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COMPLETION REPORT FOR THE AUTOMATED STENCILLING PROJECT: PREMARK MECHANIZED STENCIL

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Abstract

This thesis provides information on the development of a machine directed towards the mechanization of the control point target stenciling process for aerial photogrammetry used in highway surveying. The information starts with brief descriptions of both aerial photogrammetry and the current method of application. The initial strawman concept shown at this point is used as the basis for preliminary testing. The thesis continues with a list of target specifications, functional requirements and the results of the preliminary testing. From here a list of design requirements is created and the final system design is drafted. The concluding results of this thesis are the construction and testing of a prototype system. From the final prototype testing, it has been determine that the system developed herein has a commercial value and the potential for improving worker safety and productivity.

Chapter 1 - Introduction

1.1 - Introduction

Highway maintenance operations are some of the most dangerous duties performed to keep the highways functional. Between the years 1972 and 1988, in the state of California alone, there were 4800 highway workers injured seriously enough to keep them out of work (Sacramento Bee, 1990). The risks are so great that between the years 1972 and 1991 there were 47 deaths of California highway maintenance workers. One such death occurred on July 29, 1992, to a worker who was surveying a section of Highway 14 in Southern California. This worker was painting targets onto the roadway surface that are used as control points in surveying operations. Target painting is a manual job that requires the worker to exit the vehicle and expose himself to the traffic flow. In response to the extreme danger associated with manual operations, the Advanced Highway Maintenance and Construction Technology (AHMCT) center at UC-Davis embarked on a project to automate the stenciling task in order to remove the worker from the pavement. This thesis presents a mechanical design that can perform the painting operations with the worker within the confines of the vehicle. Accordingly, the Premark Mechanized Stencil System (PMS System), designed and developed as part of this thesis, will greatly reduce the risks to survey workers in the future.

This thesis begins with a brief description of aerial photogrammetry and highway surveying. This includes the description of the target and its use in highway surveying. The thesis continues with a description of the current method of stenciling with a "strawman concept" on how to mechanize the process. The next chapter reports on the feasibility of a mechanized application process that includes target specifications, testing, and system requirements. This is followed by a chapter on the design and construction of a prototype machine that includes the analysis of the systems components. The thesis concludes with an evaluation of the prototype machine and recommendations for further development.

1.2 - Highway Surveying

Described in this section is a synopsis of highway surveying as used by the California Department of Transportation (Caltrans). This section will provide a basic understanding of the surveying operations. It will additionally provide insights into the accuracy and reliability that must be implemented into the design of a system for the mechanization of this process.

Highway surveying provides information to the highway engineers regarding the nature and terrain of a highway. This information is used in such things as the design of off ramps, overpasses, and freeway widening. In earlier times, the information was acquired through time consuming field surveys. The data was transported to the survey department in the forms of rough sketches and notes and then transferred onto a map. These maps were later used by the engineers [Rutland, 1967]. The method of on-the-ground topographic survey was accurate, but it was very time consuming. As such, a new method was implemented that obtained the required accuracy but in a reduced amount of time. This method is known as aerial photogrammetry.

1.2.1 - Aerial Photogrammetry

Photogrammetry is the science of making measurements on photographs [Ciciarelli, 1991]. Aerial photogrammetry produces photographs taken from a high vantage point such as from an airplane. This method allows a wider area to be cover in shorter time. Briefly explaining this method, an airplane flies a predetermined path in the area concerned. Photographs are taken in rapid succession with each photograph slightly overlapping the next. Next, the photographs are delivered to the lab and analyzed. From the analysis, a map is produced.

Figure 1.1 shows the geometry of a single vertical aerial photograph. The exact analysis used in this process is beyond the scope of this thesis, but a basic understanding is established by the relationship in Eqn. 1[Ciciarelli, 1991].

$$\frac{F}{H} = \frac{i}{O} \tag{1}$$

where F = camera focal length

H = aircraft flying height

i = distance between two points on the photograph image

O = the ground distance between the two points

Equation 1 shows that the distances between two points on the ground (**O**) can accurately be calculated from the distance of two points on the photograph (**i**). By projecting the photograph onto a grid and using Eqn. 1, the coordinates of one point relative to another point can be calculated using simple geometry. This also works for vertical displacement but in a more complex way. For these points to have any meaning, the coordinates of any point must be established in some local reference frame. This is where ground control and the targets come into effect. The surveyor selects a control point on the ground, finds the

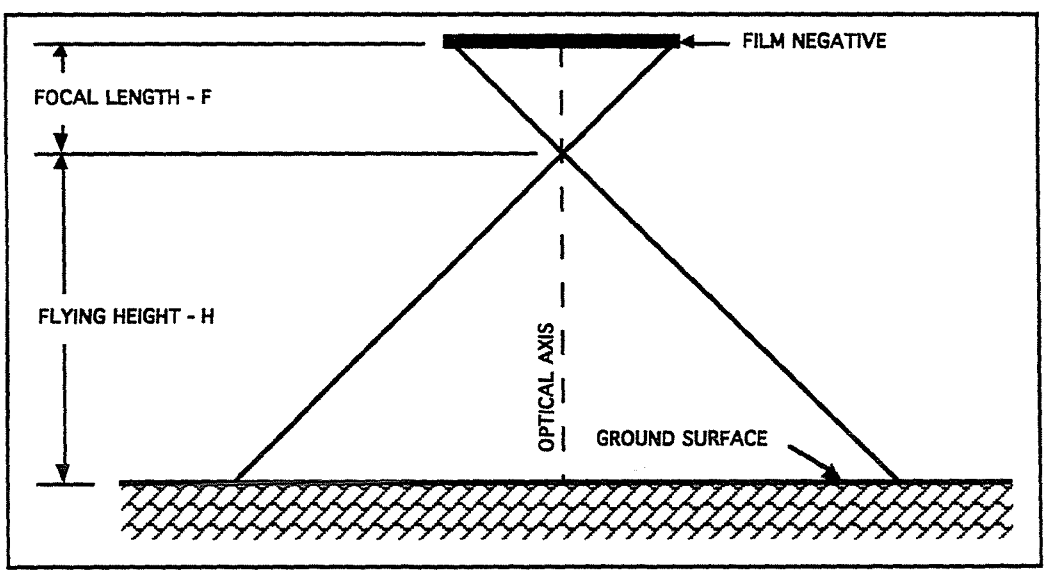


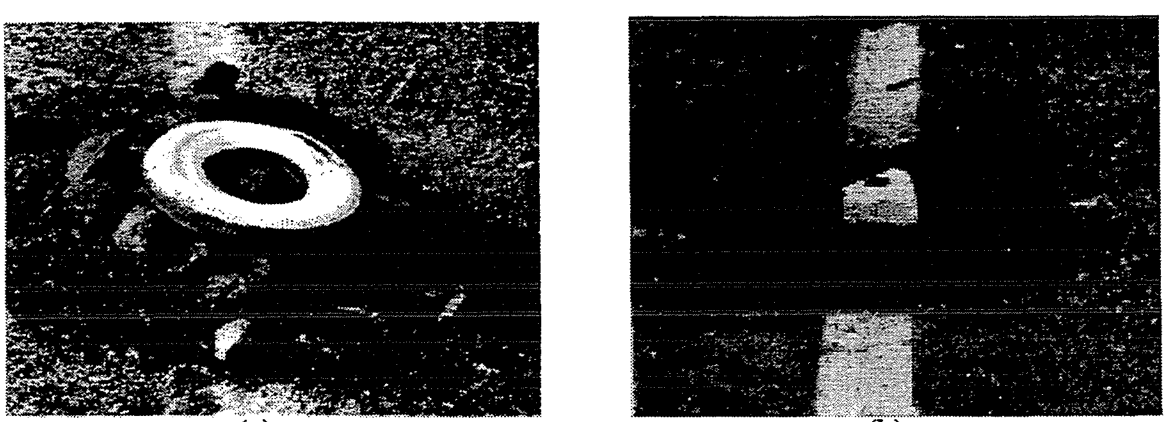
Figure 1.1 - Aerial Photogrammetry

coordinates relative to the ground reference frame, and then marks the ground, finds the coordinates relative to the ground reference frame, and then marks the point with a target that is visible on the photograph. After the area is photographed, the technician in the lab plots the other points in the photograph relative to the control point. By this basic understanding it can be seen that the target becomes a crucial part of the operation.

1.3 - Control Point Target

The control point target has evolved considerably. The earlier targets were similar to the painted tire in Fig. 1.2(a) [Katibah,1967]. This crude method produced flawed measurements because of the lack of definition in a photograph. The next stage in the target's evolution was the use of square markers made of lime set against a black background similar to the one shown in Fig. 1.2(b). These targets were highlighted by two white lines to distinguish them from other spots one the roadway. This method gave better line quality but had its problems. The flaw of this target was that it did not respond well to the elements. If the target were not used immediately, it tended to disintegrate. The use of paint became a standard in California because of the need for a more durable marker.

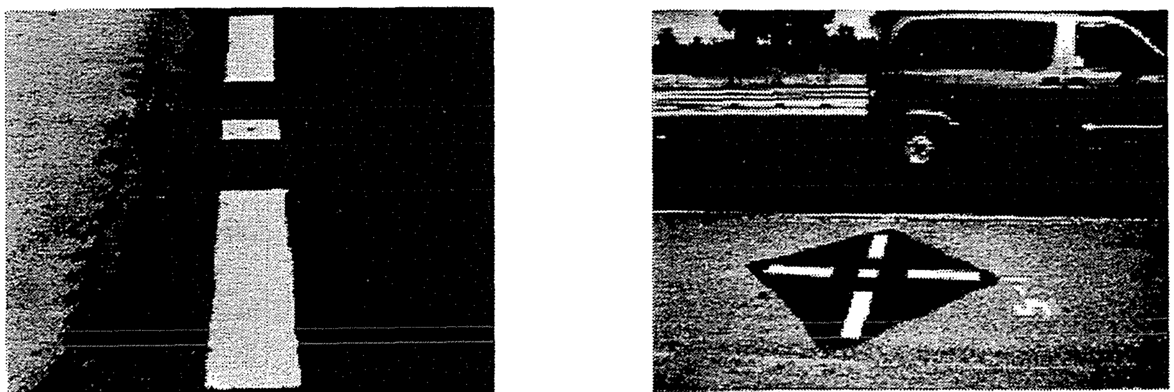
The painted target shown in Fig. 1.3(a) was an earlier version. The target was painted directly to the surface with the asphalt color as its background. The target



(a) (b)

Figure 1.2 - Earlier Control Point Targets

definition was later improved by painting a black background underneath the white lines. Fig. 1.3(b) is a picture of the target currently being used by Caltrans and it is used as a basis for this thesis. Their method of applying the target is with a stencil that produces the necessary quality for the photographs. This leads to the core of the thesis, that is, the automation or mechanization of the stencil operation for the “X” premark target.



(a) (b)

Figure 1.3 - Painted Control Point Targets

Chapter 2 - Control Point Target Application

2.1 - Introduction

There are many ways to paint the targets onto the highway surface ranging from mechanizing the current stencil process to full automation with a robotic system. The choice for this thesis was to develop a mechanized stencil system. The main reasons for this choice were the stencils target quality and the method's acceptability by the surveying crews. The process of developing a mechanized system is discussed in this chapter. This will include "the strawman concept" or initial idea of the system followed by a brief description of the design methodology used for its development. First, the current method of application is shown which will give some insight into the stenciling process and the danger incurred by the workers.

2.2 - Current Application Method

The current method of application of stenciling an "X" surveying mark on the roadway is a manual process. It consists of two sets of operations; first, the black background is painted and second, the white "X" mark is painted. These two sets are performed from one hour to two days apart depending on the availability of the crew. The time span between the two operations provides time for the black background to dry before the white "X" is paint that prevents the two paints from mixing together. Presented in this section is the white "X" painting operation.

Figure 2.1 depicts a series of pictures that show the application sequence of the stenciling operation for the "X" mark. The black background application sequence is similar to the white "X" sequence except it uses a different stencil. The following list describes the sequence depicted in Fig. 2.1a to Fig. 2.1h.

a) The black background is painted prior to the white "X".

b) The survey crew arrives at worksite and removes the template from the truck.

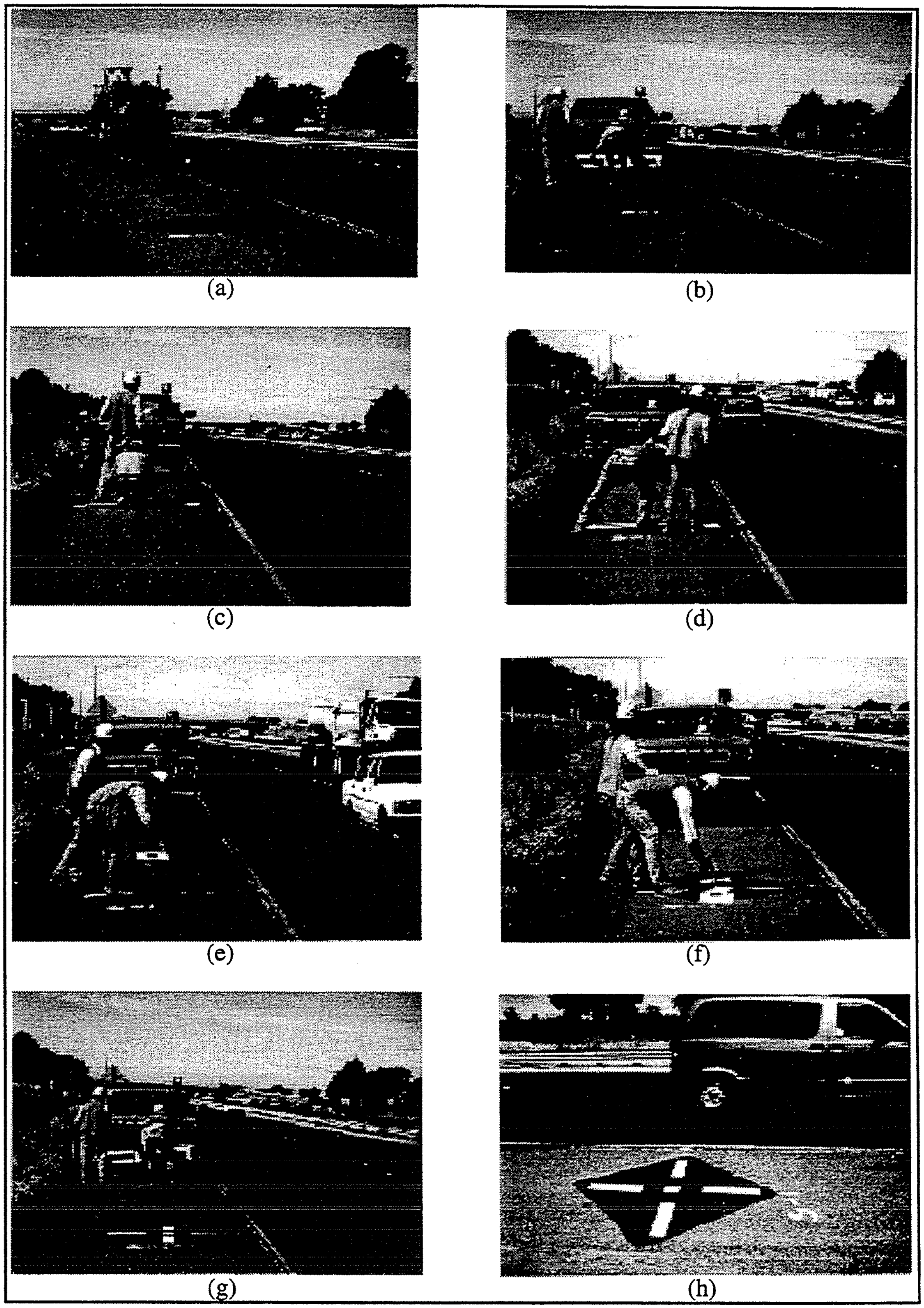


Figure 2.1 - Manual Sequence

c) The template is placed on black background for first leg of “X”.

d) The first leg is paint.

e) The template is rotated and positioned for second leg of “X”.

f) The second leg is painted

g) The template is placed onto the truck and the crew moves to the next location.

h) A picture of the completed control point target.

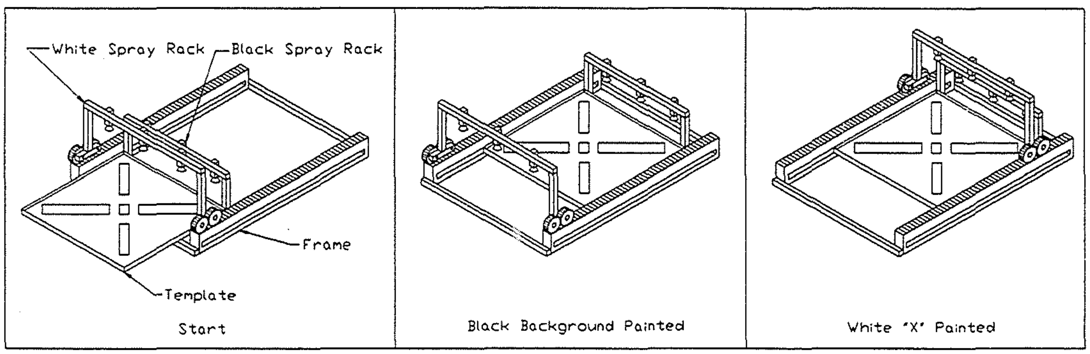
As it is clear in the figure, the crew has to work in proximity to the flow of traffic during the stenciling operation. The average time for painting the white “X” mark is 4 minutes. The black background has a similar time span which exposes the crew to traffic for a total time of 8 minute. So, it is therefore clear that a mechanized stenciling system that can be operated from within the vehicle will help reduce the risk from adjacent traffic to the survey crew. The next section will deal with this problem.

2.3 - Mechanized Stencil System

The mechanized stencil system developed in this thesis uses the same operational concept as the manual method using a mechanical stencil. The difference is in the manipulation of the template and the paint gun. In order to develop such a system, first a strawman concept was developed. This strawman concept is shown in Fig. 2.2.

It consists of a rack of black spray guns, a rack of white spray guns, an “X” template, a frame to support the system, and two drive mechanisms. Fig. 2.2(a) shows the system in its start position. From this position, the system would activate the black paint guns and their drive mechanism. The rack would move across the frame and paint the black background while pulling the “X” template into position as shown in Fig. 2.2(b). The system would then activate a drying system to dry the black paint. The final step would be to activate the white spray guns and their drive mechanism. The rack would move across the template and paint the white ”X” as shown in Fig. 2.2(c).

The development of this type of system could eliminate the need for two separate painting operations and help reduce the danger to the crew member by allowing the system to be controlled from a protective vehicle. A design methodology was followed in the development of the mechanized stenciling system. Briefly, the methodology consisted of producing target specification, performing tests to see if the system is feasible, and developing the system requirements based on the test results. Once the system requirements were developed, the detailed design of the system was completed and the system was built and tested.



(a) (b) (c)

Figure 2.2 - Strawman Concept

Chapter 3 - Feasibility Tests and System Requirements

3.1 - Introduction

As stated earlier, the objective of this thesis was to develop a method or device to mechanize the current process of painting targets onto the road surface with a stencil. The first stage in the development of the Premark Mechanized Stencil (PMS) was to produce a logical design method that would accomplish this goal. This method can be described as a series of steps that eventually leads to the design specifications and the prototype of the mechanized system.

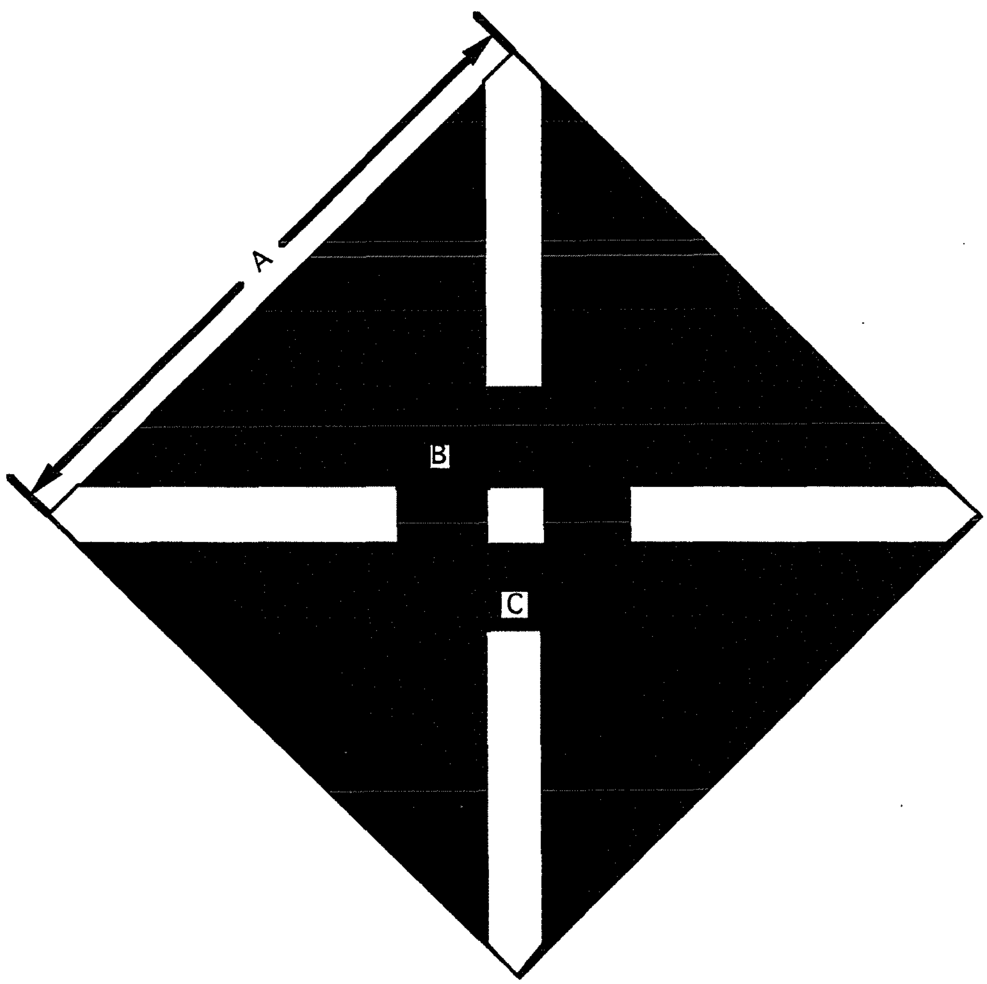
Briefly, the first step was to produce a set of specifications for the target. These specifications include dimensions, placement, and paint properties. The next step was to test equipment that was deemed necessary for the project. The last step was to produce a set of system requirements from the data acquired in the previous two steps. This chapter will describe each of these steps in greater detail and show the interaction between them.

3.2 - Target Specifications

The first step in the design of the PMS was to develop a set of specifications that would give an engineer as much information as was available concerning the target and its use. The specifications presented in this section were developed through research of the photogrammetry methods used in surveying. Some of the specifications such as size, shape, and location of the target had already been established through the ongoing use of the target, but other specifications such as paint properties have not yet been establish. The following sections will give more information on the specifications of the system with some provisions provided for more specifications. These provisions will allow for adjustments in the specifications during the later stages of the design process.

3.2.1 - Target Dimensions

The following section will show the diagram and dimensions of the target. The target shown in Fig. 3.1 is in its idea configuration. This ideal state was what the project was trying to obtain, but if this ideal pattern could not be achieved, other provisions were made to accommodate the design process. In Figs. 3.2a, b, and c, the alternative patterns are shown. The main criteria's for the target was to paint the pattern as shown, with the correct dimensions, and a high contrast of the white "X" on a black background.



A: 45″ ± 1″ (114.3cm ±2.54cm)
B: 7″ +1″ / -0″ (17.78cm +2.54cm / -0)
C: 4″ ± 1/2″ (10.16cm ±1.27cm)

Figure 3.1 - Ideal "X" Premark Dimension and Pattern

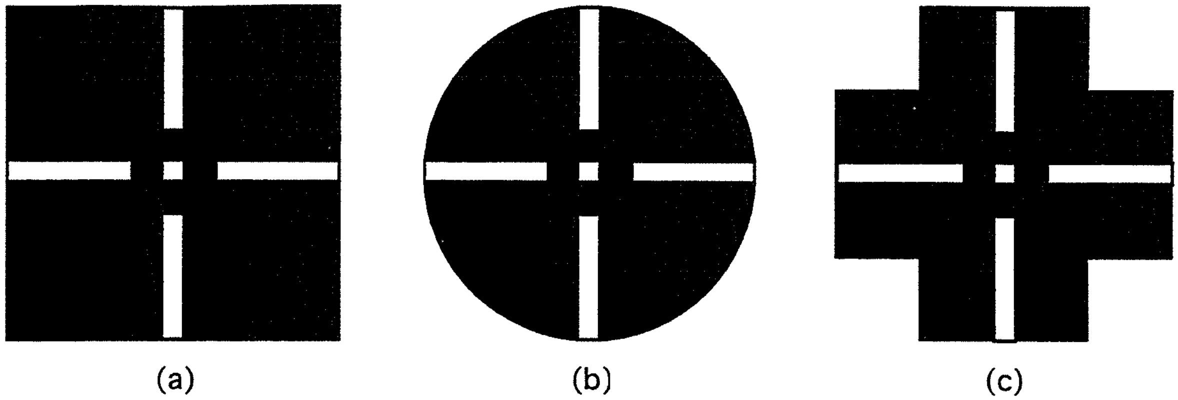


Figure 3.2 - Alternate Target Patterns

3.2.2 - Target Placement / Orientation

This section describes the placement and orientation specifications of the targets onto the roadway. These specifications are crucial for the photogrammetry specialist and the survey crews in producing an accurate description of the highway. They were chosen to provide the necessary accuracy with minimal labor and cost.

The placement and orientation specifications are more suitable for the development of a delivery vehicle and not the PMS system that performs the painting operations, but they must be taken into consideration because the location of the target effect the PMS in certain areas of operation and in the paint quality itself. The following list describes those specifications (Ref. Fig. 3.3):

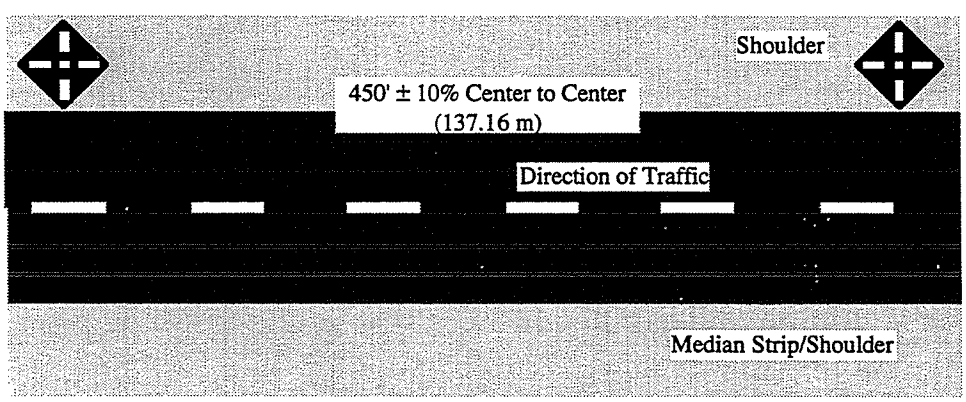


Figure 3.3 - Ideal Location and Orientation of "X" Premark

- Spaced 405 to 495 feet (123.44 to 150.88 m) apart along the roadway.
- All targets will be placed in non-traffic areas such as shoulders.

  Exception: If no such area exists, place the target in traffic lanes.
- Ideally should be oriented $\pm 5^\circ$ to direction of traffic.
- Target may be rotated to accommodate narrow shoulder conditions.

The first specification does not effect the performance or design of the PMS; it is more suitable for the delivery system development. The second specification would effect the type of paint used in the system in the area of durability. The last two specifications could deal in the delivery system, but can also be incorporated into the end effect itself. They will be considered during the design stage.

3.2.3 - Paint Properties

The purpose of this section is to describe the specifications and requirements for the paint itself. Some of the requirements had been established by photogrammeters, such as the paint color, but most were determined during the experimental stage of the design. The following list gives a brief description of each area of concern:

Color

White: Inorganic - titanium dioxide pigment suggested

Black: Inorganic - carbon pigment suggested

Refractive Index

Low as possible. Paint should be extremely flat. Exact requirements were found experimentally.

Durability

Premark should last at least 10 weeks with little degrading with a lifetime of 12 weeks.

Premark should survive in the following environment:

• TEMPERATURE: -20°F to 120°F (-29°C to 49°C)

• WEATHER: Salt spray test of simulated 10 week's length.

• LIGHT FASTNESS: UV radiation simulation of 10 weeks.

• CONGESTION: Normal shoulder use.

Bleeding Characteristics

There should be no mixing or discoloration of paint if one color is painted onto another.

Hiding Power

Only one coat of paint should be required to ensure sharp color with no road surface color showing through.

Substrate

Paint should adhere to all road surface types (AC - Asphalt Concrete, PCC - Portland Cement Concrete).

Drying Time

As quickly as possible. Ideally, within 15 minutes.

Coating Requirements

Ideally, 1 coat. Will be determined experimentally.

Paint Thickness

Thick as required to insure hiding power. Will be determined experimentally.

3.2.4 - Appearance of Target

The following list is the criteria related to the sharpness of the target. These specifications will be assessed further during testing.

• All edges of white areas on target should be crisp and well defined. Dispersion should not exceed 1/4" (.635cm) on an edge.

- Edges of white areas should not waver more than 1/4" (.635cm).
- White areas should contain at least 95% white paint visible on top layer.
- Black areas should contain at least 95% white paint visible on top layer.
- Halation effects: Due to the effects of white appearing larger than black from the air, the black gap between white areas should be large enough to be visible in the photographs. The gaps were determined by the photogrammeters and will be evaluated during testing.

3.2.5 - Safety

Improved safety was one of the main goals of this project. The following list describes the requirements that will help achieve this goal.

- Operator should be able to operate system from safe area (i.e. cab of truck, bed of truck).
- Complete system should only travel and work in one lane width area.
- Mechanism should be sturdy with no loose parts that may effect other vehicles.

3.2.6 - Environmental Concerns

The mechanism and paint must comply with all environmental codes enforced by the state of California.

3.2.7 - General Operation

The general operation requirements of the mechanism are presented in the following list.

- One operator should be needed to run the system (ideally the driver).
- The controls should be simple and easy to operate.
- The system should be able to be run either automatically or manually.
- Survey section is responsible for training operators.

3.2.8 - Maintenance

Another goal of the project was to design a device that was easy to maintain. The following list describes these requirements.

- "Off-the-shelf" items should be used in the design process.
- The system should be reliable with minimal parts and simple devices.
- Operators should be capable of fixing minor problems in the field.
- Maintenance schedules and inspection procedures should be developed after protoype field testing.

3.3 - Equipment Testing

The purpose of this section is to describe the test procedures that were used to determine the design parameters required in the development of the PMS system. The test goals were to develop an analytical model of the painting process, to construct a quantitative database for use in the design process, and to prove or disprove the initial design concept.

As stated previously, this project was to mechanize the current process of target stenciling. So for simplicity, the equipment and paints used during these tests were obtained through the equipment suppliers used by Caltrans, and when feasible, the exact equipment was used. This procedure allows the product being developed to be standardized with existing equipment. A sketch of the experimental setup is shown in Fig. 3.4. It consists of the following sub-systems.

- **Motorized Gantry System** - A test fixture developed for the painting evaluation tests. The fixture consists of a steel frame that supports a cable driven gantry. The fixture allows for both stationary and moving nozzle deposition tests. The speed of the gantry was controlled by changing the drive ratio between the fixed rate AC motor and the cable pulling the gantry.

• **SuperBee Electric Pump** - Binks model #41-9550 (BINKS Corp., Franklin Park, Illinois) is a small, high flow rate, high pressure pump powered by a 110VAC motor. The pump provided pressure regulated paint flows up to 2600 psi (17.93 MPa) and a flow rate up to 1/2 gal/min(.0315 L/sec). This pump is a standard item for the hydraulic atomized painting application used by Caltrans.

• **Automatic Air Actuated Gun** - BINKS model #550G is an air actuated paint gun used in hydraulic atomizing paint applications. This type of gun is used largely in traffic line striping and other automatic painting operations.

• **Assorted Tungsten Carbide Paint Nozzles** - Fan and hollow cone nozzles in different fan angles and orifice sizes were used in these tests. The orifices ranged from .015" - .021"(.038 - .053cm) in diameter and the fan angle from 20° - 90°.

• **Assorted Fluid and Air Fittings** - Various vendors.

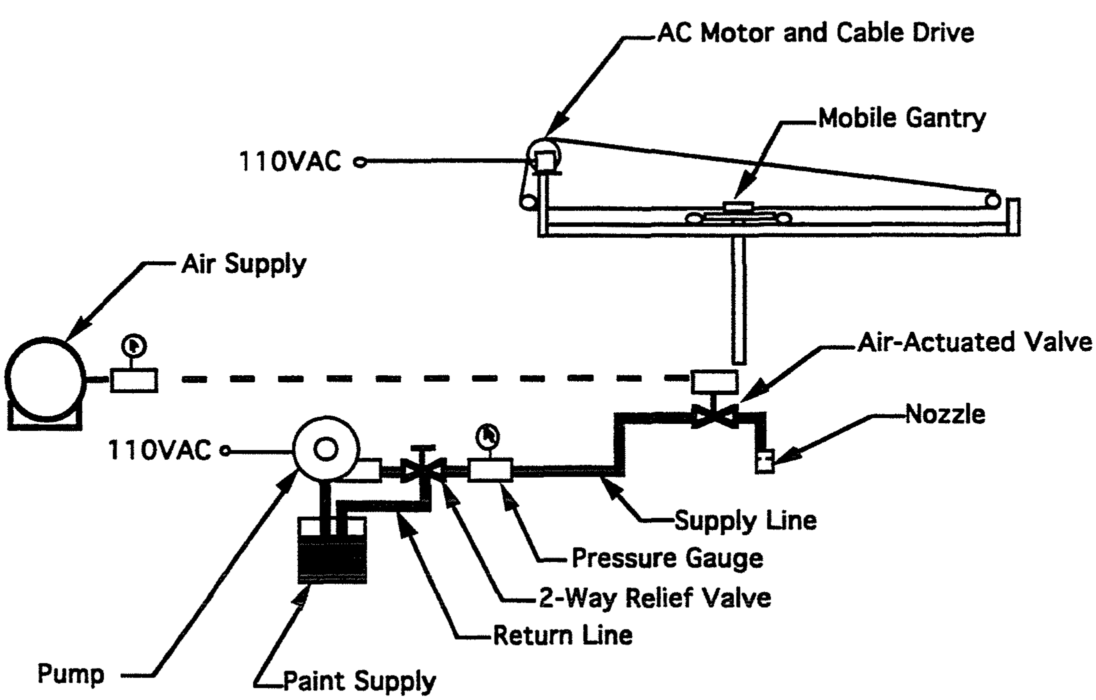


Figure 3.4 - Test Schematic

Using the apparatus shown in Fig. 3.4, tests were conducted to evaluate some of the process parameters in the stenciling operation as well as checking the validity of the initial design concept. A description of each test and its purpose are described in the following sections.

3.3.1 - Test 1: Equipment Calibration

The purpose of this test was to become familiar with the painting system and to calibrate the pump, the gun, and the gantry system. The following list will give a description of the test and the data recorded:

Test Description:

- Calibrate the painting equipment and gantry system.
- Verify the freedom of motion of the system while the paint and air systems are pressurized.
- While using all available nozzle configurations, obtain samples of the deposition characteristics under varying speeds, flow rates, and heights parameters onto test paper.

Test Data:

- Record the speed of the mobile gantry for each of the 4 speed settings.
- Record the best estimate of the optimal paint parameters.
- Save paper with paint deposition patterns for future evaluations.

3.3.2 - Test 2: Paint Parameter Evaluation

The purpose of this test was to determine the optimum combinations of painting parameters for the various nozzle geometries under evaluations. Two kinds of nozzle geometries were considered namely the fan-type nozzle and the hollow-cone nozzle. The two nozzles are shown in Fig. 3.5 and Fig. 3.6. The painting parameters under consideration were: flow rate, sweep velocity, fan-angle, height, and paint thickness. The tests in this section were performed for each nozzle geometry with paper as the painted surface. The selection standards were based on the specification requirements for paint deposition. The following list will give a description of the test and the data recorded.

Test Description:

Note: The following tests were performed using the medium speed on the gantry and the estimated optimum paint pressure and distance above painted surface obtained in Section 3.3.1.

- Conduct paint tests under varying pressure while holding distance constant.
- Repeat the tests above while holding pressure constant and varying the distance.
- Repeat the tests using the high speed setting and holding both the distance and pressure constant.
- Repeat the tests using the low speed setting and holding both the distance and pressure constant.

Note: The following tests were performed using the optimum parameters obtained in the tests performed above as a basis.

- Determine the effects of paint viscosity on the paint deposition.
- With the paper initially painted with black paint and dried, determine the minimum drying time for paint on painted surface.
- Determine maximum height above surface that will still produce adequate coverage of paint.

Test Data:

- Record the pressure, speed, water to paint ratio, distance above surface, and estimated paint thickness for thickness for each test run.
- Record the time for application of a second layer and evaluate the paint deposition for each test.
- Record height, speed, and pressure for maximum height above surface.

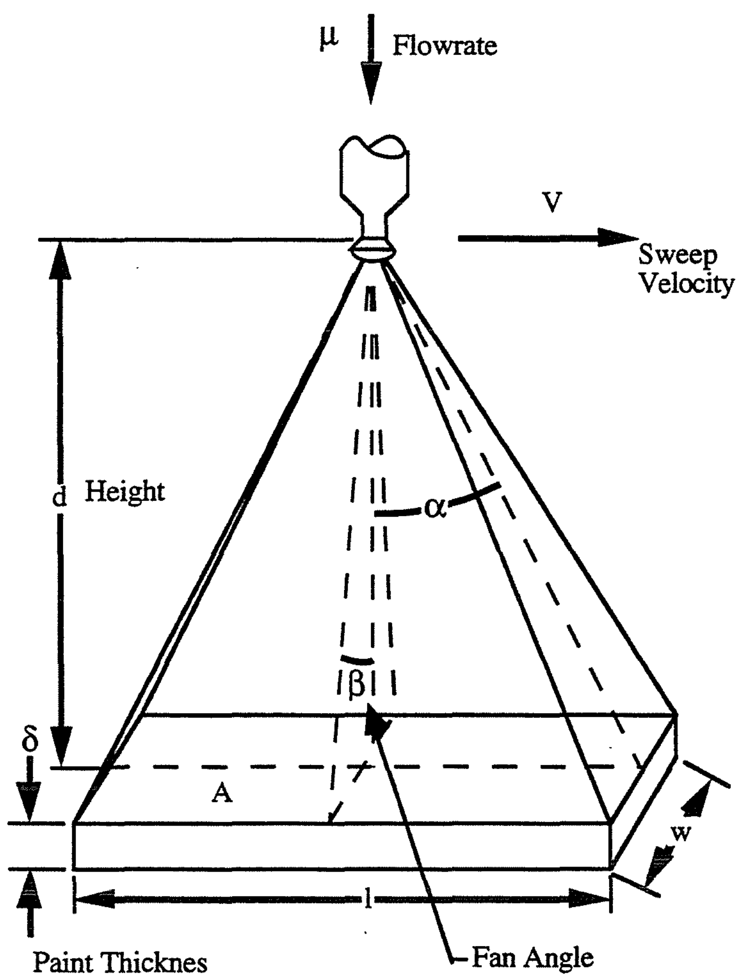


Figure 3.5 - Fan Type Nozzle Parameters

3.3.3 - Test 3: Edge Definition Evaluation

The purpose of this test was to evaluate the quality of edge definition for the template system. In addition, the effect of paint buildup was evaluated. The following tests were performed using the paint parameters and nozzle geometries determined to be optimal in Section 3.3.2. The tests were performed on paper using a straight-edge-sheet-metal template as stencil. The selection standards were based on the specification requirements for edge definition. The following list will give a description of the test and the data recorded.

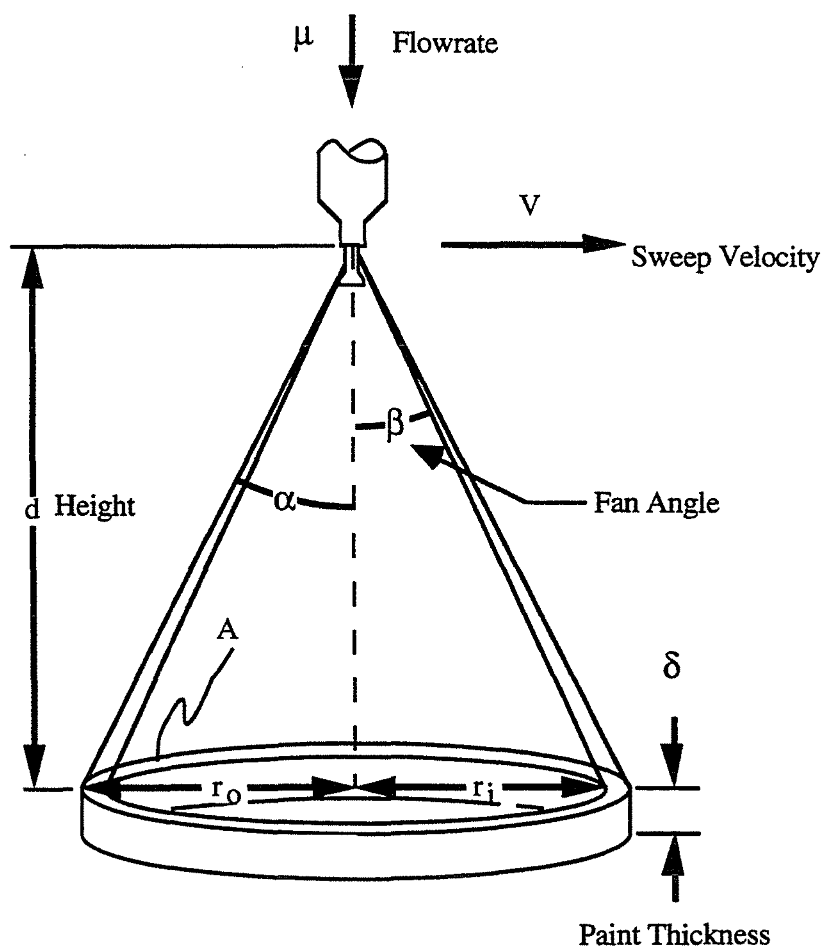


Figure 3.6 - Hollow Cone Nozzle Parameters

Test Description:

- With the paint gun moving and the height above the painted surface fixed, vary the distance between the centerline of the nozzle and the template's edge.
- With the paint gun moving and the distance between the centerline of nozzle and the templates edge fixed, vary the height above the painted surface
- With the paint gun moving and using the optimum parameters obtained from the above tests as a basis, vary both parameters to establish the optimum combination.
- With the paint gun moving and using the parameters from the last test, spray template with multiple passes to determine paint buildup effects. Do this on wet and dried paint.

Test Data:

- Record the centerline distances and evaluate edge definition.
- Record the height above painted surface and evaluate edge definition.
- Record the number of passes and evaluate the effects on the line definition for each pass.

3.3.4 - Test 4: Road Surface Test

The purpose of this test was to determine the effects of different road surfaces on the optimum parameters recorded in the previous tests. Also, the effects of surface preparation on the painted surface, its edge quality, and its durability were examined. The tests were performed on material simulating the road surfaces that meet the surface's properties and specifications. The following list will give a description of the test and the data recorded.

Test Description:

• Using a test surface free of debris, repeat the procedures from Section 3.3.3.

• Using the parameters established in the previous test, add various degrees of debris to the test surface and repeat the previous test.

Test Data:

• Record the variations of parameters and determine the optimum set for the specific road surface.

• Record the quality of the paint deposition for both conditions of with and without debris.

• Record the effects on the paint deposition in respect to the different surfaces.

3.4 - Test Results

In the previous section, an outline of the test procedures was described. In this section, the results of those tests will be shown. The test procedures described were a comprehensive outline of the tests that were deemed necessary to fully evaluate the equipment and process of stenciling. During the actual testing, many tests were deemed unnecessary as it became apparent that certain processes were not needed or would not work. The following sections will show the results of the testing performed that would aid in the design of the PMS system.

3.4.1-Test 1: Equipment Calibration

The first procedure for this section was to become familiar with the paint system and to calibrate it. This was done by painting several lines on strips of paper while varying the paint pressure and the nozzle types. These initial paint tests showed that there was a problem with pressure fluctuations in the supply pressure from the pump. The fluctuations were in the range of +/- 200 psi (1.38 MPa) measured at the pump's outlet. This fluctuation caused the width of the painted line to vary by approximately .50″ (1.27cm) along its edge. This was deemed unacceptable for further testing. After consulting with the pump's manufacturer, the pressure fluctuation was almost eliminated. This was done by adjusting the 'dead bang' switch that regulates the paint pressure at the outlet and by adding an additional 25′ (7.62m) of hose. The adjustment of the 'dead bang' switch reduced the pressure fluctuation to approximately +/-100 psi (.689 MPa), and the added hose produced a 50′ (15.24m) hose section between the pump and the spray nozzle. These adjustments resulted in acceptable performance at the nozzle.

The next step in the test was to measure the velocity of the gantry. This was done by recording the time required for the gantry to traverse a known distance that was placed between its acceleration and deceleration zones. The process was repeated ten times for each of the four speed settings and an average time was used to calculate the velocity. The following list shows the average speed for each of the speed settings:

Setting Number	Speed-ft/sec (cms/sec)
1	.32 (9.75)
2	.54 (16.56)
3	.75 (22.86)
4	1.0 (30.48)

The last step in this section of testing was to perform an initial evaluation of the two different nozzle configurations, fan and hollow-cone. This was done by obtaining paint samples of the various nozzles, and by varying the paint pressure and the gantry's speed for each. The nozzles were then assessed on their performance. Of the two nozzle types, the fan configuration appeared to be the most promising. Its initial quality, evaluated by the edge definition of the painted sample, was far superior than that of the hollow-cone types. The hollow-cone, in fact, did not develop a good flow pattern with the pressures obtainable from the pump. For this fact, the hollow-cone configuration was omitted from the rest of the testing, and the fan type was used for further evaluation.

3.4.2-Test 2: Paint Parameter Evaluation

In this test the paint parameters were evaluated to see what their effects were on the paint deposition. The primary paint parameters under consideration were the supply pressure, the nozzle height, and the nozzle speed. These three parameters were determined to have the most influence on the painting operations, and additionally, they are the easiest to control in an automatic process. The nozzles used in these tests were fan-type that consisted of the 9-1800 series with a .018″ diameter orifice and the 9-1500 series with a .015″ diameter orifice. The tests were performed using fan angles of 40, 60, and 90 degrees. To accomplish the evaluation, two of the three parameters were held constant while the third one was varied. The following sections are the results of the tests by individual nozzle.

Nozzle 9-1840

Test #1 Varying Height - In this test the pressure was set at 1700 psi (11.72 MPa), which was estimated from the previous test, with a pressure fluctuation of 100 psi (.689 MPA) when the gun was started. The speed was set at 1 ft/sec (30.48cm/sec). The results are shown in the following table.

Note: "Wave effect" is shown in Fig. 3.7 and was caused by a thick paint deposition. During the painting pass it was observed that the paint spray pushed the excess paint outward along the painted line's edge. This "wave" effected both the edge definition and the spray width. Another effect observed during this test was over spray. This appears as the height of the nozzle increases. This effect was do to the atomized paint getting blown outside the normal spray pattern. The effects are shown in figure 3.8. These terms will be used during the remainder of the nozzle tests when they appear.

Height	Spray Width	Comments
2.75 in (6.98cm)	3.0625 in (7.78cm)	The paint was thick enough to be pushed by the nozzle output flow. Less than optimal line definition, wave present.
3.625 in 9.21cm)	3.75 in (9.52cm)	Paint still thick, wave effect along both edges
4.75 in (12.06cm)	4.4375 in (11.27cm)	Paint thickness looks good, wave effect still present but not as great as previous runs. Over spray pattern developed along the edges.
4.0 in (10.16cm)	3.625 in (9.21cm)	Over spray pattern is just starting to develop. Wave effect is also present.

Test #2 Varying pressure - The height was fixed at 4" (10.16cm). The speed was set at 1 ft/sec (30.48 cm/sec). The test results are listed below.

Note: The pressure seemed to effect the width of the stripe by causing the spray angle to increase as the pressure increased. The actual relationship was difficult to determine since the "wave effect" greatly influenced the measured width of the deposition. The width seemed to stabilize above 2100 psi (14.48 MPa) which means the fan angle had fully developed.

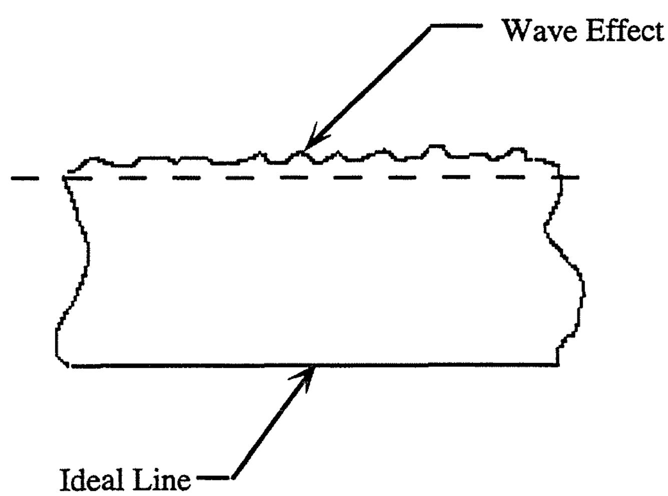


Figure 3.7 - Wave Effect

Pressure	Spray Width	Comments
1900 psi (13.10 MPa)	3.75 in (9.52 cm)	Wave pattern increasingly apparent. Still slight amount of over spray
1500 psi (10.34 MPa)	3.125 in (7.94 cm)	Wave pattern is present but only have small amount of over spray
1300 psi (8.96 MPa)	2.875 in (7.30 cm)	Wave pattern still present along with small amount of over spray
2100 psi (14.48 MPa)	3.875 in (9.84 cm)	Wave pattern has larger amplitude still getting small amount of over spray

Test #3 Varying Speed - The height was fixed at 4″ (10.16 cm). The pressure was set at 1700 psi (11.72 MPa). The results of the test are listed below.

Speed	Spray Width	Comments
.75 ft/sec (38.1cm/s)	3.5 in (8.89 cm)	Wave pattern increases in amplitude from higher speed, very little over spray.
.54 ft/sec (27.43cm/s)	3.75 in (9.52 cm)	Wave pattern continues to increase in amplitude, no over spray
.32 ft/sec (16.26cm/s)	4.375 in (11.11 cm)	Wave pattern amplitude very large, no edge quality, no over spray

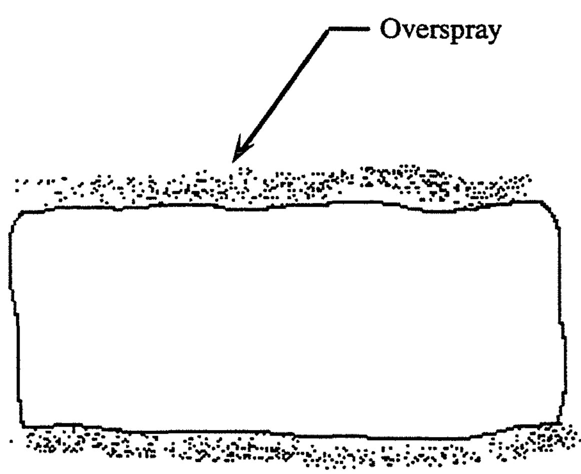


Figure 3.8 - Over spray

Nozzle 9-1890

Test #1 Varying Height - The pressure was fixed at 1700 psi (11.72 MPa). The speed was fixed at 1 ft/sec (30.48 cms/sec). The test results are listed below.

Height	Spray Width	Comments
2.75 in (6.98 cm)	5 in (12.70 cm)	No wave pattern present, the coating thickness is near optimal, slight over spray pattern present
4.75 in (12.06 cm)	8 in (20.32 cm)	No wave pattern, the paint is thin, large amount of over spray pattern

Test #2 Pressure - The height was fixed at 2.75" (6.98 cm). The speed was fixed at 1 ft/sec (30.48 cm/sec). The nozzle was left in a position rotated 45° (.785rad). The results are shown below.

Pressure	Spray Width	Comments
1900 psi (13.10 MPa)	4.875 in (12.38 cm)	Very slight wave pattern present, light over spray
2100 psi (14.48 MPa)	5 in (12.70 cm)	Slight wave pattern, same amount of over spray
2300 psi (15.86 MPa)	4.875 in (12.38 cm)	Slight wave present, same over spray

Test #3 Speed - The Height was fixed at 2.75" (6.98 cm). The pressure was fixed at 2300 psi (15.86 MPa). The results are listed below.

Speed	Spray Width	Comments
.75 ft/sec (22.86 cm/s)	5 in (12.70 cm)	Large wave pattern, light over spray
.54 ft/sec (16.46 cm/s)	5.5 in (13.97 cm)	Wave pattern increasing, very little over spray

Nozzle 9-1860

Note: The height test was the only test run on this nozzle. It seemed that enough data was available on the 1800 series nozzles to extrapolate the results of the other tests.

Test #1 Varying Height - The pressure was fixed at 1900 psi (13.10 MPa). The speed was fixed at 1 ft/sec (30.48 cm/sec). The results of the test are shown below.

Height	Spray Width	Comments
2.75 in (6.98 cm)	4.625 in (11.75 cm)	Wave pattern present along the edges, slight over spray pattern present
3.625 in (9.21 cm)	5.875 in (14.92 cm)	Wave pattern present, light over spray

Nozzle 9-1540

Test #1 Varying Speed - The height was set at 3.9375″ (10.00 cm). The pressure was set at 1700 psi (11.72 MPa). The results are listed below.

Speed	Spray Width	Comments
1 ft/sec (30.48 cm/s)	2.5 in (6.35 cm)	Large wave pattern, no over spray
.75 ft/sec (22.86 cm/s)	3 in (7.62 cm)	Wave pattern increasing in amplitude, no over spray
.54 ft/sec (16.46 cm/s)	3.5 in (8.89 cm)	Wave pattern increasing in amplitude, no over spray

Test #2 Varying Pressure - The height was fixed at 3.9375″ (10.00 cm). The speed was fixed at 1 ft/sec (30.48 cm/sec). The test results are listed below:

Pressure	Spray Width	Comments
1900 psi	2.75 in	Wave still very large, no over spray
1500 psi	2.375 in	Wave present, no over spray
1300 psi	2.125 in	Wave still present, no over spray

Test #3 Varying Height - The pressure was fixed at 1500 psi (10.34 MPa). The speed was fixed at 1 ft/sec (30.48 cm/sec). The results of the test are listed below:

Height	Spray Width	Comments
3.9375 in (10.00 cm)	2.375 in (6.03 cm)	Wave very large, no over spray
5.75 in (14.60 cm)	2.75 in (6.98 cm)	Wave still large, no over spray
8.75 in (22.22 cm)	3.125 in (7.94 cm)	Wave pattern decreasing, over spray is present
7.50 in (19.05 cm)	3.0 in (7.62 cm)	Wave pattern is present, slight over spray is present

The final tests on the 9-1500 series were deemed unnecessary. Their properties appear to be similar to the 9-1800 series except for the flowrate which is associated with the pump pressure and the nozzle's orifice. The speed change and the height change test appeared to be similar between the two series. The data collected for the 9-1800 series was considered adequate to choose the correct painting parameters for this design.

3.4.3-Test 3: Edge Definition Evaluation

To simulate the template design a fixture was made which consisted of aluminum sheets of .050″ (.127 cm) thickness cut into 3″ by 20″ (7.6 by 50.8 cm) strips. The aluminum strips were then sandwiched between strips of wood .5″ (1.27 cm) thick. Figure 3.9 shows a drawing of the fixture. For testing, the edge of the template fixture was placed at 1″ and 2″ (2.54 cm and 5.08 cm) from the centerline of the spray nozzle. These tests were performed using a 9-1860 nozzle, a paint pressure of 2000 psi (13.79 MPa), and a sweep speed of 1 ft/sec (30.48 cm/sec). The observations and comments are summarized in the following table.

Note: While the tests were being performed, it was noticed that the paint accumulated on the template edge. The paint accumulation tended to drip off the edge of the template after 3 passes. This dripping paint produced splatter marks on the edge of the stripe causing the line definition to be unacceptable. Also, it was observed that on multiple passes the paint spray tended to push the excess paint off the edge of the template.

	Height of template above surface	Edge of stripe from centerline	Comments & Observations
Template 2″ (5.08 cm) from nozzle center	0.5″ (1.27 cm) 1.0″ (2.45 cm) 1.5″ (3.81 cm)	2.1″ (5.33 cm) - -	clean line, slightly over spray outside the range of spray outside the range of spray
Template 1″ (2.54 cm) from nozzle center	0.5″ (1.27 cm) 1″ (2.45 cm) 1.5″ (3.81 cm)	1.0″ (2.45 cm) 1.25″ (3.17 cm) 1.625″ (4.13 cm)	clean line slight over spray slight over spray (All these cases gave good edge definition)

Further tests were performed to prevent the dripping paint from effecting the line definition. These tests used a template with the edges of the template bent at a 45° angle instead of the straight edge. The tests proved successful in eliminating the accumulation of paint on the template's edge, thus preventing dripping. The final design would have to take this into consideration.

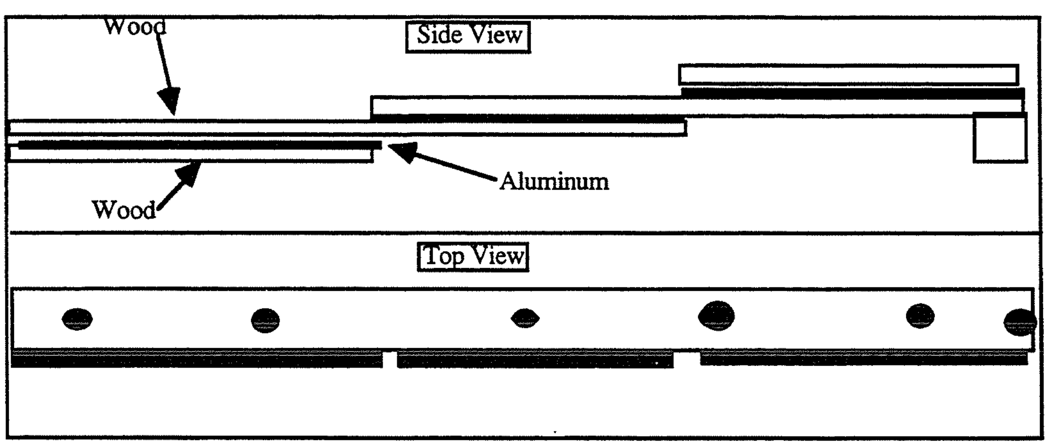


Figure 3.9 - Template Test Fixture

3.4.4-Test 4: Road Surface Test

Until this point, all the tests were performed on paper. To get an accurate assessment of the painting parameters, test#3 at a distance of 1.0" (2.54 cm) from the spray centerline was performed on a simulated road surface made out of roofing material. This material represented the road surface in both texture and consistency. The paint was sprayed using the same parameters as in test#3. The following observations were made.

1. The painted line distances and the over spray were the same as with the paper test.
2. The line definition was not as sharp, due to the coarseness of the surface, but was within acceptable range.
3. A spray pressure of 2300+ psi (15.86 MPa) improved the quality of the paint stripe.
4. The drying time was five times longer then it was on the paper.

3.4.5-Test 5: Paint on Paint Test

The following test was not presented in the test plans described earlier, but was deemed essential for the design. The template design makes it necessary to spray white paint on top of black paint. This test was performed to determine the minimum drying time required for the black paint before the white paint could be applied. All tests were performed on paper with the 9-1860 nozzle at a 1900 psi (13.10 MPa) paint pressure, a nozzle height of 2.625" (6.67 cm), and a speed of 1 ft/sec (30.48 cm/sec). The following results were observed:

Paint Application	Coverage	Comments
Fresh	Complete bleed through	Two paints mixed
1 minute	90% bleed through	no edge definition
2 minutes	50% bleed through	degraded edge definition
3 minutes	30% bleed through	edge acceptable
4 minutes	20% bleed through	edge acceptable
5 minutes	no bleed through	edge acceptable
6 minutes	slight bleed through	edge acceptable

The test was repeated with the black undercoat blown quickly with compressed air before the top coat was applied. The follow table shows those results.

Paint Application	Coverage	Comments
Fresh	90% bleed through	degraded edge
1 minute	50% bleed through	degraded edge
2 minutes	30% bleed through	acceptable edge
3 minutes	20% bleed through	acceptable edge

At the final test, the paint was blown for 1 minute before applying the top coat. This resulted in about a 10% bleed through (in thick spots) with acceptable edge definition.

3.5 - System Requirements

In this section the requirements of the system are presented. These requirements are based on the results of the tests from the previous section and will show a range of values for painting parameters and other items that deal with the stencil template itself. The following is the list of those requirements:

1. The paint guns and nozzles used in the experiments are deemed adequate for the stencil application. The nozzle configuration best suited for this design are the fan-type with an orifice range of .015" to .018" (.038 to .056 cms) and a fan-angle of 60° to 90°. The final nozzle sizes were determined after the prototype testing

2. One of the critical parameters in the stencil design is the paint supply pressure. During testing, it was shown that a minimum of 1700 psi (11.72 MPa) was necessary to maintain a proper flow through the nozzle. Further test revealed that with a higher pressure, in the range of 2500 to 3000 psi (17.24 to 20.68 MPa), the

paint deposition was more satisfactory. This higher pressure also helped prevent the nozzles from plugging.

3. Another critical parameter is the nozzle sweep speed. The speed and the paint supply pressure effect the paint thickness thus the appearance of the painted surface. During testing, a maximum speed of 1 ft/sec (30.48 cm/sec) was obtained with satisfactory results, but it was determined that a higher speed could be used with the higher supply pressure. A variable speed up to 3 ft/sec (91.44 cm/sec) will be used in the prototype.

4. The last critical parameters in the design are the nozzle height and the stencil template height. The nozzle height above the template should be adjustable between 2" to 5" (5.08 to 12.70 cm). Depending on which fan-angle is chosen, the height will be chosen which gives the optimal coverage. The exact height will be determined during the prototype testing. The template height is more critical. This height is the distance between the template and the ground. It was shown during testing that a variation of this height effect both the stripes width and the amount of overspray, therefore, the stencil system must maintain a relative height above the ground. This can be done by situating the template on a device which will be placed directly on the ground. This device must have adequate compliance to conform to an uneven or sloping ground. A height of 1" (2.54 cm) was chosen from the test data which allows for adequate clearance of the template and good edge definition of the stripe.

5. The next requirement pertains to the template itself. The template must be developed to channel the excess paint away from the edges to prevent dripping and splattering. An edge angled at 45° seemed to be the best choice to

accomplished this goal. Also, the template must have some type of reservoir to store the excess paint so that the painting nozzle does not splatter the excess paint onto the premark.

6. The last requirement is in regards to the paint-on-paint test. The test showed that in order to get a good line definition the undercoat paint should be dry to the touch. On the road surface, the drying time was measured at approximately 30 minutes, but environmental conditions should vary this time. Further testing proved that if compressed air was blown onto the undercoating, the time was reduced by a factor of five. Therefore, the PMS system should incorporate an air drying system which will dry the undercoat paint and also help clean the surface to be painted.

This is the end of the feasibility testing and system requirement chapter. The next chapter will take all that was learned in this chapter and implement them into a prototype design. The requirements shown in this chapter are used to develop the design requirements for the prototype design of the PMS system.

Chapter 4 - Product Design and Analysis

4.1 - Introduction

In this chapter the actual product will be developed, but first a few issues must be resolved. In the preceding chapters, a strawman concept was described and several pieces of equipment deemed necessary for its development were tested. The initial strawman concept, shown here again in Fig. 4.1, was conceived with the idea of mechanizing the current process of stenciling with a template. After several pieces of equipment were tested, it was determined that the initial concept would not be feasible for several reasons that are listed below.

1. The size of the system would be a problem. The template itself would have to be 45" (114.3 cm) square or more. This dimension added with a frame, motor, and painting equipment would make the system bulky and hard to manipulate. The system must be developed in a more compact form.

2. It was shown that the paint sprayed from the top of the cutout and parallel to it produced an excellent mark while painting at an angle to the cutout did not. This initial concept would require the paint to be sprayed at an angle to the cutouts thus producing a mark of low quality.

3. It was found that edges of 45° on the templates cutouts worked more reliably than straight edges. This fact would make it difficult to produce a template with these features.

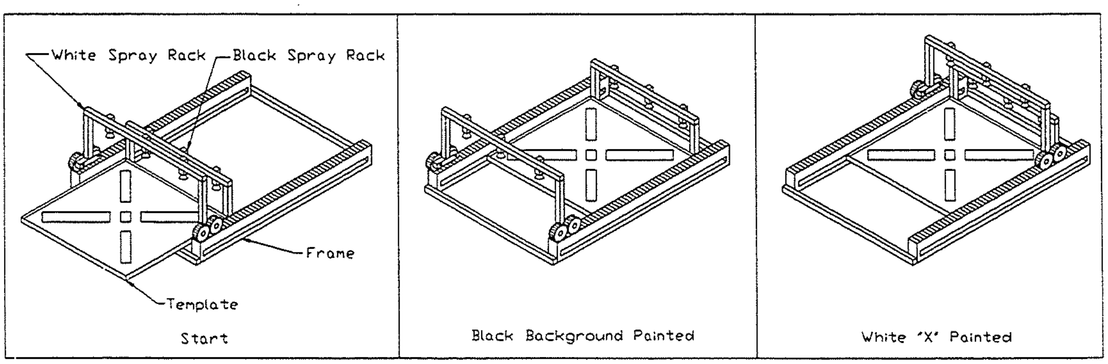


Figure 4.1 - Initial PMS Strawman Concept

Since the initial strawman concept was not realizable, determined by the data collected during testing, a new strawman concept had to be conceived. This new idea, as shown in Fig. 4.2, was based on the notion that the target is actually two straight, broken lines on a black background. The target, which consists of four legs with a center square, could easily be painted with a template that had two legs and the center square. The template could easily be produced with the required 45° angles on the cutout edges and a reservoir to hold the excess paint. The template could be housed in a frame which could be rotated with a rotation device. The paint guns could be mounted as shown and moved along the template with a linear slide system. The actual target would not be the ideal target pattern shown previously in Fig. 3.1, but would be one of the alternate targets, shown in Fig. 3.2(c) and again here in Fig. 4.3.

The sequence of operation would be to first paint one black leg than rotate the

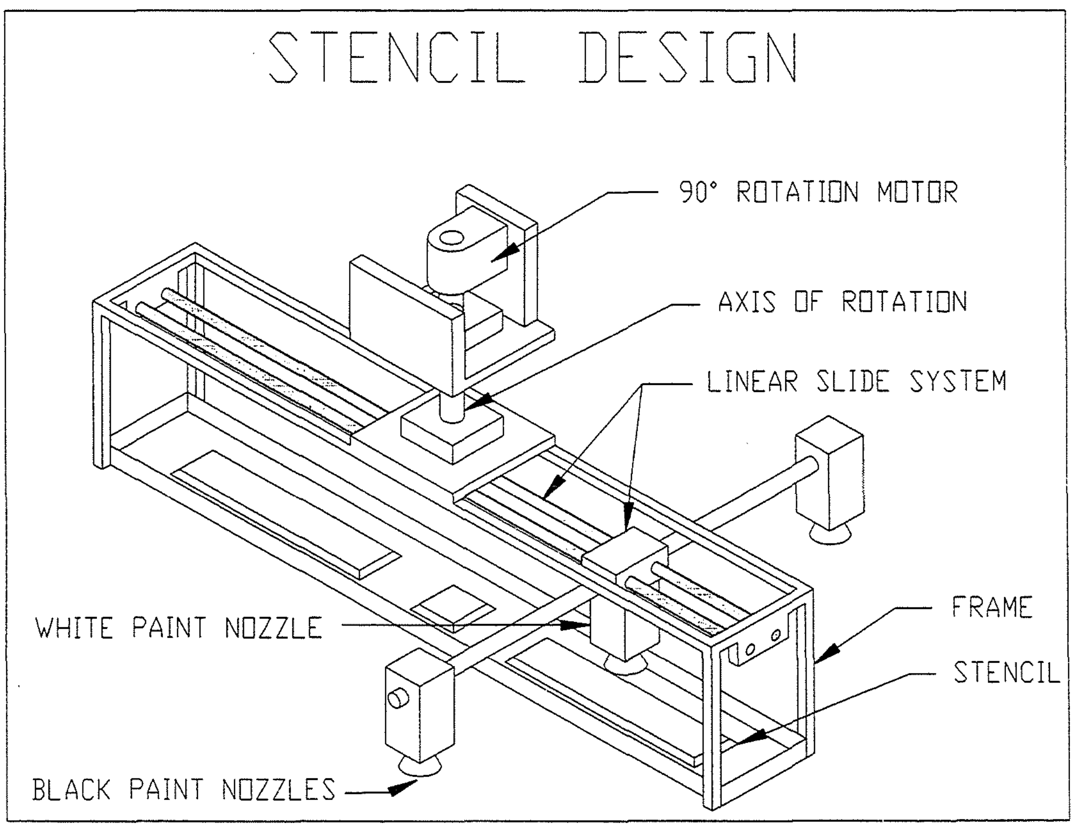


Figure 4.2 - Final Strawman Concept

frame and paint the second black leg. The unit would then be lowered to the ground and the first white leg painted. The unit would then be raised, the frame rotated, and the unit lowered again; at which time the second white leg would be painted. The unit would then be raised and the moved to the next target area. This unit and its sequence of operations would easily produce a target with the required specification mentioned before.

Now that the new strawman concept has been discussed, the remainder of this chapter will cover the steps taken which produced the PMS system from the strawman concept. Briefly, the first step was to established the design specifications that guided the product from its strawman concept to a working system. Next, each part of the system was designed or, in some cases, selected from existing products. This also included analysis of certain parts of the system. Finally, the complete assembly was produced with the required detailed drawings.

4.2 - Design Specifications

This section will describe the specifications that were required to design the PMS system. These specifications were based on the strawman concept shown in Fig. 4.2, the target specifications, and the results of the equipment testing. The list that follows was used as a guideline during the design of the PMS system.

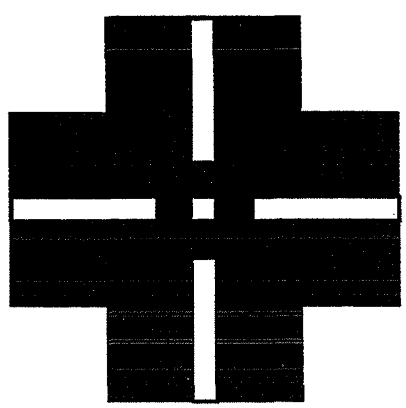


Figure 4.3 - Alternate Target

1. Workspace - In general, the workspace must fit inside of one lane-width of a roadway that is 10′ (3.05m) across. But to be more precise and for safety reasons, the workspace should not exceed the width of the vehicle used in positioning the PMS system. In this case, the vehicle being considered was a standard utility pick-up truck with a width of 7′ (2.14m). The height limit was also based on the positioning vehicle which has an approximate height of 6′ (1.83m). Based on this data, the system should fit in a workspace of 6′ high by 7′ wide by 7′ long (1.83m x 2.14m x 2.14m).

2. Power Requirements - Electricity and compressed air were chosen as the main power sources for the PMS system. Generators and air compressors are standard items in roadway maintenance. Since nothing has been design, an estimate of the required power was made for each item. The generator needs an estimated minimum of 4.0KW of power with 110VAC. The air compressor needs a minimum of 125psi (86.18 MPa) at a flowrate of 10cfm (4.72 liters/sec).

3. Accuracy - The accuracy of the PMS system must be enough to meet the tolerances of the target specifications presented earlier in this thesis. Special considerations must be taken when designing both the rotation device and the template system because these two areas are deemed the most critical in producing a quality target.

4. Operations - The system should require only one person to operate, preferably the driver of the positioning vehicle. One press of a cycle start button would make the system active once the system was placed into the work area. The operator should not have to exit the vehicle to operate the system. Safety for the operator is the main concern of the design.

5. Fail-Safe Mode - The system should be provided with fail-safe devices which would bring the unit to a safe, transportable position. This should include turning off the painting system, turning off the linear slide system, and raising the unit to a safe distance above the ground.

6. Equipment - The unit should be designed with items that may be purchased from existing equipment. These off-the-shelf items should be as standard and readily accessible as possible.

7. Material - The material used in this design should be light and sturdy. The preferred material would be aluminum. Any uncomplicated moving or rotating device should be made from simple material such as bronze bearings instead of roller bearings. This material is more easily manipulated in an assembly.

8. Manufacturability - Any part which is designed should be of simple geometry with open tolerances. The unit should be designed with a minimal of close tolerance machine parts. Any part which is machined should be able to be manufactured in any shop available. No specialty tools should be needed to produce these parts.

9. Assembly - The entire unit should be designed for easy assembly. The design should allow a person to assemble the unit with the use of basic tools. No special tools should be required. The unit should include room for maintenance such as part replacement, equipment adjustment, and complete unit cleaning.

4.3 - Components Design and Analysis

An isometric view of the complete PMS system design is displayed in Fig. 4.4. It shows some of the major components. In this section, a detailed discussion of the design will be presented starting with the frame and working up to the mounting plate. This will include the selection of components that were to be purchased, the design of items that needed to be machined, and the analysis of certain portions of the system that helped in component selection and design. During the reviewing of this chapter, it may be helpful for the reader to refer to Appendix A where the assembly and detail drawings are located.

4.3.1 - Frame

The frame is the biggest structure of the PMS system. It supports the template and the linear slide system, and it connects them to the rotation/displacement system. It was constructed of aluminum with outside dimensions of 11.75" high by 10.625" wide by

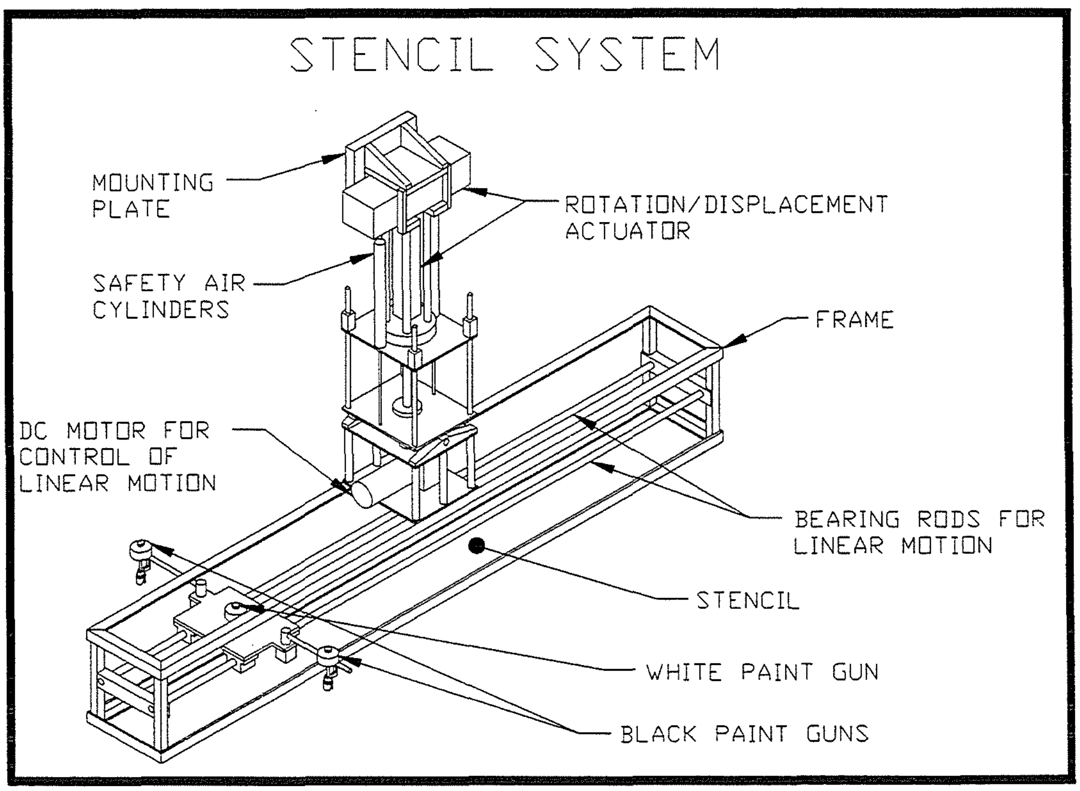


Figure 4.4 - PMS System

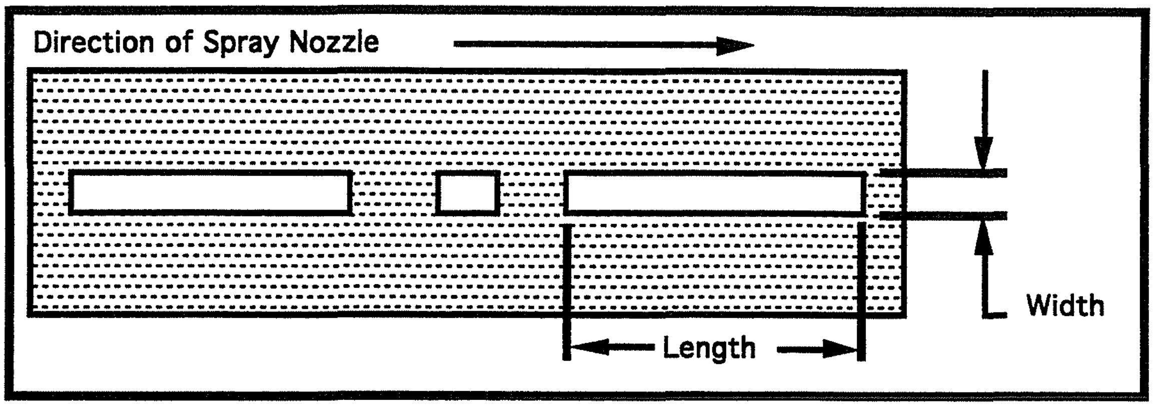


Figure 4.5 - Top View Template

81.5″ long (29.84cm x 26.99cm x 207.01cm). These dimensions are well within the required workspace.

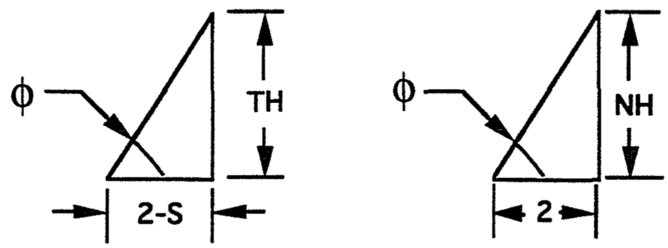
Since the loads on the frame are small (≈ 115 lbs, 511.5N) compared to the strength of the material (≈ 10 Mpsi, 6.9 GPa) [Avallone,1987], a strength analysis of the frame was deemed unnecessary. Also, the deflection of the frame should not be large and can be evaluated during prototype testing.

4.3.2 - Template Size and White Nozzle Height

The position of the template and the spray nozzle above the ground plus the dimension of the template cutouts were the most crucial parts of the PMS system. It was shown during testing that the height of the nozzle above the template effected the width dimension of the line while the template height above the ground effected the line quality. There was a relationship between these two dimensions and the size of the cutout in the template. Also, this relationship had to correspond with the fan-angle of the nozzle so that there was complete coverage of the cutouts. In this section, the width of the cutout, the height of the cutout above the ground, and the height of the nozzle above the template will be calculated. A top view of the template is shown in Fig. 4.5.

From testing it was shown that the edge quality of the target's lines was best when the cutout edge was between .50″ and 1.50″ (1.27cm and 3.81cm) above the ground; for these calculations the range was between .50″ to 1.625″ (1.27cm to 4.13cm). Also shown during testing was the best fan-angles for the spray nozzle were between 60° and 90°. The required line width was 4.0" (10.16cm). To help with the calculations, a side view of the template is shown in Fig. 4.6.

This diagram shows the relationship between the nozzle height (**NH**), the template cutout height (**TH**), the cutout width dimension (**S**), and the fan-angle (θ). With these variables and the simple equations listed below, a table of dimensions was calculated.



$$\tan\phi = \frac{TH}{2-S} \qquad (1) \qquad\qquad \phi = \tan^{-1}\left(\frac{TH}{2-S}\right) \qquad (2)$$

$$\theta = 180 - 2\phi \qquad (3) \qquad\qquad \theta = 180 - 2\tan^{-1}\left(\frac{TH}{2-S}\right) \qquad (4)$$

$$NH = 2 \times \tan\phi \qquad (5) \qquad\qquad NH = \frac{2TH}{2-S} \qquad (6)$$

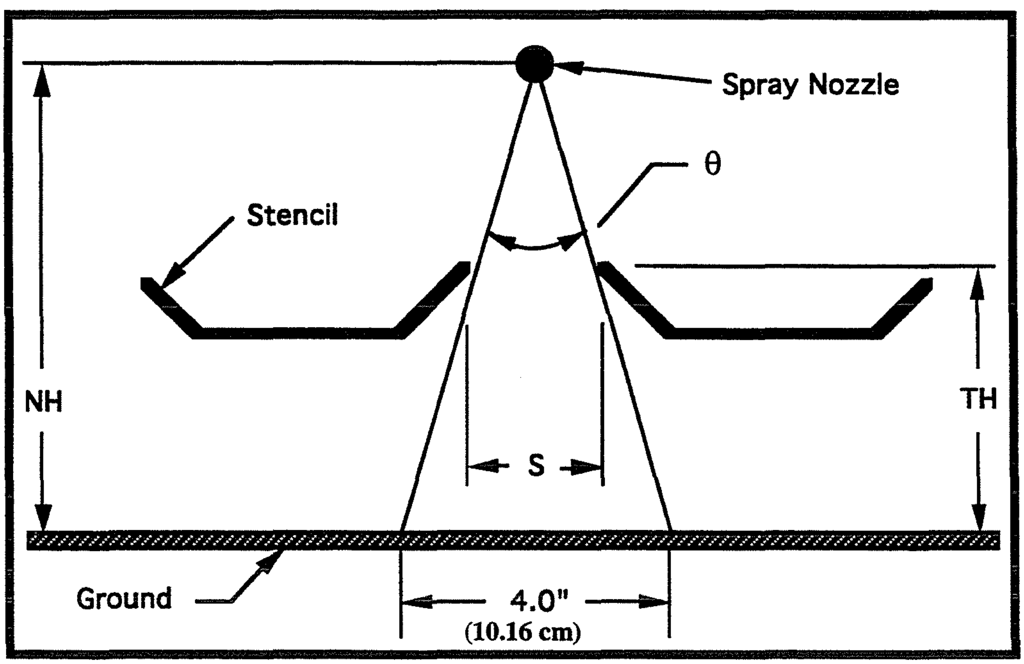


Figure 4.6 - Template Size Calculation

Since the template height (**TH**) was critical, it was varied in the equations while the cutout dimension was held constant. By doing this, the fan-angle (θ) and the nozzle height (**NH**) were calculated for each reading. Using Eqn. 4 and Eqn. 6, Table 4.1 was constructed to find the required dimensions.

From the table, the dimensions were chosen for each of the four variables; shown in highlight. The fan-angle of 53.1^{o} was the minimum allowable, so the nozzle used was above 60^{o}. The nozzle height was designed to be adjustable between 3.0 inches and 5.0 inches which allowed for any variation in the spray that was not foreseen. The length of

S (cm)	TH (cm)	Theta	NH (cm)
1.125" (2.86)	.5" (1.27)	120.5°	1.143" (2.90)
1.125" (2.86)	.625" (1.59)	108.9°	1.429" (3.63)
1.125" (2.86)	.75" (1.90)	98.8°	1.714" (4.35)
1.125" (2.86)	.875" (2.22)	90°	2.000" (5.08)
1.125" (2.86)	1.0" (2.54)	82.4°	2.286" (5.81)
1.125" (2.86)	1.125" (2.86)	75.8°	2.571" (6.53)
1.125" (2.86)	1.25" (3.18)	70°	2.857" (7.26)
1.125" (2.86)	1.375" (3.49)	64.9°	3.143" (7.98)
1.125" (2.86)	1.5" (3.81)	60.5°	3.429" (8.71)
1.125" (2.86)	1.625" (4.13)	56.6°	3.714" (9.43)
1.25" (3.18)	.5" (1.27)	112.6°	1.333" (3.38)
1.25" (3.18)	.625" (1.59)	100.4°	1.667" (4.23)
1.25" (3.18)	.75" (1.90)	90°	2.000" (5.08)
1.25" (3.18)	.875" (2.22)	81.2°	2.333" (5.93)
1.25" (3.18)	1.0" (2.54)	73.7°	2.667" (6.77)
1.25" (3.18)	1.125" (2.86)	67.4°	3.000" (7.62)
1.25" (3.18)	1.25" (3.18)	61.9°	3.333" (8.47)
1.25" (3.18)	1.375" (3.49)	57.2°	3.667" (9.31)
[redacted]			
1.25" (3.18)	1.625" (4.13)	49.6°	4.333" (11.0)
1.375" (3.49)	.5" (1.27)	102.7°	1.600" (4.06)
1.375" (3.49)	.625" (1.59)	90°	2.000" (5.08)
1.375" (3.49)	.75" (1.90)	79.6°	2.400" (6.10)
1.375" (3.49)	.875" (2.22)	71.1°	2.800" (7.11)
1.375" (3.49)	1.0" (2.54)	64°	3.200" (8.13)
1.375" (3.49)	1.125" (2.86)	58.1°	3.600" (9.14)
1.375" (3.49)	1.25" (3.18)	53.1°	4.000" (10.2)
1.375" (3.49)	1.375" (3.49)	48.9°	4.400" (11.2)
1.375" (3.49)	1.5" (3.81)	45.2°	4.800" (12.2)
1.375" (3.49)	1.625" (4.13)	42°	5.200" (13.2)

Table 4.1 - Template Calculations

the cutouts was the same as in the specifications, since the line dimension was not effected by the spray in that direction.

4.3.3 - Black Nozzle Positioning

The pervious section dealt, in part, with the white nozzle position which was more critical than the black nozzle positioning which will be discussed in this section. As shown previously in Fig. 4.4, the black spray guns were mounted on outriggers from the gun mounting plate. This configuration allows the paint spray to go underneath the template frame when the frame is raised above the ground. This arrangement was needed to achieve the requirements of a black background.

In Fig. 4.7 sketches of the outrigger and the gun are shown; the system requires two outriggers. The initial height of the nozzle was 14″ (35.6cm) when the system was in the raised position, and the initial distance from the centerline of the template was 12″ (30.5cm). These distances, along with a nozzle with a fan-angle of 90°, would give complete coverage of black paint underneath the template. To facilitate for any discrepancies in the spray pattern, the guns were made to adjust in both the up/down and left/right directions. The up/down direction was made to adjust ± 3.0″ (7.62cm), and the left/right was made to adjust ± 4.0″ (10.2cm). The exact position was determined during final testing.

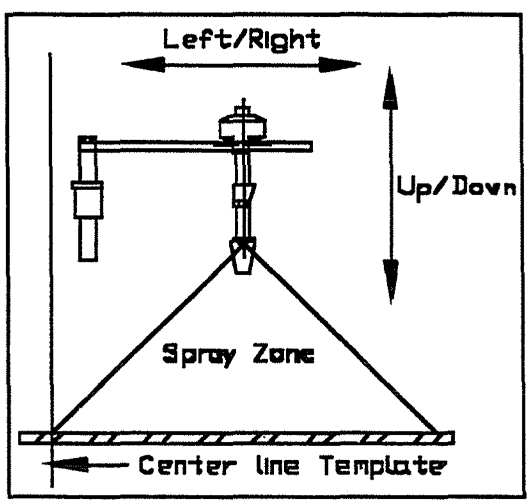


Figure 4.7 - Black Nozzle Positioning

4.3.4 - Linear Slide System

There were several systems that could have been used such as linear rails combined with a ballscrew drive system, a band cylinder, or linear rails combined with a cable driven system. The ballscrew system was not chosen because of the cost and the fact that the drive unit is situated at one end of the ball screw. That would cause the unit to have an un-symmetrical weight distribution. The band cylinder which is a rod-less air cylinder that moves a mounting plate was also not chosen because of its cost. The system that was chosen was the cable driven system shown in Fig. 4.8.

The system consisted of two .75" (1.9 cm) diameter linear rails, four linear bearings, two pulleys, a 3/16" (.48 cm) diameter 7 x 19 plastic coated aircraft cable (1/8" diameter wire rope) and a DC motor. The rails and the bearings were chosen because they were readily available, and the rails were assumed to be sturdy enough to accomplish the job. The cable was chosen because it was the smallest diameter wire rope available with a plastic coating. The pulleys are 2" diameter (50.8 cm) which is above the minimal required diameters of $14d_{wire}$ or 1.75" (44.45 cm) [Macwhyte, 1976] [Shigley, 1989]. This minimal required diameter is essential due to the risk of stress failure from bending. The DC motor was chosen because the system required the gun mounting plate to move at different speeds throughout its operations; the white spray, the black spray, and the debris cleaning and paint drying with compressed air all require different speeds to accomplish their task. The DC motor also allowed the system to be fine tuned during

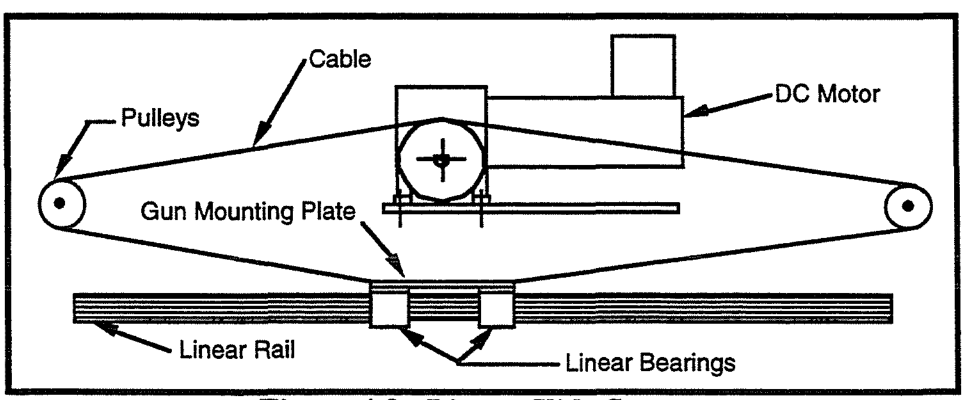
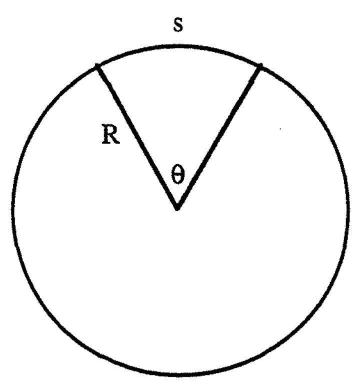


Figure 4.8 - Linear Slide System

final testing. Other features of the motor are that it had a right angle drive shaft that allowed for it to be centrally located for a balanced load and it had a drive speed of 175 RPM's (18.3 rad/sec) that could easily drive the spray guns at the required 0 - 3 ft/sec (0 - 91.44 cm/sec).

To get the required 0 - 3 ft/sec (0 - 91.44 cm/sec) speed, a drive wheel had to be designed. The drive wheel was a disc with a groove machined along its diameter. The groove was twice as wide as the cable that allowed the cable to be wound around its diameter. This configuration helped the wheel move the cable without slipping. The diameter of the groove had to be calculated to convert the 175 RPM (18.3 rad/sec) maximum rotating speed to 3 ft/sec (91.44 cm/sec). linear speed. From the following equations, the groove diameter was calculated to be 3.929" (9.98cm).



$$V = \text{Linear Speed} = \Delta s / \Delta t \qquad (1)$$

$$s = R\theta \qquad (2)$$

$$\Delta s = R\,\Delta\theta \qquad (3)$$

$$\omega = \text{Angular Speed} = \Delta\theta / \Delta t \qquad (4)$$

$$\omega = (\text{RPM}) \times 2\pi \qquad (5)$$

$$V = R\,\omega \qquad (6)$$

3 ft/sec = R x (2π)(175 rad/min) x (min/60 sec)

R = Groove Radius = .1637 ft = 1.964 in (4.99 cm)

Groove Diameter = 2R = 3.929 in (9.98 cm)

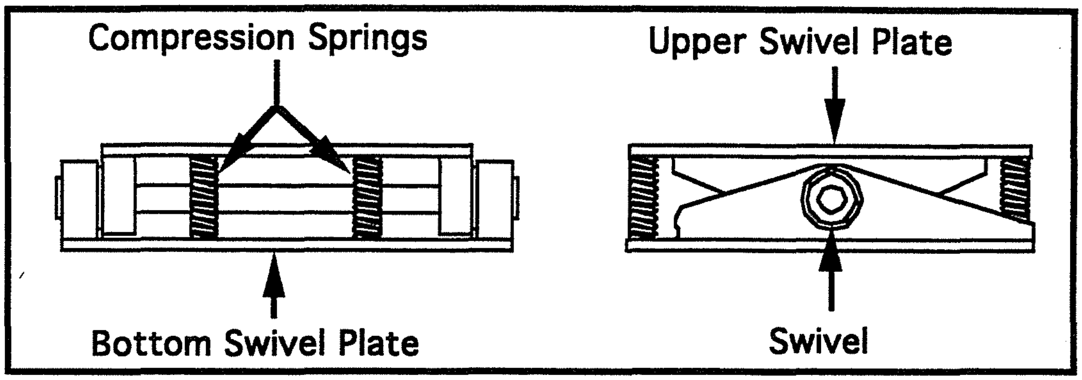


Figure 4.9 - Suspension System

4.3.5 - Suspension System

The suspension system consists of two plates that are connected by a swivel with four compression springs used for the suspension as shown in Fig. 4.9. The bottom swivel plate is mounted above the linear slide motor and is connected to the frame by six bars. The upper swivel plate is connected to the support system which will be discussed later. The configuration can be seen in Fig. 4.4. The suspension system gives the unit compliance that allows it to conform to the roadway since most roadways are not level. Another purpose for the suspension system is it will reduce the stress on the support structure if the frame is leaned upon.

A diagram of a spring in the preloaded, neutral, and compressed states are shown in Fig. 4.10. The suspension of the system consist of four compression springs; each are connected to the upper swivel plate by a bolt, a nut, and a retaining washer but are not

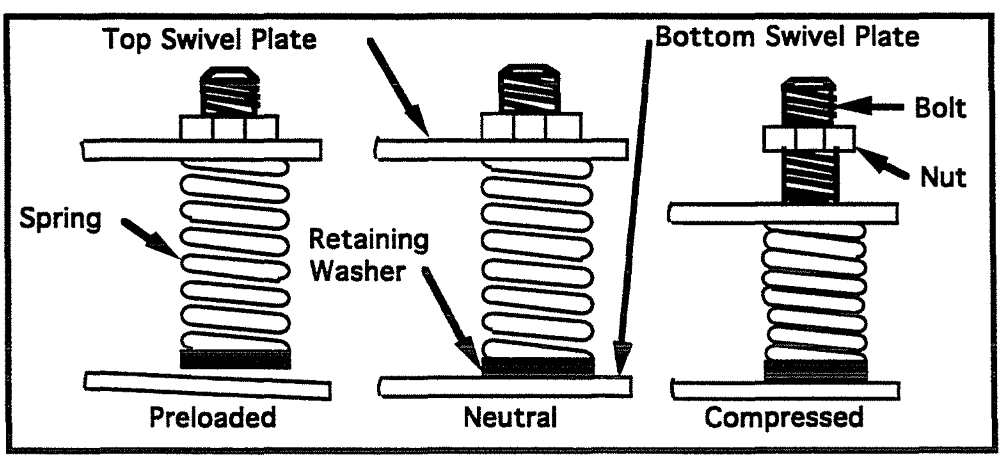


Figure 4.10 - Spring Configuration

connected to the bottom swivel plate. The springs are compressed between the top swivel plate and the retaining washer to give it a preloaded force. This preloaded force must be large enough to counteract the force caused by the positioning of the spray gun package.

To obtain the necessary force for the suspension, the correct springs had to be chosen. Fig. 4.11 shows two diagrams that were created with the required variables and dimensions (to help with the calculations). The top diagram shows the unit in a neutral position with the spray package center of mass at its furthest distance. This was determined to be the only offset weight in the design since the rest of the unit was

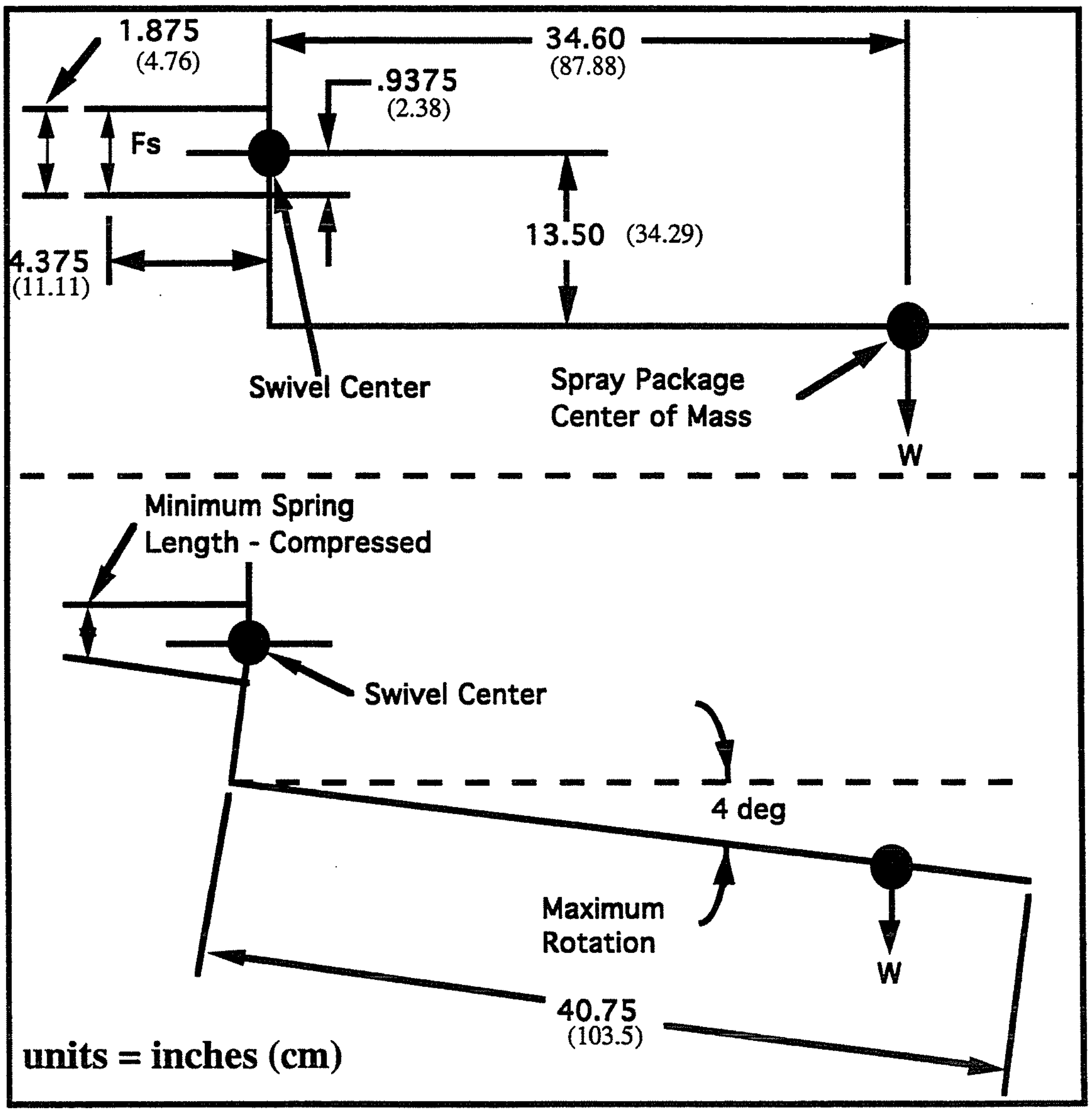


Figure 4.11- Diagram for Spring Calculations

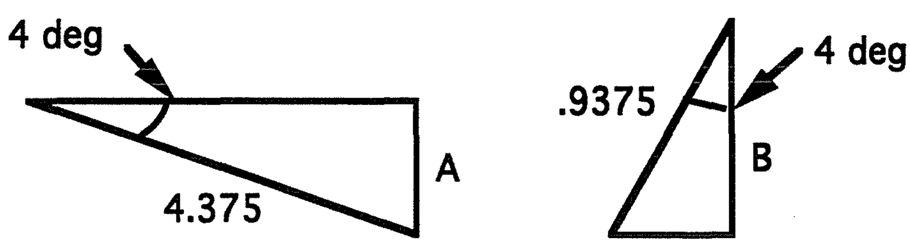
designed with a symmetrical weight distribution. The bottom diagram shows the unit at an angle of **4^o** that was estimated to be steep enough to conform to any non level road. By summing the moments around the swivel center, the preloaded force (**Fs**) was calculated, and by simple geometry, the minimal spring length in compression was calculated. These two variables, along with several given dimensions, helped in chosen the correct springs. The following calculations were used to determine those values.

Preloaded Force

$$\Sigma M_{SC} = 0 = 34.60(w) - 4.375(Fs) \tag{1}$$

$$Fs = 7.91(w) \tag{2}$$

Minimum Length



$$A = 4.375(\sin 4) = .305 \tag{3}$$

$$B = .9375(\cos 4) = .935 \tag{4}$$

By using the starting length of 1.875" (4.76 cm) and using Eqn.3 and Eqn.4 due to the rotation, the minimum spring length was calculated.

$$ML = 1.875 - .305 - (.9375 - .935) = 1.5675 \tag{5}$$

To choose the springs, a spring rate (**Sr**) had to be determined. This was done by choosing a **spring free length** of 2.0" (5.08 cm) and a spray package mass of 12 lbf (53.38 N).

$$Sr = Fs \,/\, (\text{Spring Free Length} - 1.875) \tag{6}$$

$$Sr = 94.9 \,/\, .125 = 759.2 \text{ lbf/in } (133 \text{ kN/m}) \tag{7}$$

This value was for one side of the suspension system that requires two springs. The real spring rate is 1/2 the answer in Eqn.7 which is 379.6 lbf/in (66.5 kN/m). This spring rate was the minimal rate required by the system. The actual springs chosen were much higher. The following list shows the requirements for the springs.

Spring Free Length	2.00 inches	(5.08 cm)
Spring Preload Length	1.875 inches	(4.76 cm)
Spring Compressed Length	1.567 inches	(3.98 cm)
Spring Preload Force (2 springs)	94.9 lbf	(422.13 N)
Spring Rate (2 springs)	760 lbf/in	(133 kN/m)

The rest of the system had a basic design. The plates were made out of aluminum, the swivel bearings were made from bronze material instead of enclosed ball bearing since the unit was not rotating at high speeds, and the swivel rod was made from .625" (1.59 cm) diameter stainless steel which was estimated to be strong enough to support the lower unit.

4.3.6 - Multi-Actuator, Mounting Frame, and Rotary Support System

The design requires that the frame be raised and lowered as well as rotated. The initial thought was to have two separate units to accomplish these tasks, but a component was found that could perform both duties. This multi-motion actuator, shown in Fig. 4.12, is a linear air cylinder in combination with a pneumatic rotating device. To use this type

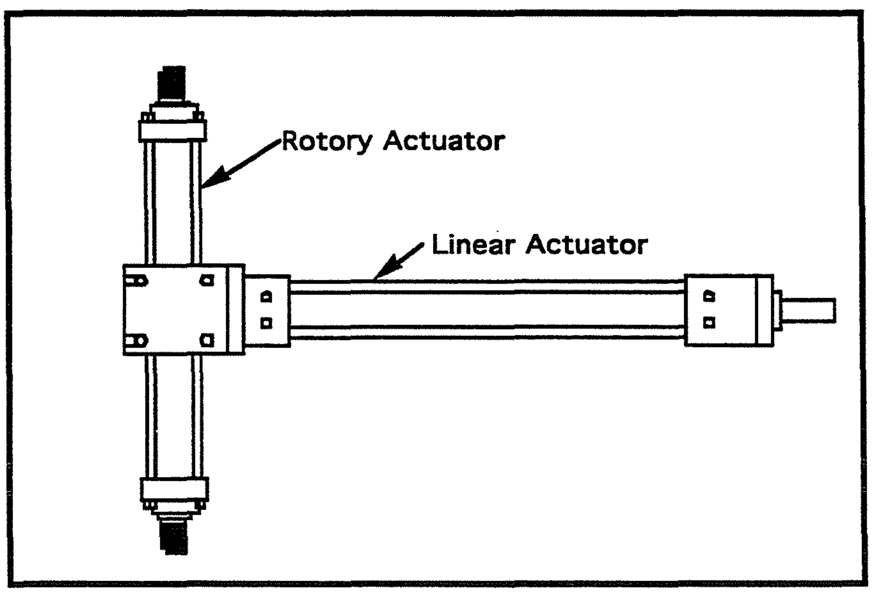


Figure 4.12 - Multi-Motion Actuator

of actuator, a support system had to be designed that would rotate as well as reduce the sideload on the linear rod. This support system is shown in Fig. 4.13.

The support system was designed to transfer any side load on the frame or lower unit up into the mounting system. This would protect the rod of the linear air cylinder from the sideloads which they are not designed for. The way the support system transfers the loads is by transferring the load from the frame into the upper swivel plate which in turn transfers it to the support rods. The support rods transfer the loads to the support plate through the linear bearings. The linear bearings allow the unit to be raised and lowered. The support plate is connected to the support mandrel that transfers the sideload to the mounting plate. The support washer connects the mandrel to the plate with clearance to allow the unit to rotate. To facilitate the rotating action, a bronze bearing was pressed into the mounting plate. This arrangement reduces the friction between the support mandrel

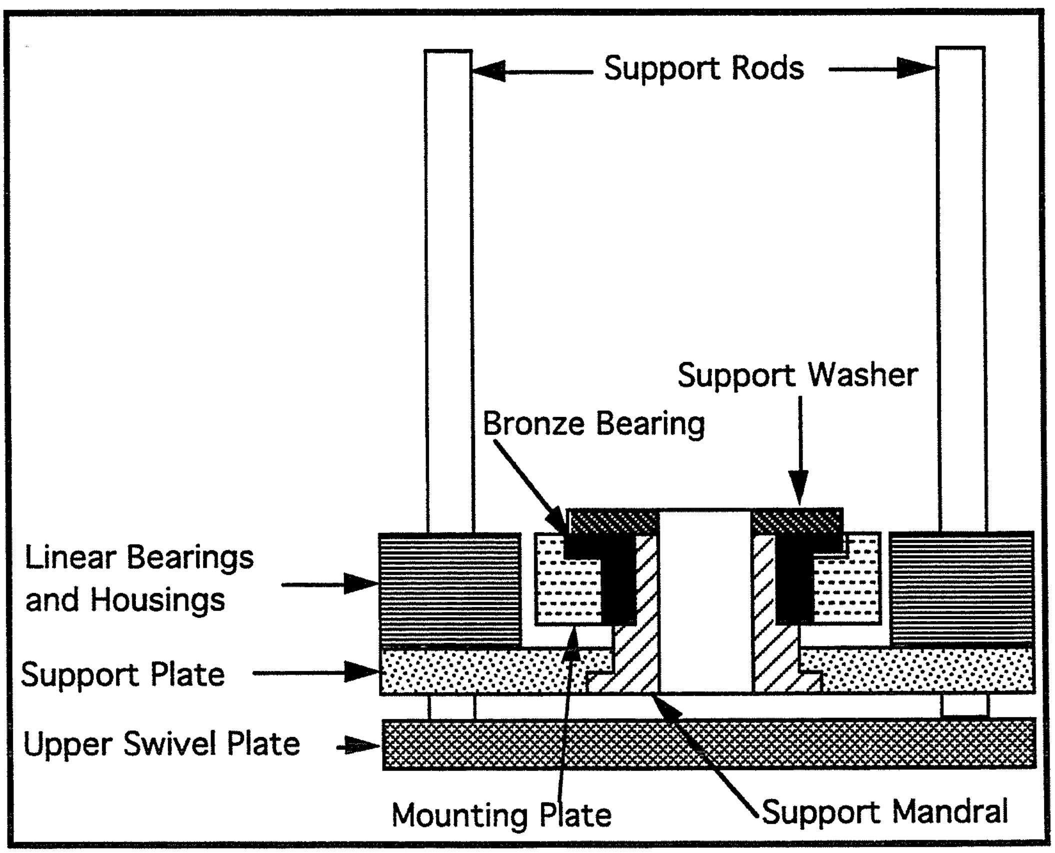


Figure 4.13 - Rotary Support System

and the mounting plate. The mounting plate is part of the mounting frame that houses the multi-motion actuator, and allows the PMS system to be mounted to a positioning mechanism. The mounting frame and actuator are shown in Fig. 4.14. The structural strength of the mounting frame was determined to be greater then the strength required for the loads induced on the unit that an analysis was deemed unnecessary.

The last requirement was to select the correct actuator size. This required two values to be calculated; the value of the load that the unit must lift, and the value of the torque required to rotate the unit. The first value was estimated to be approximately 70 lbs (311.4 N). This value was estimated by adding the approximate and known weights of

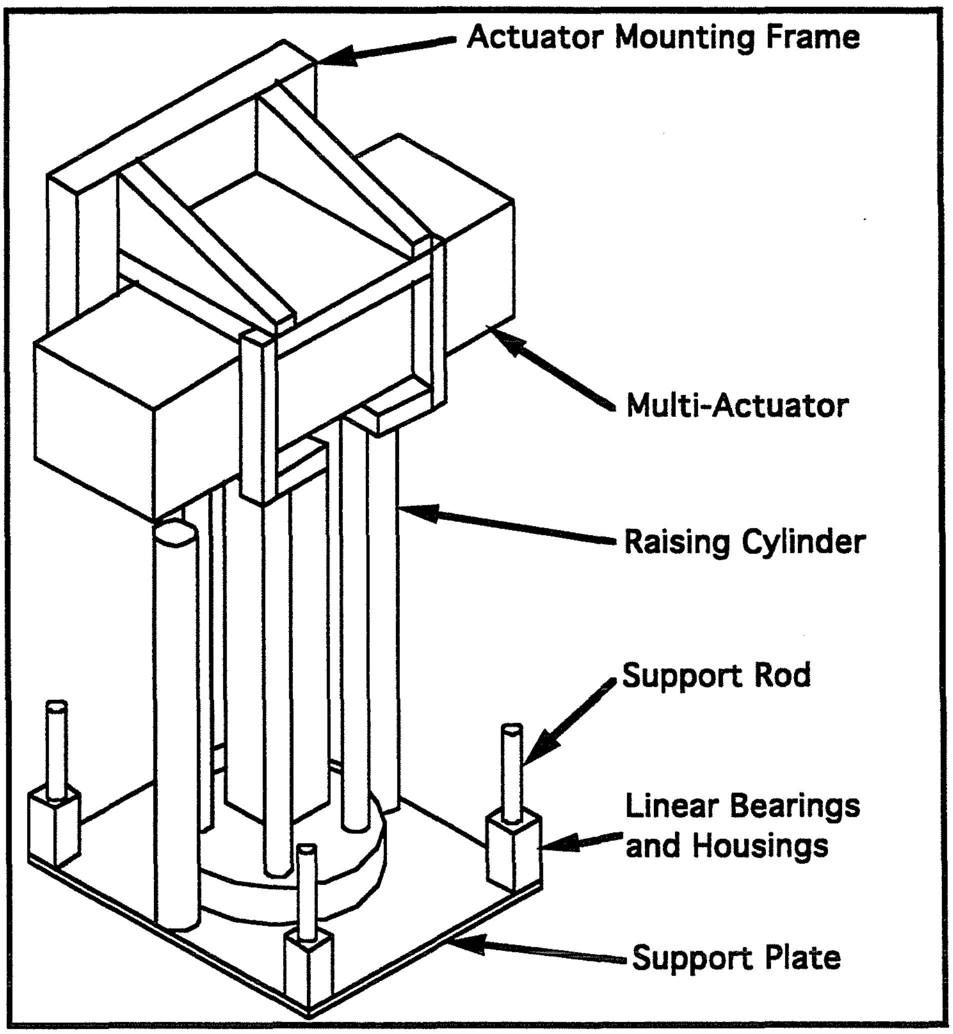


Figure 4.14 - Mounting Frame

all pieces of the lower unit below the upper swivel plate. To facilitate for any discrepancies in the approximation and any binding in the linear bearings on the support plate, the actuator was sized to lift 100lbs (444.9 N). The torque requirement for the actuator had to be calculated from the frictional forces between the support mandrel, the support washer, and the bronze bearing in the rotary support system. This was the only area that had forces that would oppose the rotary torque.

An Integral must be calculated to determine the torque requirements. A diagram of the support washer is shown in Fig. 4.15 and it shows the variables needed to do the calculations. The torque required will first have to break the static frictional force and then move against the sliding friction force. Since the static friction force is much larger then the sliding friction force, this will be the only calculation need. The values needed for these calculations are the friction coefficient for the materials (μ), the uniform pressure (p) on the washer, and the two radii. The coefficient (μ=.51) is for mild steel on bronze, total weight is 70lbf (311.4 N), the inside radius (r_{in}) is 1.375in (3.49 cm), and the outer radius (r_{out}) is 2.00in (5.08 cm).

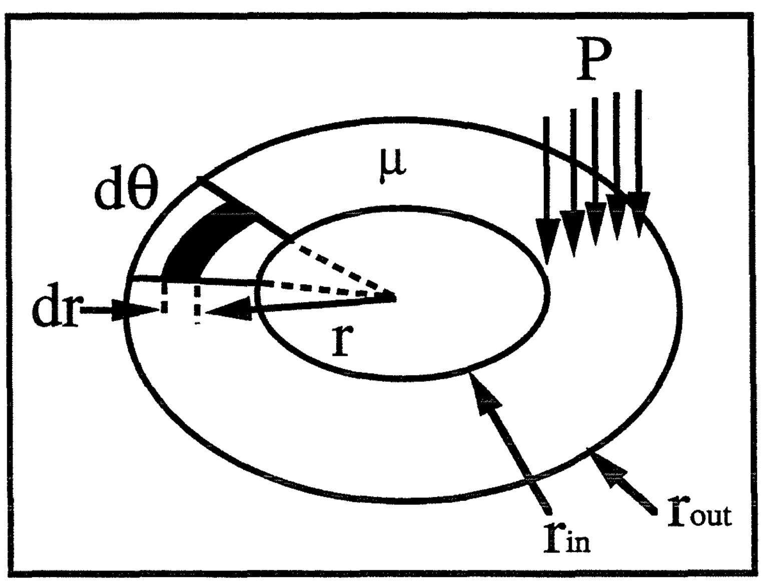


Figure 4.15 - Support Washer

$$Torque = T = p\mu \iint r^2 dr\, d\theta \quad (1)$$

$$T = p\mu \int_{r_{in}}^{r_{out}} r^2 dr \int_0^{2\pi} d\theta \quad (2)$$

$$T = 2\pi\, p\mu (r_{out}{}^3 - r_{in}{}^3) \quad (3)$$

$$p = Weight \div area = 70lbf \div \pi (r_{out}{}^2 - r_{in}{}^2) \quad (4)$$

$$T = 2(70lbf)(.51)(2^3 - 1.375^3) \div (2^2 - 1.375^2) \quad (5)$$

$$T = 182.8\ in \cdot lbf\ (20.65\ J) \quad (6)$$

From these calculations and some known requirements, a list of the specifications for the actuator was established as followed:

Lifting Requirement	100lbf (444.9 N)
Torque Requirement	183 in·lbf (20.67 N·m)
Rotation Requirement	90°
Linear Displacement Requirement	10 inches (25.4 cm)

4.3.7 - Safety Raising System

One of the main objectives of this thesis was to create a system that was safe to operate. The way the PMS system was designed (to raise and lower the frame) lends itself to a potential disaster. The frame is held up by the multi-motion actuator which is operated by both air and electric power. So, the disaster would occur if the air or electric power was turned off thus causing the frame to fall to the ground. To prevent this disaster from occurring, a system was implemented. The safety raising system was designed as a separate unit to raise the frame to a safe position above the ground. In other words, system has an independent power source separate from the main power of the PMS system. Fig. 4.16 shows a diagram of the system.

The way the system works is quite simple. The raising cylinders are ordinary air cylinders that are pressurized by an air reservoir so that the rods are in their retracted position. A combination of the lower unit's weight and the push of the multi-motion actuator lowers the frame to the ground. This action will displace the air in the cylinders back into the reservoir. If the multi-motion actuator fails, the air in the reservoir pressurizes the cylinders and raises the unit. This configuration should prevent the lower unit from being destroyed.

The system consists of two air cylinders that are positioned on the centerline of the unit. The cylinders selected were chosen because of their availability and their size. The cylinders had an effective area of 1.08 in^2 (6.97 cm^2) each that allowed for pressures in the reservoir to be between 35-50 psi (241.3 - 344.7 kPa). The cylinders were secured to the support plate and positioned as shown in Fig. 4.16.

4.3.8 - Spray Gun Air Control System

The control of the spray guns was crucial for the appearance of the target. The black spray guns were easily controlled with limit switches that activated and deactivated

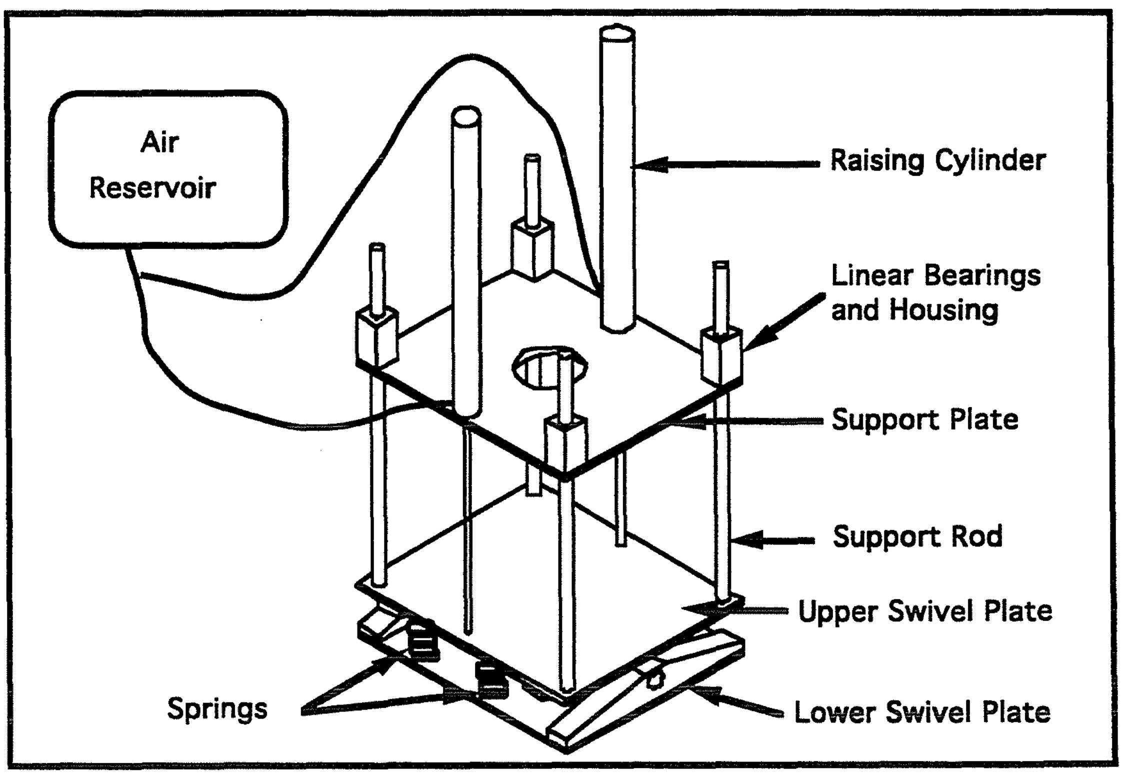


Figure 4.16 - Safety Raising System Diagram

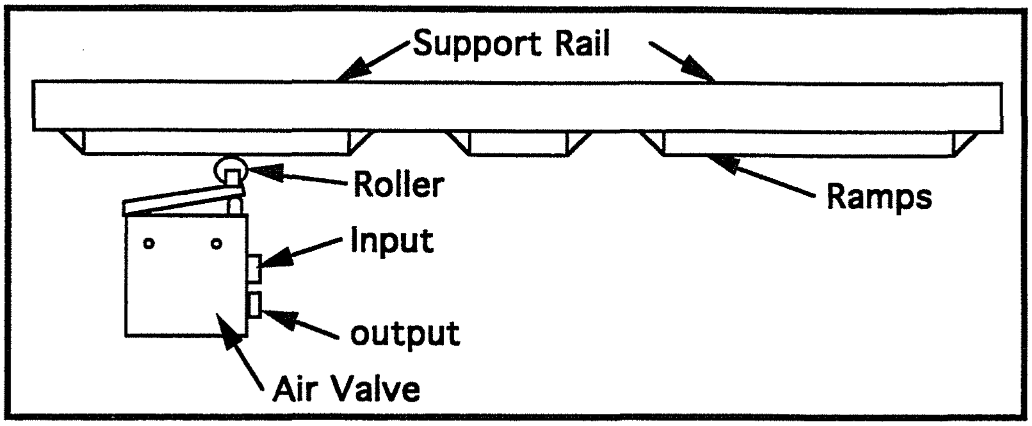


Figure 4.17 - White Spray Gun Control Valve Configuration

them, but the white spray guns needed to be turned on and off at certain intervals that corresponded to the cutouts in the template. Also, since the white lines were painted with the same template, the middle cutout had to be painted only once to prevent the center square on the target from being overpainted. There were two methods to do this; one was with electronic timing and the other mechanically. The electronic method was discarded because of the complexity of the circuitry and the difficulties with the adjustments. The mechanical system was chosen because of its simplicity and adjustability. Fig. 4.17 shows the configuration of the mechanical system.

The unit required two systems because of the method of painting. These systems were mounted to the inside of the frame, parallel to the travel of the spray guns. The air valves were mounted to the spray gun mounting plate and they were activated by the ramps as they travel along the frame. The first line of the target was sprayed with the ramp configuration shown in Fig. 4.17. After it was rotated, the first valve was deactivated and the second one was activated. The second system consists of the same configuration as the first with the exception of the middle ramp; it was eliminated. This new configuration prevents the middle square from being painted again.

4.4 - Detailed Design and Assembly

The unit was designed with the assistance of a CAD system. The CAD system allowed each piece to be sized and fitted together during the design process which reduced both time and mistakes. After the unit was completely designed, a detailed drawing was made for each fabricated piece. Next, a part's list was established which showed the purchased parts. Lastly, an assembly drawing was created which showed the complete unit and a table of parts. These items are in Appendix A.

4.5 - Prototype Integration and Testing

The next phase of the PMS System development was to produce a prototype of the machine. The required off-the-shelf items and materials were purchased and the manufactured parts were fabricated. The parts were then assembled into a prototype machine and integrated with the electrical and pneumatic systems[1]. The complete unit was placed on a support structure and tests were performed to evaluate the design. Fig. 4.18 shows a picture of the PMS System in its testing configuration.

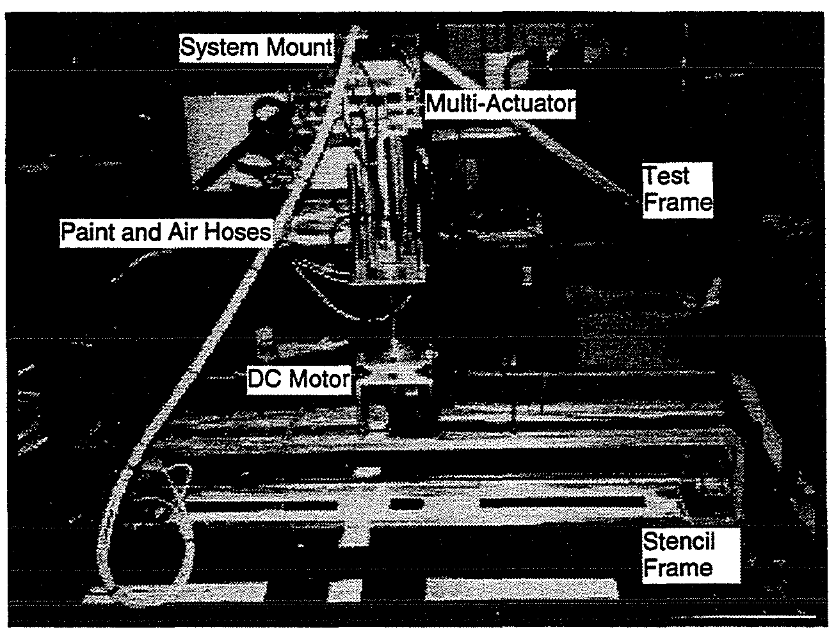


Figure 4.18 - PMS System

[1] Electric and pneumatic systems and controls were developed by Walter Nederbragt of the Advanced Highway Maintenance and Construction Technology Center at U.C. Davis.

The control unit of the PMS system allows for two modes of operation. The first mode is automatic which runs the system through a sequence of operations that paints the target. The second mode is a manual mode which allows each operation to be run individually. The tests in this section are performed in the manual mode and the targets are painted onto a simulated road surface. The object of these tests is to evaluate and calibrate each of the sub-systems for best performance. The following list shows the areas that are to be evaluated.

Linear Slide System

The main concern in this area is the speed of the DC motor. The speed of the motor must be determined for each of the operations that are performed by the system. They are the air drying mode, the white painting mode, and the black painting mode.

Spray Guns Position

In this test the positions of the guns are determined. This includes the height of the white spray gun and the height and distance from the centerline of the black spray gun.

Painting Pressure

This test determines the required pressures of the white and black paint to perform the painting operations. This includes the maximum and minimum pressures required.

Multi-Motion Actuator

The actuator is tested to determine the air pressure for both the linear cylinders which raises and lowers the unit and the rotary device.

Safety Raising System

This test determines the air pressure required to raise the system by the raising cylinders without the assistance of the multi-motion actuator.

Spray Nozzles

In this test the nozzles for the white and black spray guns are determined.

Performance

This test determines the performance and the cycle time of the target painting in an automatic mode.

4.6 - Prototype Test Results

The main purpose of the prototype testing was to obtain the values of the parameters that would produce a target that satisfies the specified requirements presented earlier in this thesis. The testing procedure consisted of adjusting the system parameters in the manual mode. First, the parameters were adjusted to the values presented in the design specifications. The parameters were than adjusted separately through a trial and error process until a satisfactory target was produced. In the final adjustments, the system was placed into its automatic mode and adjustments made until the unit produce a quality target that satisfied the requirements. The following parameters produced a target with the necessary requirements and the best performance.

Nozzles	**Orfice (cm)**	**Fan-Angle**
Black	.018 in (.0457)	80°
White	.016 in (.0406)	60°
Paint Pressure	**Maximum (MPa**	**Minimum (MPa)**
Black	3200psi (22.06)	2700psi (18.62)
White	3000psi (20.68)	2200psi (15.17)
Air Pressure	(MPa)	(MPa)
Linear Cylinder	80psi (.5516)	90psi (.6205)
Rotary Device	70psi (.4826)	90psi (.6205)
Safety Raising Cylinder	80psi (.5516)	65psi (.4482)
Drying System	90psi (.6205)	70psi (.4826)
DC Motor Speed	(m/sec)	(m/sec)
Drying Mode	1 ft/sec (.3048)	.75 ft/sec (.2286)
White Paint Mode	3 ft/sec (.9144)	2.5 ft/sec (.7620)
Black Paint Mode	2 ft/sec (.6096)	1.5 ft/sec (.4572)
Multi-Motion		
Actuator Speed*	(m/sec)	(m/sec)
Raising	1 ft/sec (.3048)	.75 ft/sec (.2286)
Lowering	.80 ft/sec (.2438)	.50 ft/sec (.1524)
Rotational	.70 rad/sec	.40 rad/sec

* The speed is regulated with flow control valves on the cylinders output

Table 4.2 - PMS System Parameters

4.7 - Prototype Operational Sequence

In this section the operational sequence of the PMS System will be described. This sequence is performed after the PMS System is turned on (generator, air compressor, and paint pumping system) and placed into the control point position. Figure 4.19 shows the sequence in a series of diagrams that are described in the following list.

1. Starting Position
2. Debris Cleaning
3. Black Stripe Painted
4. Drying
5. Rotate
6. Black Stripe Painted
7. Drying (1st pass)
8. Drying (2nd pass)
9. Lower Unit and First White Stripe Painted
10. Raise Unit and Rotate
11. Lower Unit, Second White Stripe Painted, Raise Unit
11. The Unit is in Starting Position

The sequence that was just presented is completely controlled by the system in the automatic mode. The operator presses one button to activate the cycle and the PMS System does the rest. Once the cycle is completed, the operator moves to the next control point location and repeats the process. The system also has a manual mode that allows the operator to perform any of the operations described above. This feature permits the operator to manually control the system in case the automatic mode or any sub-system fails. The total cycle time of 4.5 minutes was less then the 8 minutes required by the manual method. This time saving is another benefit of the PMS system.

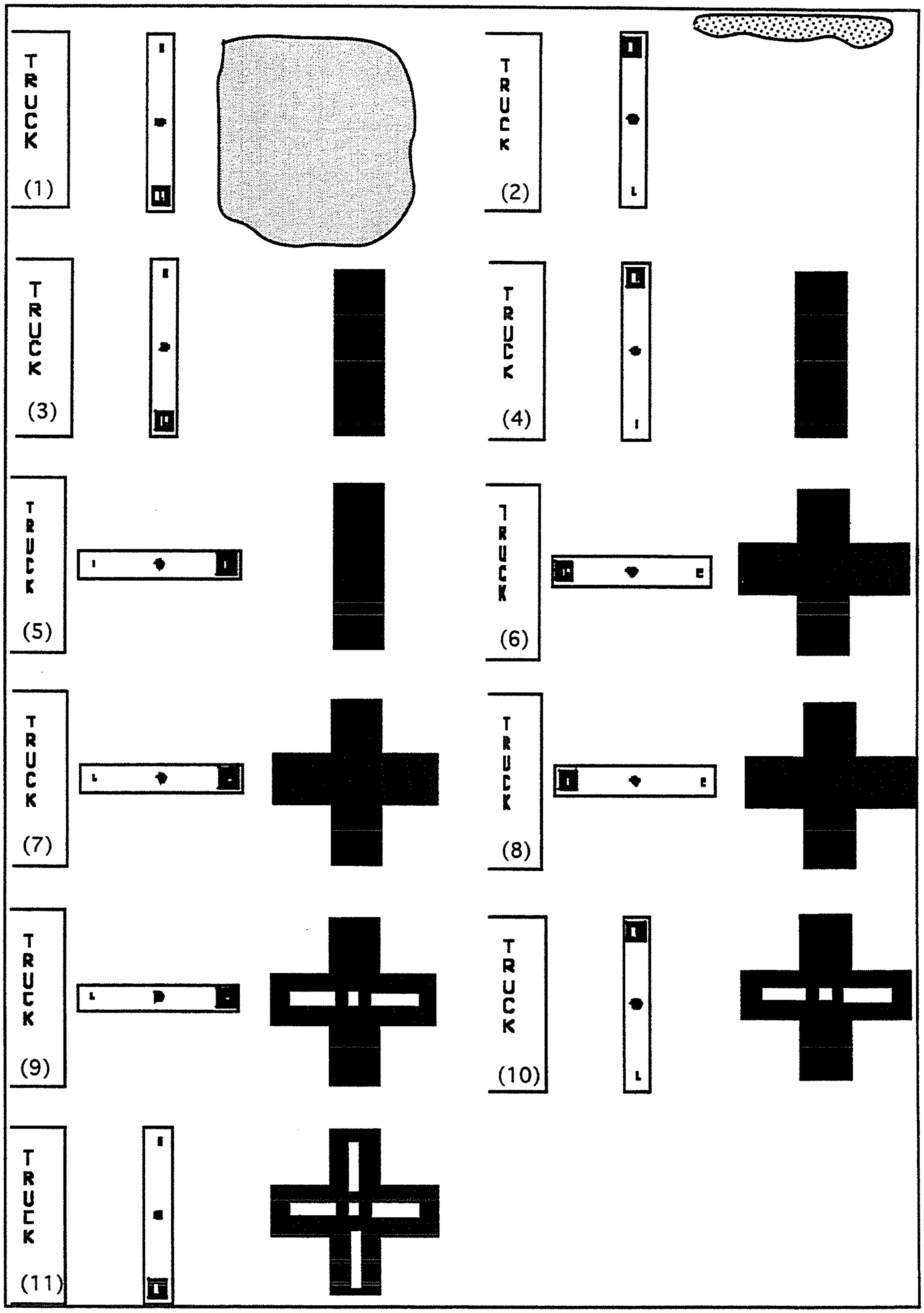


Figure 4.19 - Prototype Operational Sequence

Chapter 5 - Conclusions and Recommendations

5.1 - Conclusions

The purpose of this thesis was to develop a mechanized stencil system that could replace the current manual method of painting targets onto the highway thus reducing the risk from on-going traffic to the maintenance worker. The thesis started off with a description of the problem, and then followed a design methodology that developed and produced a prototype system. After the system's fabrication, tests were carried out to evaluate its performance. The tests concluded that the system could perform the required task within the specified requirements. The requirements that were met are in the following list.

1. Produces target within specification mentioned in Chapter 3.
2. Requires 1 person to operate system.
3. System may be controlled manually or automatically.
4. System performs operations in required workspace mentioned in Chapter 4. Workspace of system is 6.9′ x 6.9′ x 5′ (175.3cm x 175.3cm x 127 cm).
5. System raises to safe height above the ground when power is turned off.
6. The system is easily maintainable by the operator in the field.

Other benefits of this system are in the areas of cycle time and personnel. Currently, Caltrans surveys about 600 miles/year which is approximately 8000 targets/year [Broverman, 1994]. The current manual process of target stenciling takes an average of 8 minutes to accomplish. The system described in this thesis accomplishes the same task in 4.5 minutes. This saving of 3.5 minutes (≈ 466.7 hours/year) would help speed up the surveying process and provide additional time to survey more highway miles. The current process also requires a crew of 3 to 4 people to paint the targets; 2 people to paint the target, 1 person to drive the painting truck, and 1 person to drive a follower truck which protects the painting truck from the flow of traffic. The cost for a crew of 4 is approximately $1800/day. The PMS System would only require 2 people; one to operate the system and one to drive the follower truck. The potential savings are in the areas of reduce risk to 1 to 2 workers and reduced cost (≈ $900/day) due to fewer workers on the job site. The PMS System has the potential of benefiting the surveying process in both cost and risk reduction.

This can be accomplished with further development of the PMS System. The next section will describe some recommendations for further development.

5.2 - Recommendations

To understand the full potential of the PMS System, it should be tested in its actual working conditions. This would require the development of a test vehicle that positions the system onto a target area. A survey crew could test and evaluate the system. Their ideas and the data collected from the field test could be used to develop a fully commercialized model of the PMS System.

The prototype works well in a limited sense, but several parts of the design would need more analyses to evolve the prototype system into a commercialized version. The field test described above combined with further design development could accomplish this goal. To assist in the further development of the system, this thesis will end with improvements that could be implemented in a commercial design. The following list will describe the improvements.

1. The reservoir of the template is too small. The paint in the reservoir tends to splash onto the target after 5 or more cycles which tend to degrade its quality. To

improve the system, the reservoir on the template would need to be made larger or a paint recovery system needs to be developed.

2. The upper rails of the frame that supports the linear slide system may need to be redesign. The unit deflects under the force of the multi-motion actuator. The deflection is small and does not effect the performance of the system, but may cause problems from fatigue after several thousand cycles.

3. The multi-motion actuator tends to oscillate at the end of its rotation. The oscillation can be eliminated by slowing the rotation down, but adding damping to the system is a more desirable solution.

References

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Shigley, Joseph E. and Mischke, Charles R. (1989) "Mechanical Engineering Design," 5th Edition, McGraw-Hill Book Company, New York.

APPENDIX A - DRAWINGS

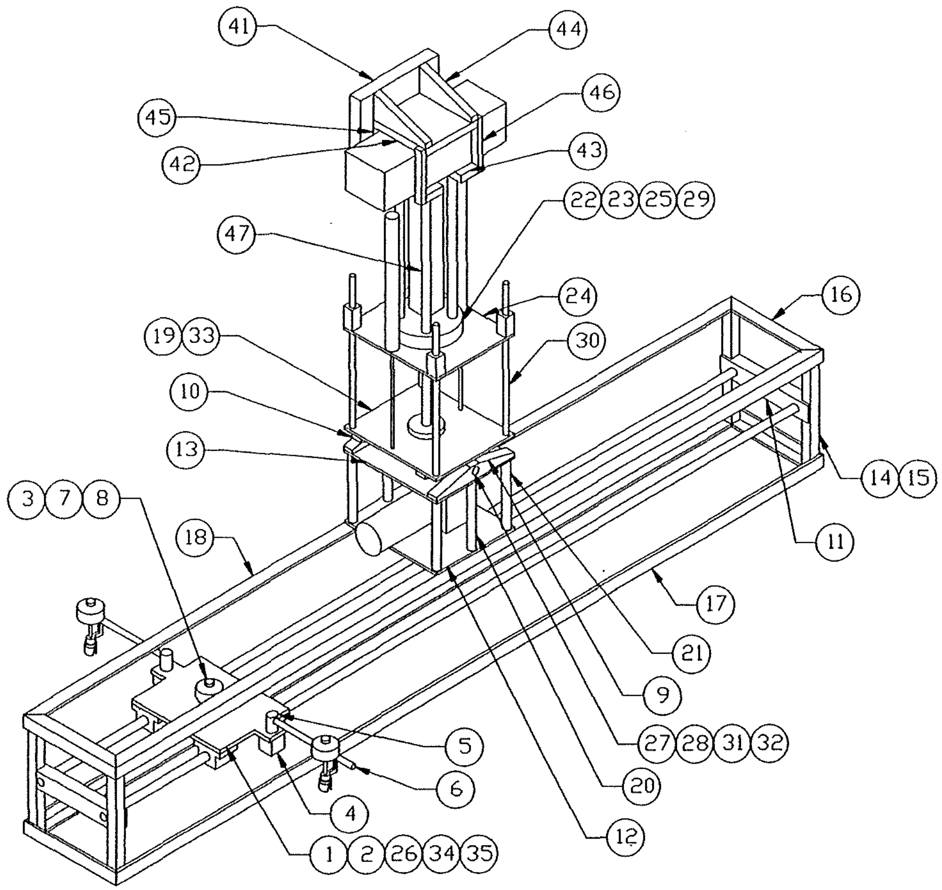
PARTS LIST

Qty	Description	Model #	Manufacturer
2	Double Acting Air Cylinder	1250DNS-10	American
1	Multi-Motion Actuator	MA11B49010PKB1B2F	PHD
2	Minivalve	234-955	Camozzi
2	Check Valve	MJCV-1	Camozzi
1	Flow Control Valve	RFU-482 02-00	Camozzi
8	Linear Bearing	6064K53	McMaster-Carr
4	Linear Shafting	6061K335	McMaster-Carr
1	Oilite Bearing	SF-88104-24	Chrysler Amplex
4	Super Ball Bearing Pillow Block	SPB-12-XS	Thomson Bearing
2	Linear Support Shaft	1AB-12-A00	Thomson Bearing
1	90V DC Gearmotor - Right Angle	4Z135	Grainger
4	Heavy Duty Compression Springs	CVO750-2000-125	SPEC
3	Airless Automatic Spray Guns	550	BINKS
1	Plastic Coated Aircraft Cable - 14ft	3686T2	McMaster-Carr
2	Medium Duty Aircraft Cable Blocks	3099T34	McMaster-Carr
2	Machined Standard Eye End Fitting	3474T32	McMaster-Carr
2	Wheels - 2"Dia.	....	Blue Collar
2	Limit Switches	7988K2	McMaster-Carr

DRAWING LIST

DWG NO.	DESCRIPTION
PMS-02-0001	SPRAY BLOCK PLATE
PMS-02-0002	SPRAY SENSOR BLOCK I
PMS-02-0003	WHITE SPRAY BLOCK - SLIDER
PMS-02-0004	BLACK SPRAY BLOCK - SLIDER
PMS-02-0005	BLACK SPRAY STAND-OFF
PMS-02-0006	BLACK SPRAY ROD
PMS-02-0007	WHITE SPRAY STAND-OFF
PMS-02-0008	WHITE SPRAY ROD
PMS-02-0009	BOTTOM SWIVEL MOUNT
PMS-02-0010	TOP SWIVEL MOUNT
PMS-02-0011	SLIDER BRACKET - PAINT SLIDER
PMS-02-0012	MOTOR MOUNT PLATE W/ HOLES
PMS-02-0013	MOTOR MOUNT PLATE W/O HOLES
PMS-02-0014	FRAME - CORNER TUBES I
PMS-02-0015	FRAME - CORNER TUBES II
PMS-02-0016	FRAME - SIDE ANGLES
PMS-02-0017	FRAME - BOTTOM ANGLES
PMS-02-0018	FRAME - TOP ANGLES
PMS-02-0019	TOP SWIVEL MOUNT PLATE
PMS-02-0020	MOTOR PLATE CENTER STAND-0FF
PMS-02-0021	MOTOR PLATE SIDE STAND-OFF
PMS-02-0022	BEARING - MOUNTING
PMS-02-0023	BEARING HOLDER BLOCK - MOUNTING
PMS-02-0024	FRAME MOUNTING PLATE
PMS-02-0025	FRAME MOUNTING MANDREL
PMS-02-0026	SPRAY SENSOR BLOCK II
PMS-02-0027	SWIVEL BEARING - BOTTOM SWIVEL
PMS-02-0028	SWIVEL BEARING - TOP SWIVEL
PMS-02-0029	FRAME MOUNTING MANDREL - WASHER
PMS-02-0030	THOMPSON 15" ROD MODIFICATION
PMS-02-0031	SWIVEL SHAFT
PMS-02-0032	SWIVEL SHAFT RETAINING WASHERS
PMS-02-0033	SPRING WASHER
PMS-02-0034	CABLE HOLDER I
PMS-02-0035	CABLE HOLDER II
PMS-02-0036	RAMP SUPPORT TUBE
PMS-02-0037	CROSS SUPPORT
PMS-02-0038	WHEEL PLATE STAND-OFF
PMS-02-0039	WHEEL MOUNTING PLATE
PMS-02-0040	RAMP
PMS-02-0041	CENTER RAMP
PMS-02-0042	STENCIL TEMPLATE
PMS-02-0101	ACTUATOR MOUNT - TRUCK MOUNTING PLATE
PMS-02-0102	ACTUATOR MOUNT - TOP PLATE
PMS-02-0103	ACTUATOR MOUNT - BOTTOM PLATE
PMS-02-0104	ACTUATOR MOUNT - SIDE PLATE
PMS-02-0105	ACTUATOR MOUNT - BACK SPACER PLATE
PMS-02-0106	ACTUATOR MOUNT - FRONT SUPPORT
PMS-02-0107	ACTUATOR MOUNT - SUPPORT RODS

REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
D		INITIAL RELEASE	8/25/93	VN/DC	YES



ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
47		MOUNT	PMS0107	1
46		MOUNT	PMS0106	1
45		MOUNT	PMS0105	1
44		MOUNT	PMS0104	1
43		MOUNT	PMS0103	1
42		MOUNT	PMS0102	1
41		MOUNT	PMS0101	1
35		HOLDER	PMS0035	1
34		HOLDER	PMS0034	1
33		WASHER	PMS0033	1
32		WASHER	PMS0032	1
31		SHAFT	PMS0031	1
30		ROD	PMS0030	1
29		WASHER	PMS0029	1
28		SWIVEL	PMS0028	1
27		SWIVEL	PMS0027	1
26		BLOCK	PMS0026	1
25		MANDREL	PMS0025	1
24		PLATE	PMS0024	1
23		BEARING	PMS0023	1
22		BEARING	PMS0022	1
21		STANDOFF	PMS0021	1
20		STANDOFF	PMS0020	1
19		PLATE - SWIV.	PMS0019	1
18		FRAME - TOP	PMS0018	1
17		FRAME - BOT.	PMS0017	1
16		FRAME - SIDE	PMS0016	1
15		FRAME - CORN.	PMS0015	1
14		FRAME - CORN.	PMS0014	1
13		PLATE	PMS0013	1
12		PLATE - MOTOR	PMS0012	1
11		BRACKET	PMS0011	1
10		SWIVEL MOUNT	PMS0010	1
9		SWIVEL MOUNT	PMS0009	1
8		ROD	PMS0008	1
7		STANDOFF	PMS0007	1
6		ROD	PMS0006	1
5		STANDOFF	PMS0005	1
4		SLIDER	PMS0004	1
3		SLIDER	PMS0003	1
2		BLOCK - SENI	PMS0002	1
1		PLATE - GUN HOLDER	PMS0001	1

PART LIST

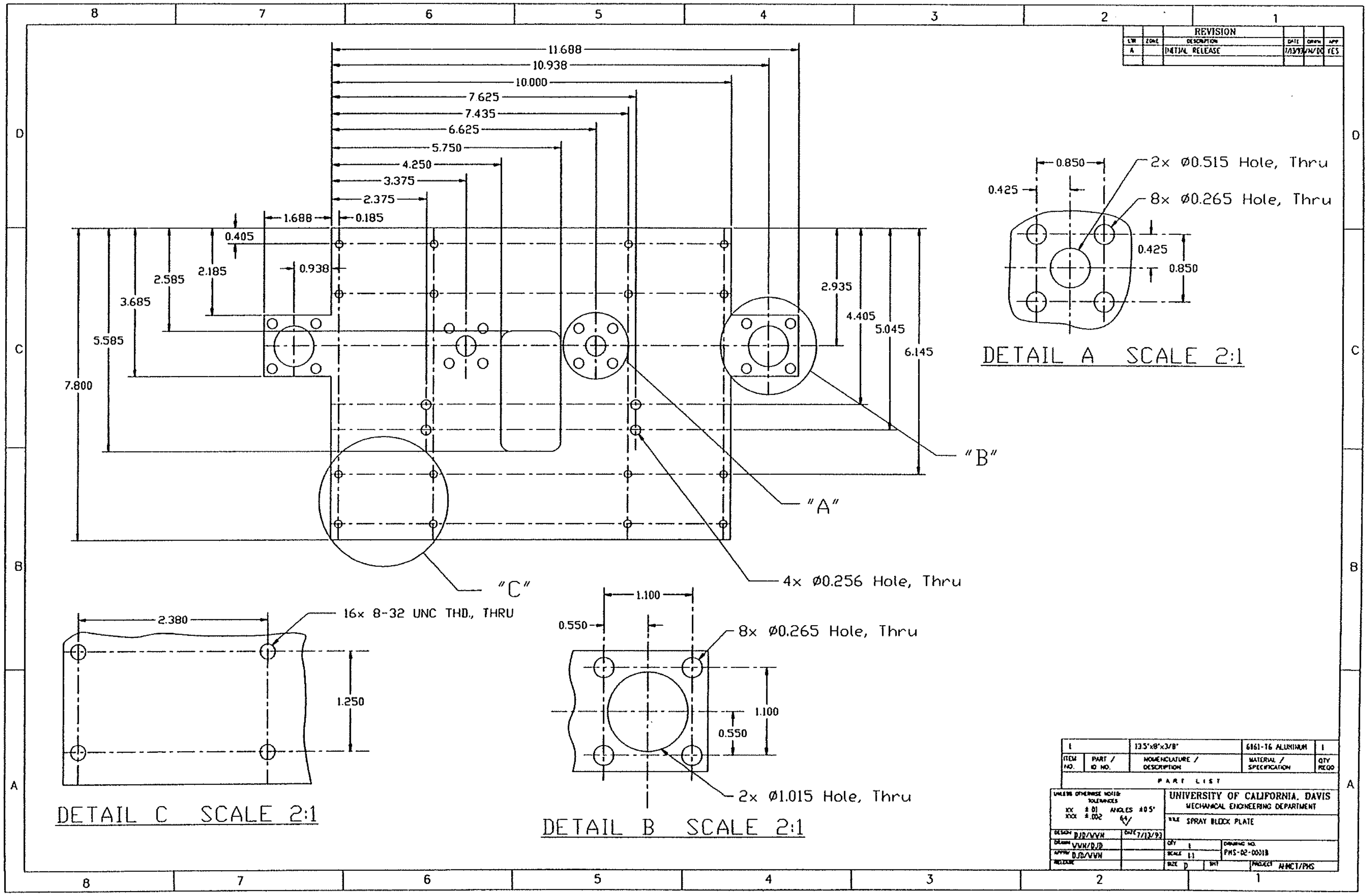
UNLESS OTHERWISE NOTED TOLERANCES
XX ±N/A ANGLES ±N/A
XXX ±N/A N/A

DESIGN DJD/VVN DATE 11/25/93
DRAWN VVN
CHECK VVN
RELEASE

UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT

TITLE STENCIL SYSTEM
ASSEMBLY DRAWING

QTY N/A
SCALE N/A
DRAWING NO. PMS-02B
SIZE D SHT PROJECT AHMCT/PMS



REVISION
INITIAL RELEASE
11.688
10.938
10.000
7.625
7.435
6.625
5.750
4.250
3.375
2.375
1.688
0.185
0.405
0.938
2.185
2.585
3.685
5.585
7.800
2.935
4.405
5.045
6.145
"A"
"B"
"C"
4x Ø0.256 Hole, Thru
0.850
0.425
2x Ø0.515 Hole, Thru
8x Ø0.265 Hole, Thru
0.425
0.850
DETAIL A SCALE 2:1
2.380
16x 8-32 UNC THD., THRU
1.250
DETAIL C SCALE 2:1
1.100
0.550
8x Ø0.265 Hole, Thru
1.100
0.550
2x Ø1.015 Hole, Thru
DETAIL B SCALE 2:1
13.5"x8"x3/8"
6161-T6 ALUMINUM
ITEM NO.
PART / ID NO.
NOMENCLATURE / DESCRIPTION
MATERIAL / SPECIFICATION
QTY REQD
PART LIST
UNLESS OTHERWISE NOTED: TOLERANCES
XX ±.01 ANGLES ±0.5°
XXX ±.002
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
TITLE SPRAY BLOCK PLATE
DESIGN DJD/VVN
DATE 7/13/93
DRAWN VVN/DJD
APPRV DJD/VVN
RELEASE
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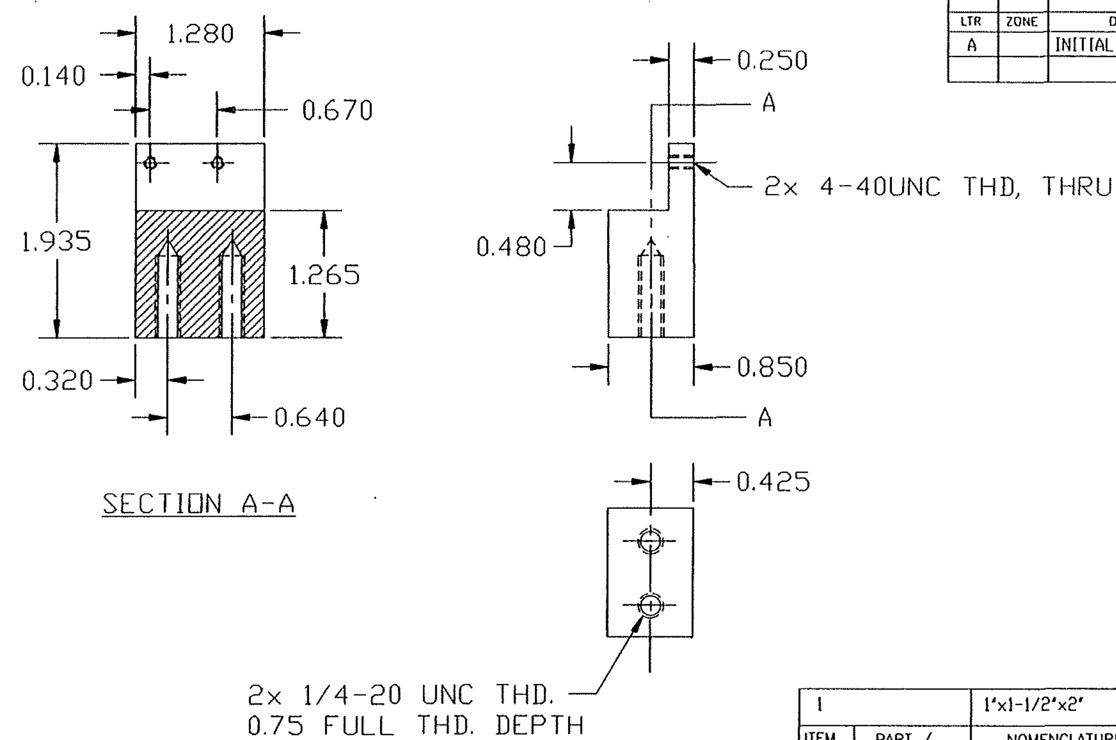
SIZE D
SHT
PROJECT AHMCT/PHS



REVISION					
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A		INITIAL RELEASE	7/13/93	WWN/DJD	YES

ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
1		1"x1-1/2"x2"	6061-T6 ALUMINUM	2

PART LIST

UNLESS OTHERWISE NOTED: TOLERANCES .XX ±.01 .XXX ±.002 ANGLES ±0.5° 64√	UNIVERSITY OF CALIFORNIA, DAVIS MECHANICAL ENGINEERING DEPARTMENT
DESIGN DJD/WWN, DATE 7/13/93	TITLE SPRAY SENSOR BLOCK
DRAWN WWN/DJD	QTY 2; DRAWING NO. PMS-02-0002B
APPRV DJD/WWN	SCALE 1:1
RELEASE	SIZE B; SHT; PROJECT AHMCT/PMS

REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
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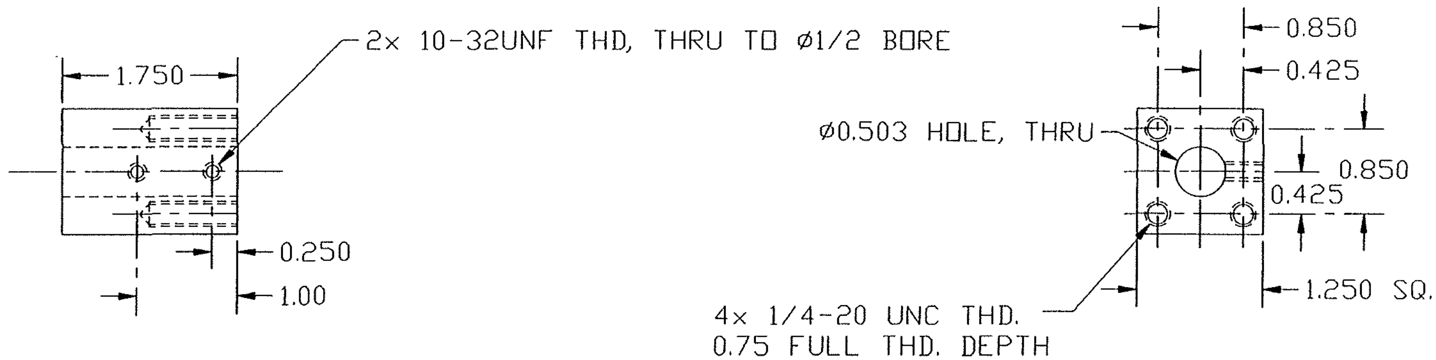

ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
1		1.25"x1.25"x2"	6061-T6 ALUMINUM	2

PART LIST

UNLESS OTHERWISE NOTED: TOLERANCES .XX ±.01 .XXX ±.002 ANGLES ±0.5° 64	UNIVERSITY OF CALIFORNIA, DAVIS MECHANICAL ENGINEERING DEPARTMENT
DESIGN DJD/WWN — DATE 7/13/93	TITLE WHITE SPRAY BLOCK SLIDER
DRAWN WWN/DJD	QTY 2 — DRAWING NO. PMS-02-0003B
APPRV DJD/WWN	SCALE 1:1
RELEASE	SIZE B — SHT — PROJECT AHMCT/PMS

REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
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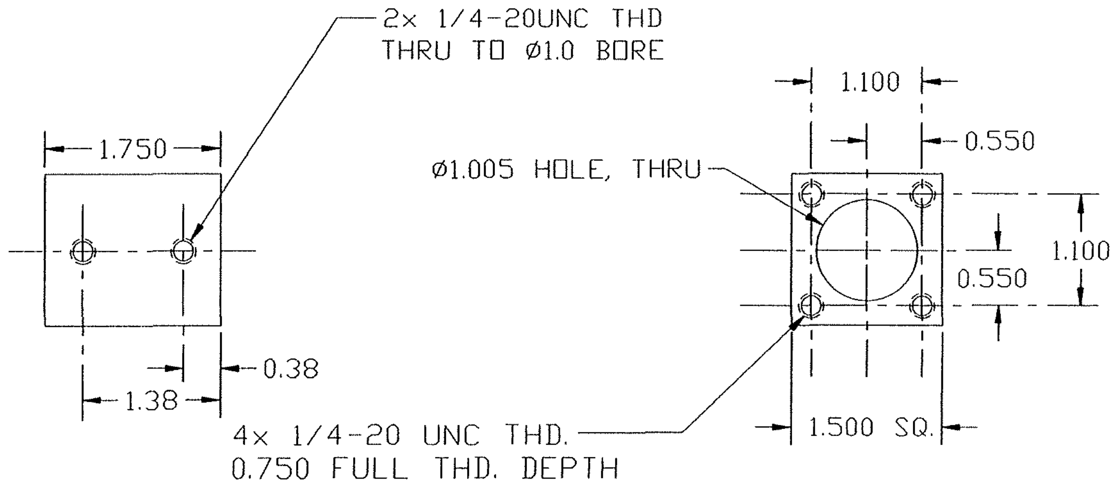

1		1.5"x1.5"x2"	6061-T6 ALUMINUM	2
ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD

PART LIST

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

DESIGN DJD/WWN	DATE 7/13/93	
DRAWN WWN/DJD		
APPRV DJD/WWN		
RELEASE		

UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT

TITLE BLACK SPRAY BLOCK - SLIDER

QTY 2	DRAWING NO. PMS-02-0004B
SCALE 1:1	
SIZE B / SHT	PROJECT AHMCT/PMS

REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
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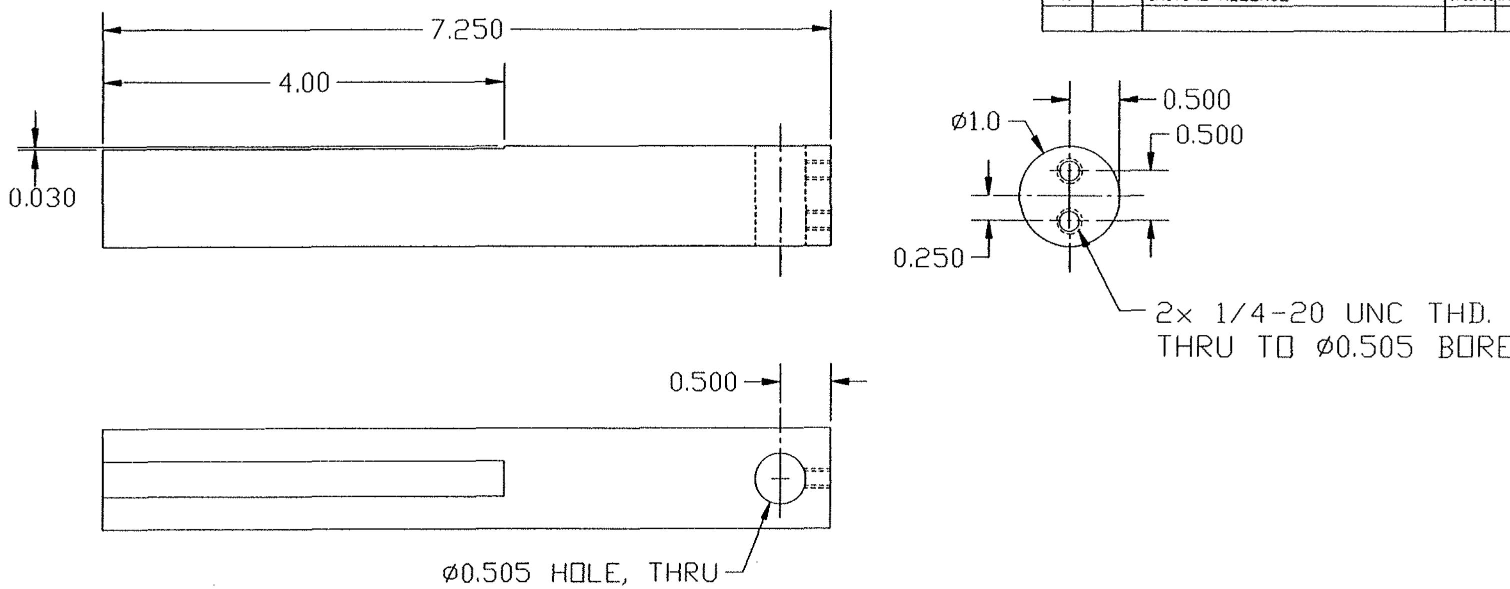


ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
1		1" DIA x 7.5" LENGTH	6061-T6 ALUMINUM	2

PART LIST

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

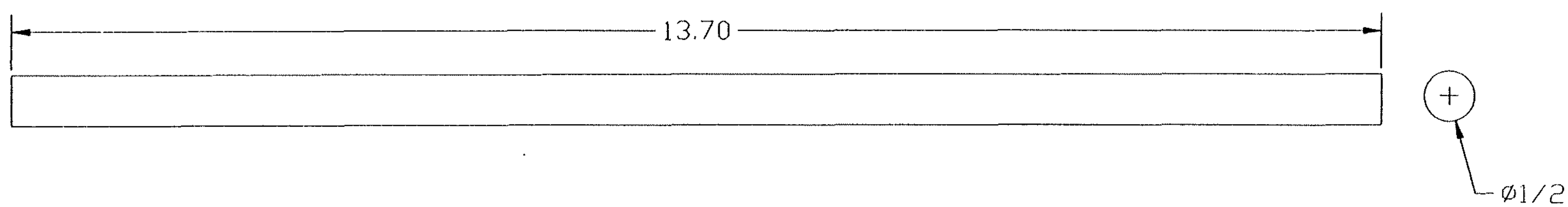
DESIGN DJD/WWN	DATE 7/13/93	
DRAWN WWN/DJD		
APPRV DJD/WWN		
RELEASE		

UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT

TITLE BLACK SPRAY STAND-OFFS

QTY 2	DRAWING NO. PMS-02-0005B	
SCALE 1:1		
SIZE B	SHT	PROJECT AHMCT/PMS

LTR	ZONE	REVISION DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	7/13/93	WN/DJ	YES



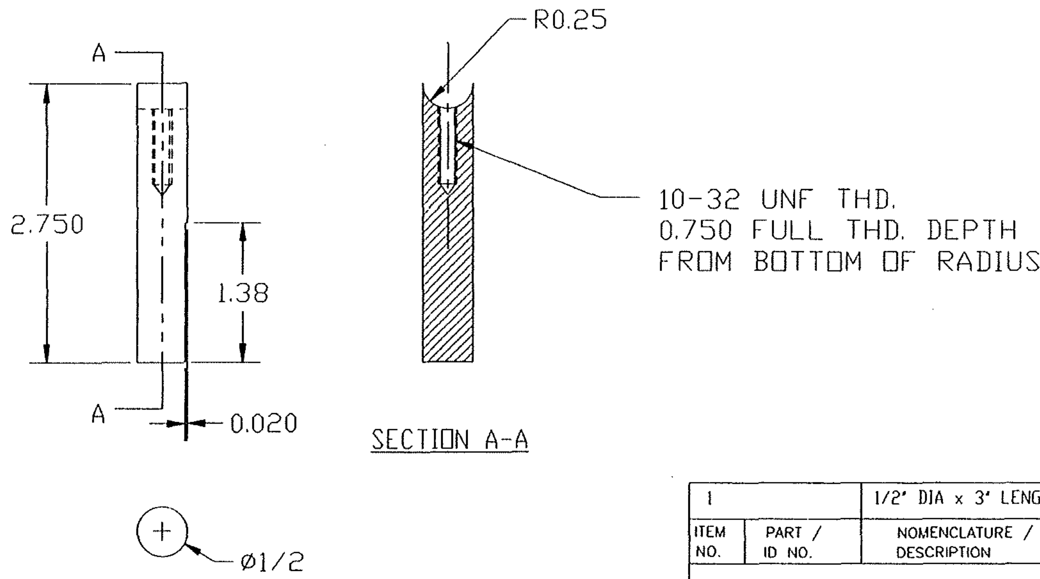
ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
1		1/2" DIA x 14" LENGTH	6061-T6 ALUMINUM	2

PART LIST

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

UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT

DESIGN DJD/WWN	DATE 7/13/93	TITLE BLACK SPRAY STAND-OFF ROD	
DRAWN WWN/DJD		QTY 2	DRAWING NO. PMS-02-0006B
APPRV DJD/WWN		SCALE 1:1	
RELEASE		SIZE B / SHT	PROJECT AHMCT/PMS



REVISION

LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	7/13/93	WN/DD	YES

ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
1		1/2" DIA x 3" LENGTH	6061-T6 ALUMINUM	2

PART LIST

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

UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT

TITLE WHITE SPRAY STAND-OFFS

DESIGN DJD/WWN	DATE 7/13/93		
DRAWN WWN/DJD		QTY 2	DRAWING NO. PMS-02-0007B
APPRV DJD/WWN		SCALE 1:1	
RELEASE		SIZE B	SHT	PROJECT AHMCT/PMS

REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
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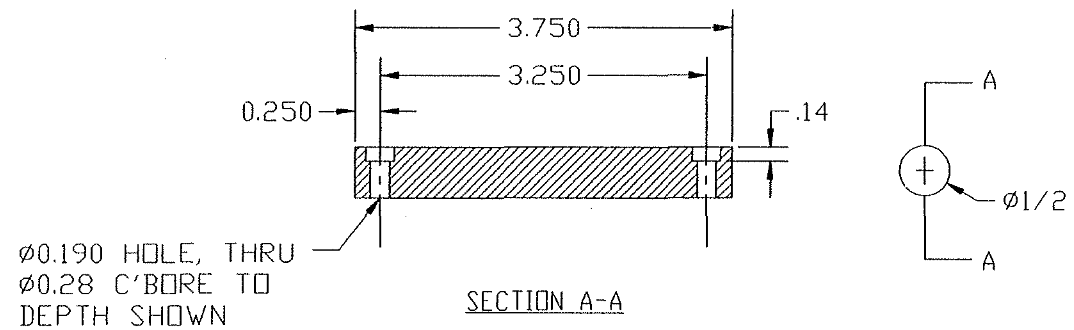

ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
1		1/2" DIA x 3.5" LENGTH	6061-T6 ALUMINUM	1

PART LIST

UNLESS OTHERWISE NOTED: TOLERANCES .XX ±.01 .XXX ±.002 ANGLES ±0.5° 64√		UNIVERSITY OF CALIFORNIA, DAVIS MECHANICAL ENGINEERING DEPARTMENT
DESIGN DJD/WWN	DATE 7/13/93	TITLE WHITE SPRAY STAND-OFFS ROD
DRAWN WWN/DJD		QTY 1 / DRAWING NO. PMS-02-0008B
APPRV DJD/WWN		SCALE 1:1
RELEASE		SIZE A / SHT / PROJECT AHMCT/PMS

REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
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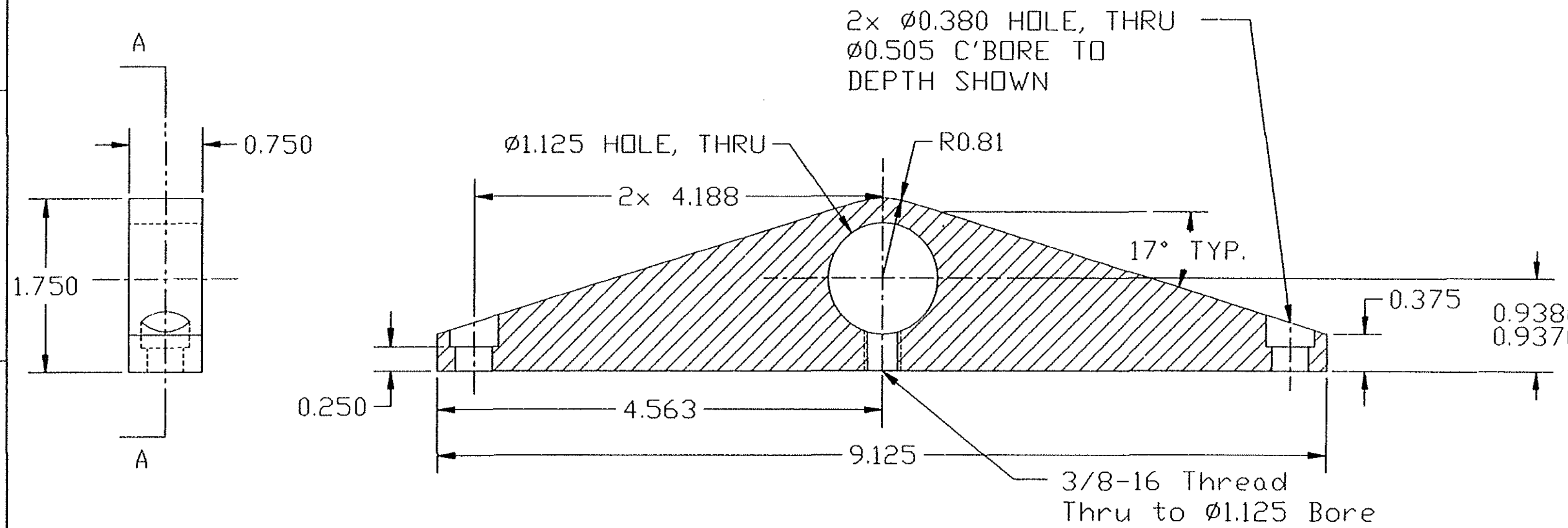

SECTION A-A

ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
1		3/4"x2"x10"	6061-T6 ALUMINUM	2

PART LIST

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

DESIGN DJD/WWN	DATE 7/13/93	UNIVERSITY OF CALIFORNIA, DAVIS MECHANICAL ENGINEERING DEPARTMENT	
		TITLE BOTTOM SWIVEL MOUNT	
DRAWN WWN/DJD		QTY 2	DRAWING NO. PMS-02-0009B
APPRV DJD/WWN		SCALE 1:1	
RELEASE		SIZE B / SHT	PROJECT AHMCT/PMS

LTR	ZONE	REVISION DESCRIPTION	DATE	DRWN	APP
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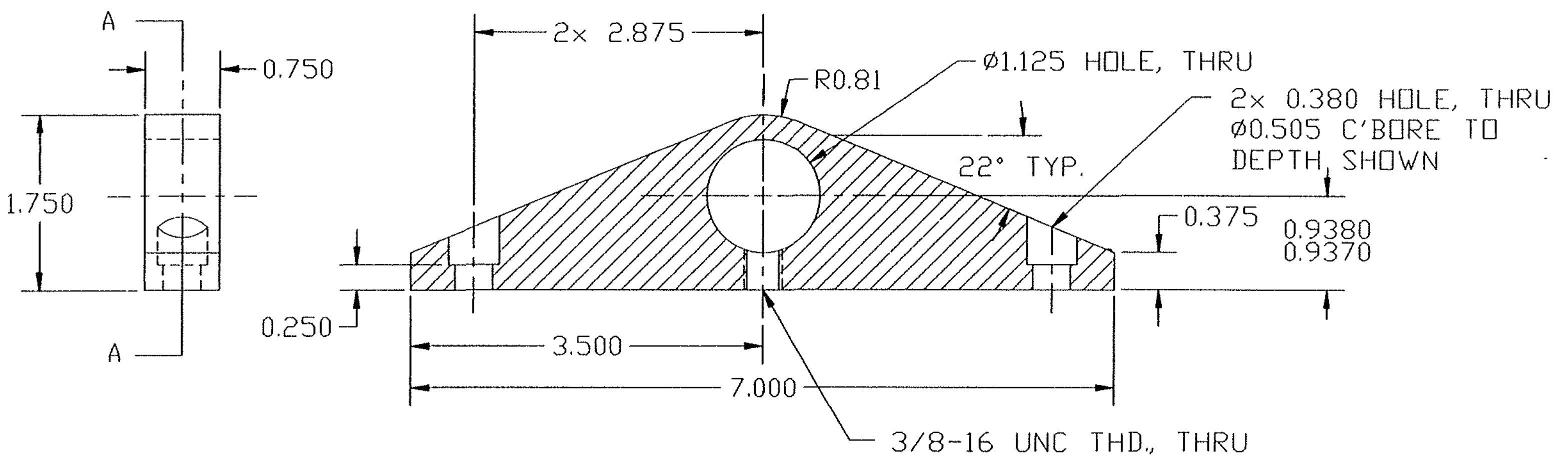


SECTION A-A

ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
1		3/4"x2"x7"	6061-T6 ALUMINUM	2

PART LIST

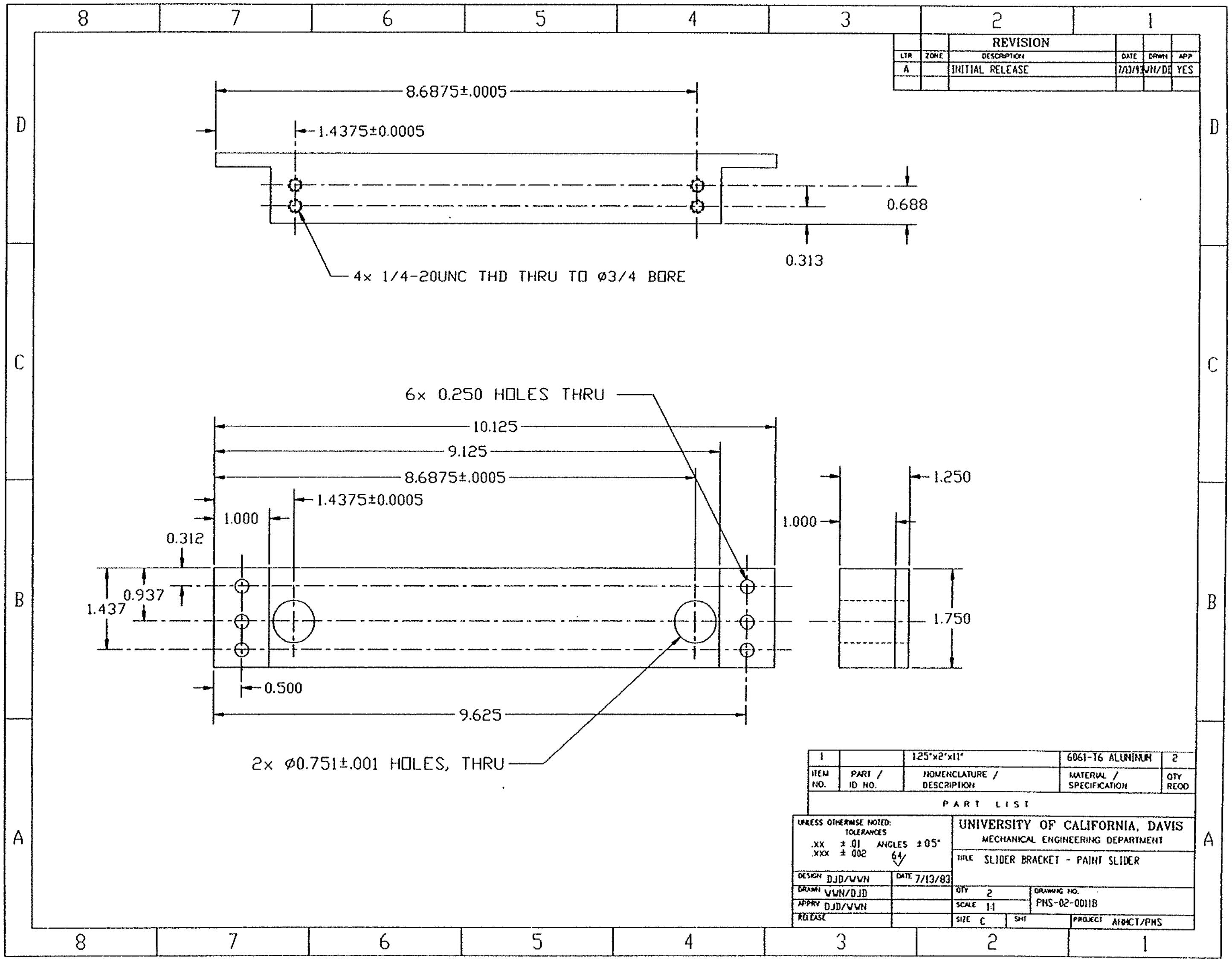
UNLESS OTHERWISE NOTED:
TOLERANCES
.XX ±.01 ANGLES ±0.5°
.XXX ±.002
64√

DESIGN DJD/WWN	DATE 7/13/93	
DRAWN WWN/DJD		
APPRV DJD/WWN		
RELEASE		

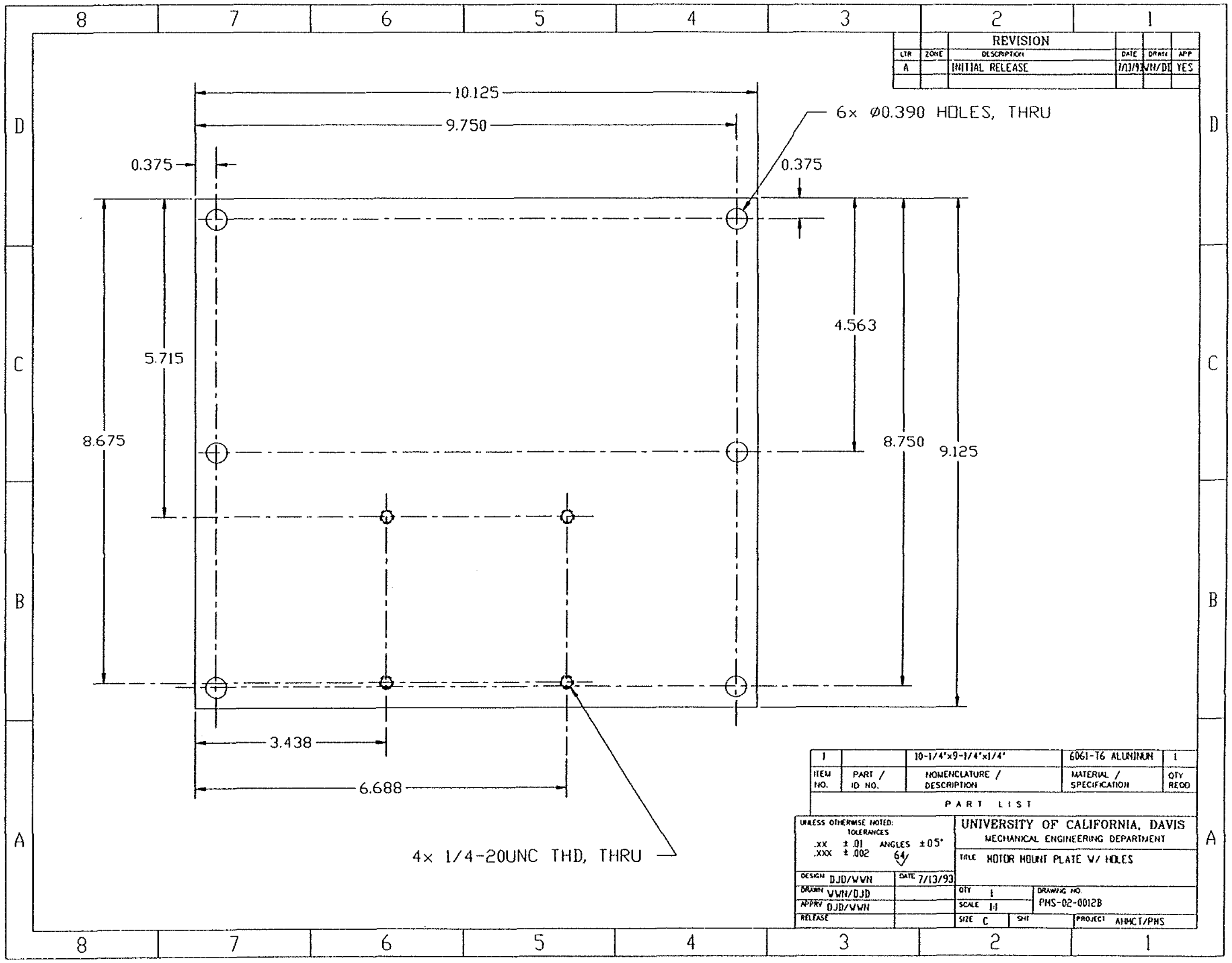
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT

TITLE TOP SWIVEL MOUNT

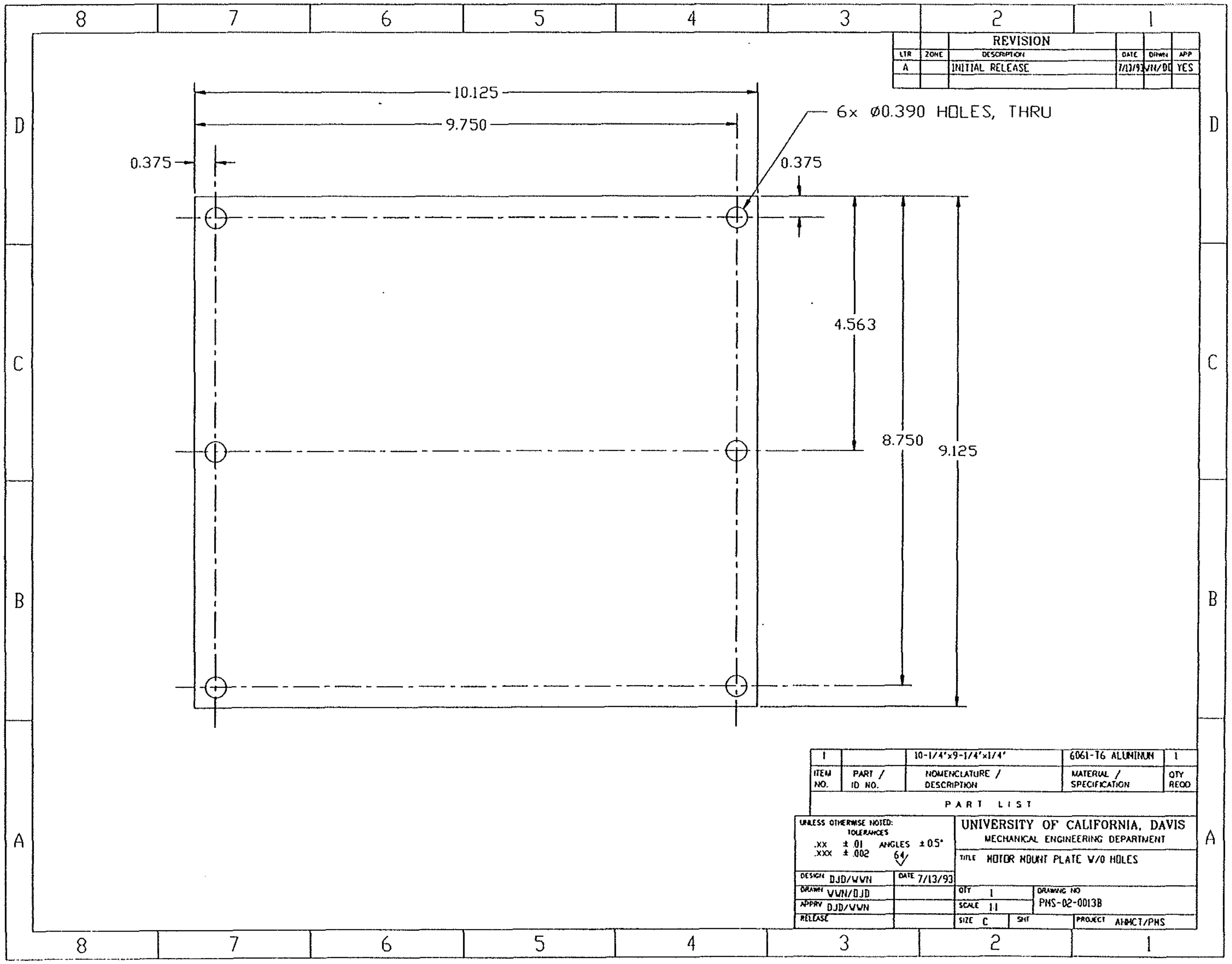
QTY 2		DRAWING NO. PMS-02-0010B	
SCALE 1:1			
SIZE B	SHT	PROJECT AHMCT/PMS	



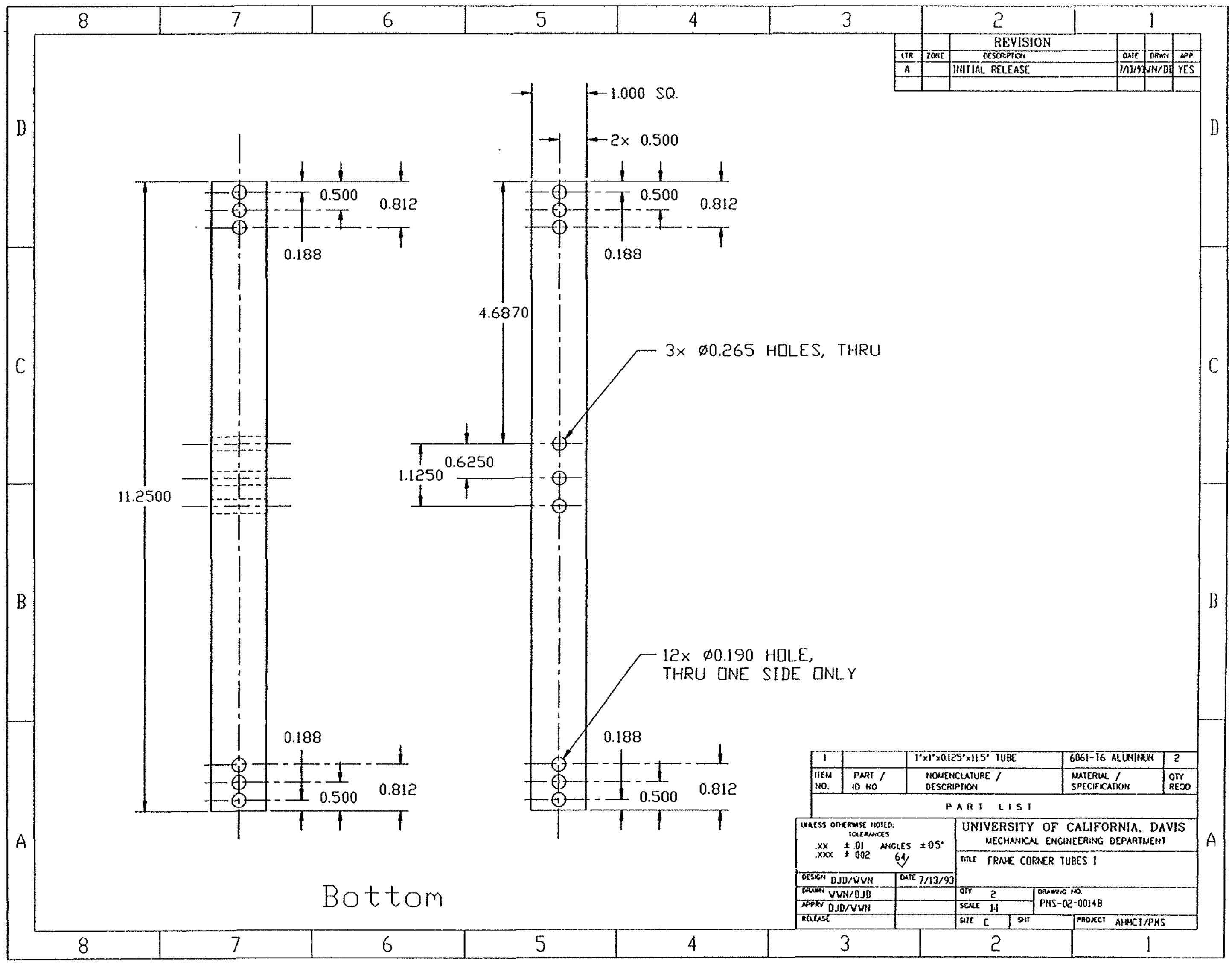
REVISION
LTR ZONE DESCRIPTION DATE DRWN APP
A INITIAL RELEASE YES
8.6875±.0005
1.4375±0.0005
0.688
0.313
4x 1/4-20UNC THD THRU TO ø3/4 BORE
6x 0.250 HOLES THRU
10.125
9.125
8.6875±.0005
1.4375±0.0005
1.000
0.312
0.937
1.437
0.500
9.625
2x ø0.751±.001 HOLES, THRU
1.250
1.000
1.750
1 125"x2"x11" 6061-T6 ALUMINUM 2
ITEM NO. PART / ID NO. NOMENCLATURE / DESCRIPTION MATERIAL / SPECIFICATION QTY REQD
PART LIST
UNLESS OTHERWISE NOTED: TOLERANCES
.XX ± .01 ANGLES ±05°
.XXX ± .002
64
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
TITLE SLIDER BRACKET - PAINT SLIDER
DESIGN DJD/VWN DATE 7/13/83
DRAWN VWN/DJD
APPRV DJD/VWN
RELEASE
QTY 2
SCALE 1:1
DRAWING NO. PHS-02-0011B
SIZE C SHT
PROJECT AHMCT/PHS



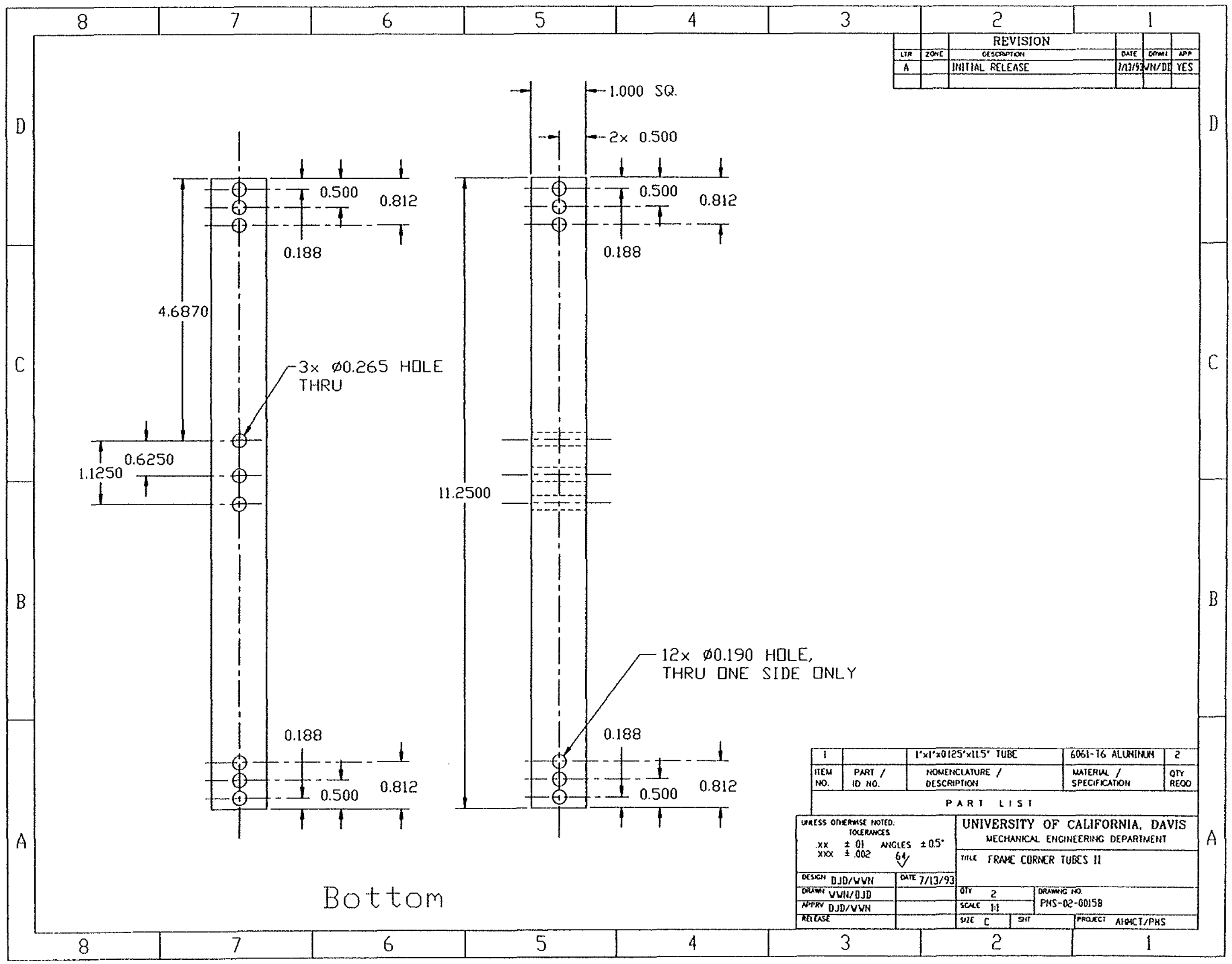
REVISION
LTR ZONE DESCRIPTION DATE DRWN APP
A INITIAL RELEASE YES
10.125
9.750
0.375
6x Ø0.390 HOLES, THRU
0.375
4.563
5.715
8.675
8.750
9.125
3.438
6.688
4x 1/4-20UNC THD, THRU
1 10-1/4"x9-1/4"x1/4" 6061-T6 ALUMINUM 1
ITEM NO. PART / ID NO. NOMENCLATURE / DESCRIPTION MATERIAL / SPECIFICATION QTY REQD
PART LIST
UNLESS OTHERWISE NOTED: TOLERANCES
.XX ± .01 ANGLES ±05°
.XXX ± .002
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
TITLE MOTOR MOUNT PLATE W/ HOLES
DESIGN DJD/WWN DATE 7/13/93
DRAWN WWN/DJD
APPRV DJD/WWN
RELEASE
QTY 1
SCALE 1:1
DRAWING NO. PMS-02-0012B
SIZE C SHT
PROJECT AHMCT/PMS



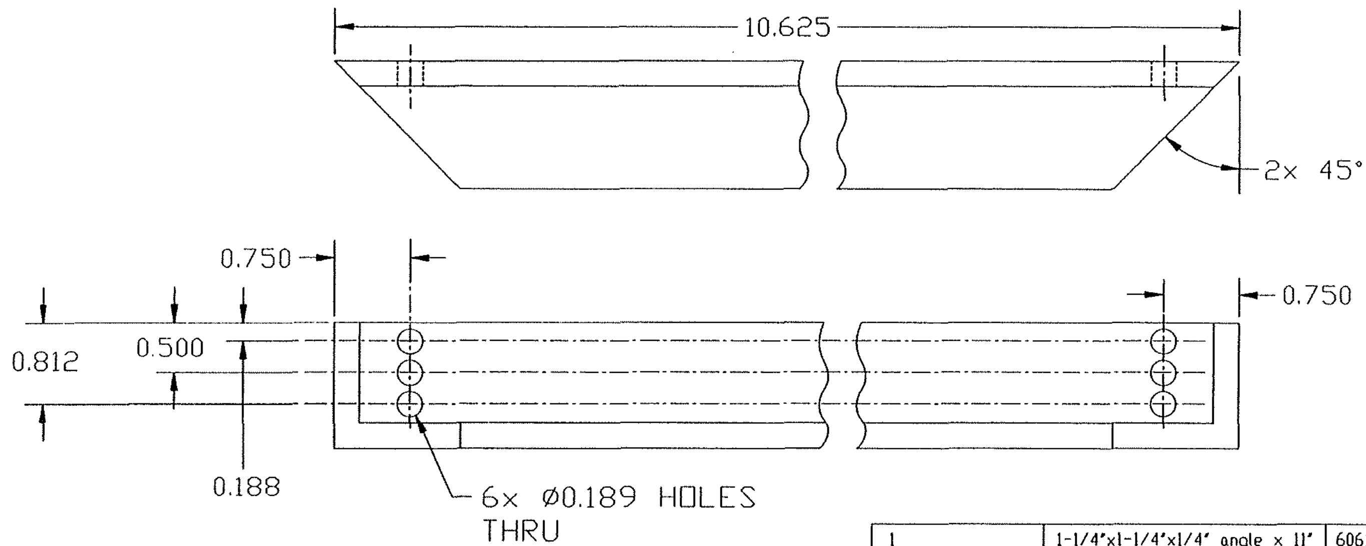
REVISION
LTR ZONE DESCRIPTION DATE DRWN APP
A INITIAL RELEASE 7/13/93 WN/DD YES
10.125
9.750
0.375
6x Ø0.390 HOLES, THRU
0.375
4.563
8.750
9.125
1 10-1/4"x9-1/4"x1/4" 6061-T6 ALUMINUM 1
ITEM NO. PART / ID NO. NOMENCLATURE / DESCRIPTION MATERIAL / SPECIFICATION QTY REQD
PART LIST
UNLESS OTHERWISE NOTED: TOLERANCES
.XX ± .01 ANGLES ± 0.5°
.XXX ± .002
64
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
TITLE MOTOR MOUNT PLATE W/O HOLES
DESIGN DJD/WVN DATE 7/13/93
DRAWN WVN/DJD
APPRV DJD/WVN
RELEASE
QTY 1
SCALE 1:1
DRAWING NO PMS-02-0013B
SIZE C SHT
PROJECT AHMCT/PHS



REVISION
LTR ZONE DESCRIPTION DATE DRWN APP
A INITIAL RELEASE 7/13/93 VWN/DJD YES
1.000 SQ.
2x 0.500
0.500
0.812
0.188
4.6870
3x ø0.265 HOLES, THRU
0.6250
1.1250
11.2500
12x ø0.190 HOLE, THRU ONE SIDE ONLY
Bottom
1 1"x1"x0.125"x11.5" TUBE 6061-T6 ALUMINUM 2
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 FRAME CORNER TUBES I
DESIGN DJD/VWN DATE 7/13/93
DRAWN VWN/DJD
APPRV DJD/VWN
RELEASE
QTY 2
SCALE 1:1
DRAWING NO. PNS-02-0014B
SIZE C
SHT
PROJECT AHMCT/PNS


REVISION
LTR ZONE DESCRIPTION DATE DRWN APP
A INITIAL RELEASE 7/13/93 VWN/DD YES
1.000 SQ.
2x 0.500
0.500
0.812
0.188
4.6870
3x ⌀0.265 HOLE THRU
0.6250
1.1250
11.2500
12x ⌀0.190 HOLE, THRU ONE SIDE ONLY
Bottom
1 1"x1"x0.125"x11.5" TUBE 6061-T6 ALUMINUM 2
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 FRAME CORNER TUBES II
DESIGN DJD/VWN DATE 7/13/93
DRAWN VWN/DJD
APPRV DJD/VWN
RELEASE
QTY 2
SCALE 1:1
SIZE C
SHT
DRAWING NO. PHS-02-0015B
PROJECT AHMCT/PHS

REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	7/13/93	WN/DD	YES



ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
1		1-1/4"x1-1/4"x1/4" angle x 11"	6061-T6 ALUMINUM	4

PART LIST

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

UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT

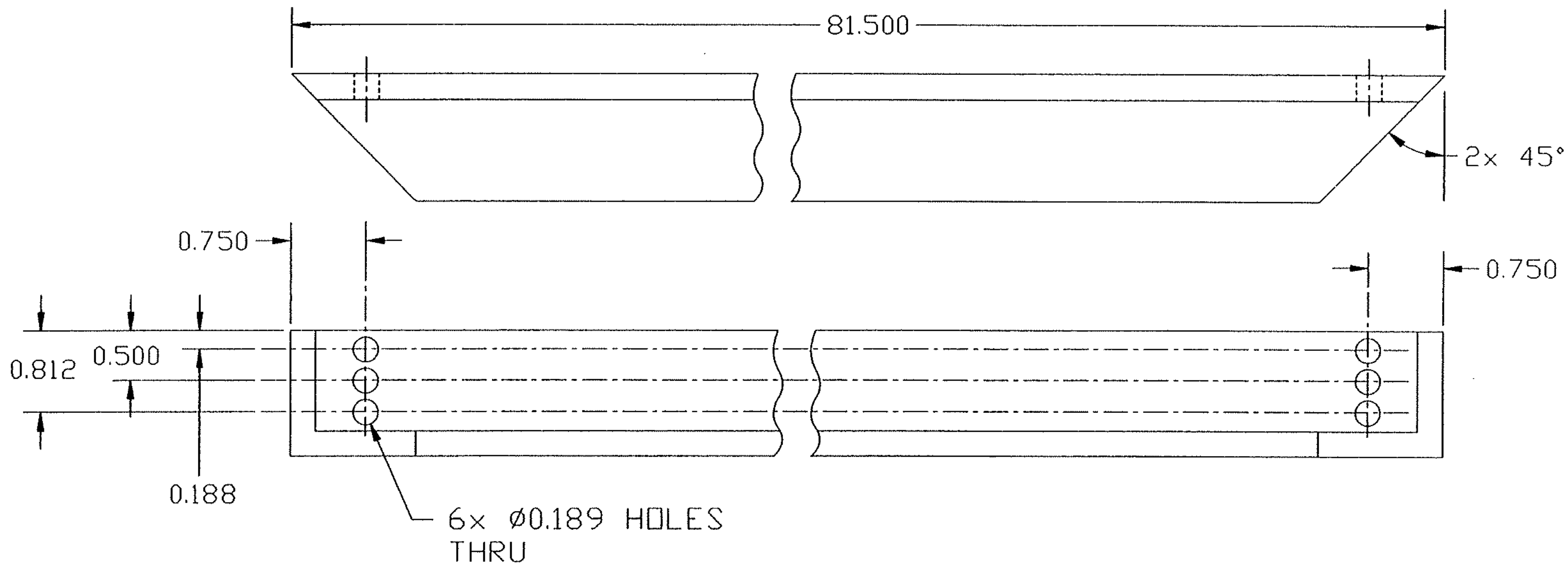
TITLE FRAME - SIDE ANGLES

DESIGN DJD/WWN	DATE 7/13/93	QTY 4
DRAWN WWN/DJD		SCALE 1:1
APPRV DJD/WWN		SIZE B
RELEASE		SHT

DRAWING NO. PMS-02-0016B

PROJECT AHMCT/PMS

LTR	ZONE	REVISION DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	7/13/93	WN/DD	YES

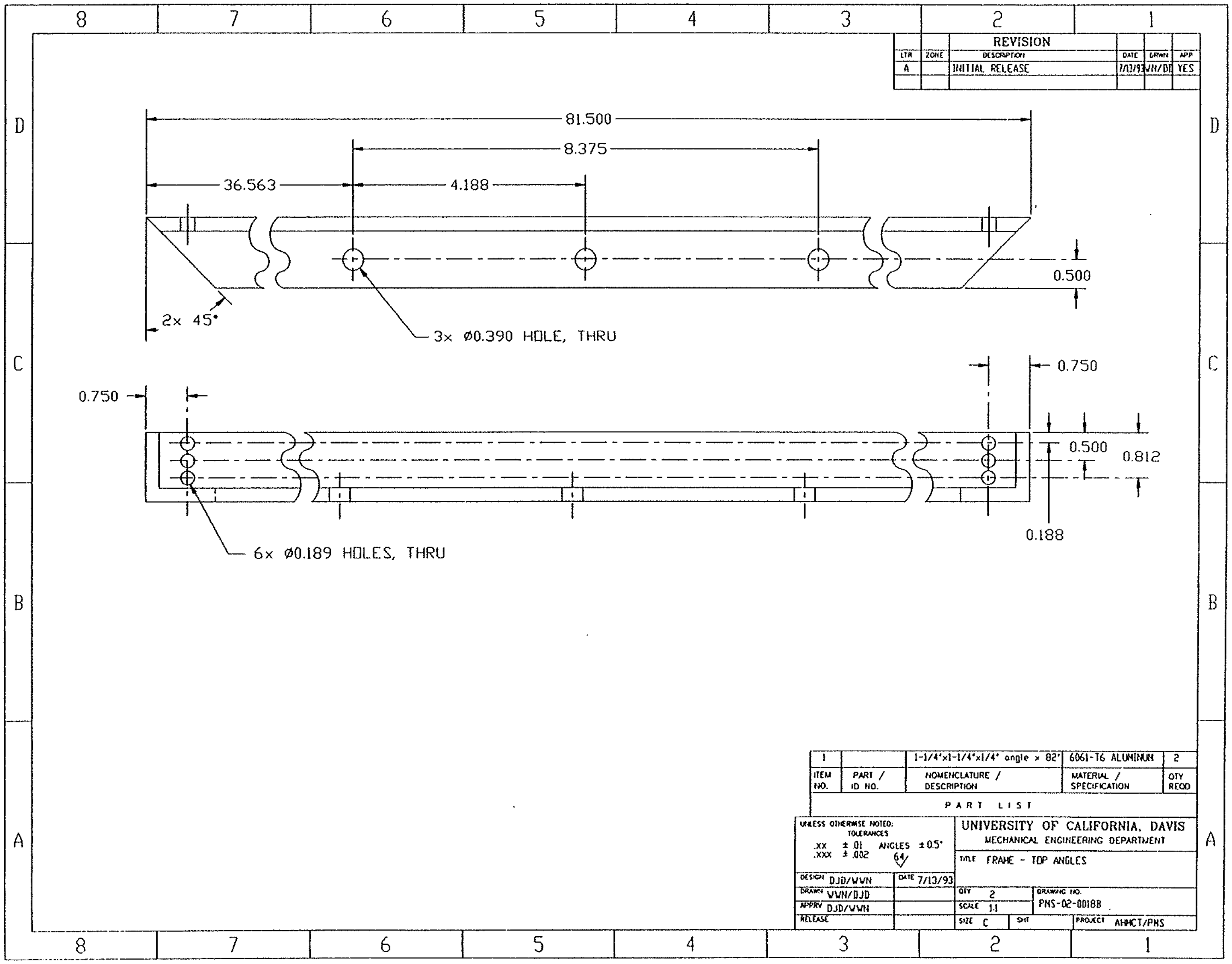


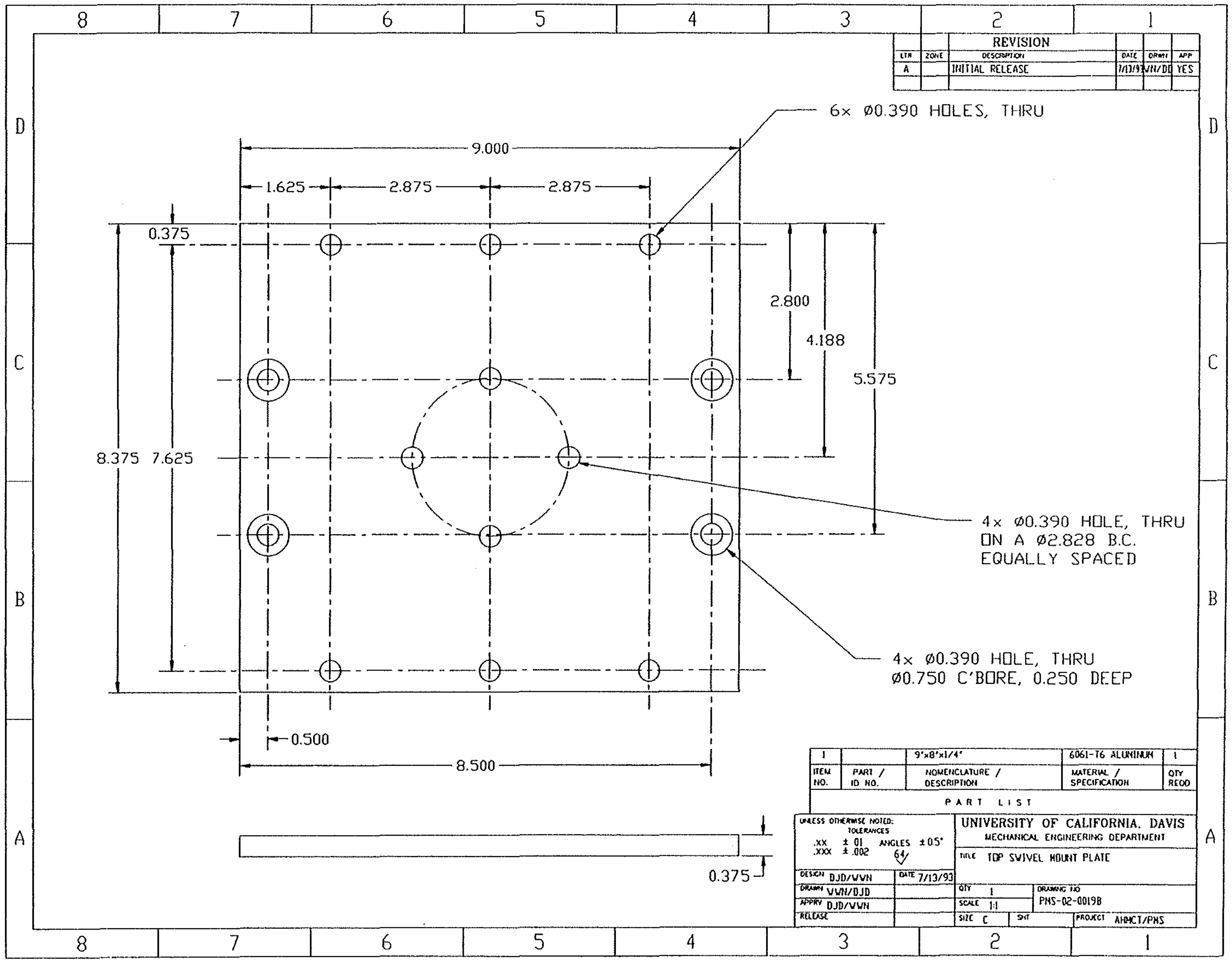
ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
1		1-1/4"x1-1/4"x1/4" angle x 82"	6061-T6 ALUMINUM	2

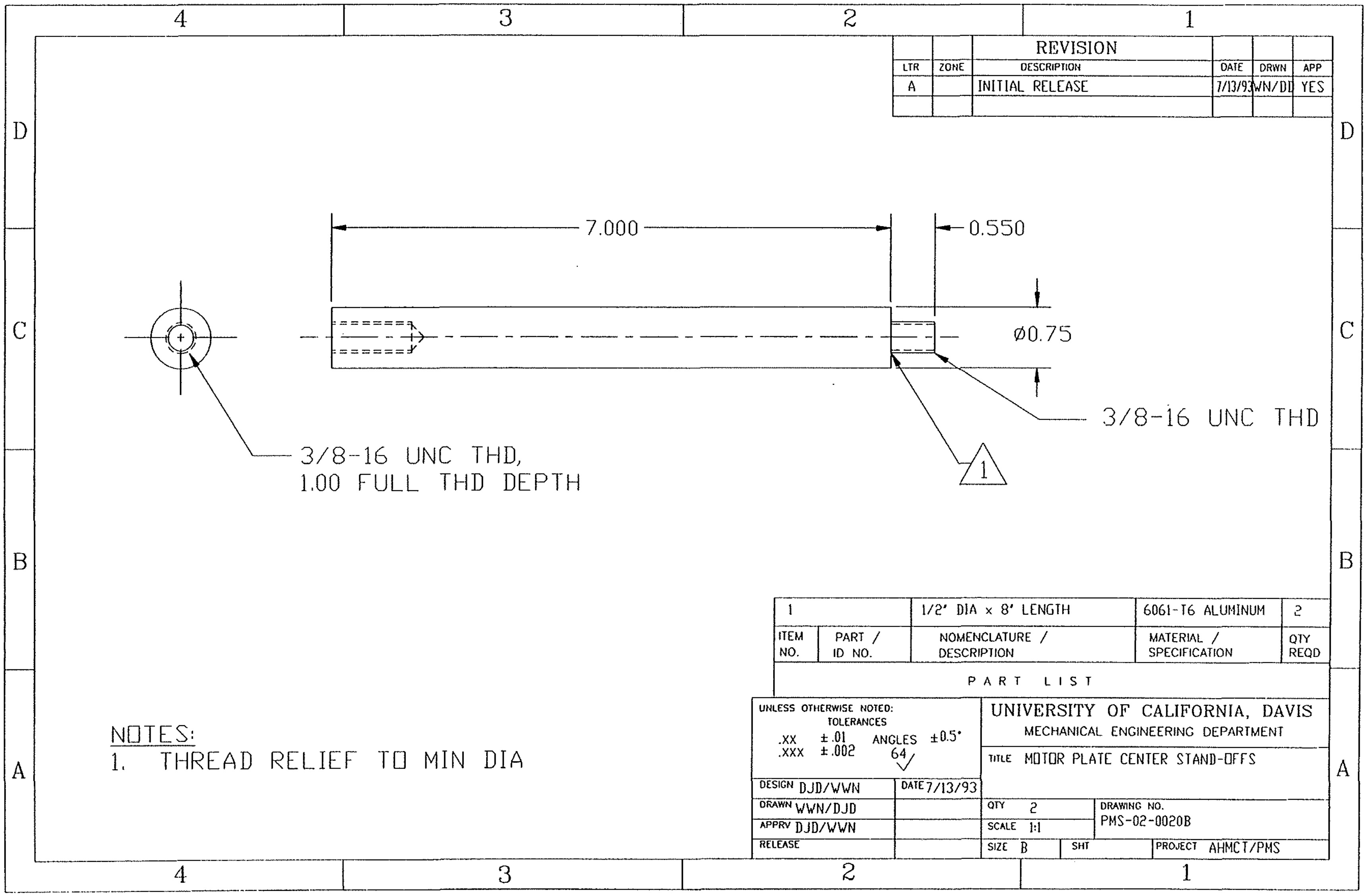
PART LIST

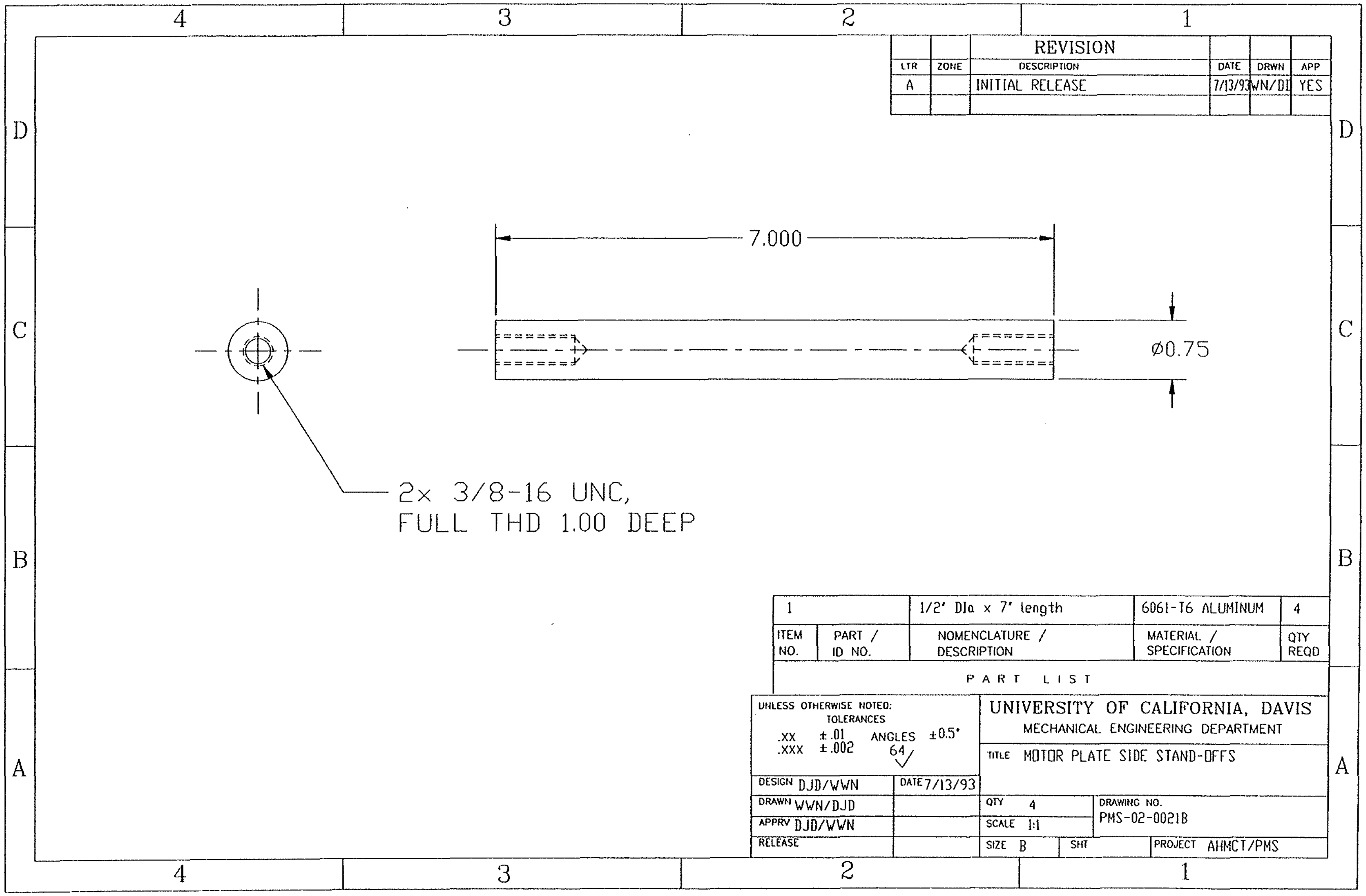
UNLESS OTHERWISE NOTED:
TOLERANCES
.XX ±.01
.XXX ±.002
ANGLES ±0.5°
64 √

DESIGN DJD/WWN	DATE 7/13/93	UNIVERSITY OF CALIFORNIA, DAVIS MECHANICAL ENGINEERING DEPARTMENT	
DRAWN WWN/DJD		TITLE FRAME - BOTTOM ANGLE	
APPRV DJD/WWN		QTY 2	DRAWING NO. PMS-02-0017B
RELEASE		SCALE 1:1	
		SIZE B	SHT	PROJECT AHMCT/PMS

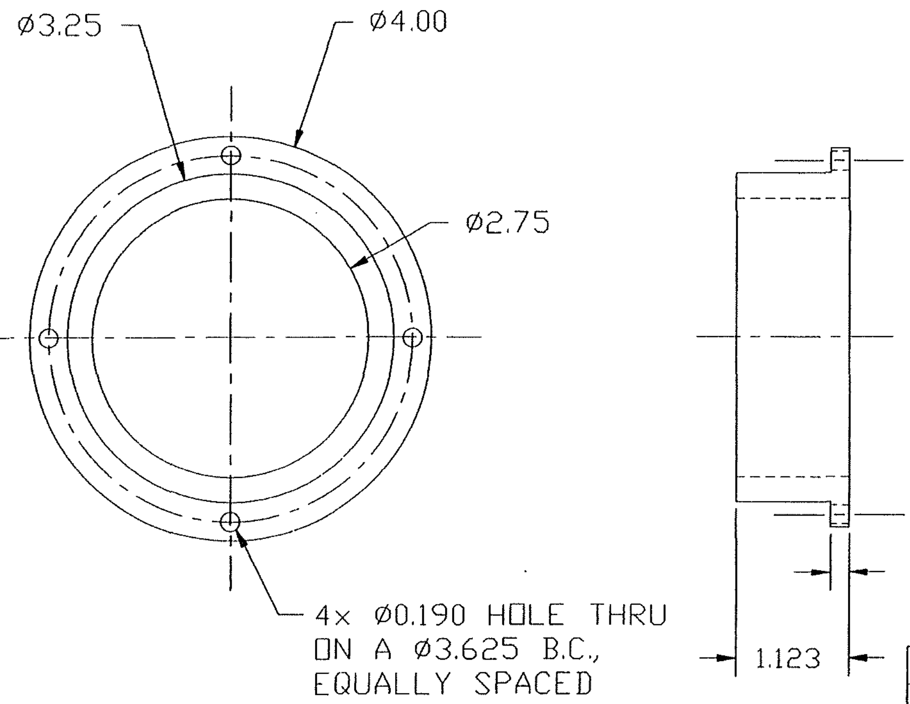

REVISION
LTR | ZONE | DESCRIPTION | DATE | DRWN | APP
A | INITIAL RELEASE | 7/13/93 | WN/DJ | YES
81.500
8.375
36.563
4.188
0.500
2x 45°
3x Ø0.390 HOLE, THRU
0.750
0.750
0.500
0.812
0.188
6x Ø0.189 HOLES, THRU
1 | 1-1/4"x1-1/4"x1/4" angle x 82" | 6061-T6 ALUMINUM | 2
ITEM NO. | PART / ID NO. | NOMENCLATURE / DESCRIPTION | MATERIAL / SPECIFICATION | QTY REQD
PART LIST
UNLESS OTHERWISE NOTED: TOLERANCES
.XX ± .01 ANGLES ± 0.5°
.XXX ± .002
64
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
TITLE FRAME - TOP ANGLES
DESIGN DJD/WWN
DATE 7/13/93
DRAWN WWN/DJD
APPRV DJD/WWN
RELEASE
QTY 2
SCALE 1:1
DRAWING NO. PNS-02-0018B
SIZE C
SHT
PROJECT AHMCT/PNS


REVISION
A INITIAL RELEASE 7/13/93 VWN/DD YES
6x Ø0.390 HOLES, THRU
9.000
1.625
2.875
2.875
0.375
2.800
4.188
5.575
8.375 7.625
4x Ø0.390 HOLE, THRU
ON A Ø2.828 B.C.
EQUALLY SPACED
4x Ø0.390 HOLE, THRU
Ø0.750 C'BORE, 0.250 DEEP
0.500
8.500
0.375
9"x8"x1/4"
6061-T6 ALUMINUM
PART LIST
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
TOP SWIVEL MOUNT PLATE
DESIGN DJD/VWN
DRAWN VWN/DJD
APPRV DJD/VWN
DATE 7/13/93
SCALE 1:1
PMS-02-0019B
AHMCT/PMS


REVISION
LTR ZONE DESCRIPTION DATE DRWN APP
A INITIAL RELEASE 7/13/93 WWN/DJD YES
7.000
0.550
Ø0.75
3/8-16 UNC THD
3/8-16 UNC THD,
1.00 FULL THD DEPTH
1
NOTES:
1. THREAD RELIEF TO MIN DIA
1 1/2" DIA x 8" LENGTH 6061-T6 ALUMINUM 2
ITEM NO. PART / ID NO. NOMENCLATURE / DESCRIPTION MATERIAL / SPECIFICATION QTY REQD
PART LIST
UNLESS OTHERWISE NOTED: TOLERANCES
.XX ±.01 ANGLES ±0.5°
.XXX ±.002
64
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
TITLE MOTOR PLATE CENTER STAND-OFFS
DESIGN DJD/WWN DATE 7/13/93
DRAWN WWN/DJD
APPRV DJD/WWN
RELEASE
QTY 2
SCALE 1:1
DRAWING NO. PMS-02-0020B
SIZE B
SHT
PROJECT AHMCT/PMS


REVISION
LTR ZONE DESCRIPTION DATE DRWN APP
A INITIAL RELEASE 7/13/93 WWN/DJD YES
7.000
Ø0.75
2x 3/8-16 UNC,
FULL THD 1.00 DEEP
1 1/2" DIa x 7" length 6061-T6 ALUMINUM 4
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 MOTOR PLATE SIDE STAND-OFFS
DESIGN DJD/WWN DATE 7/13/93
DRAWN WWN/DJD
APPRV DJD/WWN
RELEASE
QTY 4
SCALE 1:1
SIZE B
SHT
DRAWING NO. PMS-02-0021B
PROJECT AHMCT/PMS

REVISION						
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	7/13/93	WN/DJ	YES

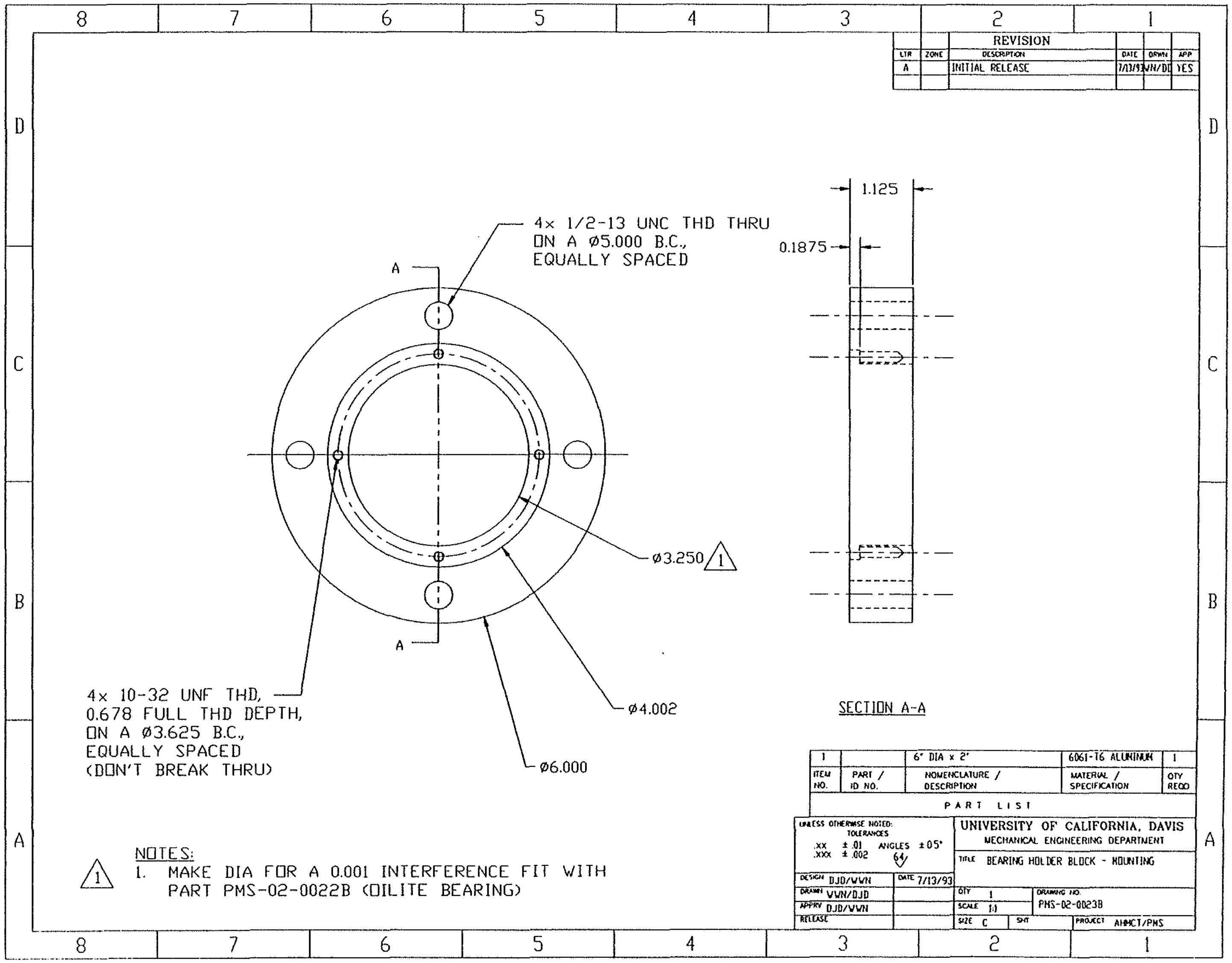


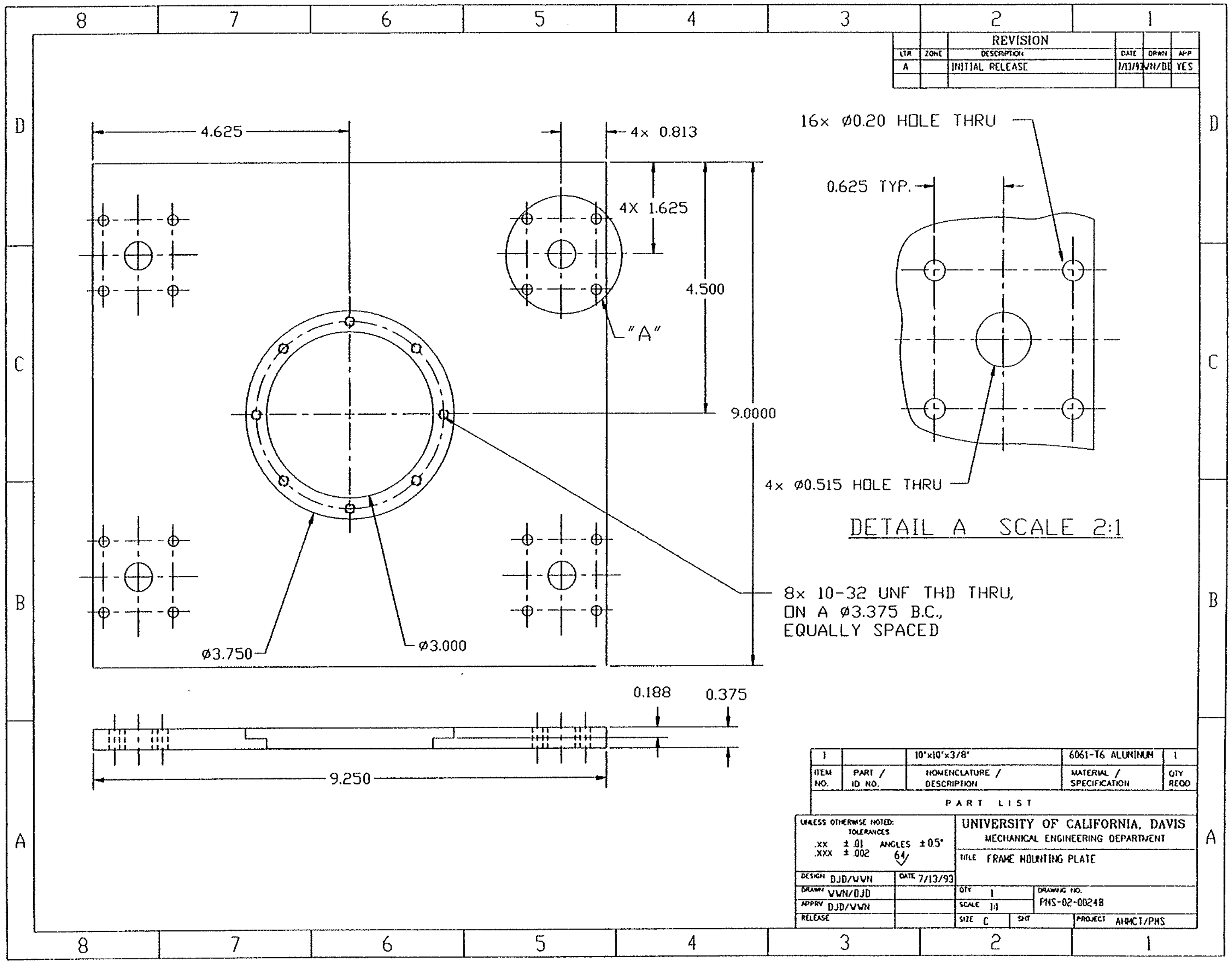
NOTES:
1. MADE FROM BEARING SF-88104-24

ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
1		BEARING SF-88104-24	OILITE	1

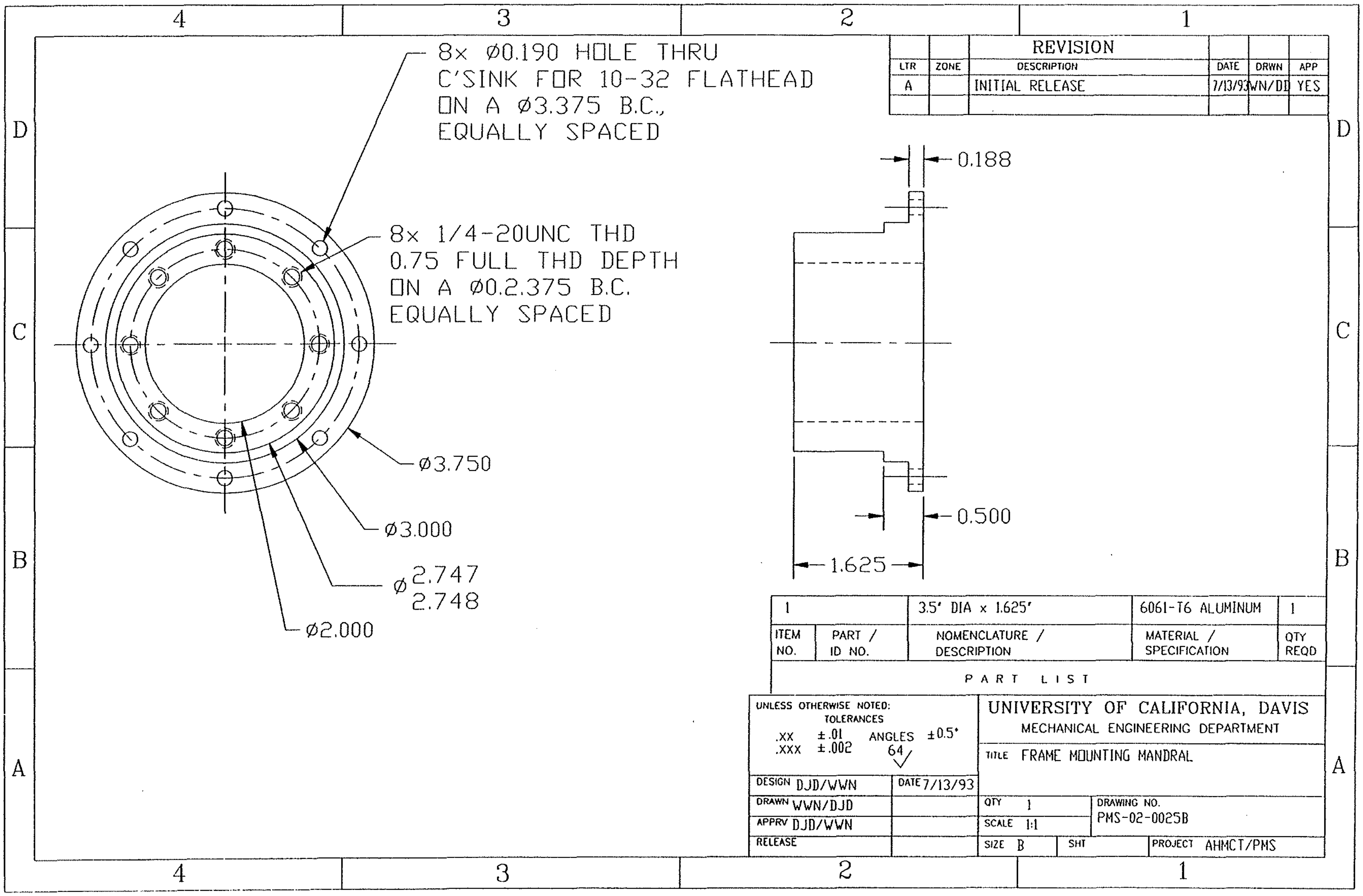
PART LIST

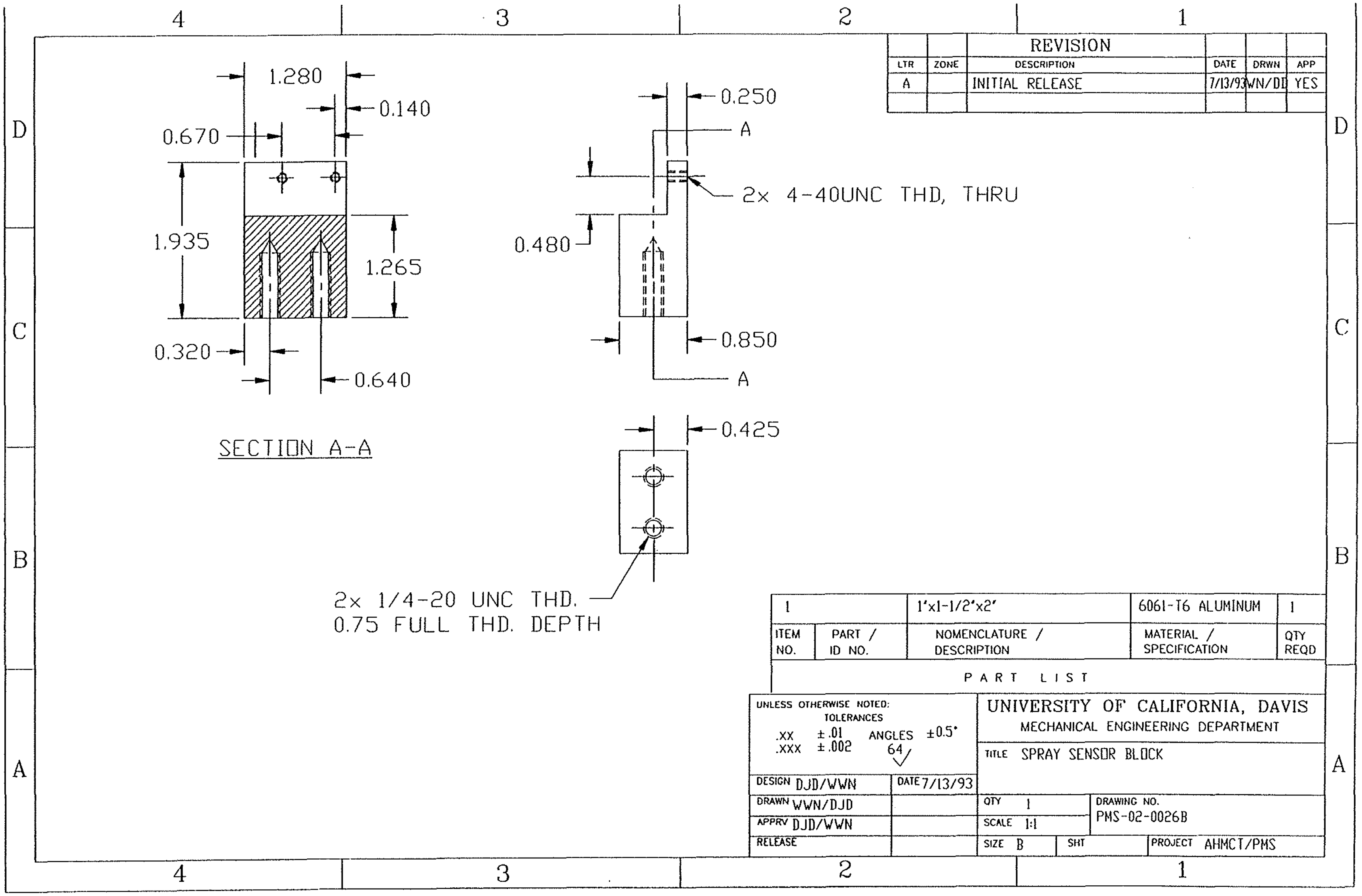
UNLESS OTHERWISE NOTED: TOLERANCES .XX ±.01 .XXX ±.002 ANGLES ±0.5° 64√	UNIVERSITY OF CALIFORNIA, DAVIS MECHANICAL ENGINEERING DEPARTMENT
DESIGN DJD/WWN, DATE 7/13/93	TITLE BEARING MOUNTING
DRAWN WWN/DJD	QTY 1; DRAWING NO. PMS-02-0022B
APPRV DJD/WWN	SCALE 1:1
RELEASE	SIZE B; SHT; PROJECT AHMCT/PMS


REVISION
LTR ZONE DESCRIPTION DATE DRWN APP
A INITIAL RELEASE 7/13/93 WVN/DJD YES
1.125
0.1875
4x 1/2-13 UNC THD THRU
ON A ø5.000 B.C.,
EQUALLY SPACED
A
A
ø3.250 1
ø4.002
ø6.000
4x 10-32 UNF THD,
0.678 FULL THD DEPTH,
ON A ø3.625 B.C.,
EQUALLY SPACED
(DON'T BREAK THRU)
SECTION A-A
NOTES:
1 1. MAKE DIA FOR A 0.001 INTERFERENCE FIT WITH
PART PMS-02-0022B (OILITE BEARING)
1 | | 6" DIA x 2" | 6061-T6 ALUMINUM | 1
ITEM NO. | PART / ID NO. | NOMENCLATURE / DESCRIPTION | MATERIAL / SPECIFICATION | QTY REQD
PART LIST
UNLESS OTHERWISE NOTED: TOLERANCES
.XX ± .01 ANGLES ±0.5°
.XXX ± .002
64
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
TITLE BEARING HOLDER BLOCK - MOUNTING
DESIGN DJD/WVN DATE 7/13/93
DRAWN WVN/DJD
APPRV DJD/WVN
RELEASE
QTY 1
SCALE 1:1
DRAWING NO. PMS-02-0023B
SIZE C
SHT
PROJECT AHMCT/PMS

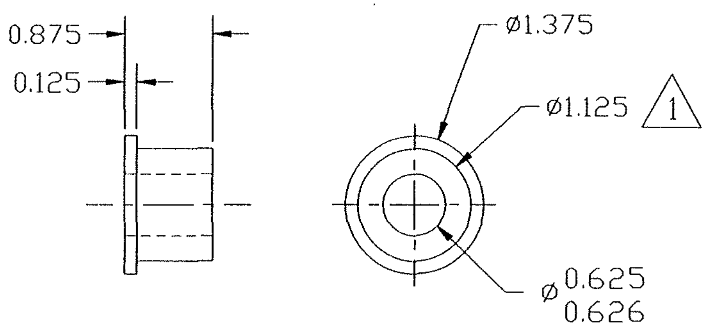


REVISION
LTR ZONE DESCRIPTION DATE DRWN APP
A INITIAL RELEASE 7/13/93 VWN/DD YES
4.625
4x 0.813
4X 1.625
4.500
9.0000
"A"
ø3.750
ø3.000
8x 10-32 UNF THD THRU, ON A ø3.375 B.C., EQUALLY SPACED
16x ø0.20 HOLE THRU
0.625 TYP.
4x ø0.515 HOLE THRU
DETAIL A SCALE 2:1
0.188
0.375
9.250
1 10"x10"x3/8" 6061-T6 ALUMINUM 1
ITEM NO. PART / ID NO. NOMENCLATURE / DESCRIPTION MATERIAL / SPECIFICATION QTY REQD
PART LIST
UNLESS OTHERWISE NOTED: TOLERANCES
.XX ± .01 ANGLES ±0.5°
.XXX ± .002
64
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
TITLE FRAME MOUNTING PLATE
DESIGN DJD/VWN DATE 7/13/93
DRAWN VWN/DJD
APPRV DJD/VWN
RELEASE
QTY 1
SCALE 1:1
DRAWING NO. PMS-02-0024B
SIZE C SHT
PROJECT AHMCT/PMS


8x Ø0.190 HOLE THRU
C'SINK FOR 10-32 FLATHEAD
ON A Ø3.375 B.C.,
EQUALLY SPACED
8x 1/4-20UNC THD
0.75 FULL THD DEPTH
ON A Ø0.2.375 B.C.
EQUALLY SPACED
Ø3.750
Ø3.000
Ø 2.747 2.748
Ø2.000
0.188
0.500
1.625
REVISION
LTR ZONE DESCRIPTION DATE DRWN APP
A INITIAL RELEASE 7/13/93 WN/DD YES
1 3.5' DIA x 1.625' 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 DJD/WWN DATE 7/13/93
DRAWN WWN/DJD
APPRV DJD/WWN
RELEASE
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
TITLE FRAME MOUNTING MANDRAL
QTY 1
SCALE 1:1
DRAWING NO. PMS-02-0025B
SIZE B SHT PROJECT AHMCT/PMS


REVISION
LTR | ZONE | DESCRIPTION | DATE | DRWN | APP
A | INITIAL RELEASE | 7/13/93 | WN/DD | YES
1.280
0.140
0.670
1.935
1.265
0.320
0.640
SECTION A-A
0.250
A
2x 4-40UNC THD, THRU
0.480
0.850
A
0.425
2x 1/4-20 UNC THD.
0.75 FULL THD. DEPTH
1 | 1"x1-1/2"x2" | 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 SPRAY SENSOR BLOCK
DESIGN DJD/WWN
DATE 7/13/93
DRAWN WWN/DJD
APPRV DJD/WWN
RELEASE
QTY 1
SCALE 1:1
SIZE B
SHT
DRAWING NO. PMS-02-0026B
PROJECT AHMCT/PMS

REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	7/13/93	WWN/DJD	YES



NOTES:

1. MAKE DIA FOR A 0.001 INTERFERENCE FIT WITH PART PMS-02-0010B

ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
1		1.5" DIA x 1" LENGTH	OILITE	2

PART LIST

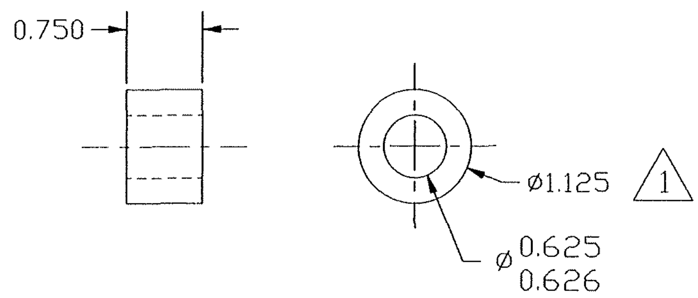
UNLESS OTHERWISE NOTED:
TOLERANCES
.XX ±.01 ANGLES ±0.5°
.XXX ±.002
64

UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT

TITLE SWIVEL BEARING - BOTTOM

DESIGN DJD/WWN	DATE 7/13/93	QTY 2	DRAWING NO. PMS-02-0027B
DRAWN WWN/DJD		SCALE 1:1	
APPRV DJD/WWN		SIZE B	SHT
RELEASE		PROJECT AHMCT/PMS	

REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	7/13/93	WN/DD	YES



NOTES:

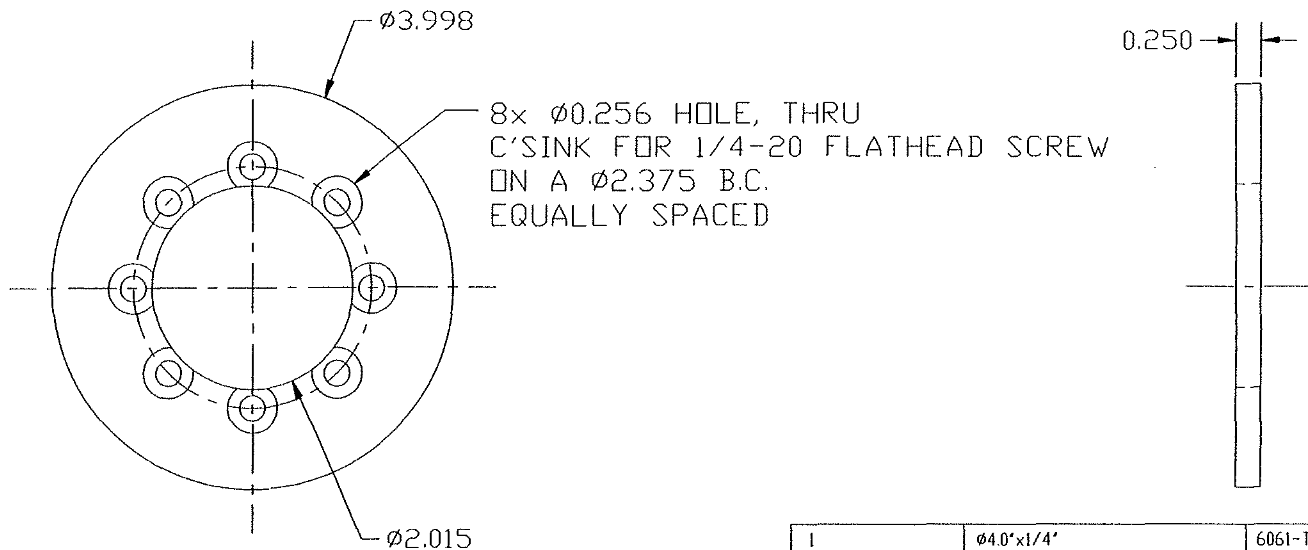
△1 1. MAKE DIA FOR A 0.001 INTERFERENCE FIT WITH PART PMS-02-0009B

1		1.125" DIA x 1"	OILITE	2
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 SWIVEL BEARING - TOP	
DESIGN DJD/WWN	DATE 7/13/93	
DRAWN WWN/DJD	QTY 2	DRAWING NO. PMS-02-0028B
APPRV DJD/WWN	SCALE 1:1	
RELEASE	SIZE B SHT	PROJECT AHMCT/PMS

LTR	ZONE	REVISION DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	8/11/93	WN/DD	YES



ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
1		Ø4.0"x1/4"	6061-T6 ALUMINUM	1

PART LIST

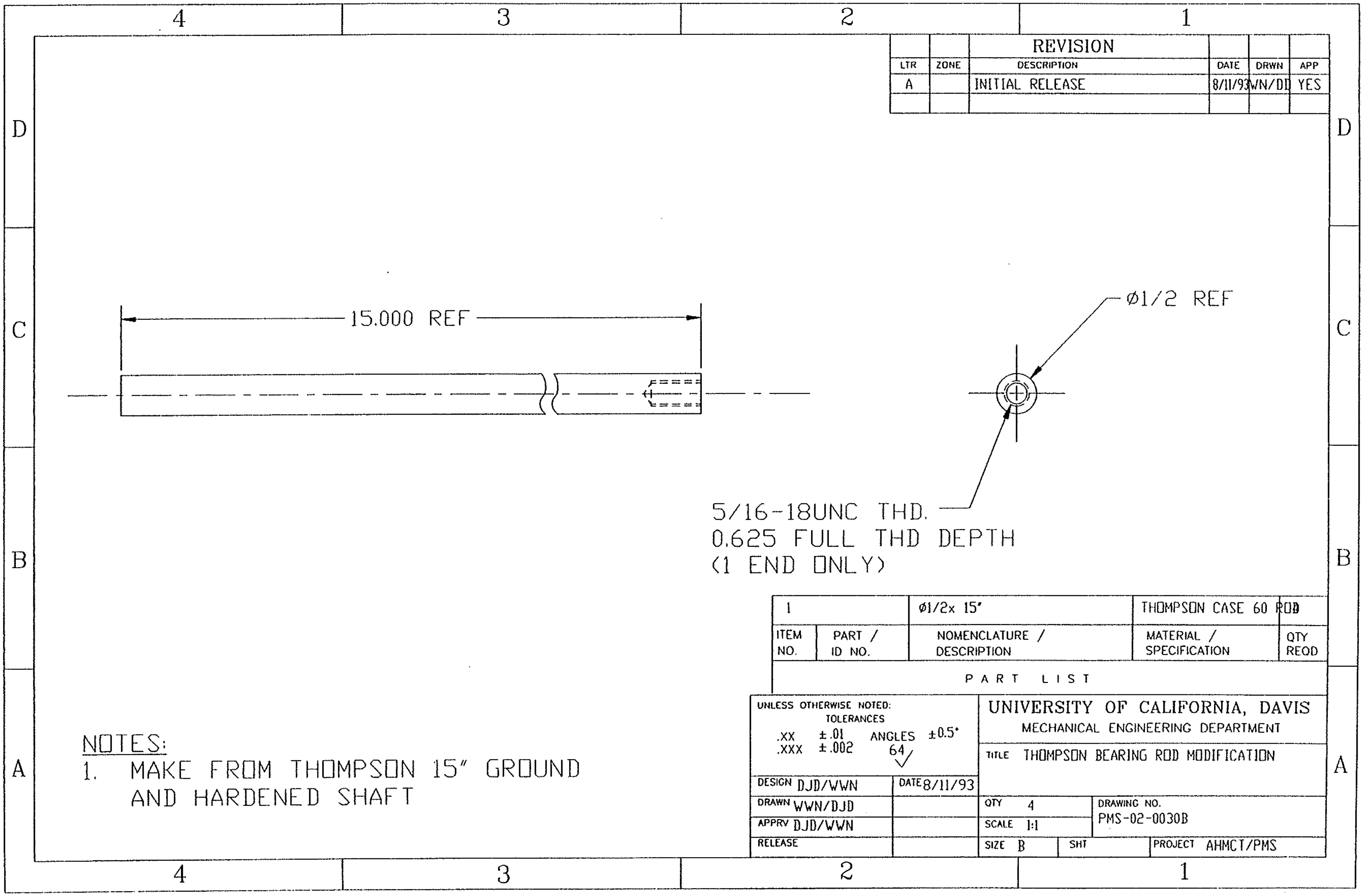
UNLESS OTHERWISE NOTED:
TOLERANCES
.XX ±.01
.XXX ±.002
ANGLES ±0.5°
64√

DESIGN DJD/WWN	DATE 8/11/93	
DRAWN WWN/DJD		
APPRV DJD/WWN		
RELEASE		

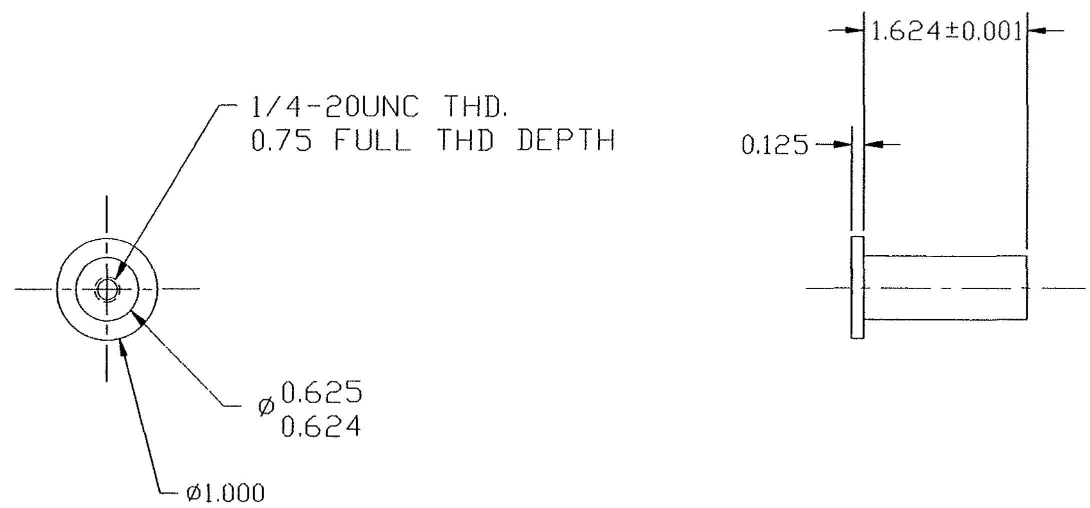
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT

TITLE FRAME MOUNTING MANDREL - WASHER

QTY 1	DRAWING NO. PMS-02-0029B	
SCALE 1:1		
SIZE B	SHT	PROJECT AHMCT/PMS


REVISION
LTR
ZONE
DESCRIPTION
DATE
DRWN
APP
A
INITIAL RELEASE
8/11/93
WWN/DDJ
YES
15.000 REF
Ø1/2 REF
5/16-18UNC THD.
0.625 FULL THD DEPTH
(1 END ONLY)
1
Ø1/2x 15"
THOMPSON CASE 60 ROD
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 THOMPSON BEARING ROD MODIFICATION
DESIGN DJD/WWN
DATE 8/11/93
DRAWN WWN/DJD
APPRV DJD/WWN
RELEASE
QTY 4
SCALE 1:1
SIZE B
SHT
DRAWING NO. PMS-02-0030B
PROJECT AHMCT/PMS
NOTES:
1. MAKE FROM THOMPSON 15" GROUND AND HARDENED SHAFT

REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	8/11/93	WN/DD	YES



ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
1		Ø1.00"x2"	303 S.S.	2

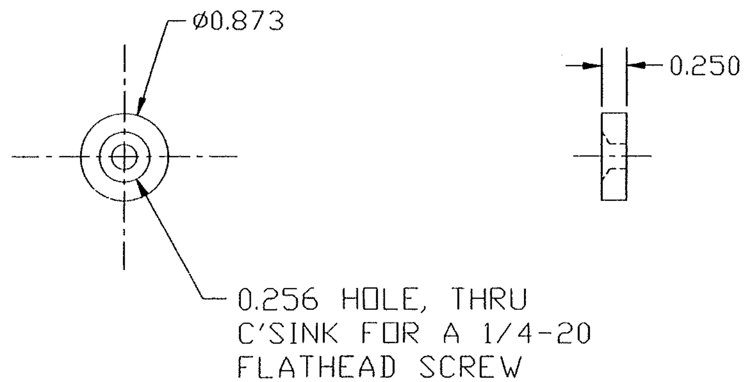
PART LIST

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

UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT

TITLE SWIVEL SHAFT

DESIGN DJD/WWN	DATE 8/11/93	QTY 2	DRAWING NO. PMS-02-0031B
DRAWN WWN/DJD		SCALE 1:1	
APPRV DJD/WWN		SIZE B	SHT
RELEASE		PROJECT AHMCT/PMS	



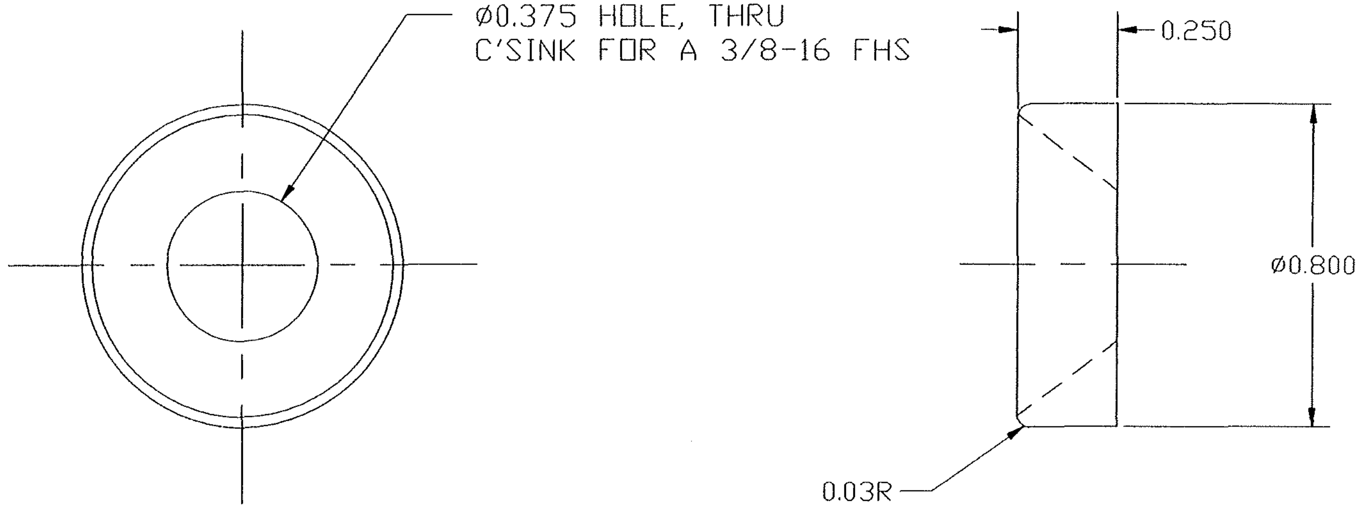
REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	8/11/93	WN/DD	YES

ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
1		Ø1.0x1/4"	6061-T6 ALUMINUM	2

PART LIST

UNLESS OTHERWISE NOTED: TOLERANCES .XX ±.01 .XXX ±.002 ANGLES ±0.5° 64√		UNIVERSITY OF CALIFORNIA, DAVIS MECHANICAL ENGINEERING DEPARTMENT	
DESIGN DJD/WWN	DATE 8/11/93	TITLE SWIVEL SHAFT RETAINING WASHERS	
DRAWN WWN/DJD		QTY 2	DRAWING NO. PMS-02-0032B
APPRV DJD/WWN		SCALE 1:1	
RELEASE		SIZE B SHT	PROJECT AHMCT/PMS

LTR	ZONE	REVISION DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	8/11/93	WN/DJ	YES



ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
1		Ø0.800" x 0.250	303 S.S.	4

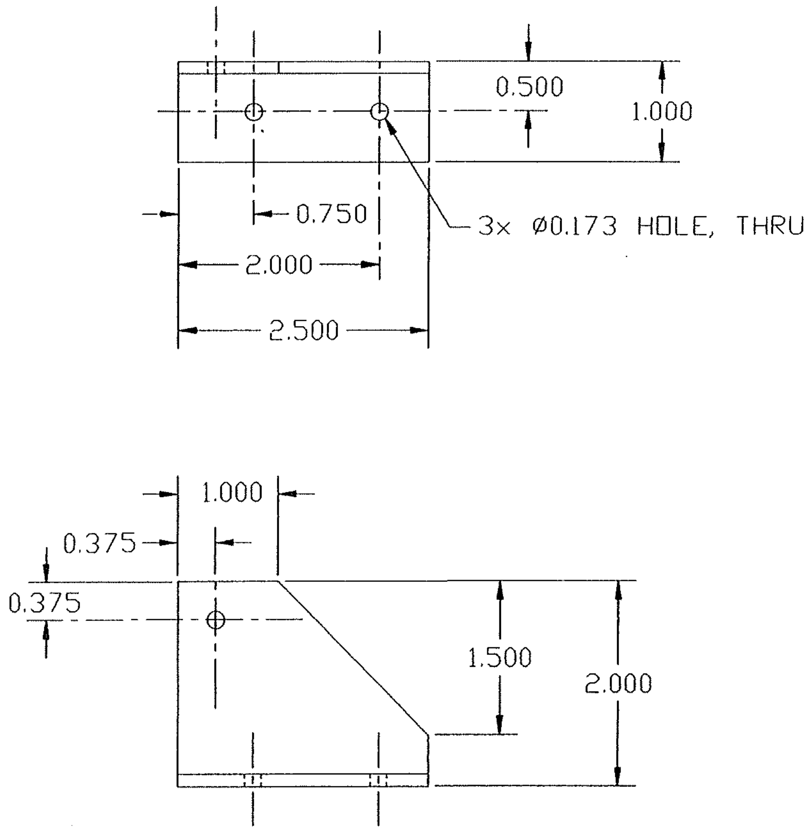
PART LIST

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

UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT

TITLE SPRING WASHER

DESIGN DJD/WWN	DATE 8/11/93	QTY 4
DRAWN WWN/DJD		SCALE 4x
APPRV DJD/WWN		DRAWING NO. PMS-02-0033
RELEASE		SIZE B · SHT · PROJECT AHMCT/PMS



REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	8/11/93	WN/DD	YES

ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
1		2"x2"x1/8" angle x 2.5"L	6061-T6 ALUMINUM	1

PART LIST

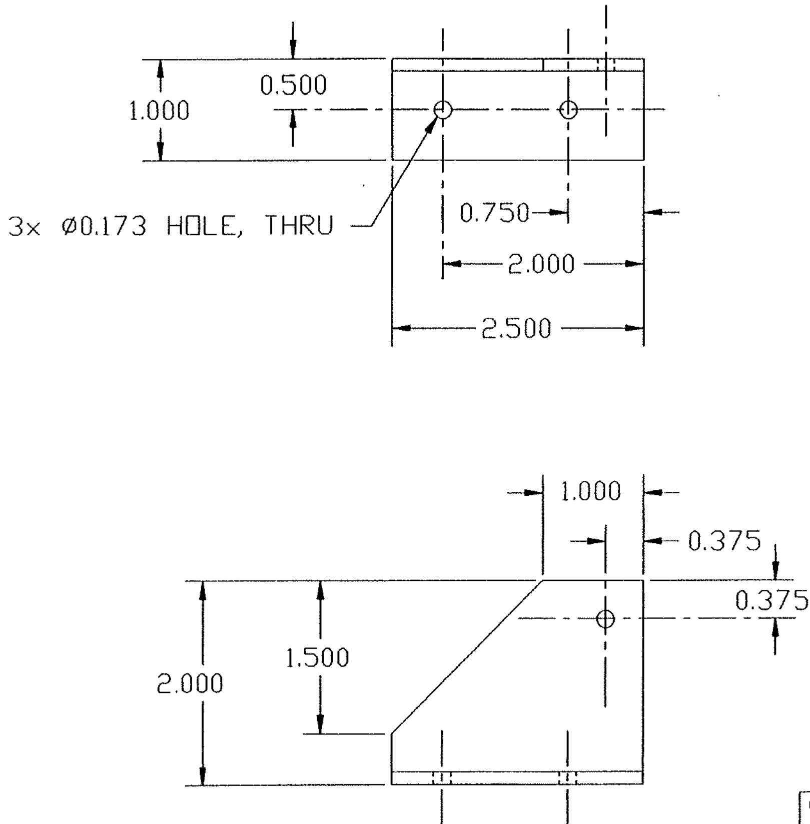
UNLESS OTHERWISE NOTED:
TOLERANCES
.XX ±.01
.XXX ±.002
ANGLES ±0.5°
64 √

DESIGN DJD/WWN	DATE 8/11/93	
DRAWN WWN/DJD		
APPRV DJD/WWN		
RELEASE		

UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT

TITLE CABLE HOLDER I

QTY 1	DRAWING NO. PMS-02-0034B	
SCALE 1:1		
SIZE B	SHT	PROJECT AHMCT/PMS



REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	8/11/93	WN/DJ	YES

ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
1		2"x2"x1/8" angle x 2.5"L	6061-T6 ALUMINUM	1

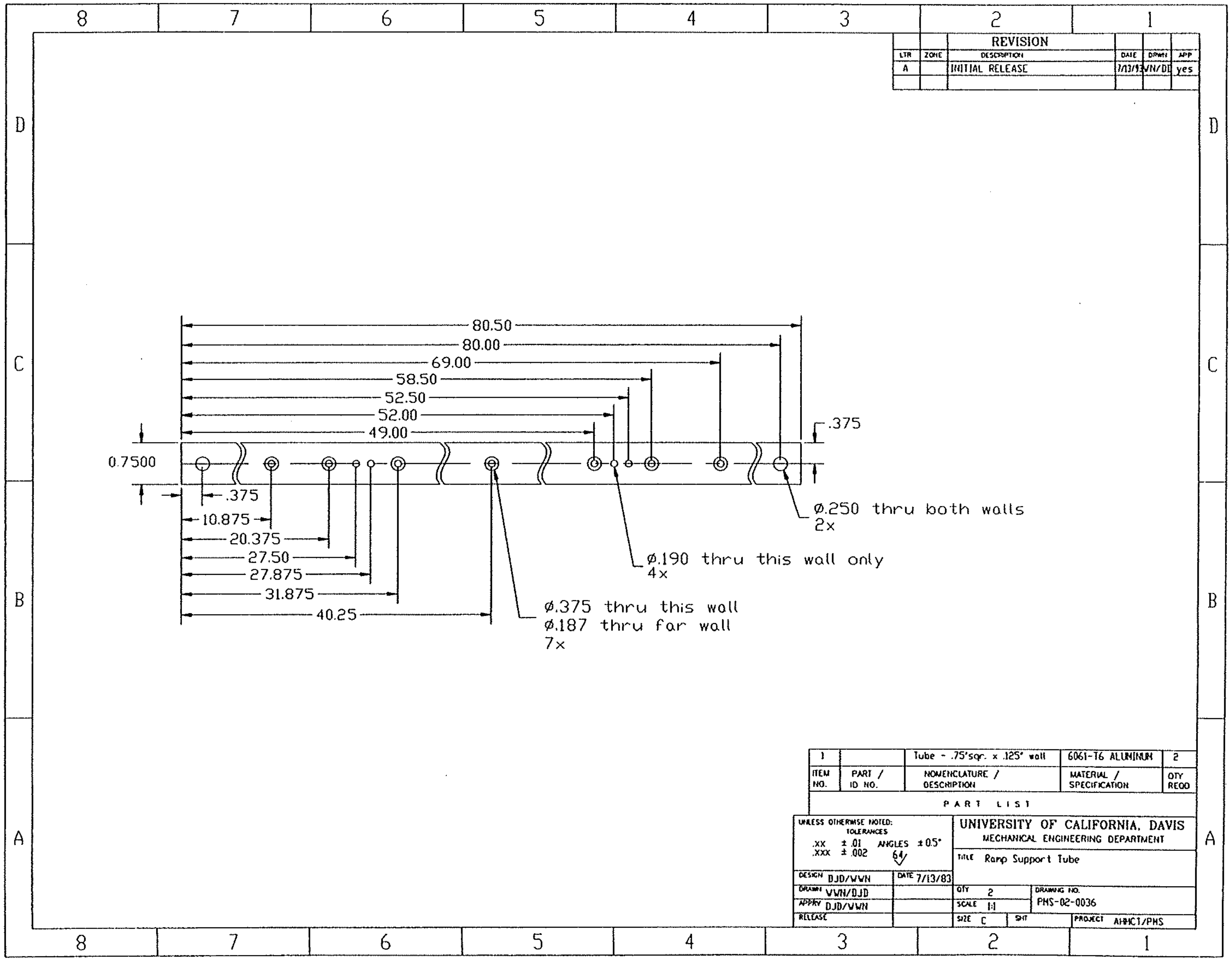
PART LIST

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

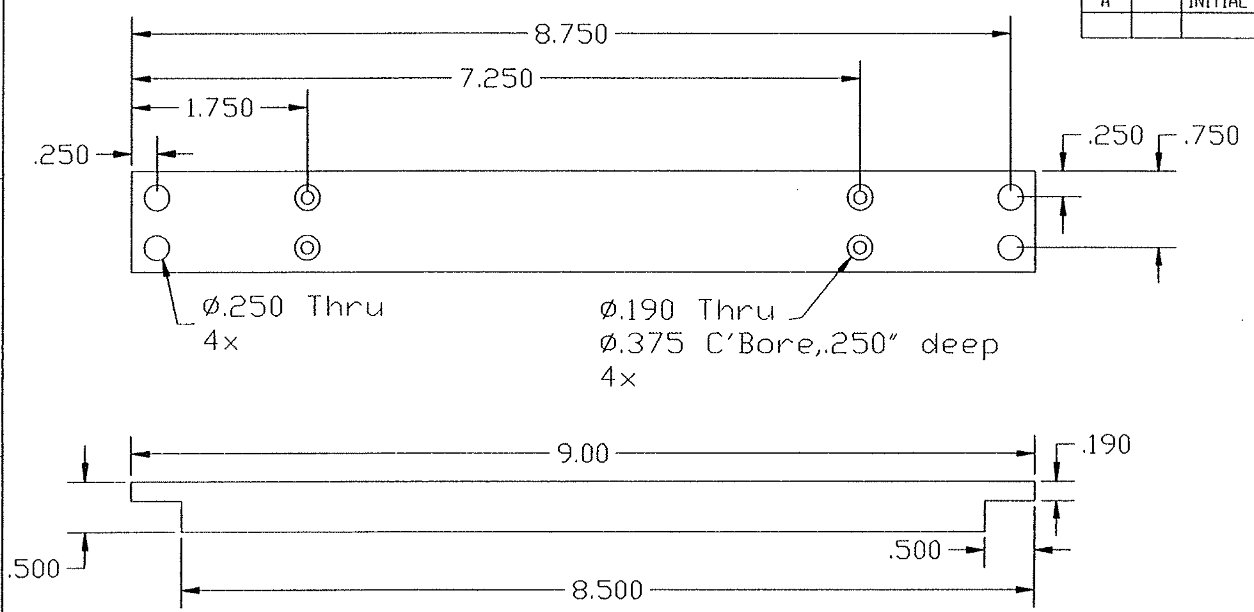
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT

TITLE CABLE HOLDER II

DESIGN DJD/WWN	DATE 8/11/93	QTY 1	DRAWING NO. PMS-02-0035B
DRAWN WWN/DJD		SCALE 1:1	
APPRV DJD/WWN		SIZE B	SHT
RELEASE			PROJECT AHMCT/PMS



REVISION
LTR
ZONE
DESCRIPTION
DATE
DRWN
APP
A
INITIAL RELEASE
yes
80.50
80.00
69.00
58.50
52.50
52.00
49.00
.375
0.7500
.375
10.875
20.375
27.50
27.875
31.875
40.25
Ø.250 thru both walls
2x
Ø.190 thru this wall only
4x
Ø.375 thru this wall
Ø.187 thru far wall
7x
1
Tube - .75'sqr. x .125' wall
6061-T6 ALUMINUM
2
ITEM NO.
PART / ID NO.
NOMENCLATURE / DESCRIPTION
MATERIAL / SPECIFICATION
QTY REQD
PART LIST
UNLESS OTHERWISE NOTED:
TOLERANCES
.XX ± .01 ANGLES ± 0.5°
.XXX ± .002
64
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
TITLE Ramp Support Tube
DESIGN DJD/VWN
DATE 7/13/83
DRAWN VWN/DJD
APPRV DJD/VWN
RELEASE
QTY 2
SCALE 1:1
DRAWING NO. PHS-02-0036
SIZE C
SHT
PROJECT AHMCT/PHS



REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	7/13/93	WN/DJ	YES

ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
1		1" x 1/2" x 9"	6061-T6 ALUMINUM	2

PART LIST

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

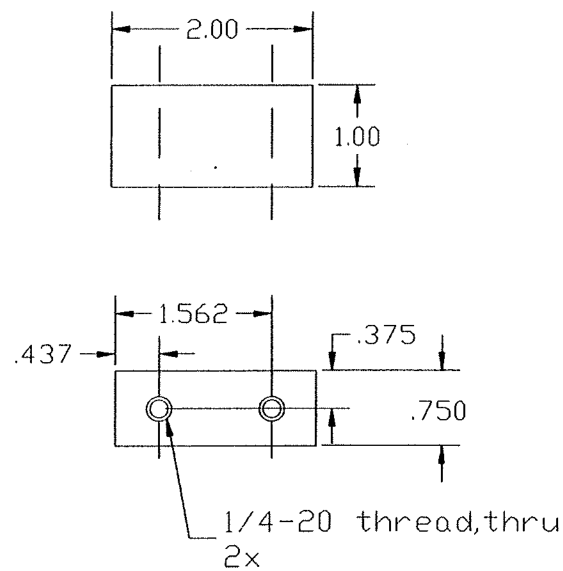
DESIGN DJD/WWN	DATE 7/13/83	
DRAWN WWN/DJD		
APPRV DJD/WWN		
RELEASE		

UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT

TITLE Cross Support

QTY 2	DRAWING NO. PMS-02-0037
SCALE 1:1	
SIZE B	SHT	PROJECT AHMCT/PMS

REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	7/13/93	WN/DJ	YES

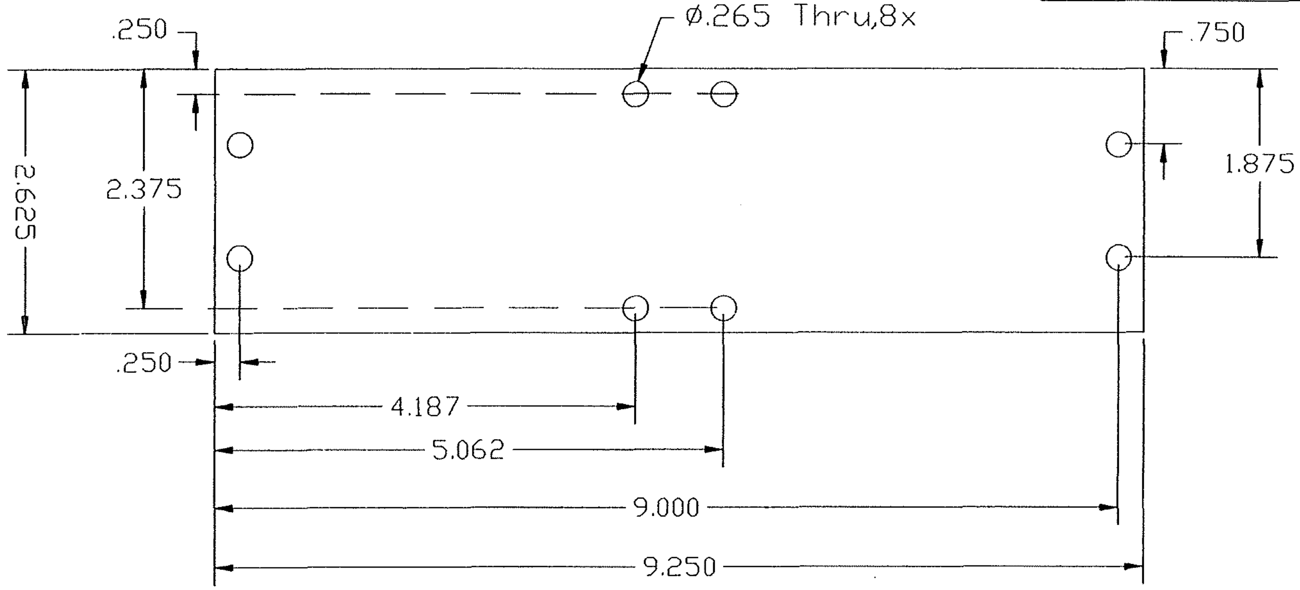


ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
1		2"x 1"x 3/4"	6061-T6 ALUMINUM	4

PART LIST

UNLESS OTHERWISE NOTED: TOLERANCES .XX ±.01 .XXX ±.002 ANGLES ±0.5° 64√		UNIVERSITY OF CALIFORNIA, DAVIS MECHANICAL ENGINEERING DEPARTMENT	
DESIGN DJD/WWN	DATE 7/13/83	TITLE Wheel Plate Stand-off	
DRAWN WWN/DJD		QTY 4	DRAWING NO. PMS-02-0038
APPRV DJD/WWN		SCALE 1:1	
RELEASE		SIZE B SHT	PROJECT AHMCT/PMS

REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	7/13/93	WN/DD	YES



ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
1		2.625"x 9.250"x .250"	6061-T6 ALUMINUM	2

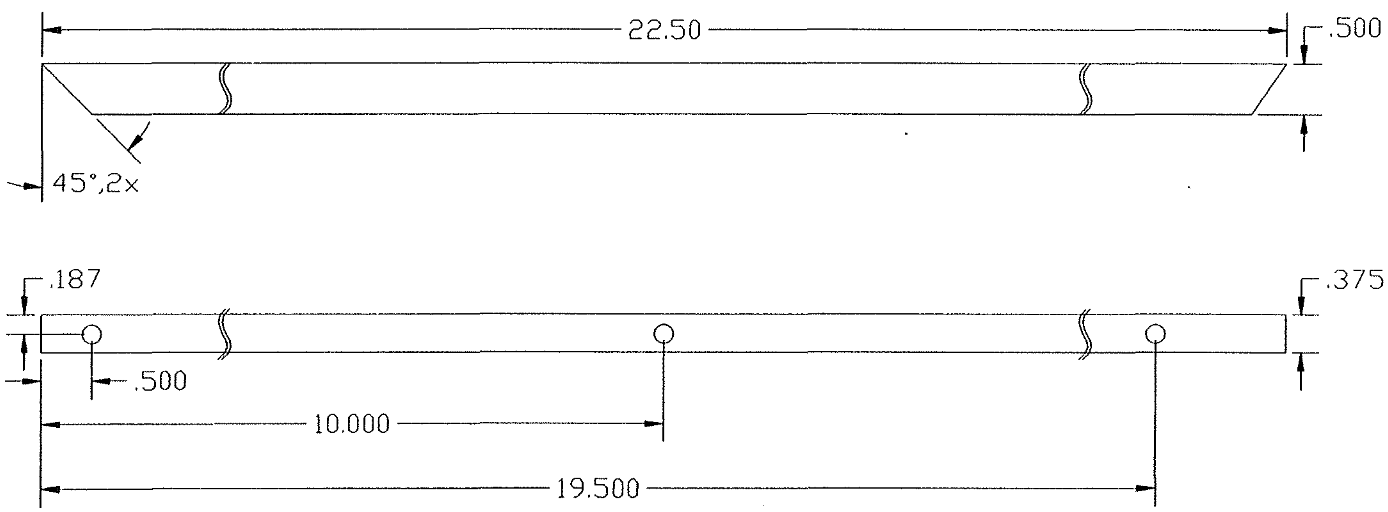
PART LIST

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

UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT

DESIGN DJD/WWN	DATE 7/13/83	TITLE Wheel Mounting Plate	
DRAWN WWN/DJD		QTY 2	DRAWING NO. PMS-02-0039
APPRV DJD/WWN		SCALE 1:1	
RELEASE		SIZE B / SHT	PROJECT AHMCT/PMS

REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	7/13/93	WN/DD	YES



ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
1		22.50"x .50"x .375"	6061-T6 ALUMINUM	4

PART LIST

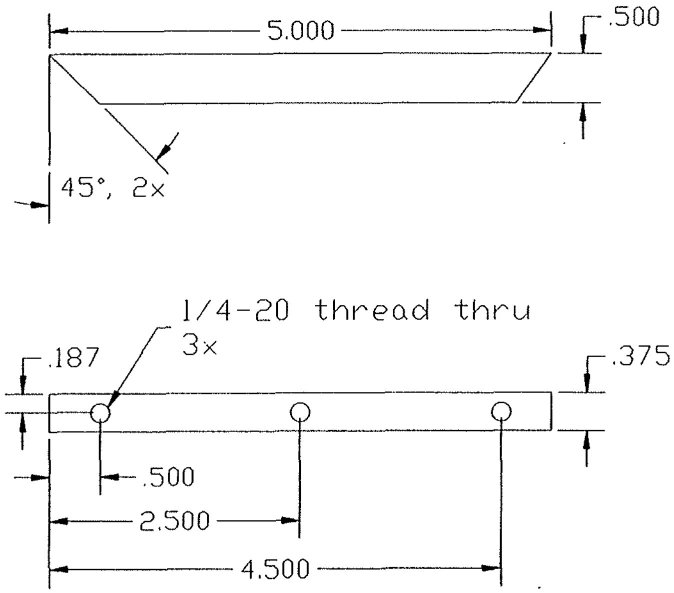
UNLESS OTHERWISE NOTED:
TOLERANCES
.XX ±.01
.XXX ±.002
ANGLES ±0.5°
64√

UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT

TITLE Ramp

DESIGN DJD/WWN	DATE 7/13/83	QTY 4	DRAWING NO. PMS-02-0040
DRAWN WWN/DJD		SCALE 1:1	
APPRV DJD/WWN		SIZE B	SHT
RELEASE		PROJECT AHMCT/PMS	

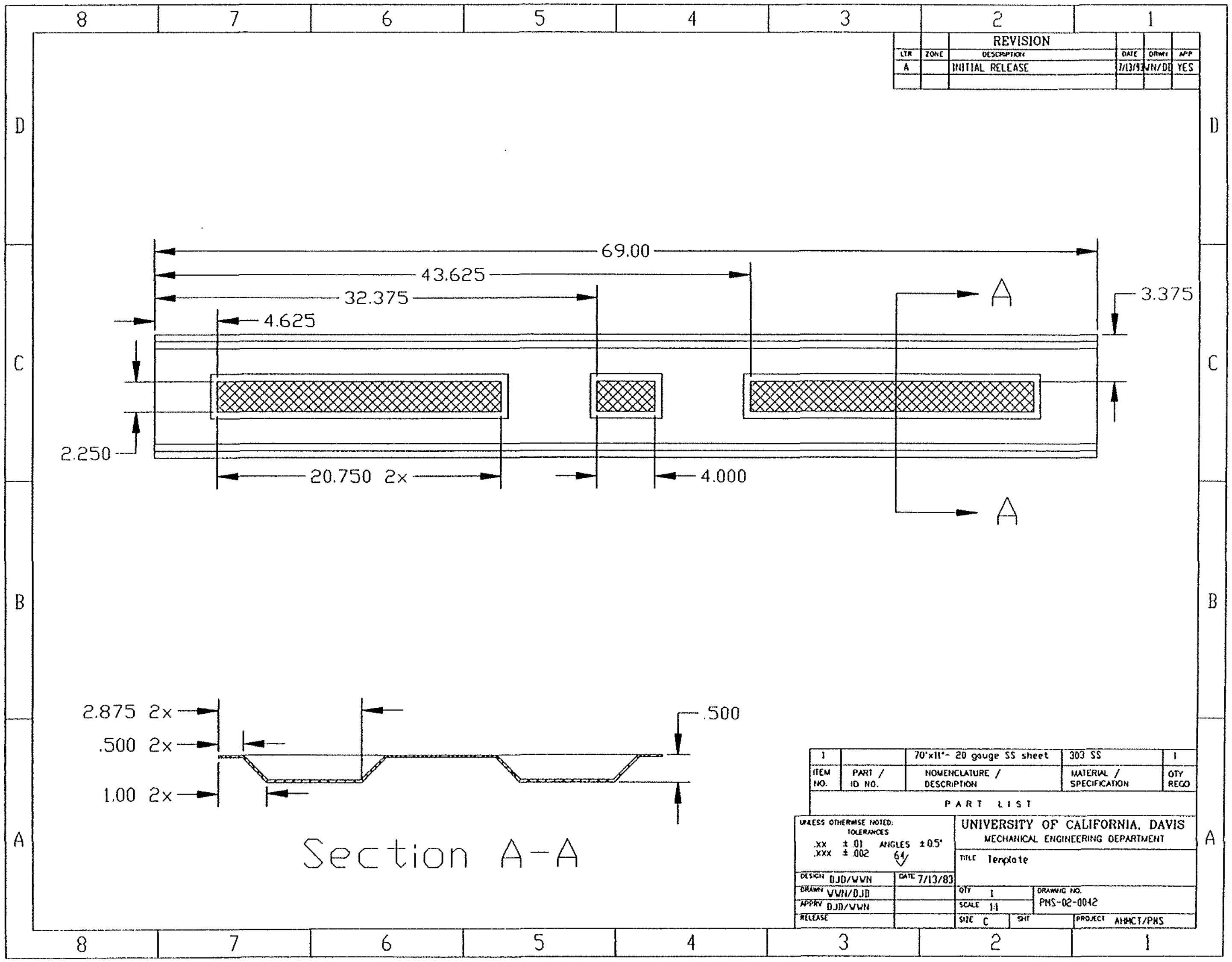
REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	7/13/93	WN/DD	YES

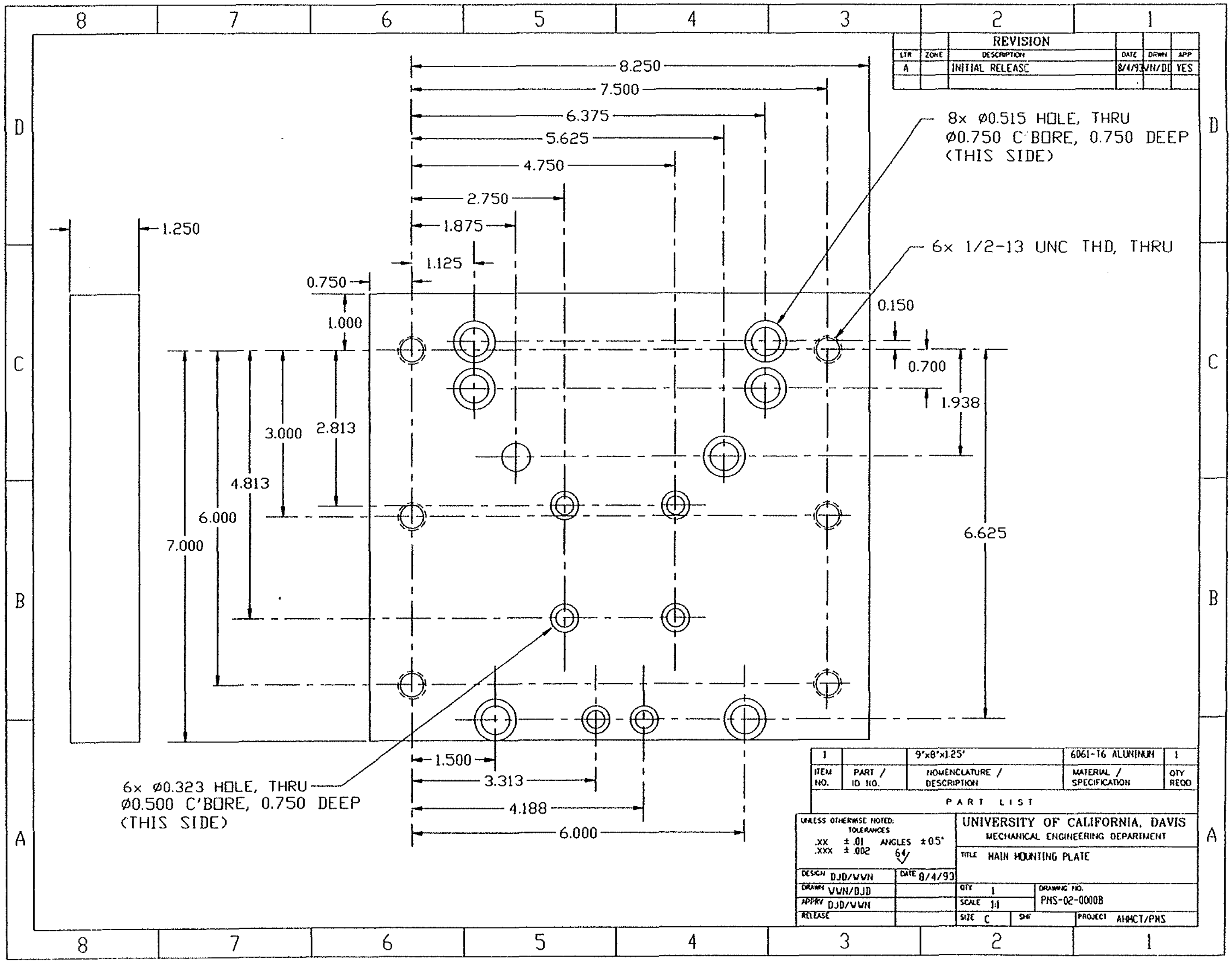


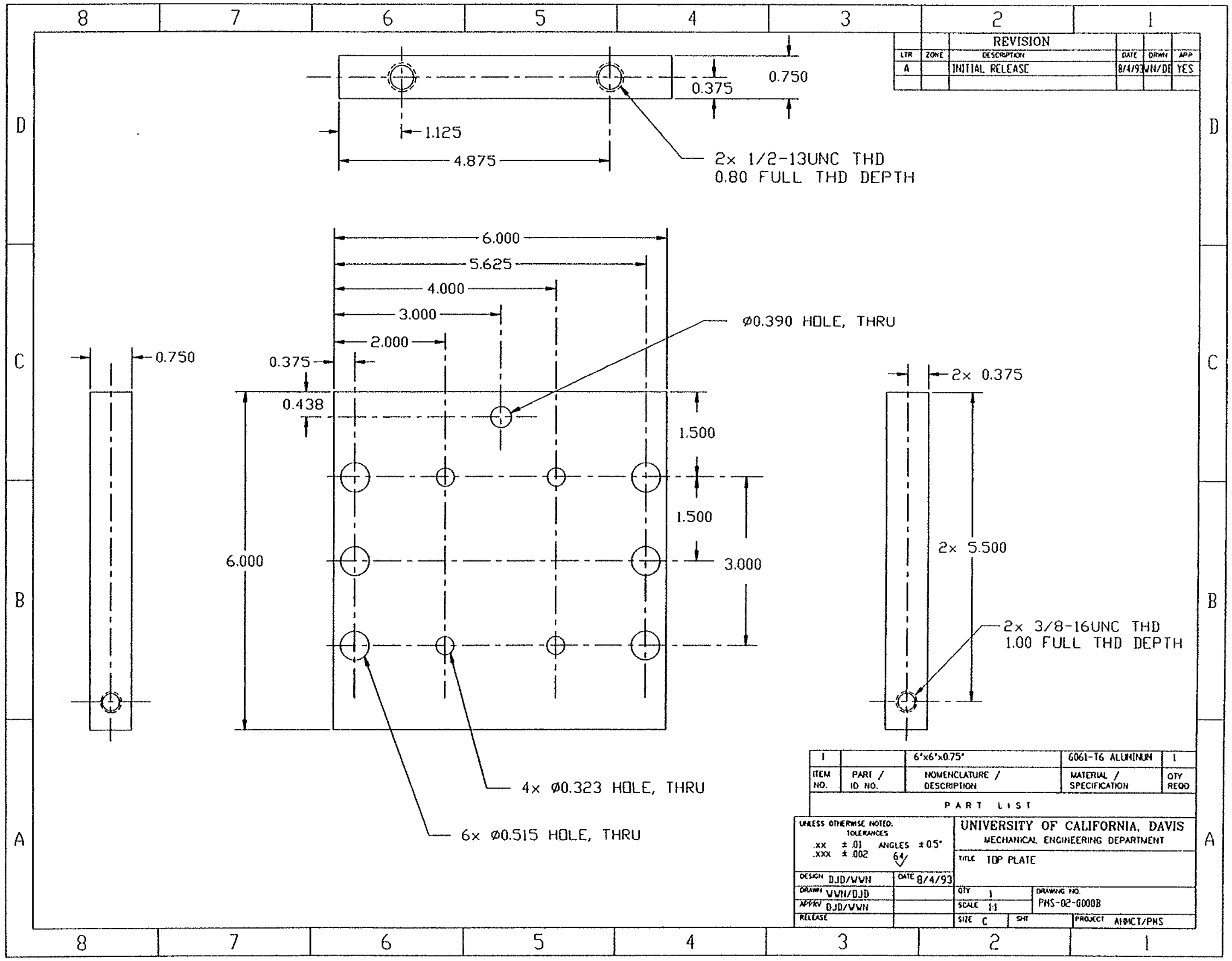
1		5"x .50"x .375"	6061-T6 ALUMINUM	1
ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD

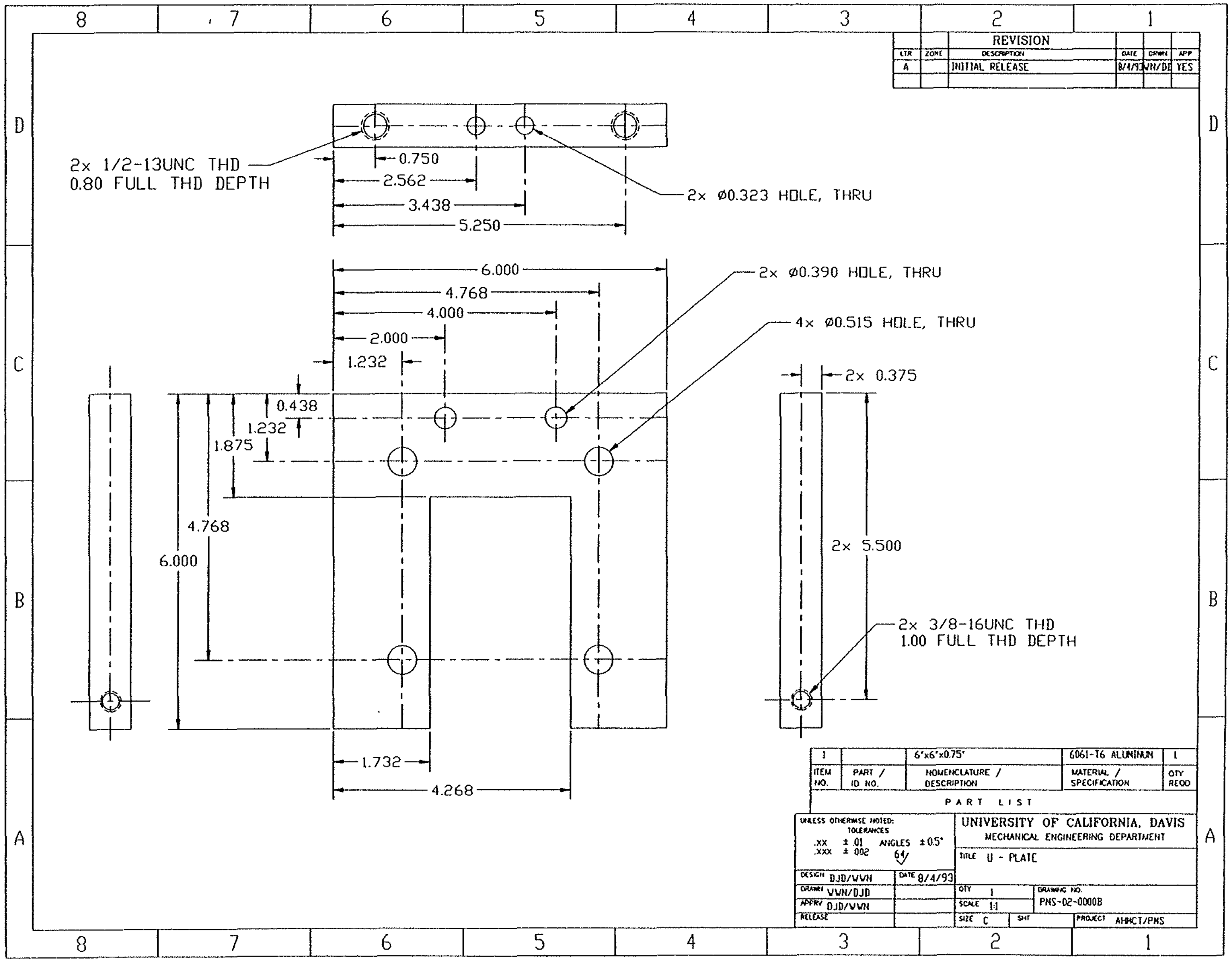
PART LIST

UNLESS OTHERWISE NOTED: TOLERANCES .XX ±.01 .XXX ±.002 ANGLES ±0.5° 64√		UNIVERSITY OF CALIFORNIA, DAVIS MECHANICAL ENGINEERING DEPARTMENT		
DESIGN DJD/WWN	DATE 7/13/83	TITLE Center Ramp		
DRAWN WWN/DJD		QTY 1	DRAWING NO. PMS-02-0041	
APPRV DJD/WWN		SCALE 1:1		
RELEASE		SIZE B	SHT	PROJECT AHMCT/PMS

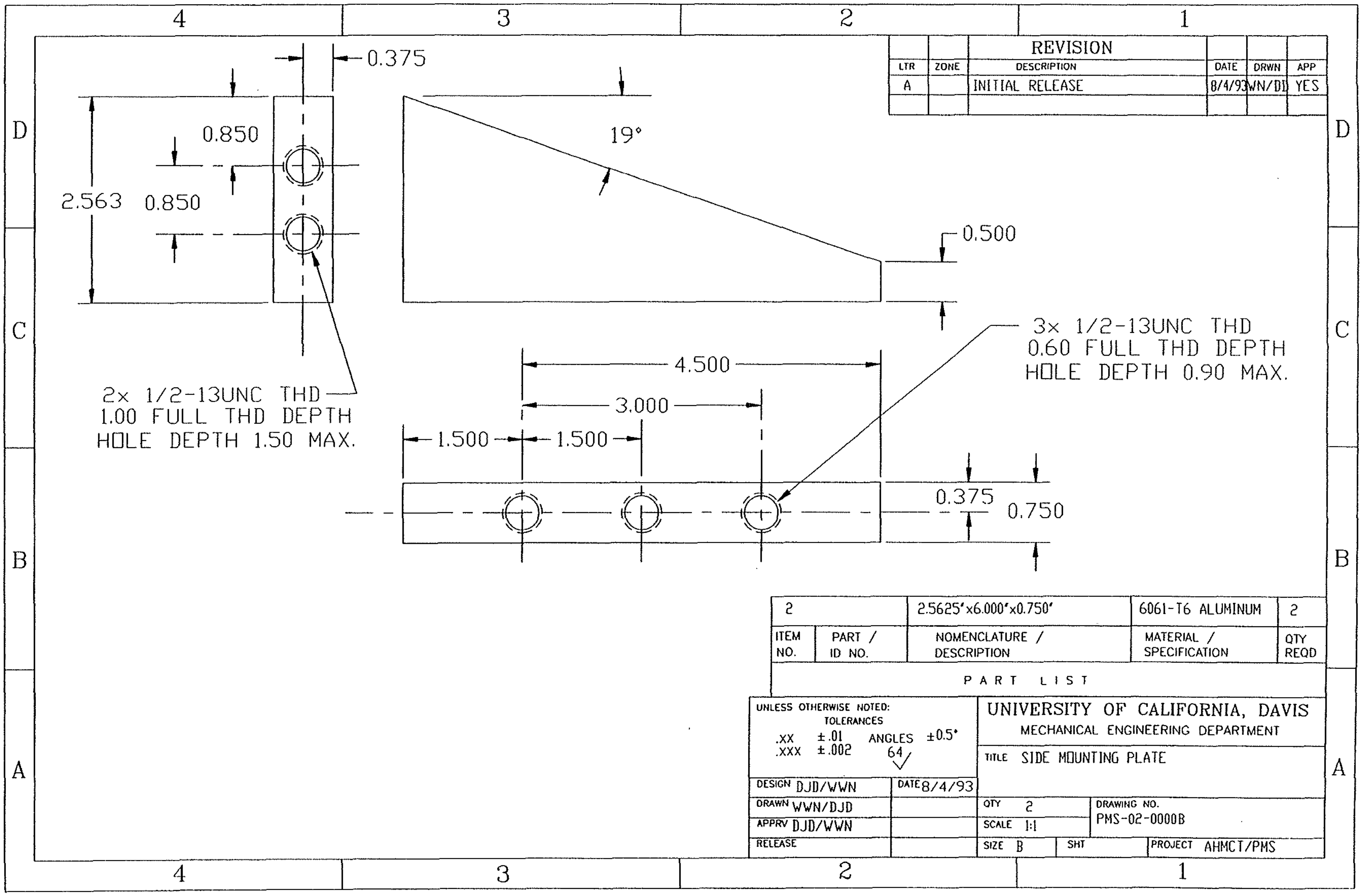

REVISION
LTR
ZONE
DESCRIPTION
DATE
DRWN
APP
A
INITIAL RELEASE
7/13/93
WN/DD
YES
69.00
43.625
32.375
4.625
3.375
A
2.250
20.750 2x
4.000
2.875 2x
.500 2x
1.00 2x
.500
Section A-A
1
70'x11'- 20 gauge SS sheet
303 SS
ITEM NO.
PART / ID NO.
NOMENCLATURE / DESCRIPTION
MATERIAL / SPECIFICATION
QTY REQD
PART LIST
UNLESS OTHERWISE NOTED: TOLERANCES
.xx ± .01 ANGLES ± 0.5°
.xxx ± .002
64
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
TITLE Template
DESIGN DJD/WWN
DATE 7/13/83
DRAWN WWN/DJD
APPRV DJD/WWN
RELEASE
QTY 1
SCALE 1:1
DRAWING NO. PHS-02-0042
SIZE C
SHT
PROJECT AHMCT/PHS


REVISION
LTR ZONE DESCRIPTION DATE DRWN APP
A INITIAL RELEASE 8/4/93 VN/DD YES
8.250
7.500
6.375
5.625
4.750
2.750
1.875
1.125
0.750
1.250
1.000
3.000
2.813
4.813
6.000
7.000
0.150
0.700
1.938
6.625
1.500
3.313
4.188
6.000
8x Ø0.515 HOLE, THRU
Ø0.750 C'BORE, 0.750 DEEP
(THIS SIDE)
6x 1/2-13 UNC THD, THRU
6x Ø0.323 HOLE, THRU
Ø0.500 C'BORE, 0.750 DEEP
(THIS SIDE)
1 9"x8"x1.25" 6061-T6 ALUMINUM 1
ITEM NO. PART / ID NO. NOMENCLATURE / DESCRIPTION MATERIAL / SPECIFICATION QTY REQD
PART LIST
UNLESS OTHERWISE NOTED: TOLERANCES
.XX ± .01 ANGLES ± 0.5°
.XXX ± .002
64
DESIGN DJD/VWN DATE 8/4/93
DRAWN VWN/DJD
APPRV DJD/VWN
RELEASE
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
TITLE MAIN MOUNTING PLATE
QTY 1
SCALE 1:1
DRAWING NO. PMS-02-0000B
SIZE C
SHT
PROJECT AHMCT/PMS


REVISION
LTR ZONE DESCRIPTION DATE DRWN APP
A INITIAL RELEASE 8/4/93 WN/DF YES
0.375
0.750
1.125
4.875
2x 1/2-13UNC THD
0.80 FULL THD DEPTH
6.000
5.625
4.000
3.000
2.000
Ø0.390 HOLE, THRU
0.750
0.375
0.438
2x 0.375
1.500
1.500
3.000
6.000
2x 5.500
2x 3/8-16UNC THD
1.00 FULL THD DEPTH
4x Ø0.323 HOLE, THRU
6x Ø0.515 HOLE, THRU
1 6"x6"x0.75" 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 TOP PLATE
DESIGN DJD/WVN DATE 8/4/93
DRAWN VWN/DJD
APPRV DJD/VWN
RELEASE
QTY 1
SCALE 1:1
SIZE C
DRAWING NO. PNS-02-0000B
PROJECT AHMCT/PHS



REVISION
LTR ZONE DESCRIPTION DATE DRWN APP
A INITIAL RELEASE 8/4/93 VWN/DJD YES
2x 1/2-13UNC THD
0.80 FULL THD DEPTH
0.750
2.562
3.438
5.250
2x Ø0.323 HOLE, THRU
6.000
4.768
4.000
2.000
1.232
2x Ø0.390 HOLE, THRU
4x Ø0.515 HOLE, THRU
2x 0.375
0.438
1.232
1.875
4.768
6.000
2x 5.500
2x 3/8-16UNC THD
1.00 FULL THD DEPTH
1.732
4.268
1 6"x6"x0.75" 6061-T6 ALUMINUM 1
ITEM NO. PART / ID NO. NOMENCLATURE / DESCRIPTION MATERIAL / SPECIFICATION QTY REQD
PART LIST
UNLESS OTHERWISE NOTED: TOLERANCES
.XX ± .01 ANGLES ±0.5°
.XXX ± .002
64
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
TITLE U - PLATE
DESIGN DJD/VWN
DATE 8/4/93
DRAWN VWN/DJD
APPRV DJD/VWN
RELEASE
QTY 1
SCALE 1:1
DRAWING NO. PNS-02-0000B
SIZE C
SHT
PROJECT AHMCT/PNS



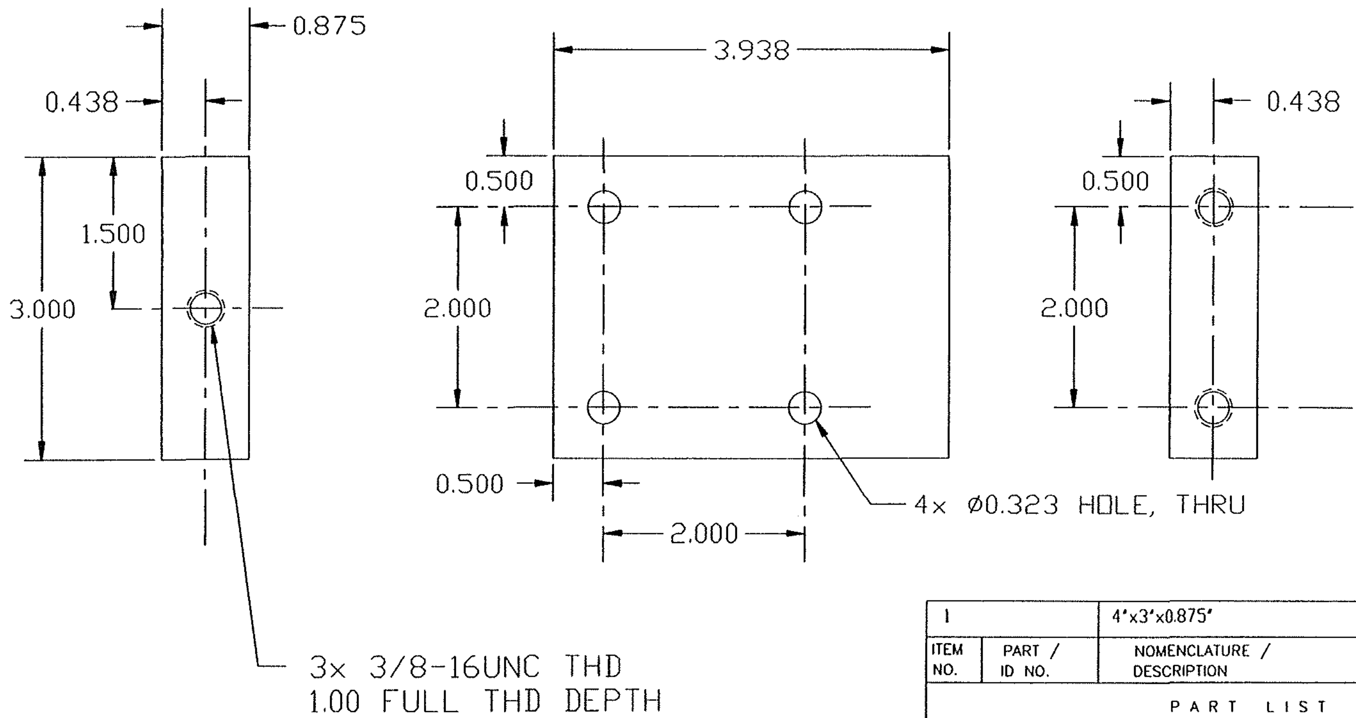
REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	8/4/93	WN/DJ	YES

2		2.5625"x6.000"x0.750"	6061-T6 ALUMINUM	2
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	
DESIGN DJD/WWN	DATE 8/4/93	TITLE SIDE MOUNTING PLATE	
DRAWN WWN/DJD		QTY 2	DRAWING NO. PMS-02-0000B
APPRV DJD/WWN		SCALE 1:1	
RELEASE		SIZE B SHT	PROJECT AHMCT/PMS

LTR	ZONE	REVISION DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	8/4/93	WN/DD	YES



ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
1		4"x3"x0.875"	6061-T6 ALUMINUM	1

PART LIST

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

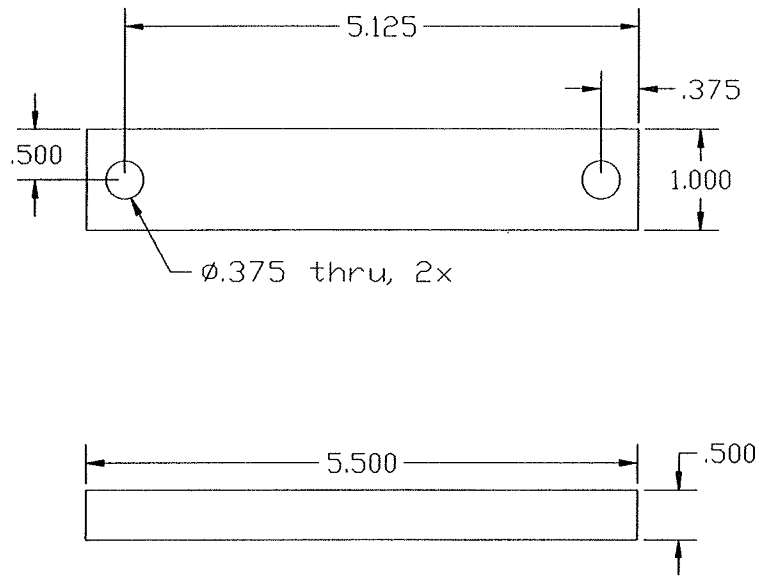
DESIGN DJD/WWN	DATE 8/4/93	
DRAWN WWN/DJD		
APPRV DJD/WWN		
RELEASE		

UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT

TITLE ANOTHER PLATE

QTY 1	DRAWING NO. PMS-02-0000B	
SCALE 1:1		
SIZE B	SHT	PROJECT AHMCT/PMS

REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	7/13/93	WN/DL	YES



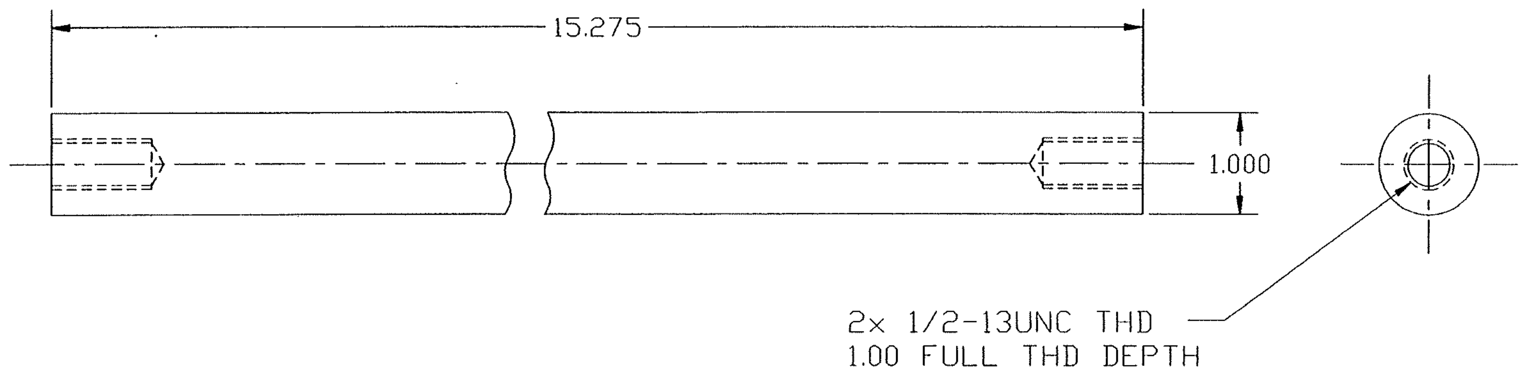
ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
1		5.5"x1.0"x .50"	6061-T6 ALUMINUM	2

PART LIST

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

DESIGN DJD/WWN	DATE 7/13/83	UNIVERSITY OF CALIFORNIA, DAVIS MECHANICAL ENGINEERING DEPARTMENT	
DRAWN WWN/DJD		TITLE Actuator Mount-Front Support	
APPRV DJD/WWN		QTY 2 SCALE 1:1	DRAWING NO. PMS-02-0106
RELEASE		SIZE B SHT	PROJECT AHMCT/PMS

REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	8/4/93	WN/DJ	YES



ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
1		ϕ1.0x15.375"	6061-T6 ALUMINUM	4

PART LIST

UNLESS OTHERWISE NOTED: TOLERANCES .XX ±.01 .XXX ±.002 ANGLES ±0.5° 64√		UNIVERSITY OF CALIFORNIA, DAVIS MECHANICAL ENGINEERING DEPARTMENT		
		TITLE MOUNTING RODS		
DESIGN DJD/WWN	DATE 8/4/93			
DRAWN WWN/DJD		QTY 4	DRAWING NO. PMS-02-0000B	
APPRV DJD/WWN		SCALE 1:1		
RELEASE		SIZE B	SHT	PROJECT AHMCT/PMS