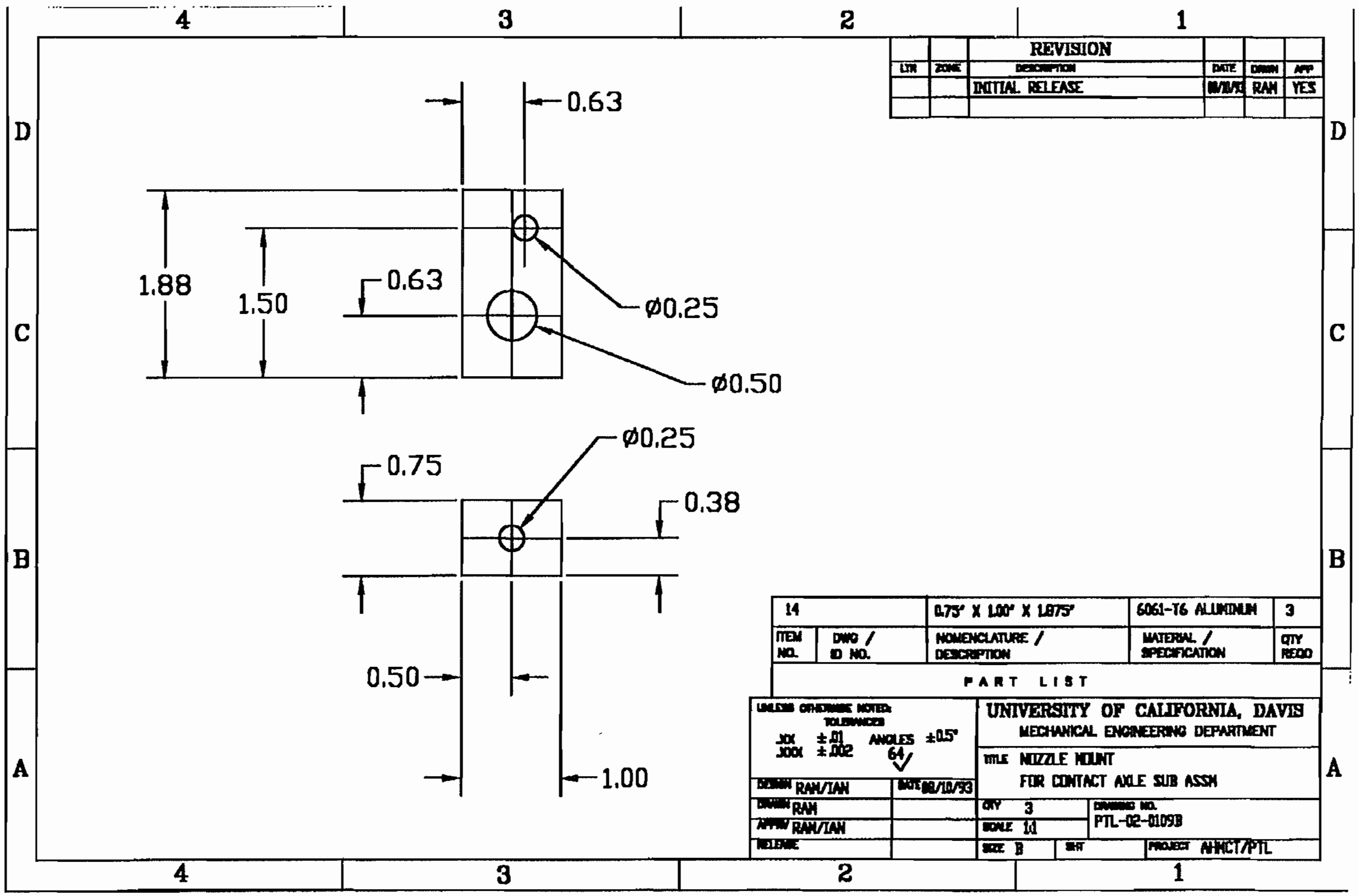

REVISION
LTR | ZONE | DESCRIPTION | DATE | DRAWN | APP
INITIAL RELEASE | RAM | YES
11.000
0.750
0.750
0.750
2X HOLE THRU FOR 1/4-20 SCREWS
0.188
0.188
1.500
1.500
4X HOLE THRU FOR 1/4-20 SCREWS
HOLE THRU FOR 6-32 SCREW
0.875
7.250
0.188
0.438
0.625
0.875
1.000
6.250
7 | PTL-02-0104B | 1.5" X 1.5" X 0.1875" X 11.0 | 6061-T6 ALUMINUM | 1
ITEM NO. | PART / ID NO. | NOMENCLATURE / DESCRIPTION | MATERIAL / SPECIFICATION | QTY REQD
PART LIST
UNLESS OTHERWISE NOTED: TOLERANCES
.XX ±.01
.XXX ±.002
ANGLES ±0.5°
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
TITLE ARM EXTENSION RT FOR CONTACT AXLE SUB ASSM
DESIGN RAM/IAN
DATE 08/10/93
DRAWN RAM
APPRV RAM/IAN
RELEASE
QTY 1
SCALE 1:1
SIZE B
SHT
DRAWING NO. PTL-02-0104B
PROJECT AHMCT/PTL

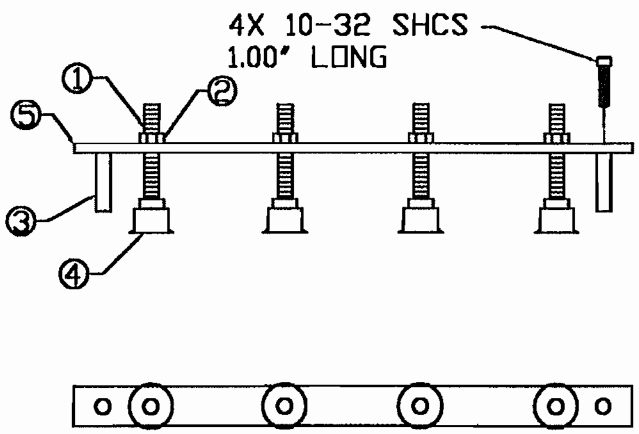

REVISION
LTR ZONE DESCRIPTION DATE DRWN APP
INITIAL RELEASE RAM YES
11.000
0.750
0.750
2X HOLE THRU FOR
1/4-20 SCREWS
1.500
0.1875
1.500
0.1875
HOLE THRU FOR
6-32 SCREW
0.875
4X HOLE THRU FOR
1/4-20 SCREWS
7.250
0.188
0.438
0.625
0.875
1.000
6.250
8 PTL-02-0105B 1.5" X 1.5" X .1875" X 11" 6061-T6 ALUMINUM 1
ITEM NO. PART / ID NO. NOMENCLATURE / DESCRIPTION MATERIAL / SPECIFICATION QTY REQD
PART LIST
UNLESS OTHERWISE NOTED: TOLERANCES .XX ±.01 .XXX ±.002 ANGLES ±0.5° 64
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
TITLE ARM EXTENSION LT
FOR CONTACT AXLE SUB ASSM
DESIGN RAM/IAN DATE 08/10/93
DRAWN RAM
APPRV RAM/IAN
RELEASE
QTY 1
SCALE 1:1
DRAWING NO. PTL-02-0105B
SIZE B SHT
PROJECT AHMCT/PTL


1.250
1.250 SQ.
0.875
0.4375
4x Ø0.1875 HOLE THRU
0.875
0.4375
Ø0.875 HOLE, THRU
REVISION
LTR
ZONE
DESCRIPTION
DATE
DRAWN
APP
INITIAL RELEASE
RAM
YES
9
PTL-02-0106B
1.25" X 1.25" X 1.25"
6061-T6 ALUMINUM
2
ITEM NO.
DWG / ID NO.
NOMENCLATURE / DESCRIPTION
MATERIAL / SPECIFICATION
QTY REQD
PART LIST
UNLESS OTHERWISE NOTED: TOLERANCES
.XX ±.01
.XXX ±.002
ANGLES ±0.5°
64
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
TITLE BEARING BLOCK
FOR CONTACT AXLE SUB ASSM
DESIGN RAM/IAN
DATE 08/10/93
DRAWN RAM
APPRV RAM/IAN
RELEASE
QTY 2
SCALE 1:1
SIZE B
SHT
DRAWING NO.
PTL-02-0106B
PROJECT AHMCT/PTL


0.3125
1.3750
0.2500
1.3125
0.8125
2.0000
4X TAP HOLE FOR 1/4-20 SCREWS 0.75" DEEP
1.3125
2X TAP HOLE FOR 1/4-20 SCREWS 0.75" DEEP
0.7500
0.7500
1.3125
0.7500
REVISION
INITIAL RELEASE
RAM
YES
10 PTL-02-0107B 2" X 1.313" X 1.313" 6061-T6 ALUMINUM 2
ITEM NO.
PART / ID NO.
NOMENCLATURE / DESCRIPTION
MATERIAL / SPECIFICATION
QTY REQD
PART LIST
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
EXTENSION SUPPORT BLOCK
FOR CONTACT AXLE SUB ASSH
RAM/IAN
08/10/93
RAM
RAM/IAN
PTL-02-0107B
AHMCT/PTL


REVISION
INITIAL RELEASE
RAM
YES
1/4-20 THREADS
0.250
0.375
PTL-02-0108B
LIMIT PIN
STEEL
2
ITEM NO.
DWG / ID NO.
NOMENCLATURE / DESCRIPTION
MATERIAL / SPECIFICATION
QTY REQD
PART LIST
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
LIMIT PIN
FOR CONTACT AXLE SUB ASSM
RAM/IAN
08/10/93
RAM
RAM/IAN
QTY 2
SCALE 1:1
PTL-02-0108B
PROJECT AHMCT/PTL


0.63
1.88
1.50
0.63
⌀0.25
⌀0.50
⌀0.25
0.75
0.38
0.50
1.00
REVISION
LTR
ZONE
DESCRIPTION
DATE
DRWN
APP
INITIAL RELEASE
RAH
YES
14
0.75" X 1.00" X 1.875"
6061-T6 ALUMINUM
3
ITEM NO.
DWG / ID NO.
NOMENCLATURE / DESCRIPTION
MATERIAL / SPECIFICATION
QTY REQD
PART LIST
UNLESS OTHERWISE NOTED: TOLERANCES
.XX ±.01
.XXX ±.002
ANGLES ±0.5°
64
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
TITLE NOZZLE MOUNT
FOR CONTACT AXLE SUB ASSM
DESIGN RAH/IAN
DATE 08/10/93
DRAWN RAH
APPRV RAH/IAN
RELEASE
QTY 3
SCALE 1:1
DRAWING NO.
PTL-02-0109B
SIZE B
SHT
PROJECT AHMCT/PTL



REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
		INITIAL RELEASE	[illegible]	RAM	YES

PART LIST

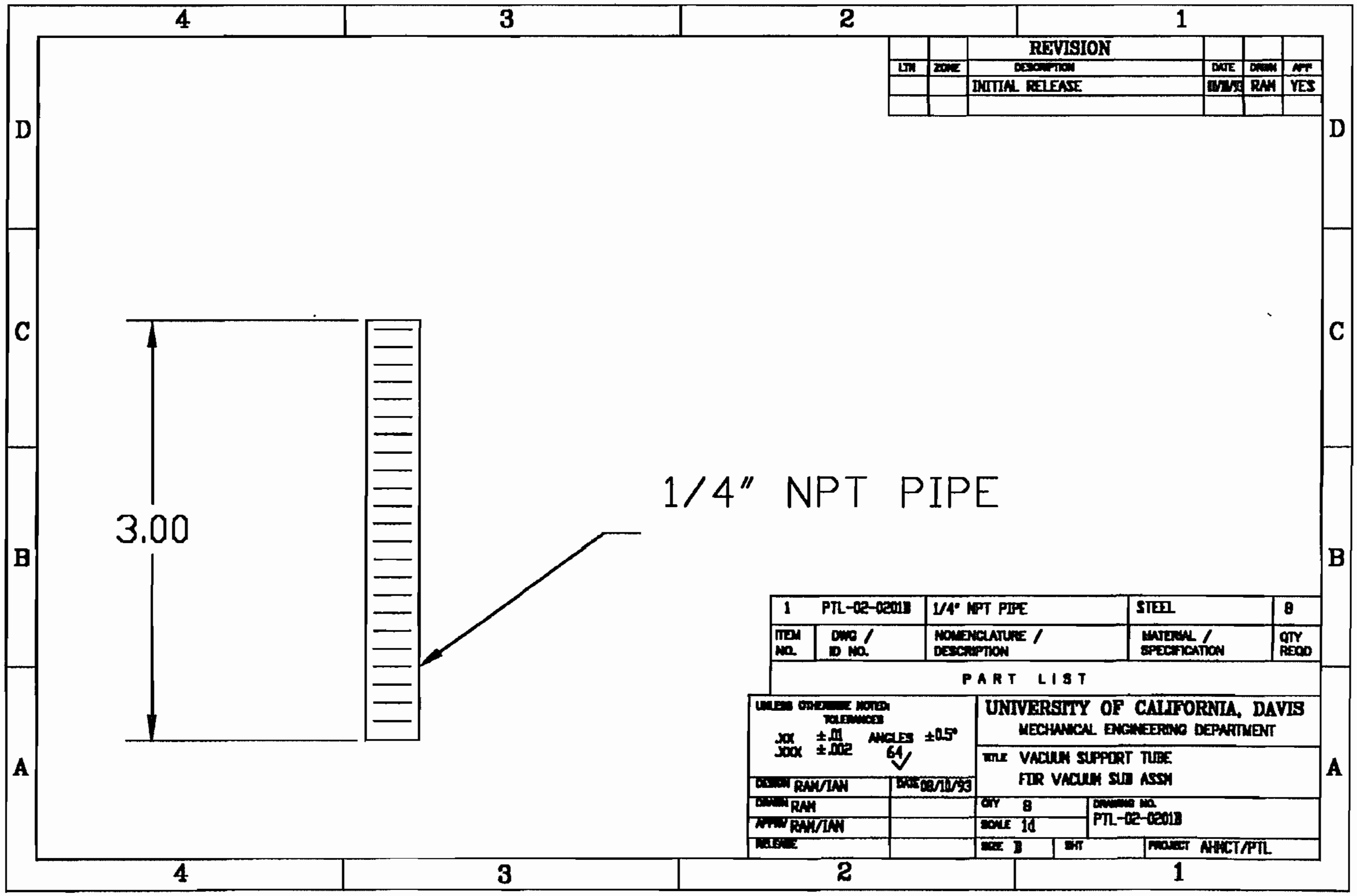
ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
5	PTL-02-0201B	VACUUM SUPPORT BEAM	6061-T6 ALUMINUM	2
4	AIR CONCEPTS	O.D.-1.125/VAC CUP	RUBBER	8
3	PTL-02-0202B	VACUUM SUPPORT ROD	6061-T6 ALUMINUM	4
2		7/16" NUT	STEEL	8
1	PTL-02-0203B	VACUUM SUPPORT TUBE	STEEL	8

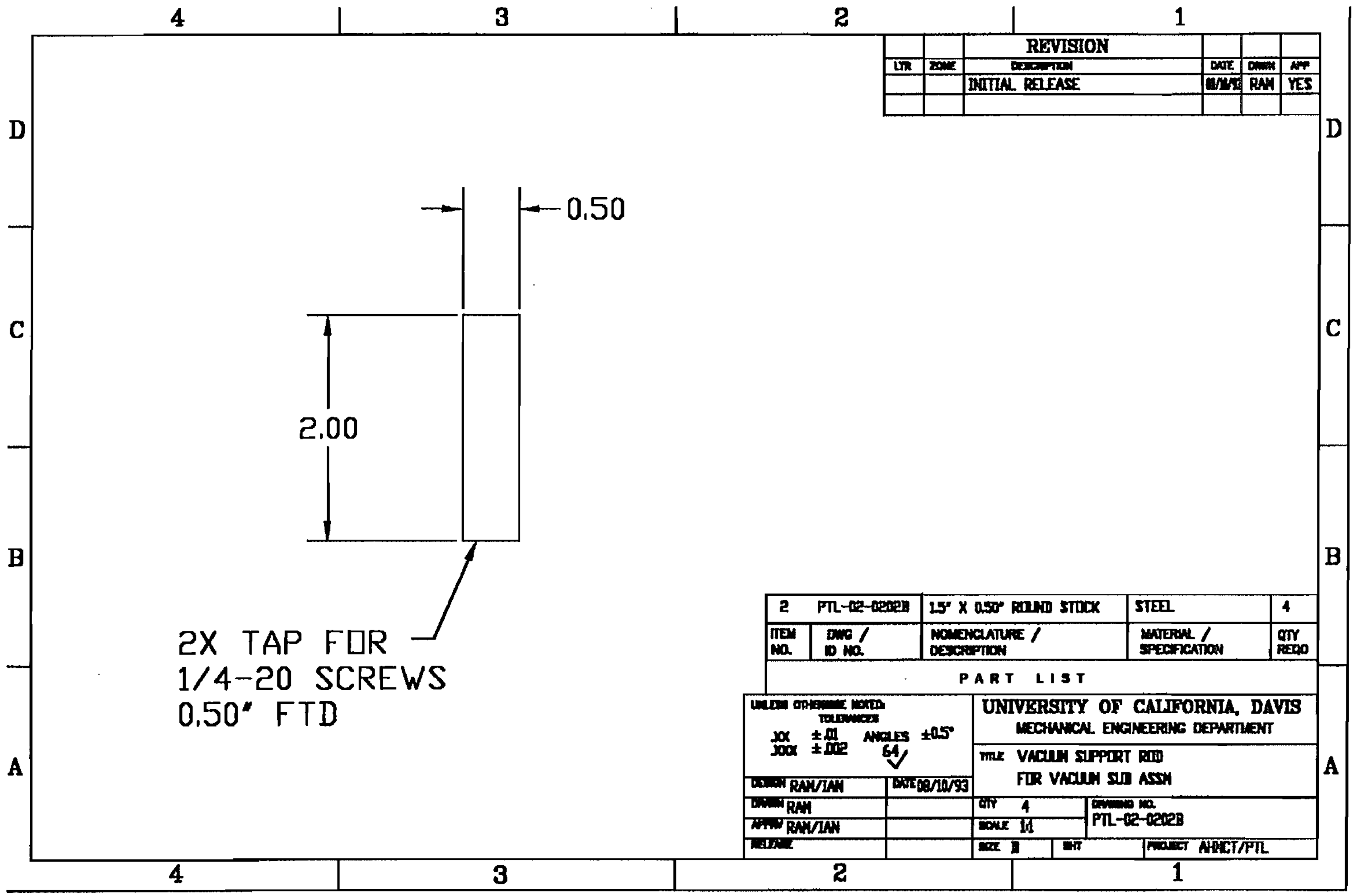
UNLESS OTHERWISE NOTED:
TOLERANCES
.XX ±.01 ANGLES ±0.5°
.XXX ±.002
64√

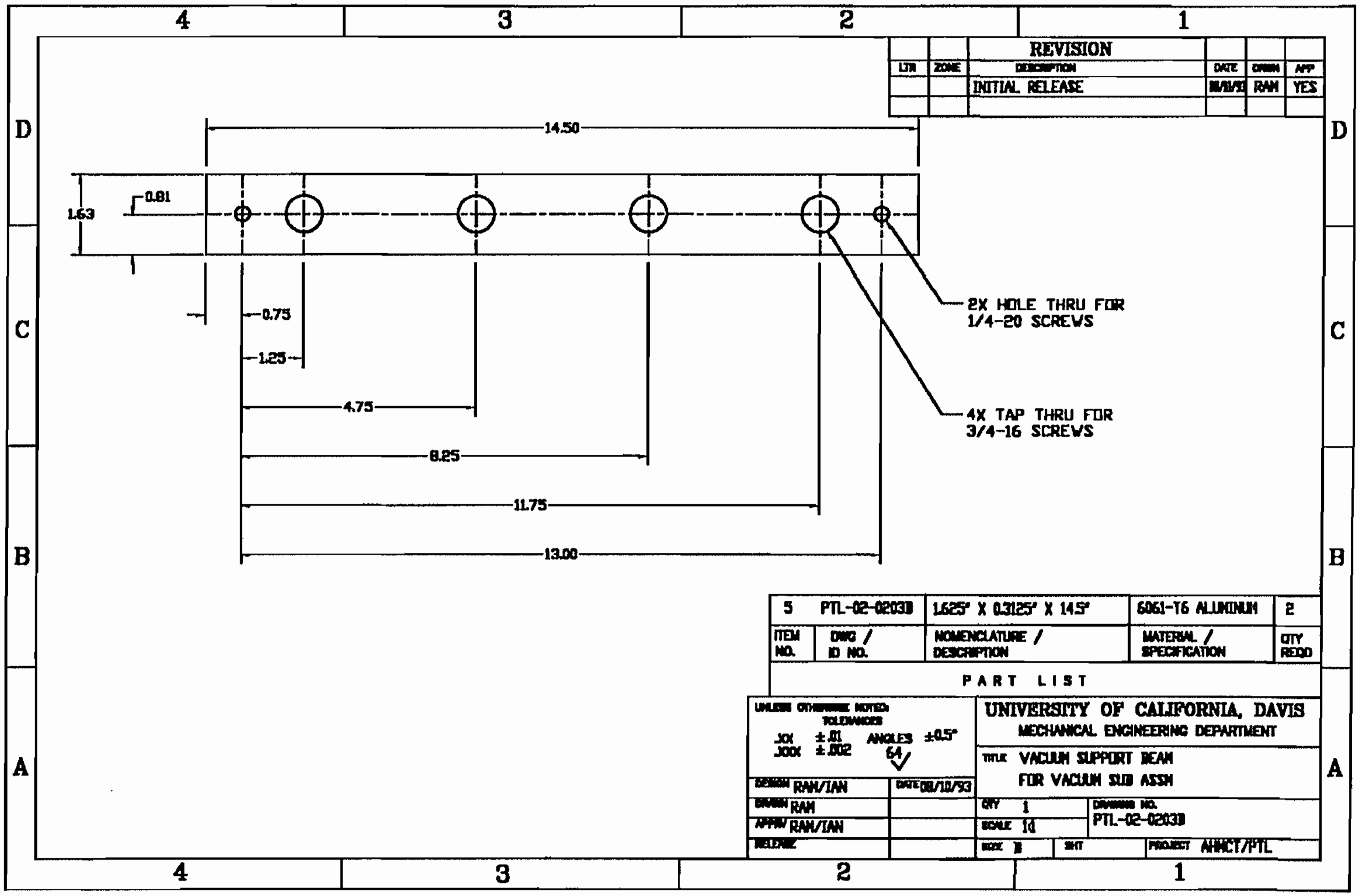
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT

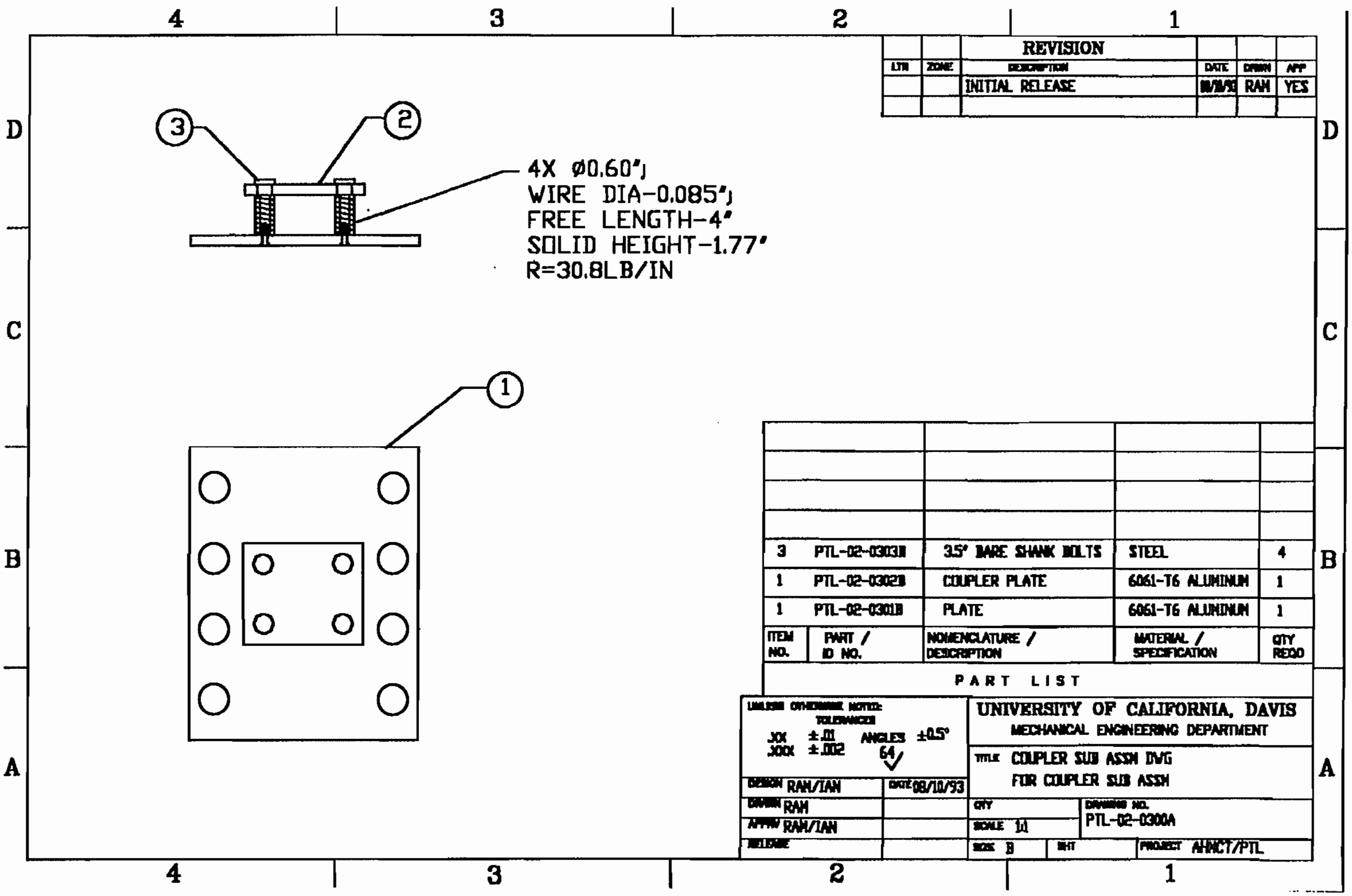
TITLE VACUUM SUPPORT SUB ASSM FOR VACUUM SUB ASSM

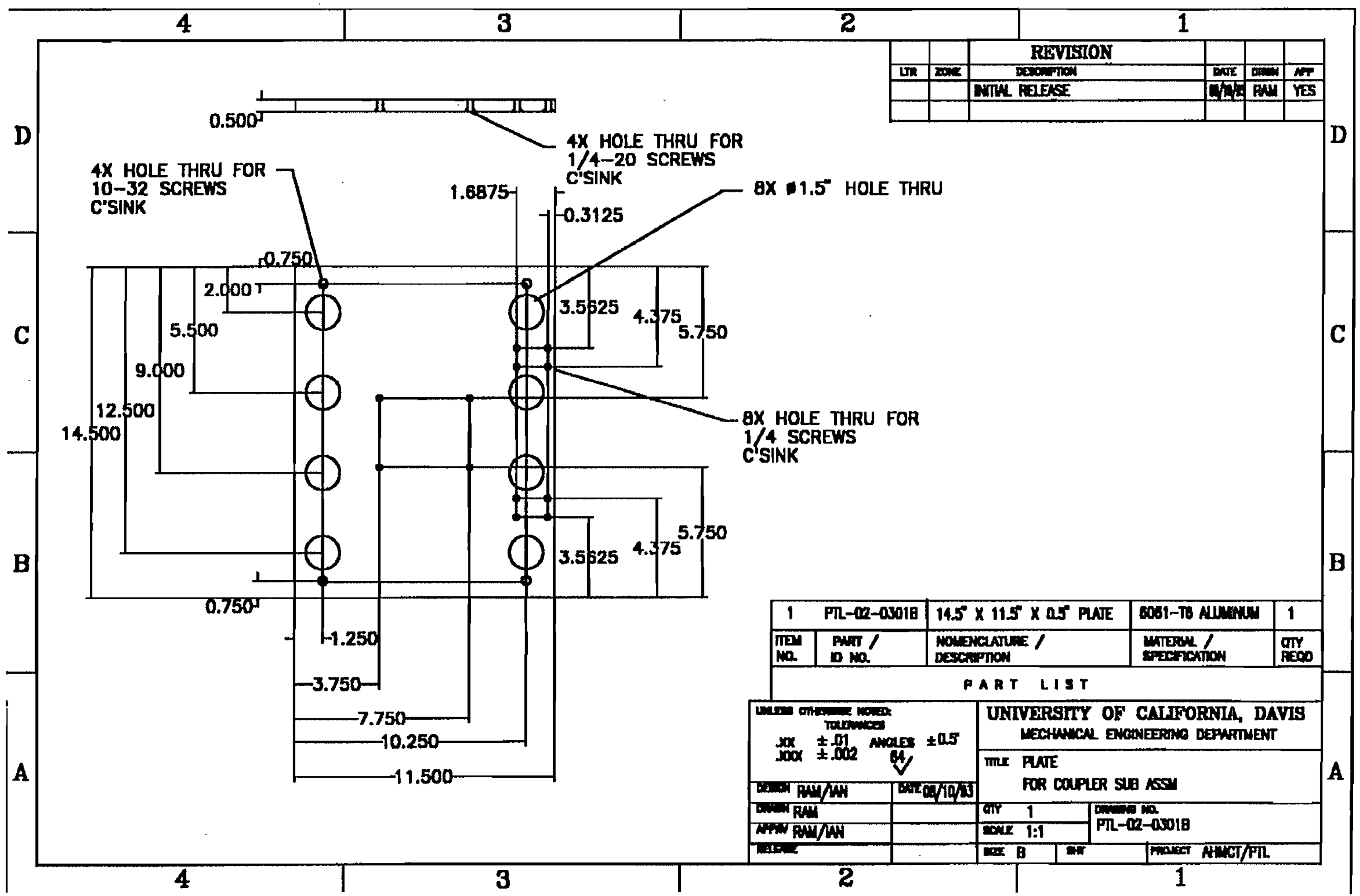
DESIGN RAM/IAN	DATE 08/10/93	QTY	DRAWING NO. PTL-02-0200A
DRAWN RAM		SCALE 1:1	
APPRV RAM/IAN			
RELEASE		SIZE B	SHT	PROJECT AHMCT/PTL

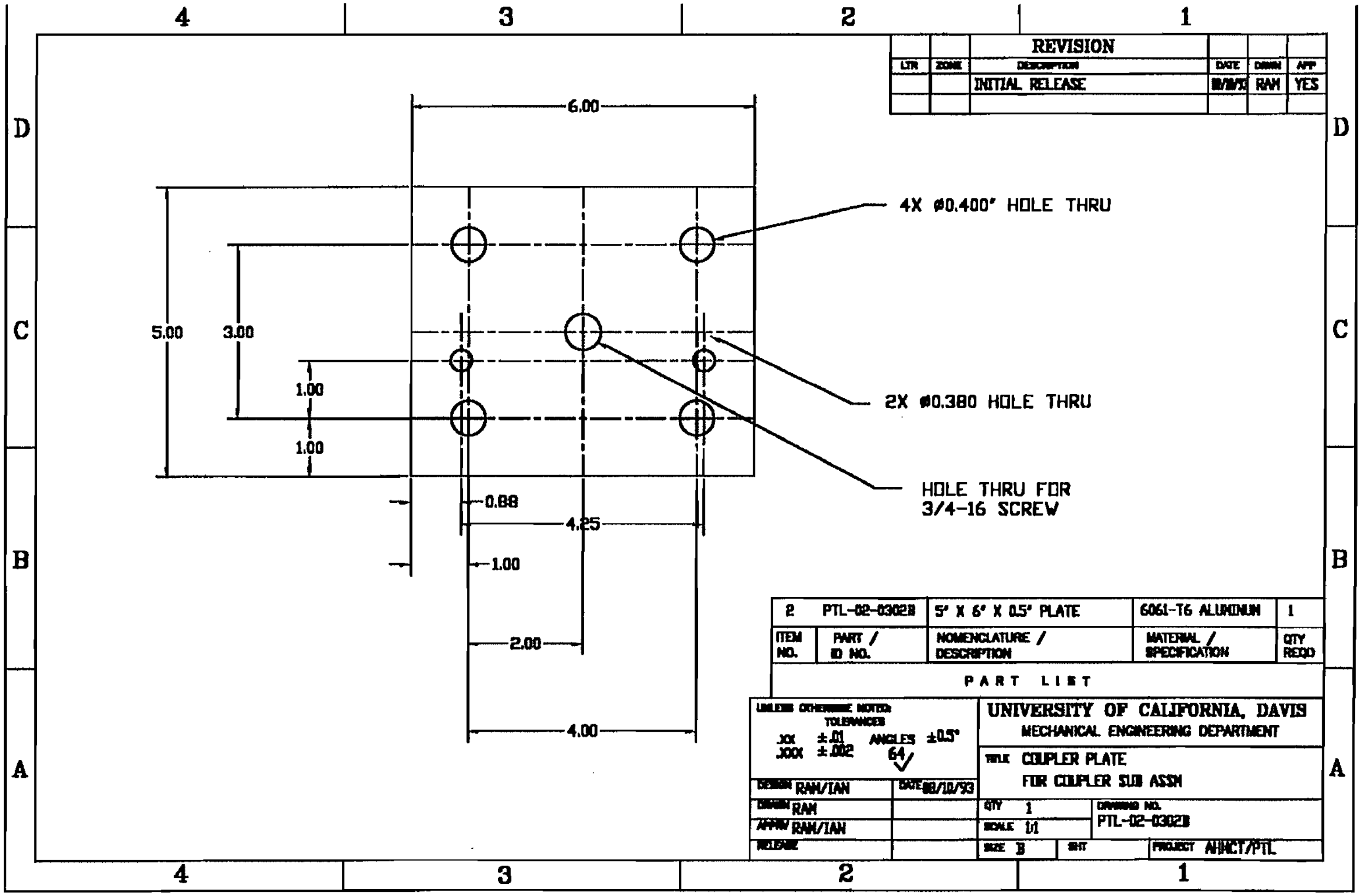

REVISION
LTR
ZONE
DESCRIPTION
DATE
DRAWN
APP
INITIAL RELEASE
RAM
YES
3.00
1/4" NPT PIPE
1
PTL-02-0201B
1/4" NPT PIPE
STEEL
8
ITEM NO.
DWG / ID NO.
NOMENCLATURE / DESCRIPTION
MATERIAL / SPECIFICATION
QTY REQD
PART LIST
UNLESS OTHERWISE NOTED:
TOLERANCES
.XX ±.01
.XXX ±.002
ANGLES ±0.5°
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
TITLE VACUUM SUPPORT TUBE
FOR VACUUM SUB ASSM
DESIGN RAM/IAN
DATE 08/10/93
DRAWN RAM
APPRV RAM/IAN
RELEASE
QTY 8
SCALE 1:1
DRAWING NO.
PTL-02-0201B
SIZE B
SHT
PROJECT AHMCT/PTL

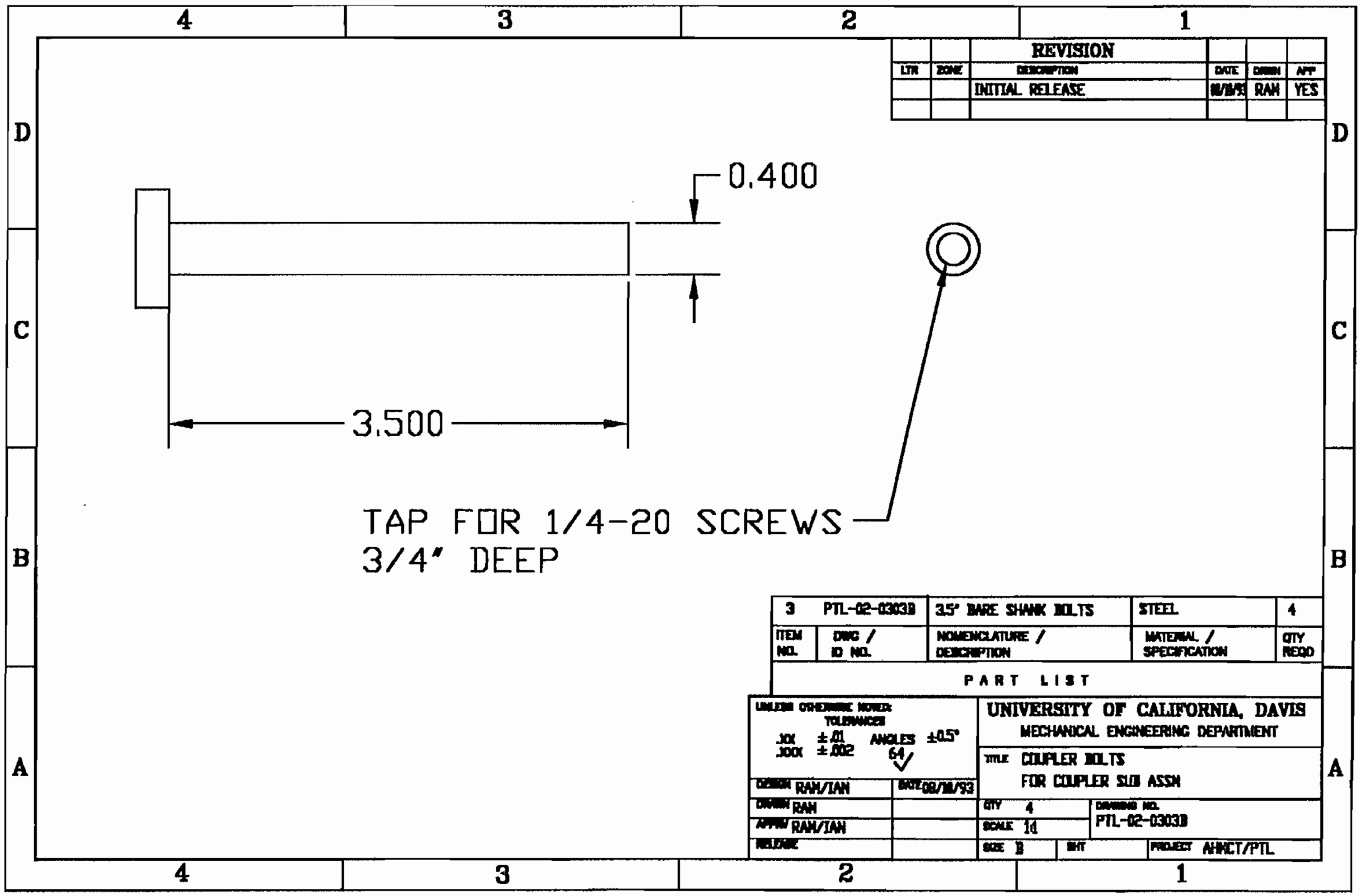

REVISION
LTR
ZONE
DESCRIPTION
DATE
DRWN
APP
INITIAL RELEASE
RAM
YES
0.50
2.00
2X TAP FOR
1/4-20 SCREWS
0.50" FTD
2
PTL-02-0202B
1.5" X 0.50" ROUND STOCK
STEEL
4
ITEM NO.
DWG / ID NO.
NOMENCLATURE / DESCRIPTION
MATERIAL / SPECIFICATION
QTY REQD
PART LIST
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
TITLE VACUUM SUPPORT ROD
FOR VACUUM SUB ASSM
.XX ±.01
.XXX ±.002
ANGLES ±0.5°
DESIGN RAM/IAN
DATE 08/10/93
DRAWN RAM
APPRV RAM/IAN
RELEASE
QTY 4
SCALE 1:1
DRAWING NO.
PTL-02-0202B
SIZE B
SHT
PROJECT AHMCT/PTL

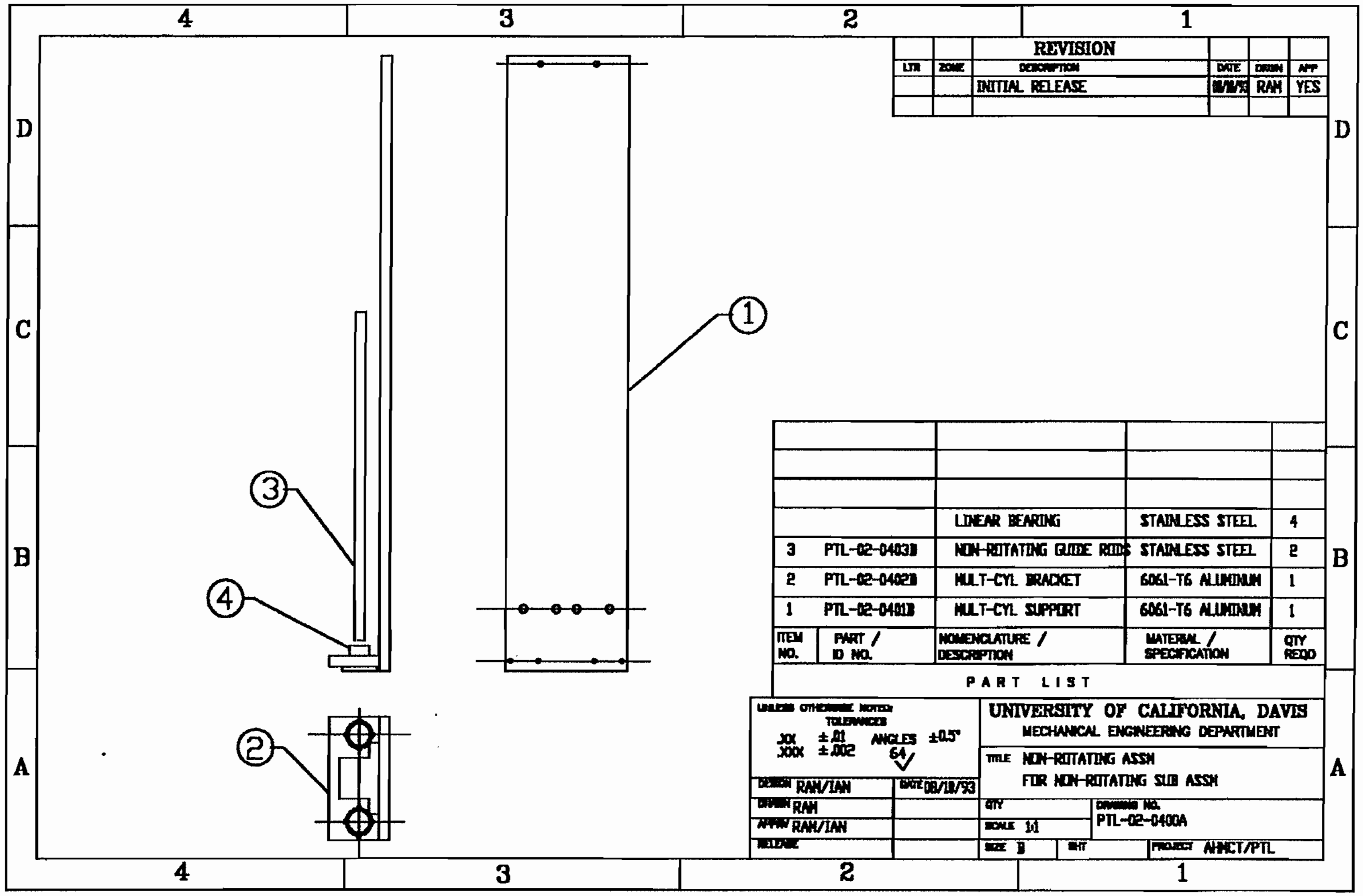

REVISION
LTR
ZONE
DESCRIPTION
DATE
DRWN
APP
INITIAL RELEASE
RAM
YES
14.50
1.63
0.81
0.75
1.25
4.75
8.25
11.75
13.00
2X HOLE THRU FOR
1/4-20 SCREWS
4X TAP THRU FOR
3/4-16 SCREWS
5
PTL-02-0203B
1.625" X 0.3125" X 14.5"
6061-T6 ALUMINUM
2
ITEM NO.
DWG / ID NO.
NOMENCLATURE / DESCRIPTION
MATERIAL / SPECIFICATION
QTY REQD
PART LIST
UNLESS OTHERWISE NOTED:
TOLERANCES
.XX ±.01
.XXX ±.002
ANGLES ±0.5°
64
DESIGN RAM/IAN
DATE 08/10/93
DRAWN RAM
APPRV RAM/IAN
RELEASE
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
TITLE VACUUM SUPPORT BEAM
FOR VACUUM SUB ASSM
QTY 1
DRAWING NO.
PTL-02-0203B
SCALE 1:1
SIZE B
SHT
PROJECT AHMCT/PTL


4X Ø0.60"
WIRE DIA-0.085"
FREE LENGTH-4"
SOLID HEIGHT-1.77"
R=30.8LB/IN
REVISION
LTR ZONE DESCRIPTION DATE DRWN APP
INITIAL RELEASE RAH YES
3 PTL-02-0303B 3.5" BARE SHANK BOLTS STEEL 4
1 PTL-02-0302B COUPLER PLATE 6061-T6 ALUMINUM 1
1 PTL-02-0301B PLATE 6061-T6 ALUMINUM 1
ITEM NO. PART / ID NO. NOMENCLATURE / DESCRIPTION MATERIAL / SPECIFICATION QTY REQD
PART LIST
UNLESS OTHERWISE NOTED: TOLERANCES
.XX ±.01 .XXX ±.002 ANGLES ±0.5°
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
TITLE COUPLER SUB ASSM DWG FOR COUPLER SUB ASSM
DESIGN RAH/IAN DATE 08/10/93
DRAWN RAH
APPRV RAH/IAN
RELEASE
QTY
DRAWING NO. PTL-02-0300A
SCALE 1:1
SIZE B SHT
PROJECT AHMCT/PTL


REVISION
LTR
ZONE
DESCRIPTION
DATE
DRWN
APP
INITIAL RELEASE
RAM
YES
0.500
4X HOLE THRU FOR
1/4-20 SCREWS
C'SINK
4X HOLE THRU FOR
10-32 SCREWS
C'SINK
1.6875
0.3125
8X ⌀1.5" HOLE THRU
0.750
2.000
5.500
9.000
12.500
14.500
3.5625
4.375
5.750
8X HOLE THRU FOR
1/4 SCREWS
C'SINK
3.5625
4.375
5.750
0.750
1.250
3.750
7.750
10.250
11.500
1
PTL-02-0301B
14.5" X 11.5" X 0.5" PLATE
6061-T6 ALUMINUM
1
ITEM NO.
PART / ID NO.
NOMENCLATURE / DESCRIPTION
MATERIAL / SPECIFICATION
QTY REQD
PART LIST
UNLESS OTHERWISE NOTED:
TOLERANCES
.XX ±.01
.XXX ±.002
ANGLES ±0.5°
64
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
TITLE PLATE
FOR COUPLER SUB ASSM
DESIGN RAM/IAN
DATE 08/10/03
DRAWN RAM
APPRV RAM/IAN
RELEASE
QTY 1
DRAWING NO.
PTL-02-0301B
SCALE 1:1
SIZE B
SHT
PROJECT AHMCT/PTL
D
C
B
A
4
3
2
1

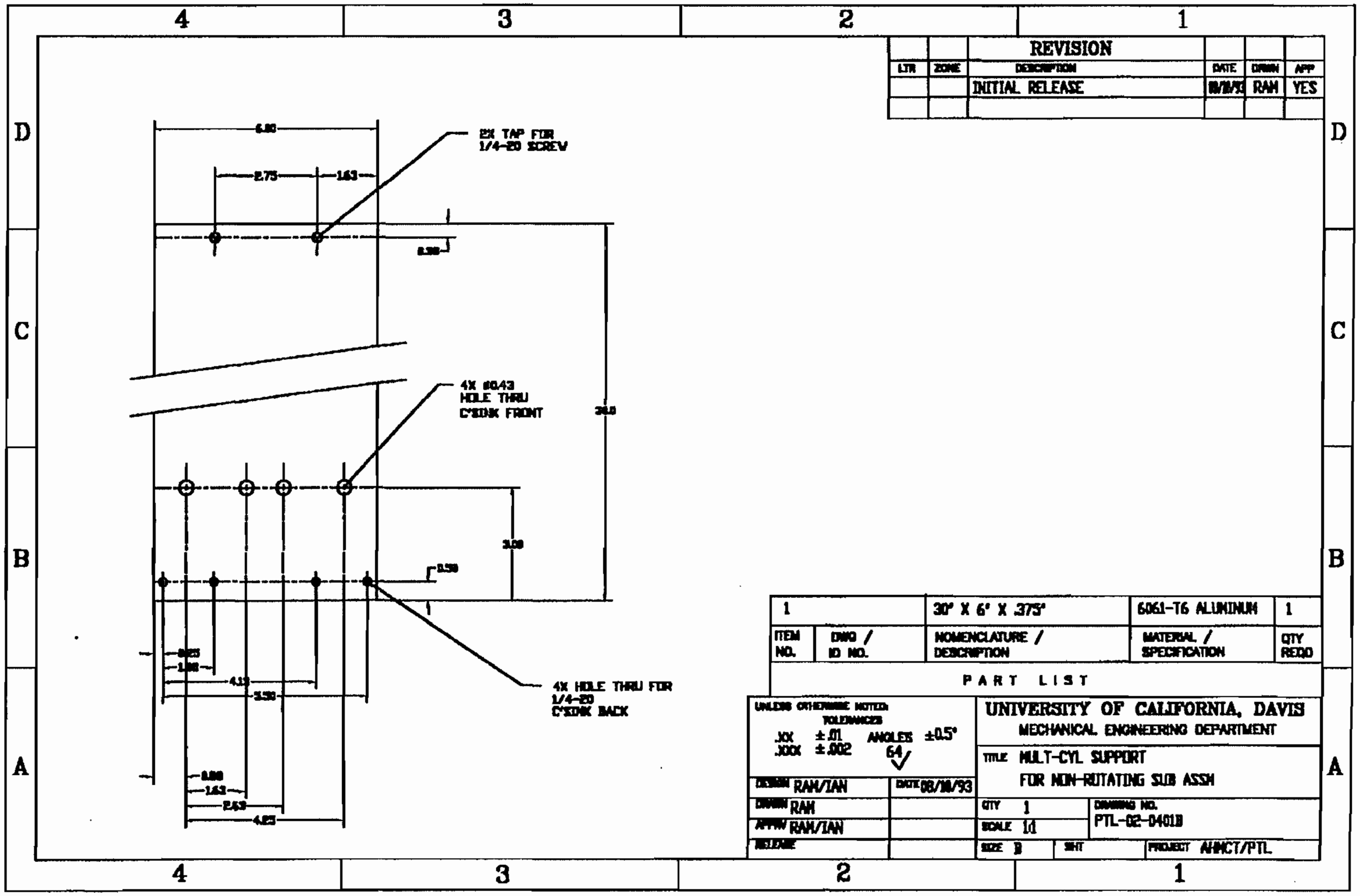

REVISION
LTR
ZONE
DESCRIPTION
DATE
DRWN
APP
INITIAL RELEASE
RAM
YES
6.00
4X ø0.400" HOLE THRU
5.00
3.00
1.00
1.00
2X ø0.380 HOLE THRU
HOLE THRU FOR
3/4-16 SCREW
0.88
4.25
1.00
2.00
4.00
2
PTL-02-0302B
5" X 6" X 0.5" PLATE
6061-T6 ALUMINUM
1
ITEM NO.
PART / ID NO.
NOMENCLATURE / DESCRIPTION
MATERIAL / SPECIFICATION
QTY REQD
PART LIST
UNLESS OTHERWISE NOTED: TOLERANCES
.XX ±.01
.XXX ±.002
ANGLES ±0.5°
64
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
TITLE COUPLER PLATE
FOR COUPLER SUB ASSM
DESIGN RAM/IAN
DATE 08/10/93
DRAWN RAM
APPRV RAM/IAN
RELEASE
QTY 1
SCALE 1/1
SIZE B
SHT
DRAWING NO.
PTL-02-0302B
PROJECT AHMCT/PTL

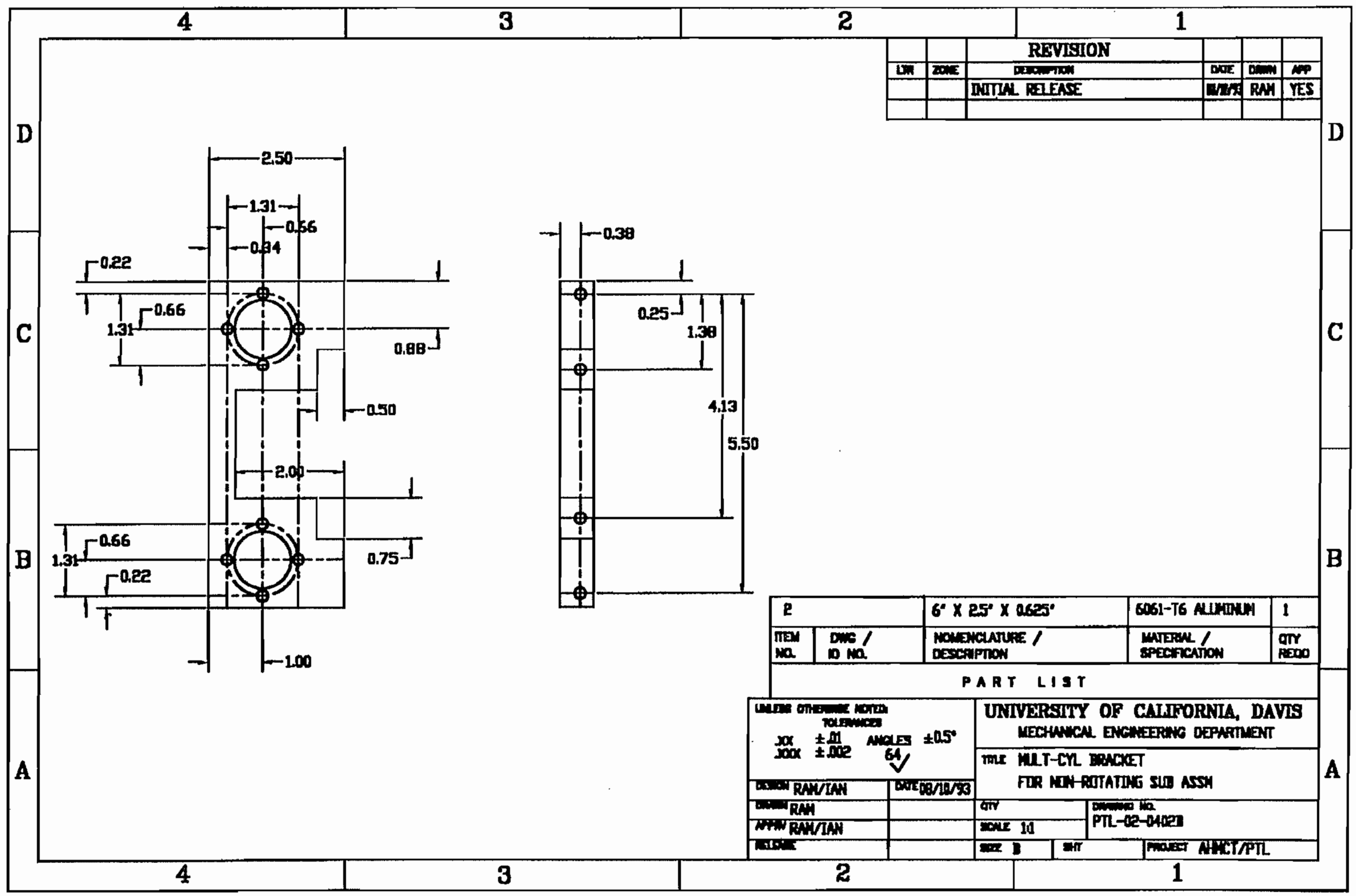

REVISION
LTR
ZONE
DESCRIPTION
DATE
DRWN
APP
INITIAL RELEASE
RAH
YES
0.400
3.500
TAP FOR 1/4-20 SCREWS
3/4" DEEP
3
PTL-02-0303B
3.5" BARE SHANK BOLTS
STEEL
4
ITEM NO.
DWG / ID NO.
NOMENCLATURE / DESCRIPTION
MATERIAL / SPECIFICATION
QTY REQD
PART LIST
TOLERANCES
.XX ±.01
.XXX ±.002
ANGLES ±0.5°
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
TITLE COUPLER BOLTS
FOR COUPLER SUB ASSM
RAH/IAN
RAH
RAH/IAN
QTY 4
DRAWING NO.
PTL-02-0303B
PROJECT AHMCT/PTL

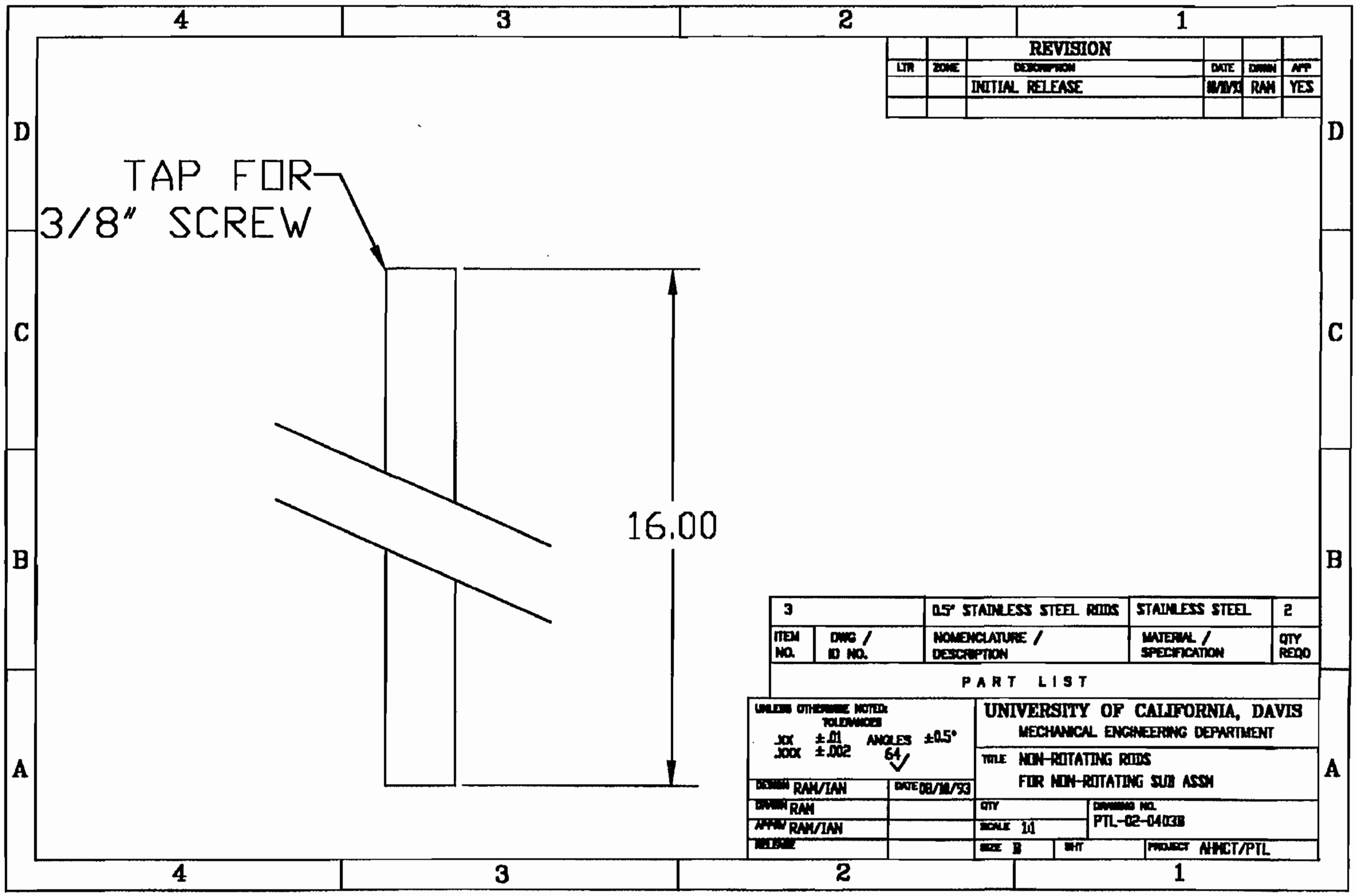

REVISION
LTR
ZONE
DESCRIPTION
DATE
DRWN
APP
INITIAL RELEASE
10/18/93
RAM
YES
LINEAR BEARING
STAINLESS STEEL
4
3
PTL-02-0403Ø
NON-ROTATING GUIDE RODS
STAINLESS STEEL
2
2
PTL-02-0402B
MULT-CYL BRACKET
6061-T6 ALUMINUM
1
1
PTL-02-0401B
MULT-CYL SUPPORT
6061-T6 ALUMINUM
1
ITEM NO.
PART / ID NO.
NOMENCLATURE / DESCRIPTION
MATERIAL / SPECIFICATION
QTY REQD
PART LIST
UNLESS OTHERWISE NOTED: TOLERANCES
.XX ±.01
.XXX ±.002
ANGLES ±0.5°
64
DESIGN RAM/IAN
DATE 08/18/93
DRAWN RAM
APPRV RAM/IAN
RELEASE
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
TITLE NON-ROTATING ASSM
FOR NON-ROTATING SUB ASSM
QTY
DRAWING NO.
PTL-02-0400A
SCALE 1:1
SIZE B
SHT
PROJECT AHMCT/PTL

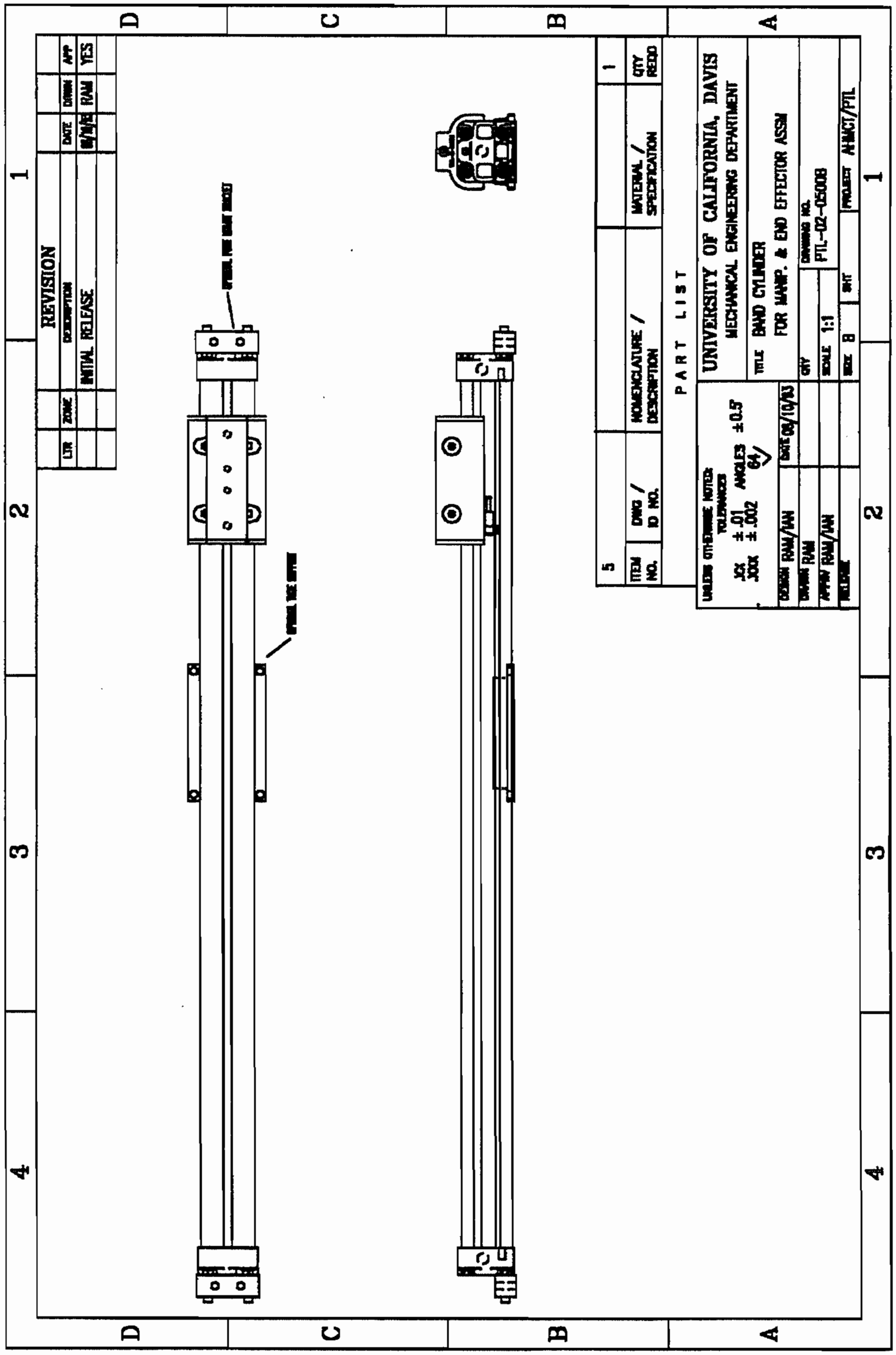
APPENDIX E

Detail Drawings of PTL



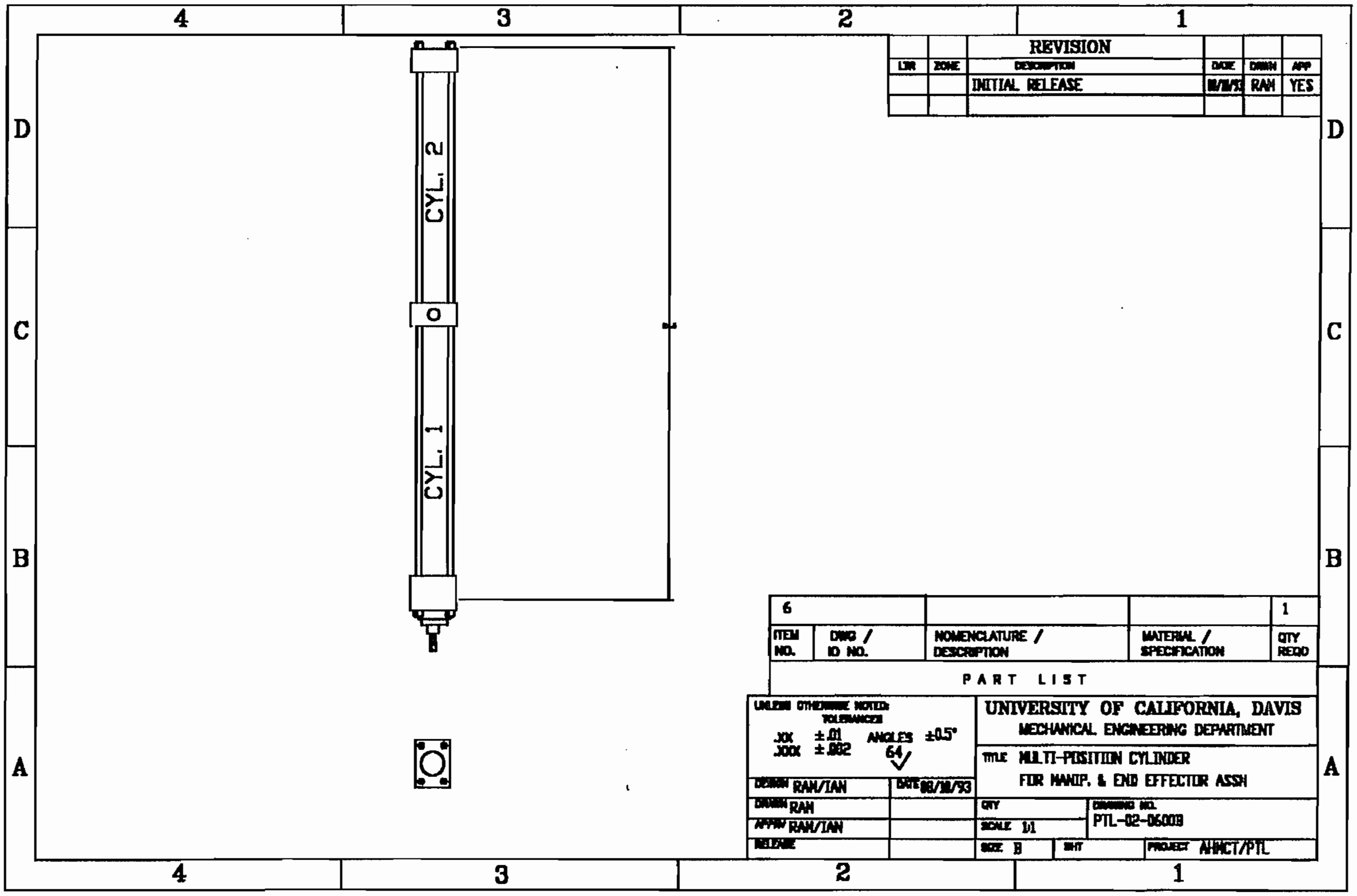

REVISION
LTR
ZONE
DESCRIPTION
DATE
DRAWN
APP
INITIAL RELEASE
RAM
YES
2.50
1.31
0.56
0.34
0.22
0.66
1.31
0.88
0.50
2.00
0.66
1.31
0.22
0.75
1.00
0.38
0.25
1.38
4.13
5.50
2
6" X 2.5" X 0.625"
6061-T6 ALUMINUM
1
ITEM NO.
DWG / ID NO.
NOMENCLATURE / DESCRIPTION
MATERIAL / SPECIFICATION
QTY REQD
PART LIST
UNLESS OTHERWISE NOTED: TOLERANCES
.XX ±.01
.XXX ±.002
ANGLES ±0.5°
64
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
TITLE MULT-CYL BRACKET FOR NON-ROTATING SUB ASSM
DESIGN RAM/IAN
DATE 08/18/93
DRAWN RAM
APPRV RAM/IAN
RELEASE
QTY
SCALE 1:1
SIZE B
SHT
DRAWING NO. PTL-02-0402B
PROJECT AHMCT/PTL

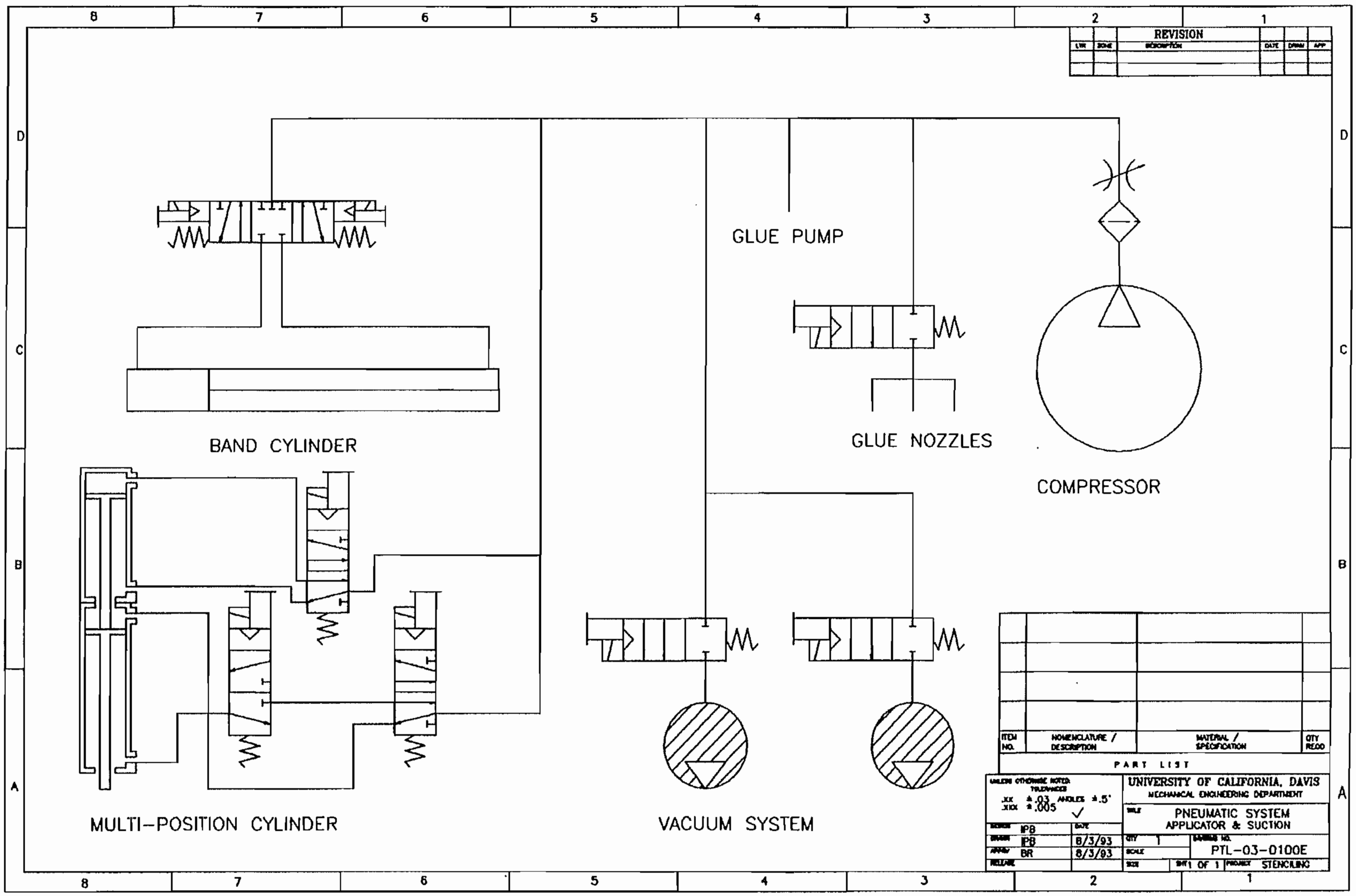

TAP FOR
3/8" SCREW
16.00
REVISION
LTR ZONE DESCRIPTION DATE DRWN APP
INITIAL RELEASE RAM YES
3
0.5" STAINLESS STEEL RODS
STAINLESS STEEL
2
ITEM NO.
DWG / ID NO.
NOMENCLATURE / DESCRIPTION
MATERIAL / SPECIFICATION
QTY REQD
PART LIST
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
.XX ±.01
.XXX ±.002
ANGLES ±0.5°
64
TITLE NON-ROTATING RODS
FOR NON-ROTATING SUB ASSM
RAM/IAN
RAM
RAM/IAN
DRAWING NO.
PTL-02-0403B
SCALE 1:1
SIZE B
PROJECT AHMCT/PTL

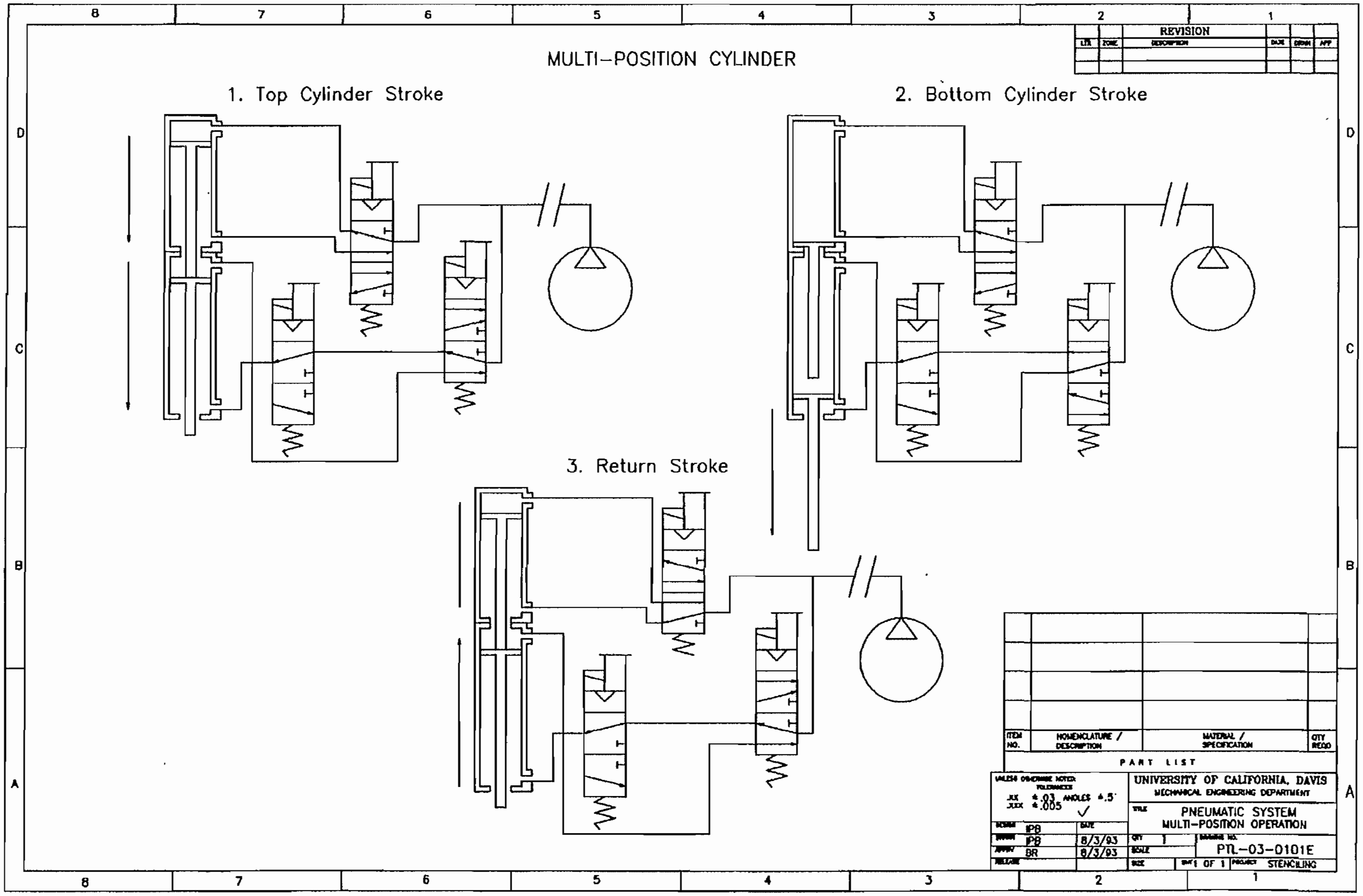

REVISION
INITIAL RELEASE
RAM
YES
PART LIST
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
BAND CYLINDER
FOR MANIP. & END EFFECTOR ASSM
PTL-02-0500B
AHMCT/PTL
SCALE 1:1
±.01
±.002
ANGLES ±0.5°
DATE 09/10/93
DESIGN RAM/IAN
DRAWN RAM
APPRV RAM/IAN

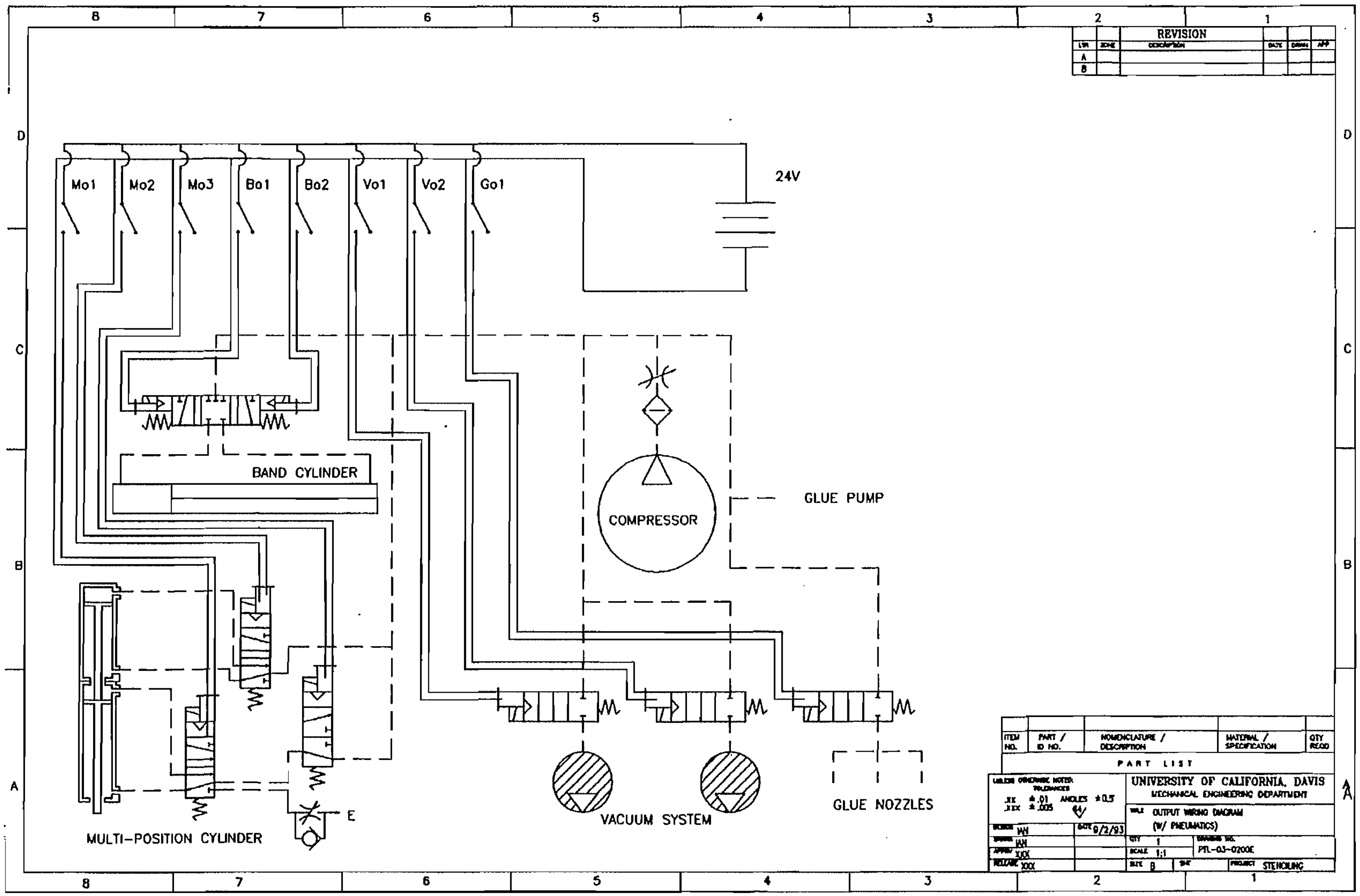
APPENDIX E

Detail Drawings of PTL

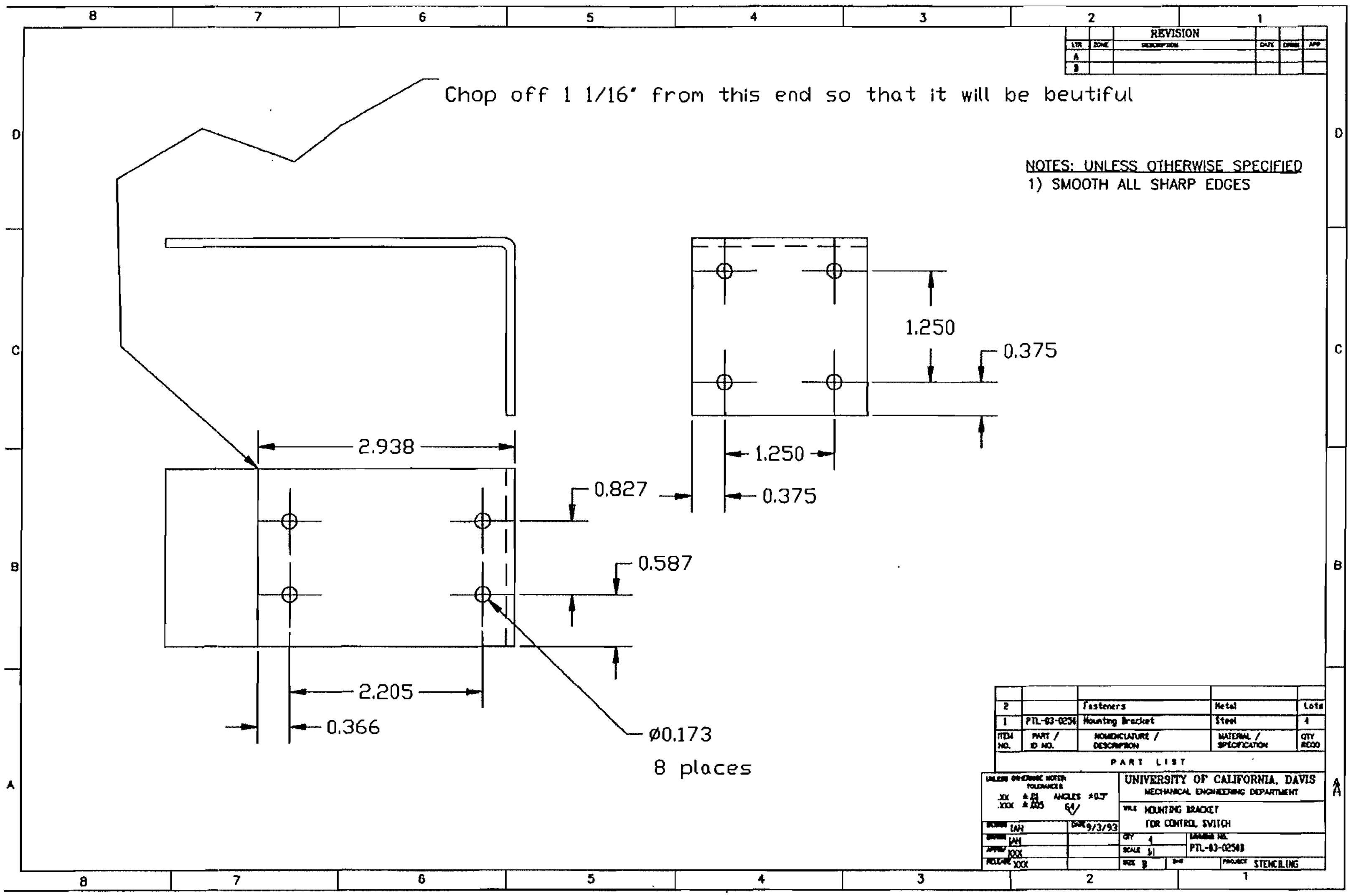



REVISION
GLUE PUMP
GLUE NOZZLES
COMPRESSOR
BAND CYLINDER
MULTI-POSITION CYLINDER
VACUUM SYSTEM
ITEM NO.
NOMENCLATURE / DESCRIPTION
MATERIAL / SPECIFICATION
QTY REQD
PART LIST
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
.XX ±.03 ANGLES ±.5°
.XXX ±.005
IPB
IPB 8/3/93
BR 8/3/93
PNEUMATIC SYSTEM
APPLICATOR & SUCTION
PTL-03-0100E
1 OF 1
STENCILING


MULTI-POSITION CYLINDER
1. Top Cylinder Stroke
2. Bottom Cylinder Stroke
3. Return Stroke
REVISION
PART LIST
ITEM NO.
NOMENCLATURE / DESCRIPTION
MATERIAL / SPECIFICATION
QTY REQD
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
PNEUMATIC SYSTEM
MULTI-POSITION OPERATION
IPB
IPB 8/3/93
BR 8/3/93
1
PTL-03-0101E
1 OF 1
STENCILING

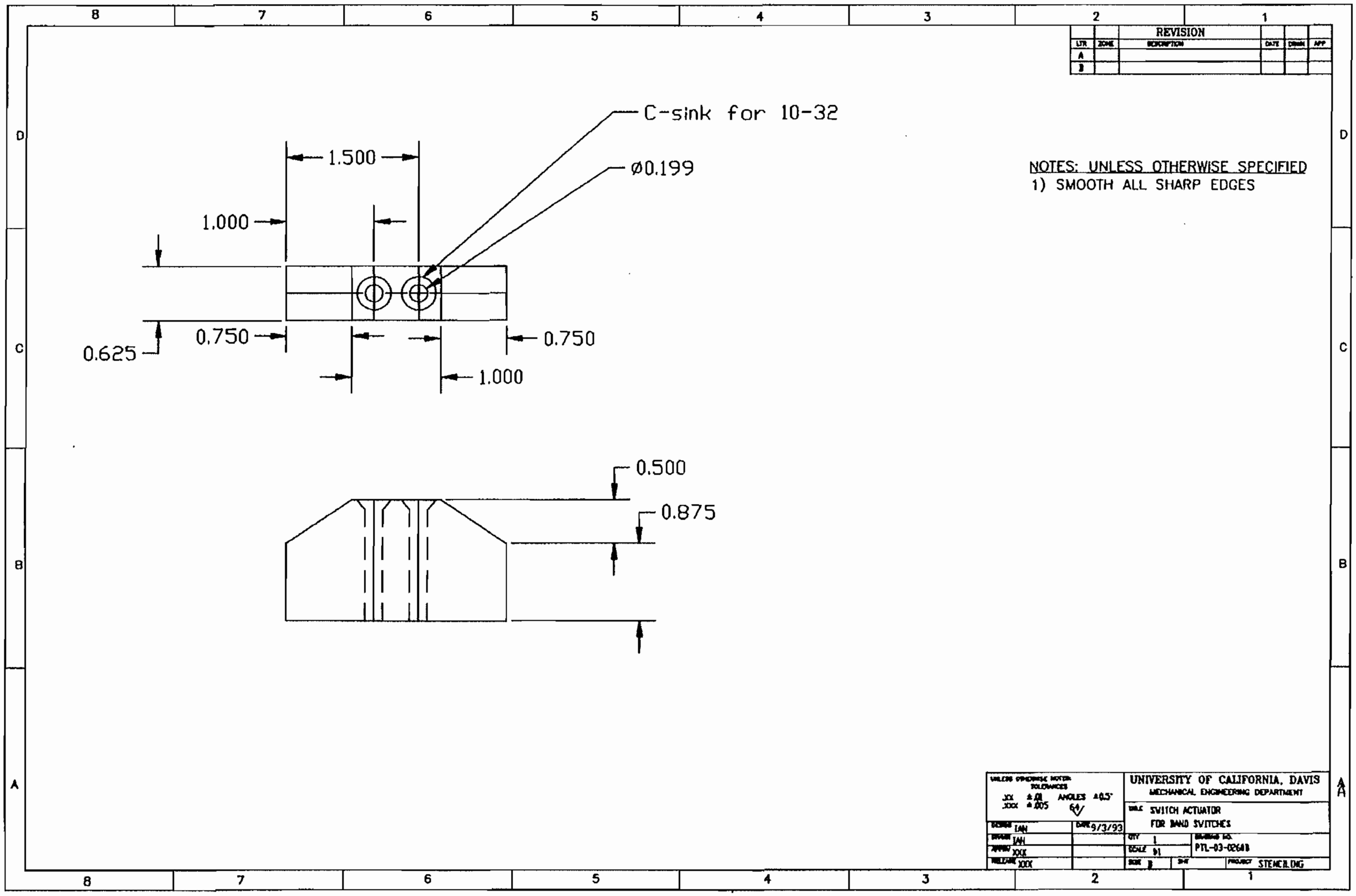

REVISION
Mo1
Mo2
Mo3
Bo1
Bo2
Vo1
Vo2
Go1
24V
BAND CYLINDER
COMPRESSOR
GLUE PUMP
MULTI-POSITION CYLINDER
E
VACUUM SYSTEM
GLUE NOZZLES
ITEM NO.
PART / ID NO.
NOMENCLATURE / DESCRIPTION
MATERIAL / SPECIFICATION
QTY REQD
PART LIST
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
OUTPUT WIRING DIAGRAM
(W/ PNEUMATICS)
9/2/93
PTL-03-0200E
STENCILING

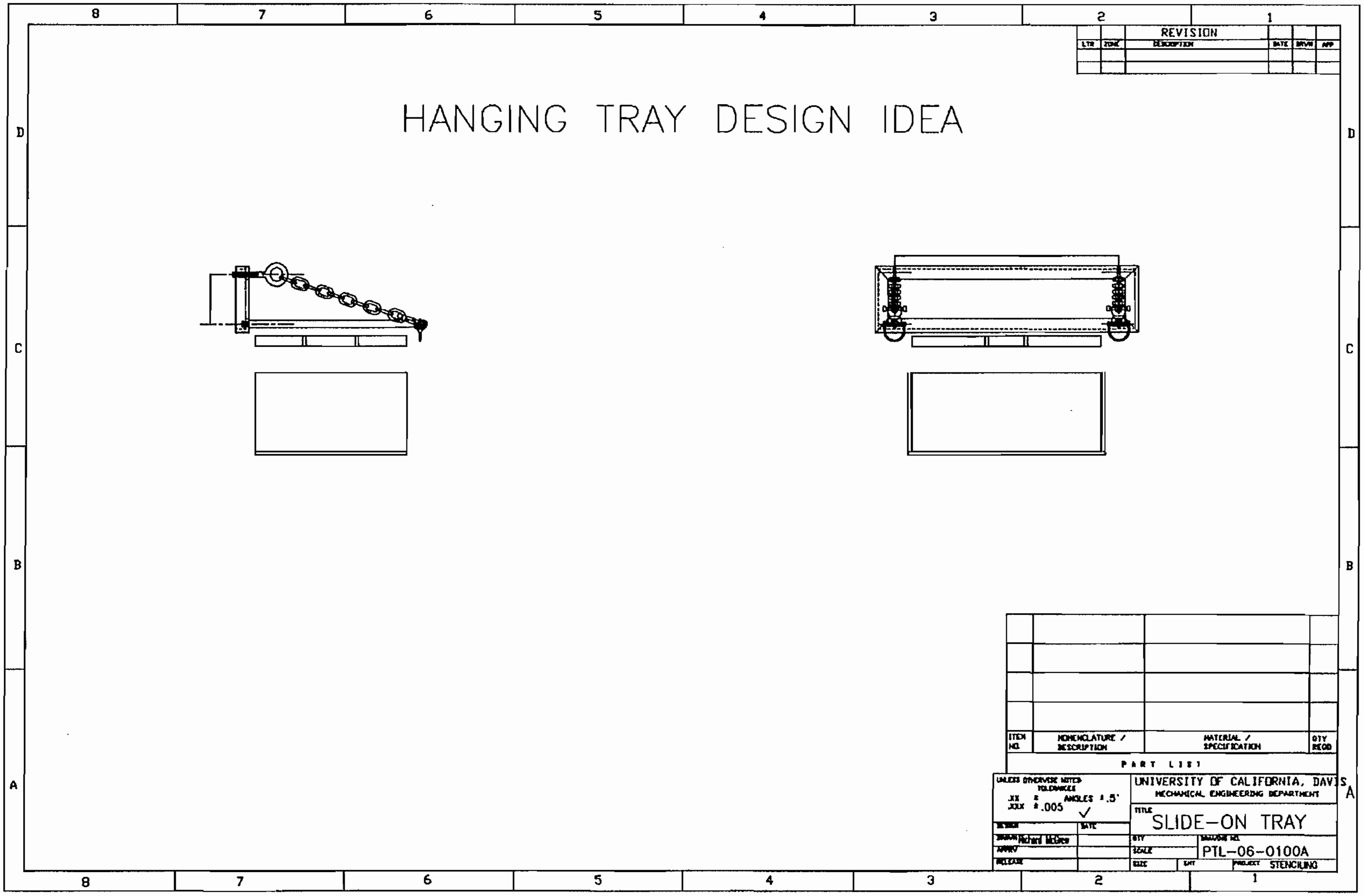
APPENDIX E
Detail Drawings of PTL

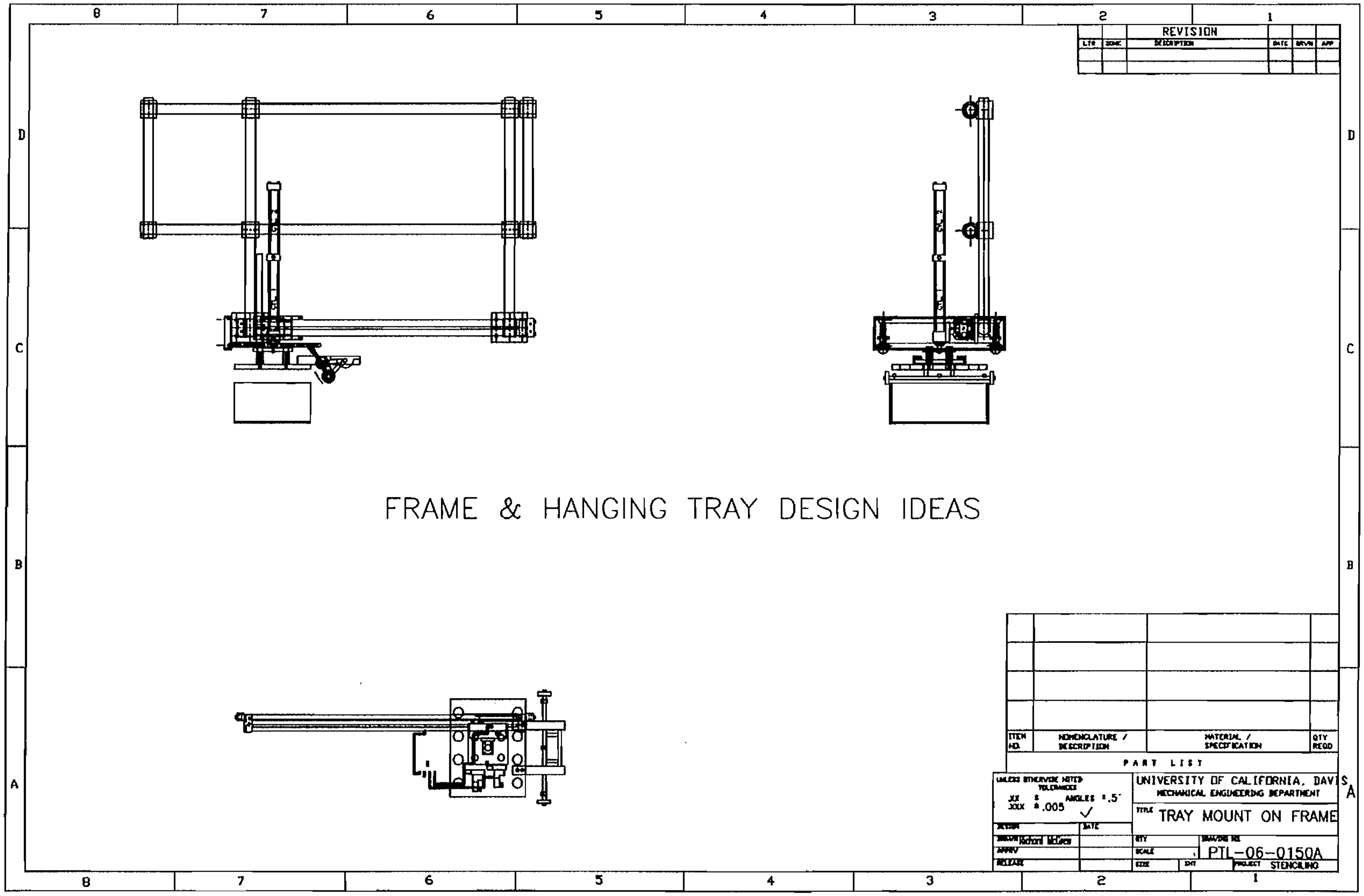


APPENDIX E

Detail Drawings of PTL



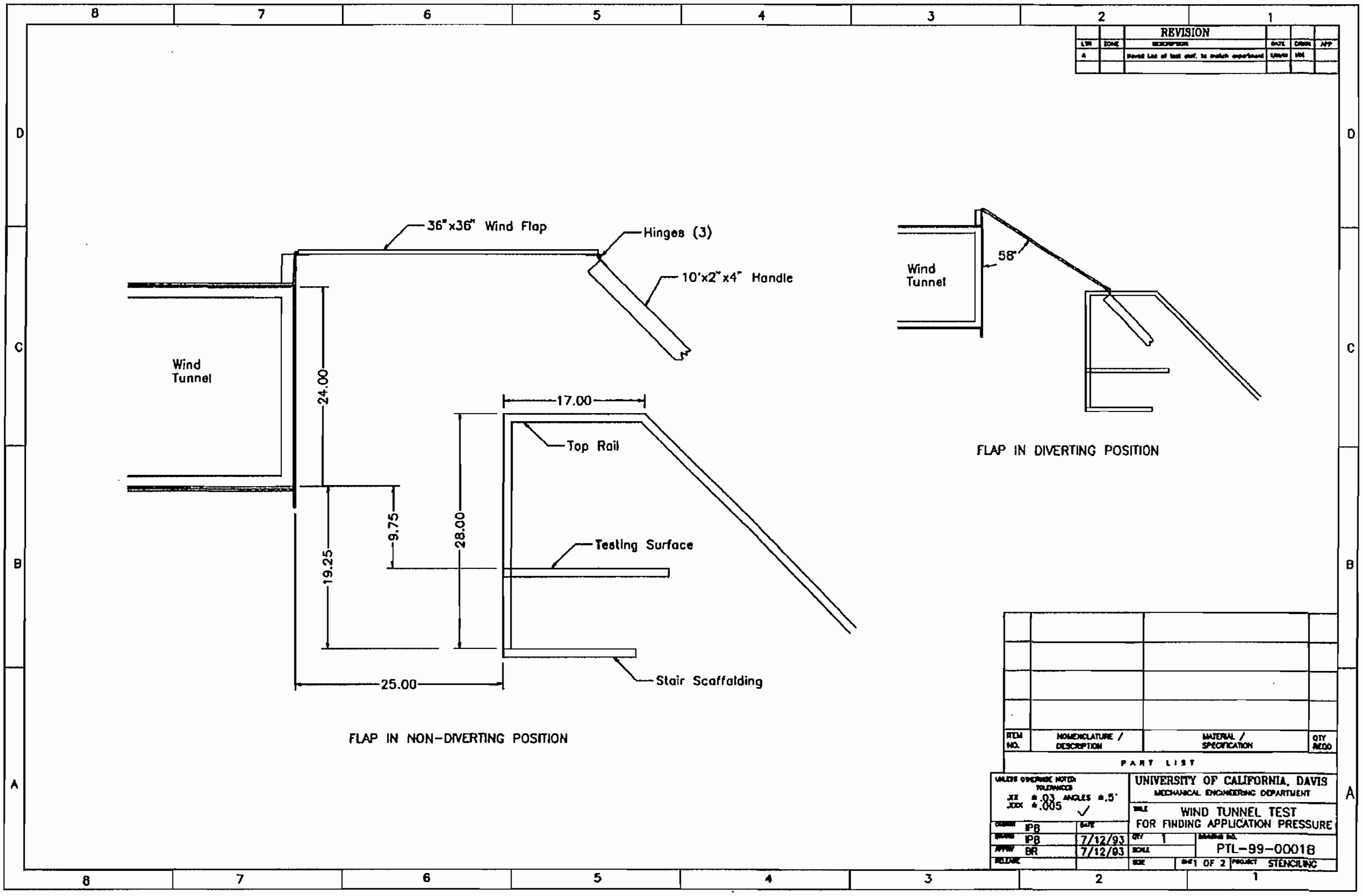

HANGING TRAY DESIGN IDEA
REVISION
PART LIST
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
SLIDE-ON TRAY
PTL-06-0100A
STENCILING

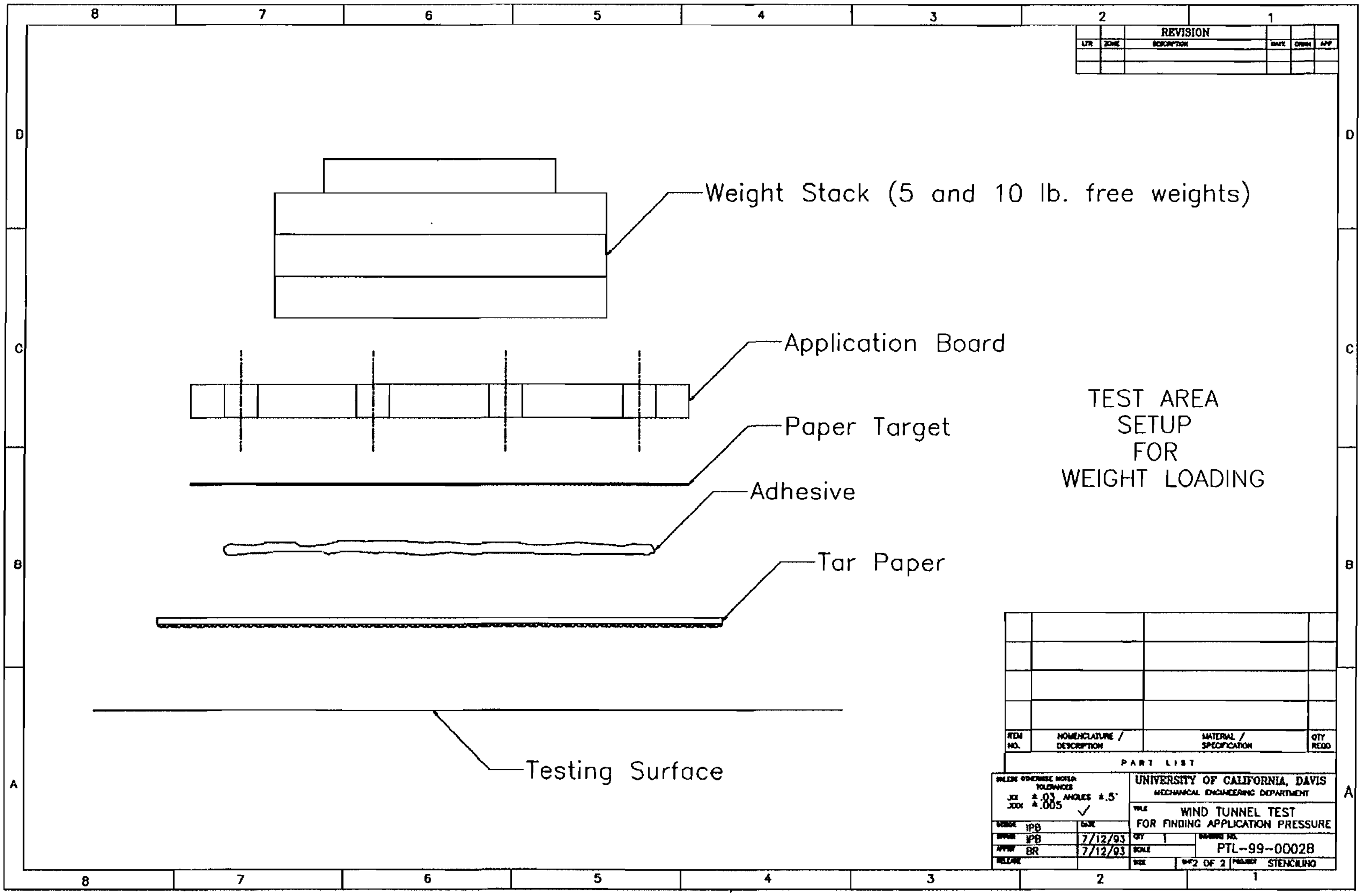


REVISION
FRAME & HANGING TRAY DESIGN IDEAS
PART LIST
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
TRAY MOUNT ON FRAME
Richard McGee
PTL-06-0150A
STENCILING

APPENDIX E

Detail Drawings of PTL




REVISION
Weight Stack (5 and 10 lb. free weights)
Application Board
Paper Target
Adhesive
Tar Paper
Testing Surface
TEST AREA
SETUP
FOR
WEIGHT LOADING
ITEM NO.
NOMENCLATURE / DESCRIPTION
MATERIAL / SPECIFICATION
QTY REQD
PART LIST
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
WIND TUNNEL TEST
FOR FINDING APPLICATION PRESSURE
IPB
IPB 7/12/93
BR 7/12/93
PTL-99-00028
2 OF 2
STENCILING

APPENDIX E

Detail Drawings of PTL