California AHMCT Research Center
University of California at Davis
California Department of Transportation

DEVELOPMENT OF AN AUTOMATED CONE PLACEMENT AND RETRIEVAL MACHINE

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16. Abstract

This report discusses the conceptual design of the Automated Cone Machine (ACM) that is currently under development at the University of California, Davis. Current methods used by the California Department of Transportation (Caltrans) for deploying and retrieving traffic cones on highways involve exposing crew members to the hazards of fast moving traffic and flying debris. While some commercial cone handling machines have proven somewhat effective, vast improvements in operator safety can be made.

The ACM has been designed and developed to provide a reliable means of placing and retrieving traffic cones on the highway. The objective of this automated system is to maximize safety while maintaining current operation speed and efficiency. The ACM will minimize the exposure of workers to fast moving traffic by having all mechanisms controlled from within the confines of the truck cab.

This report discusses the development of the ACM and includes the design details of the retrieval system, placement system, funnel system, stowage system, operating control system, and the hydraulic drive system. The design process that includes the generation of the conceptual ideas and the methods for final concept selection is described in considerable detail for all of these subsystems. The operating control system utilizes a micro controller to integrate and activate the hydraulic powered ACM subsystems in predetermined sequences to effectively perform cone handling operations.

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ABSTRACT

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EXECUTIVE SUMMARY

This report documents the development of the Automated Cone Machine (ACM) at the Advanced Highway Maintenance and Construction Technology Center (AHMCT) at the University of California at Davis. Included in this report is the conceptual development of several subsystems of the ACM, experimental testing of these subsystems, and component strength evaluations. The primary purpose of the ACM is to drastically reduce the dangers associated with lane closure operations. This is accomplished by minimizing the amount of time the road crew is exposed to traffic. During cone operations, the crew members remain within the cab of the cone truck to operate the ACM.

The functional specifications of the ACM have been developed from the direct observation of lane closure operations and traffic manuals from the California Department of Transportation (Caltrans). These operations make use of a vehicle known as the cone body. This vehicle utilizes a suitable bed designed primarily for cone deployment and retrieval and maintains a storage capacity of 80 cones. The ACM will have the same capabilities as this current cone body vehicle while providing the operator with a safer working environment. These capabilities include operational procedures for dispensing cones in the forward direction from either side of the truck, retrieving cones in either direction from either side of the cone truck, stacking and unstacking cones as needed for retrieval and dispensing respectively, and

maintaining a lane closure by retrieving and replacing toppled cones from a closed lane. These procedures are executed at speeds up to 16 km/hr (10 mph). The cone truck with the modular ACM configurations installed can also be used as a multiple purpose vehicle during lane maintenance operations.

The investigation of existing cone machines has revealed two commercially available products. The first mechanism, the French made Baliseur Cone Picker, is costly and bulky and requires the usage of specially designed rigid cones. Mechanisms using this type of cone are subject to problems on the warmer days fairly common to California since the cone's rigidity is crucial for operational consistency. While the Cone Picker has enormous cone carrying capacity, it can only pick cones in the forward direction. Caltrans lane closures typically require the vehicle to retrieve cones in the reverse direction so that the beginning of the lane closure remains intact until the cone removal operation is completed. This procedure is crucial since it warns oncoming traffic of the presence of the road crew on the highway.

The second mechanism, the Addco Cone Wheel, is considerably large and can only operate in the forward direction. The Cone Wheel also requires an operator to remain outside the safe confines of the truck cab. This operator must constantly feed and remove traffic cones into and out of a bulky wheel during placement and retrieval operations. This operator is highly vulnerable to the dangers of flying road debris and high speed traffic.

The usage of the Automated Cone Machine should not significantly alter current cone placement and retrieval procedures. The ACM provides a significantly safer means of cone handling without compromising current operation time and efficiency. Since the ACM depends on modular components that can be integrated onto existing cone trucks, costs should be reasonably low. The preliminary findings of the mechanism are both promising and encouraging while the necessary modifications to the existing cone vehicle are minimal.

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DISCLAIMER / DISCLOSURE

The research reported herein was performed as part of the Highway Maintenance and Construction Program (AHMCT), within the Department of Mechanical and Aeronautical Engineering at the University of California, Davis and the Division of New Technology and Materials Research at the California Department of Transportation. It is evolutionary and voluntary. It is a cooperative venture of local state and federal governments and universities.

The contents of this report reflect the views of the author(s) who is (are) responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the STATE OF CALIFORNIA or the FEDERAL HIGHWAY ADMINISTRATION and the UNIVERSITY OF CALIFORNIA. The report does not constitute a standard, specification, or regulation.

1. CHAPTER ONE
INTRODUCTION

1.1 Background

There are many highway operations that require a separation between a designated work area and the lanes open to fast moving traffic. In 1993, Californians drove a total of 428 billion km (266 billion miles) and highway maintenance costs for the California Department of Transportation (Caltrans) reached $340 million (Slater, 1993 Highway Statistics). These figures show that the highways are busy and therefore dangerous to the work crews who continually maintain them. Fast moving traffic and debris traveling at high speeds create an extremely hazardous environment. Highly visible safety markers are commonly used to close a number of lanes and to create a safety zone where crew workers can perform maintenance and construction on the highway. Although a variety of safety markers exist, the traffic cones are most common because they store compactly, are easily transported, and require no assembly. The traffic cones are widely available in different sizes and weights to satisfy various climates and road surface conditions.

The manual deployment of traffic cones is a method used worldwide and often is performed by placing cones from the tailgate of a pick up truck. Current lane closure operations in many of the Caltrans districts make use of a vehicle known as the cone body. The Caltrans developed cone body provides a more suitable bed designed primarily for cone deployment and retrieval. The cone body consists of a customized bed that mounts to the frame rails of standard trucks with a gross vehicle weight of 4500 kg (10000 lb.) or larger. Eighty traffic cones placed in two horizontal stacks lay on a conveyor located along the longitudinal centerline of the cone body. Along either side of this conveyor is an open bucket that holds a reversible two position seat. These buckets are low and close to the ground so that workers have adequate accessibility to the road surface. While the cone body is significantly safer than handling cones from the tailgate of a truck, vast improvements in safety are possible.

The objective of this project is to improve the safety conditions of the cone operations by reducing the exposure of workers to the harsh environment of open, fast moving traffic and by utilizing efficient automation. The development of the Automated Cone Machine (ACM) at the Advanced Highway Maintenance and Construction Technology (AHMCT) Center is focused on bringing all personnel and control mechanisms inside the safe confines of the cab, effectively handling all duties necessary in cone operations, and maintaining the speed and efficiency of current manual operations. Important issues for this design of the ACM will be its versatility, its robustness, and its safe operating capabilities.

The ACM will consist of five main components: the Funnel System (FS), the Integrated Dispensing and Retrieval Configuration (IDRC), the Lateral Conveyor System (LCS), the Automated Cone Stowage System (ACSS), and the Coordinated Control Unit (CCU). The Funnel System is a movable unit that can be mounted at the four corners of the vehicle and it is responsible for properly orienting deployed traffic cones. The IDRC consists of a storable drop box and an arm mechanism. The drop box is located along the side of the vehicle and it serves as the site where traffic cones are deployed to the road surface. Located on the side of the box, the arm mechanism has been designed to retrieve previously deployed cones. The LCS acts as a transfer mechanism between the IDRC and the ACSS. The ACSS is designed to take cones retrieved by the arm and place them into storage and to take stored cones and send them to the lateral conveyor for deployment. The CCU will integrate the activation of the IDRC, the LCS, and the ACSS to effectively perform traffic cone retrieval and deployment.

The purpose of this report is to describe the development of the ACM concept and provide details of the system as implemented and tested. Included are the details of the development of the Automated Cone Stowage System and the Coordinated Control Unit. The ACSS must actively handle cones from the LCS and from the two stacks of stored cones located on the cone body's main conveyor. A series of sensors will locate the positions of the cones on the lateral conveyor and those placed into stowage. Hydraulic grippers are used to grab the traffic cones while a simple belt driven pulley system moves the cones between the lateral conveyor and the stack of stored cones. The CCU will make use of a Z-world Little Giant micro-controller to process the necessary logic and the sequence of predetermined events for integrating all the described systems.

1.2 Literature Search

A literature search was performed to investigate existing mechanisms that could be used for traffic cone retrieval and deployment. The Derwent World Patent System, located at Shields Library at the University of California Davis, was used to search through a listing of over seven million international and recent United States patents. A secondary search using the CASSIS System and the Official Gazette of the United States Patent and Trademark Office was used to investigate all United States patents. These two searches revealed three patents for machines that perform traffic cone retrieval and deployment duties: the Traffic Cone Retriever, the Cone Wheel Dispenser and Collector, and the Baliseur Cone Picker.

The Traffic Cone Retriever, shown in Figure 1.1, was the first patented concept for picking up deployed cones. Although the Traffic Cone Retriever was issued a patent in 1973, there has been no evidence showing that this device saw commercial production. Patent number 3750900 revealed that this device could operate with a single driver and at speeds of more than 56 km/hr (35 mph). While this vehicle did not have deployment capabilities, it could retrieve and store between 1500 and 2000 traffic cones. The large Traffic Cone Retriever picked up standing cones by first capturing them with two revolving paddle wheels. The traffic cone would then be taken upward and rearward by a conveyor. The cone would then placed in a depositing area where the cones were stacked vertically. Once the cones were stacked to a predetermined height, the cone stack would be released on sloped rollers and be placed to the rear end of the vehicle. The cone stacks could also be moved laterally on rollers to maximize the vehicle's large storage capacity.

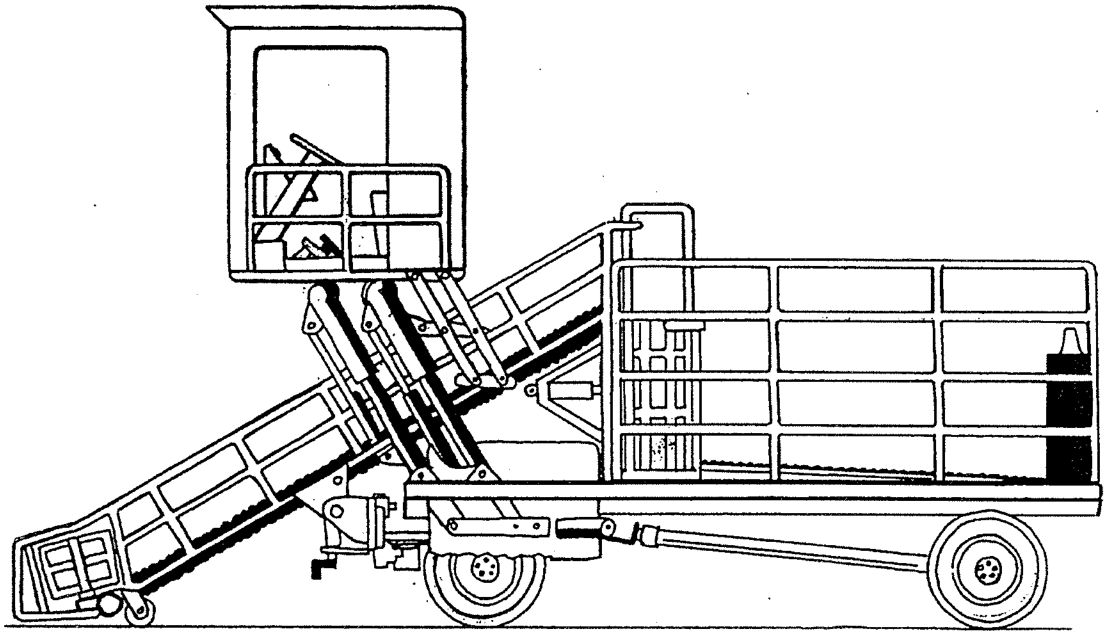

Figure 1.1 Traffic Cone Retriever (from Fig. 1 of patent 3750900)

In 1986 the French made Baliseur Cone Picker, shown in Figure 1.2, was issued United States patent number 4597706. Produced by a company known as SEP, the Cone Picker is a fully automated machine that can retrieve and deploy traffic cones. This machine has an operating speed of approximately 18 km/hr (11 mph) and has a storage capacity of 240 traffic cones. During retrieval procedures, the driver must evaluate the orientation of the deployed traffic cone. If the traffic cone is upright, the Cone Picker utilizes a bar to tip the cone over and expose the bottom of the cone base. This is the desired orientation for a cone to be retrieved. If the traffic cone has fallen, the driver must manipulate the cone into one of two positions. With the use of short vertical bars the cones can be oriented in either a base first or cone tip first configuration. If manipulated into a base first configuration, the cone can be picked up as if it were an upright cone. However, if the cone is placed in a cone tip first position, a horizontal bar is lowered to contact the base of the cone and flip it so that the cone falls into the base first configuration. With the vehicle moving forward, a prong can enter through the open bottom of the cone and lift the cone upwards.

Once a cone has been picked up, a chain link conveyor is used to lift the cone upwards to a small chute that leads to the storage area. The cone is stripped from the prong by a simple bar mechanism and it falls through the small chute. The falling cone is stacked vertically in one of the ten vertical cylinders that form a circular ring. This assembly rotates to allow effective accessibility to desired cylinders and to maximize the storage capacity.

The drop-off mechanisms are located beneath the two most rearward cylinders and can access the cone located at the bottom of their respective storage stacks. Once activated, the bottom cone of one of the stacks falls to the ground where it is surrounded by directive guides. The traffic cone is held for a moment to ensure upright stability and then it is released. The directive guides move the cone to the side of the vehicle where it is placed in the proper lateral position. These deploying mechanisms on the rearward cylinders can activate independently or simultaneously.

Figure 1.2 The Baliseur Cone Picker (from SEP advertisement)

The Cone Wheel Dispenser and Collector, patent number 5054648, is produced by Addco, a Canadian based company. This device, shown in Figure 1.3, was given a patent in 1991 and is currently in use in several states around the country. The vehicle consists of a large wheel mechanism approximately 1.2 m (4 ft) in diameter that is stored on the bed of a large sized truck. The rotating wheel mechanism consists of two conical disks that are sufficiently spaced to wedge a traffic cone between them. Once deployed to the side of the truck, the Cone Wheel is ready for traffic cone retrieval and placement. This vehicle had an operational speed of 40 km/hr (25 mph). During drop-off procedures, an operator seated on the bed inserts a cone in a chute located at the top of the large wheel mechanism. The large wheel rotates and makes the deposited cone travel in its circular path. Upon reaching the bottom of the large wheel, a bar strips the cone free and ensures a firm upright placement on the road surface. During retrieval procedures, the previously deployed cones are simply run over by the rotating wheel. The traffic cone becomes wedged between the two disks and is carried upwards as the large wheel rotates. A bar similar to the one used in drop-off procedure is used to free the cone from the wheel and to allow the operator to manually store the cone.

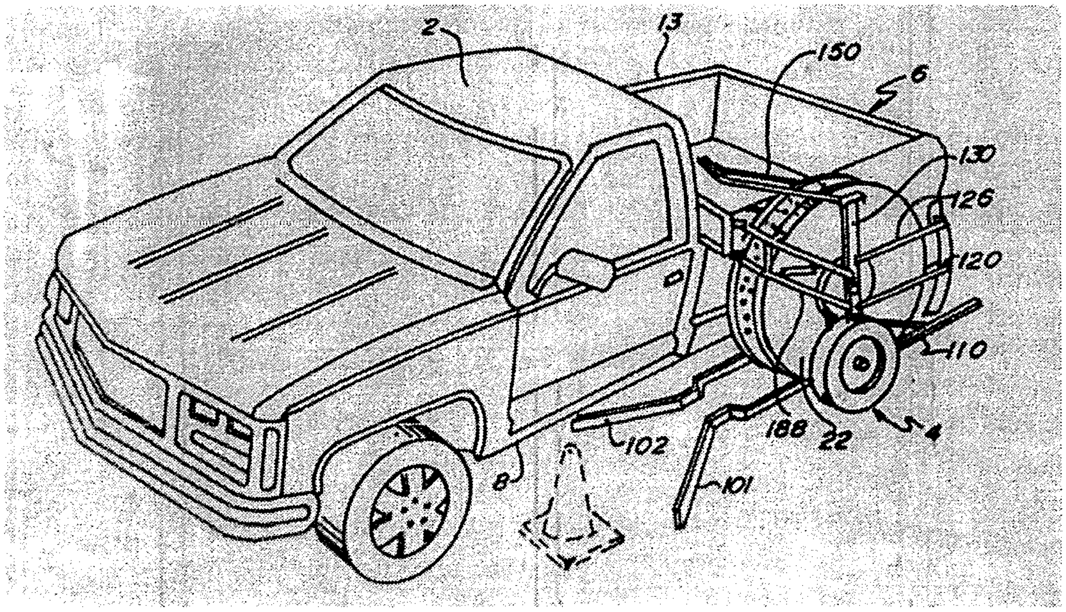

Figure 1.3 Cone Wheel Dispenser and Collector (from Fig. 1 of patent 5054648)

1.3 Caltrans Traffic Cones

The traffic cones typically used in Caltrans operations stand 710 mm (28 in) tall and weigh approximately 4.5 kg (10 lbs). However, it was found that the design of traffic cones is non-standardized and certain dimensions can vary from one manufacturer to another. While cone height and weight seem to be somewhat standard requirements, features such as the slope angle of the cone and width of the base can be significantly different. Since the districts in California sometimes purchase traffic cones from different vendors, it was necessary to obtain a wide selection of traffic cones and investigate their physical properties.

The traffic cones chosen by Caltrans have two distinctive parts, the conical section and the base. The thin walled conical section is colored with high visibility orange while the significantly thicker and heavier square base section is gray. Small extensions are located on the bottom of the bases and serve to elevate the traffic cone approximately 19 mm (0.75 in) off the road surface. The cones are hollow which allow them to be stacked for easy storage and transportation.

The traffic cones are molded out of polyvinyl chloride (PVC) plastic. The material properties of the PVC vary with different temperatures. The traffic cones become extremely compliant with the conical section being soft and easily collapsible at higher temperatures while they become very rigid and difficult to compress at lower temperatures. There have been instances when the tips of the traffic cones become brittle enough to crack. While these differences cause little problems during manual operations, the consideration of these temperature dependent variations is vital for the design of an automated system.

After contacting a number of vendors, a list of different traffic cone manufacturers was compiled. Standard 710 mm (28 in) cones were purchased from each manufacturer to investigate their differences in basic dimensions and mass properties. The results are displayed below in Table 1.1. The traffic cones actually varied between 688 to 724 mm (27.1 to 28.5 in) in height and 3.2 to 4.5 kg (7 to 10 lb) in mass. Although most of the manufacturers offered a 3.2 kg (7 lb) version, Caltrans prefers the heavier 4.5 kg (10 lb) versions since they are more stable and more suitable to windy environments. Of all the traffic cones that were obtained, the cones from A&B Reflectorizing and Traffic Safety Services were the most similar to those used by Caltrans.

Table 1.1 Physical Properties of Traffic Cones

Vendor	Height of Cone mm (in)	Mass of Cone kg (lb)	Width of Base mm (in)	Height of CG above ground mm (in)	Y-axis Moment of Inertia kg-m^2 (lb-in^2)	Z-axis Moment of Inertia kg-m^2 (lb-in^2)
A&B Reflectorizing 3.6 kg (8 lb)	711 (28.0)	3.52 (7.75)	378 (14.9)	123 (4.83)	0.126 (432)	0.080 (275)
A&B Reflectorizing 4.5 kg (10 lb)	699 (27.5)	4.77 (10.5)	358 (14.1)	113 (4.44)	0.152 (520)	0.108 (370)
American Barricade 3.2 kg (7 lb)	719 (28.3)	3.18 (7.00)	389 (15.3)	143 (5.63)	0.117 (398)	0.061 (210)
American Barricade 4.5 kg (10 lb)	711 (28.0)	4.54 (10.0)	389 (15.3)	134 (5.27)	0.169 (576)	0.100 (343)
Lakeside Plastic 3.2 kg (7 lb)	711 (28.0)	3.31 (7.30)	394 (15.5)	135 (5.31)	0.126 (431)	0.073 (251)
Lakeside Plastic 4.5 kg (10 lb)	724 (28.5)	4.86 (10.7)	394 (15.5)	119 (4.70)	0.172 (589)	0.117 (399)
Plastifab 3.6 kg (8 lb)	699 (27.5)	3.75 (8.25)	356 (14.0)	85 (3.35)	0.112 (383)	0.092 (316)
Traffic Safety Services 3.2 kg (7 lb)	699 (27,5)	3.52 (7.75)	363 (14.3)	142 (5.61)	0.130 (444)	0.071 (242)
Traffic Safety Services 4.5 kg (10 lb)	688 (27.1)	4.43 (9.75)	366 (14.4)	116 (4.57)	0.141 (483)	0.099 (339)

1.4 Current Caltrans Methods

1.4.1 Lane Closure Configuration

The lane closure procedure is executed prior to the construction or maintenance operation to create a safe work zone for all Caltrans crews. To insure that traffic has ample warning of a lane closure, several standard set up procedures and configurations are required. The cone body vehicle is followed by a large protective shadow vehicle designed for high speed collisions. The shadow truck is responsible for matching the speed of the cone body and for shielding the cone body and its crew from the traffic behind them. The lane closure, shown in Figure 1.4, is typically composed of three sections: the Advance Warning Area, the Transition Area, and the Buffer and Work Area. Some variations of this pattern are necessary to accommodate different highway environments.

The Advance Warning Area marks the beginning of the lane closure and consists of the four warning signs placed 213 to 305 m (700 to 1000 ft) apart. The first three signs are diamond shaped and measure 1.2 m by 1.2 m (4 ft by 4 ft). They display warnings that road construction is ahead and that specific lanes will be closed to traffic. The cone body vehicle pulls onto the shoulder and the crew exits the vehicle to assemble these signs. These three signs have collapsible frameworks and they are stored in holding tubes located on the rear of the cone body. The crews use tripods to hold the signs and several sandbags to securely weigh them down. Alongside each of these assemblies, the crews leave a single traffic cone to further warn traffic of the upcoming closure. The larger fourth sign is trailer mounted and typically displays either a large arrow or a brief message that indicates the direction of the merge. The trailer is unhitched on the shoulder of the road and four cones are commonly deployed approximately 15 m (50 ft) apart to accompany it.

The Transition Area consists of a taper that forces a merge away from the lane closure. The taper begins from the shoulder of the road where the fourth sign has been positioned and extends to a minimum of 305 m (1000 ft) for every lane that is closed. The traffic cones are typically spaced 15 m (50 ft) apart and they form a straight line path from the shoulder to the specified lane to be closed.

The Buffer and Work Area begins at the end of the taper and runs parallel with the highway lanes. The traffic cones are placed approximately 30 m (100 ft) apart and 0.3 to 0.6 m (1 to 2 ft) from the edge of the lane. This space prevents cones from being struck by oncoming traffic and from being toppled over by the gusts that fast moving vehicles can create. The buffer area consists of a 213 to 305 m (700 to 1000 ft) space between the end of the taper and the actual work site. Simple lane closure signs are usually placed in this area in case the taper has been broken. The traffic cones of the Buffer and Work Area usually end 30 m (100 ft) past the work site.

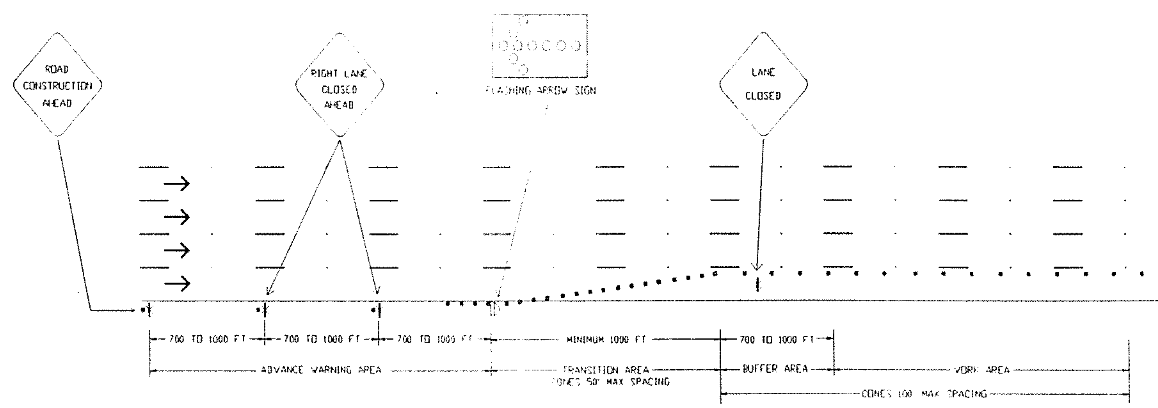

Figure 1.4 Lane Closure Configuration (from Caltrans Traffic Manual, 1990)

1.4.2 Procedures for Deployment and Retrieval of Traffic Cones

The Caltrans designed cone body, as shown in Figure 1.5, is in wide use among many districts of California. During cone deployment and retrieval operations, one crew member drives the vehicle while the other handles the traffic cones from the seated bucket area. The configuration of the cone body provides convenient accessibility to the highway road surface and the stored stack of cones located on the longitudinal conveyor belt. With the proper coordination between the driver and the cone handler, the procedures for deployment and retrieval of traffic cones can be simple and effective.

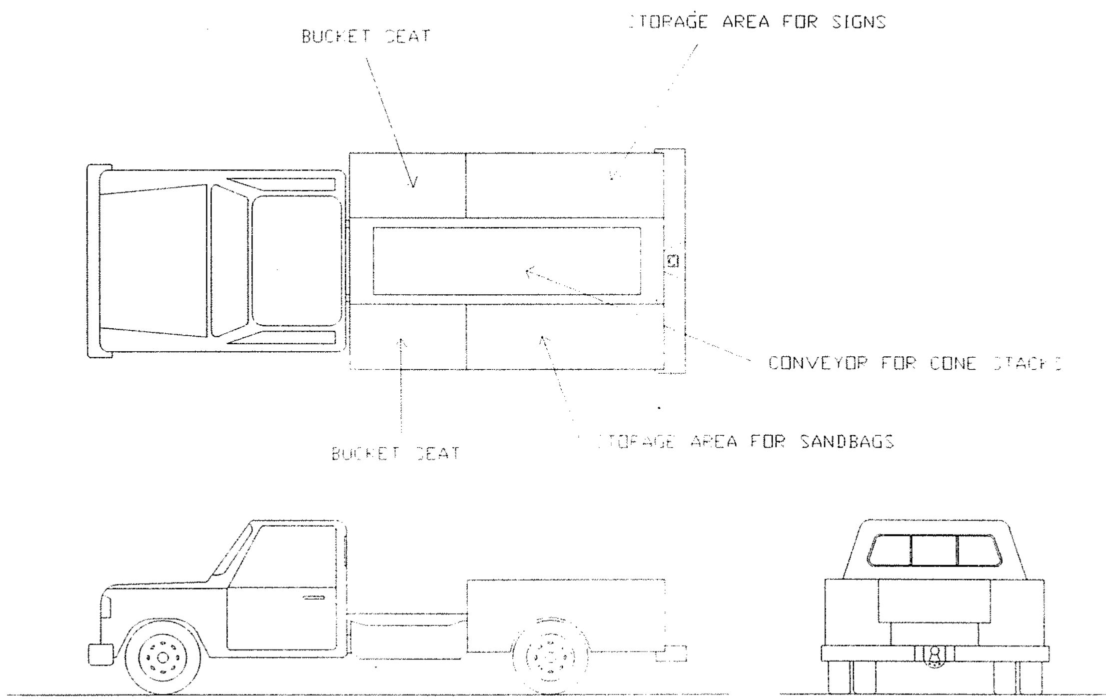

Figure 1.5 Cone body vehicle

During a cone drop off operation, the cone body vehicle and the shadow vehicle are driven forward at approximately 16 km/hr (10 mph). The cone handler in the cone body's bucket seat faces backwards and accesses the stored stack of cones by using the foot activated buttons to feed the stowage conveyor forward. Considerable effort and balance is necessary to handle the traffic cones for deployment. The crew worker in the bucket must pull the traffic cone from the horizontal stack, grab the tip, reach out past the confines of the cone body, and manipulate the cone to match the relative velocity of the truck. This is all necessary for proper longitudinal placement of the cone on the road surface. The arm extension of the worker in the bucket and the path chosen by the driver are important for accurate lateral placement. The cone handler gauges the specified distance by counting the number of one way reflective markers, Bott dots, that pass by. Since they are spaced 48 feet apart, the cone handler will drop off a cone after every Bott dot during the Transition area and after every two Bott dots during the Buffer and Work Area.

The lane opening procedure requires the cone truck to start at the end where the last cone was deployed. The cone truck is then driven backwards at approximately 16 km/hr (10 mph). A worker seated in the side bucket closest to the deployed cones must reach beyond the confines of the vehicle and grab them as they pass by. This is shown in Figure 1.6 and Figure 1.7. The cones are reoriented by the worker and then placed at the end of the storage stack. The conveyor is fed backward during retrieval operations to provide the necessary space for cone storage. The manual retrieval of traffic cones is as equally difficult as manual deployment. Communication between the vehicle driver and the worker in the bucket is emphasized in cone retrieval to ensure accurate pick up positioning.

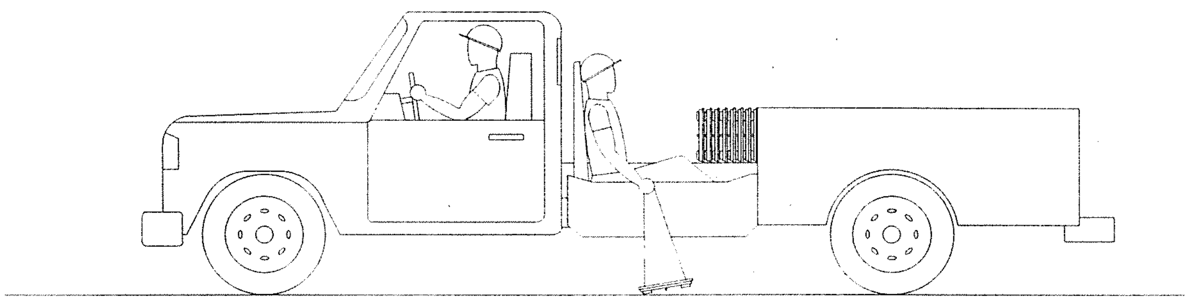

Figure 1.6 Cone body vehicle with crew workers (side view)

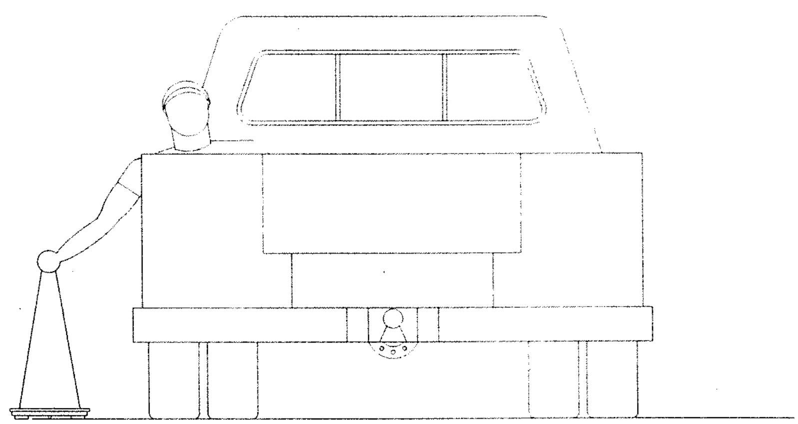

Figure 1.7 Cone body with crew workers (rear view)

1.5 Traffic Cone Related Injuries

A potential problem that arises with the current Caltrans cone operations is injury to the worker located in one of the bucket seats. Two types of situations exist. First, since the worker is located in an open compartment along side the activity of fast moving vehicles, either a vehicle collision or impact with lose flying debris could have fatal results. Secondly, the type of work performed by this worker in handling the cones has a potential to harm due to the adverse physical exertions performed. The type of motion performed exhibits large stress on the following body areas: lower back, shoulder, and elbow. A study conducted by Caltrans, from 1989 to the 1996, revealed a total of 170 cone related injuries. Table 1.2 lists accidents and injuries that typically result from the handling of cones.

Table 1.2 Cone Handling Related Injuries

Total Traffic Cone Related Injuries: 170 (from 1989-1996)	
Sum of categories is less than 100%	
(1) Most Common Type of Activity Resulting In Injury	Percentage of Each Category
(a) Lifting	47%
(b) Reaching	14%
(c) Assigned Duties	9%
(d) Bending	8%
(2) Most Common Type of Accident	
(a) Body Motion/Repetitive	47%
(b) Body Motion/Single Event	26%
(c) Trip/Slip/Fall	6%
(3) Most Common Part of Body Injured	
(a) Back/Lower	27%
(b) Shoulder	22%
(c) Elbow	7%
(4) Most Common Type of Injury	
(a) Strain	72%
(b) Sprain	10%
(c) Soreness	6%

Clearly, it is advantageous to purse a new method or vehicle system to replace the worker located in the bucket seats. Considering this study only covered a time span of seven years for Caltrans cone operations, the amount of worker down time, as a whole that could be saved, is extremely encouraging.

1.6 Need for Automation

Although the lane closure operation is fairly simple and effective, the crew members in the cone body are highly susceptible to several hazards on the highway. While the design of the cone body's bucket seats allow adequate accessibility to the road surface, the worker is not properly shielded from the many traffic related dangers. Obviously, dirt and dust can be sent swirling by the traffic gusts and can potentially be dangerous to the eyes of the exposed workers. The upper body region and the face are also vulnerable to airborne road debris. Since it is required to reach out of the cone body to pick and place cones, the crew member becomes vulnerable to collisions by nearby vehicles moving in excess of 89 km/hr (55 mph). Only a small distance of approximately one meter separates this worker's hand from the vehicles in the next lane. When the worker repetitively extends outwards with a 4.5 kg (10 lb) cone in hand susceptibility to joint injuries in the wrist, elbow, shoulder, and back regions increases greatly. While this cone body offers some protection for crew members, further improvements can be made by reducing exposure of workers to open traffic and by having all operations be performed by automation.

Automation of the cone deployment and retrieval process will provide a safer environment for crew workers on the highway. The fast moving traffic and high traffic density present an inherently dangerous environment. The primary objective is to design a system such that all crew workers would be able to remain in the safe confines of the truck cab while controlling all cone handling functions. With automated mechanisms that could transport traffic cones to and from the road surface, crew workers would no longer be needed in the open buckets. Not only would the workers be safe from the various hazards of fast moving traffic, but the amount of physical effort would be minimized. Due to the fact that the noise level on the freeway is considerably high, allowing all workers to remain in the cab would also provide better communication during the operation.

1.7 Evaluation of Existing Machines

While the Traffic Cone Retriever, the Cone Wheel Dispenser and Collector, and the Baliseur Cone Picker have all served to make cone deployment and retrieval either safer or more efficient, they do not meet the functional and safety specifications required by current Caltrans operations. The two designs that saw production, the Addco's Cone Wheel and the SEP's Baliseur Cone Picker, were reviewed and investigated by Caltrans. While these two designs showed logical technologies for deploying and retrieving cones, the environment of the California highways and the requirements of Caltrans rendered them unusable.

The advantages of the Traffic Cone Retriever were its large storing capacity and its impressive operating speed. However, since the Traffic Cone Retriever can only retrieve and store traffic cones, it clearly does not serve the necessary requirement of cone deployment. Fallen cones also present a difficult problem for this machine since it has no way of manipulating the orientation of cones on the road surface. Furthermore, the bulky nature of the retrieving mechanisms and the large frame of the vehicle made this design impractical.

The Addco Cone Wheel was investigated by Caltrans and simply did not satisfy the necessary requirements of safety and robustness. While the Cone Wheel serves adequately under controlled conditions, its design reveals difficulties under certain situations. For instance, the Cone Wheel requires significant road space for the large wheel to deploy and retract. It is also necessary for this to be done at the work site because when the wheel is deployed, the vehicle becomes too large to maneuver in traffic. The deployment and retraction of the large wheel also requires manual assistance from personnel located on the road. This exposure to open traffic is incredibly hazardous for the working crew. Since the operator of the machine must remain seated on the truck bed, there is high risk due to the moving traffic, the potentially dangerous mechanisms of the large wheel, and the loose debris on the highway.

The Baliseur Cone Picker is the safer and more versatile machine of the three designs. The Cone Picker is robust when picking up cones positioned in different orientations. It also has an adequate storage capacity and operating speed. However, the Baliseur has been designed to retrieve and deploy custom made cones that are different then those used by Caltrans. While the shape of the customized cone are comparable to those used by Caltrans, they do not satisfy the necessary specifications of dimensions, weight, and material properties. Because the customized cone is much lighter than the Caltrans cone, problems in durability and stack ability would arise. The Cone Picker would also be problematic for Caltrans use because the mechanisms are designed to be placed on a large Renault truck frame. Since a redesign of the technologies to fit a U.S. made vehicle would require many hardware changes, the Baliseur Cone Picker would be impractical and cost ineffective.

1.8 Problem Description and Project Objectives

The investigation of commercially available machines has shown that none of the existing automated machines satisfy the Caltrans requirements for the deployment and retrieval of traffic cones. While the current Caltrans operation is adequate in terms of effectiveness, crew workers are exposed to a hazardous environment and are required to endure potentially injurious repetitive motion. The objective of this project is to develop an automated system that will improve the safety of the cone deployment and retrieval operation without compromising current operating speeds and efficiencies. Investigation of the present cone laying methods has demonstrated that, in order to successfully meet the needs of workers, the automated machine has to maintain much of the versatility and robustness of equipment used in the manual operations. Prior to development of machine concepts, a thorough attempt to understand the requirements of the cone laying operation is required. This report includes a description of the development process and details of the existing prototype equipment.

2. CHAPTER TWO
SPECIFICATIONS OF THE AUTOMATED CONE MACHINE

2.1 Functional Specifications

The ACM is designed to deploy and retrieve highway traffic cones in Caltrans operations with the principal objective of increasing the safety of crew workers without compromising the current operation speeds and efficiencies. By having all workers remain within the cab of the vehicle and by utilizing automated mechanisms, the safety of the workers can be maximized. Shielded from the multitude of highway hazards, the crew members will be able to communicate and concentrate more effectively. To achieve a high level of flexibility and to keep production costs down, the automated components are designed to be mounted on a modified Caltrans cone body one-ton truck. The major modifications are to extend the truck frame and to move the cone body rearward to allow for a 43 cm (17 in) gap between the truck cab and the cone body. This space is necessary for several of the ACM's automated components. Utilizing the modified cone body will allow the bucket seats and the stowage conveyor to remain intact and accessible for manual use if necessary.

2.2 Cone Deployment and Retrieval

The ACM will place cones on the road surface from either side of the vehicle as it is done during present Caltrans operations. Cone deployment will occur at speeds up to 24 km/hr (15 mph) in the forward direction. The driver is required to correctly maneuver the vehicle to accurately position the cones both laterally and longitudinally. The driver will also have the option to place a single cone in a designated spot or a series of cones at fixed distances of 7.6, 15, or 30 m (25, 50, or 100 ft) apart. A control panel located within the truck cab will have switches that will manually activate these options.

The ACM will retrieve standing and fallen cones on either side of the vehicle and in both the forward and reverse directions. The driver must pay close attention to the orientation of the deployed cones in order to properly configure the components of the ACM. At speeds up to 16 km/h (10 mph), the driver is required to maneuver the vehicle within +/- 15 cm (6 in) of the deployed cones so that a funnel system and a tipping system can properly orient the cones for pick up. The driver is also responsible for directing the vehicle to create the standard lane closure configurations used currently by Caltrans

2.3 Lane Maintenance

As the highway task is performed, the lane closure configuration must be periodically monitored for fallen cones. Thus, the ACM will be able to switch between the deployment mode and retrieval mode with considerable ease. When coming upon a fallen cone, the ACM is simply put into retrieval mode and the cone is picked up. The driver maneuvers the vehicle to the spot where the cone originally stood, changes from retrieval mode to deployment mode, and places a cone onto the road surface.

2.4 Vehicle Setup

The ACM requires some simple manual setup of its components depending on the operating mode and the direction of travel. This procedure, however, can be done away from traffic and prior to the actual cone deployment or retrieval operation. The mechanisms of the ACM that extend beyond the legal width requirements during operational use can be stored mechanically without the operator exiting the vehicle.

2.5 Traffic Cones

The ACM has a minimum storage capacity of eighty traffic cones on its longitudinal conveyor belt. The component systems of the ACM are capable of handling cones that are 710 mm (28 in) in height and 4.5 kg (10 lb) in weight. While a great variety of cones of this size and weight are available from different manufacturers, the ACM will adhere to the standards of the cones produced by Traffic Safety Services. These cones appear to be the most similar to those used in the majority of Caltrans operations. Usage of different sized cones or damaged cones may cause jamming in several components of the ACM. If this occurs, the ACM must be shutdown and manual assistance would be required to remove the obstructing cone.

2.6 Personnel

The ACM requires only one worker to serve as both operator and driver since a panel that both monitors and controls the automated mechanisms is located inside the truck cab. However, as described in Chapter 1, during all actual cone operations, a total of five warning signs must be manually assembled and deployed in the Advance Warning Area and Buffer Area. Current Caltrans operations typically require that the driver and another crew member exit the vehicle and place these signs in their respective positions. While the ACM applies automation to the handling of cones, it is not capable of deploying, assembling, or retrieving warning signs. Thus, the two workers are still required to perform this duty. The second worker would also be responsible for the manual retrieval of damaged cones that would not be accepted by the automated systems.

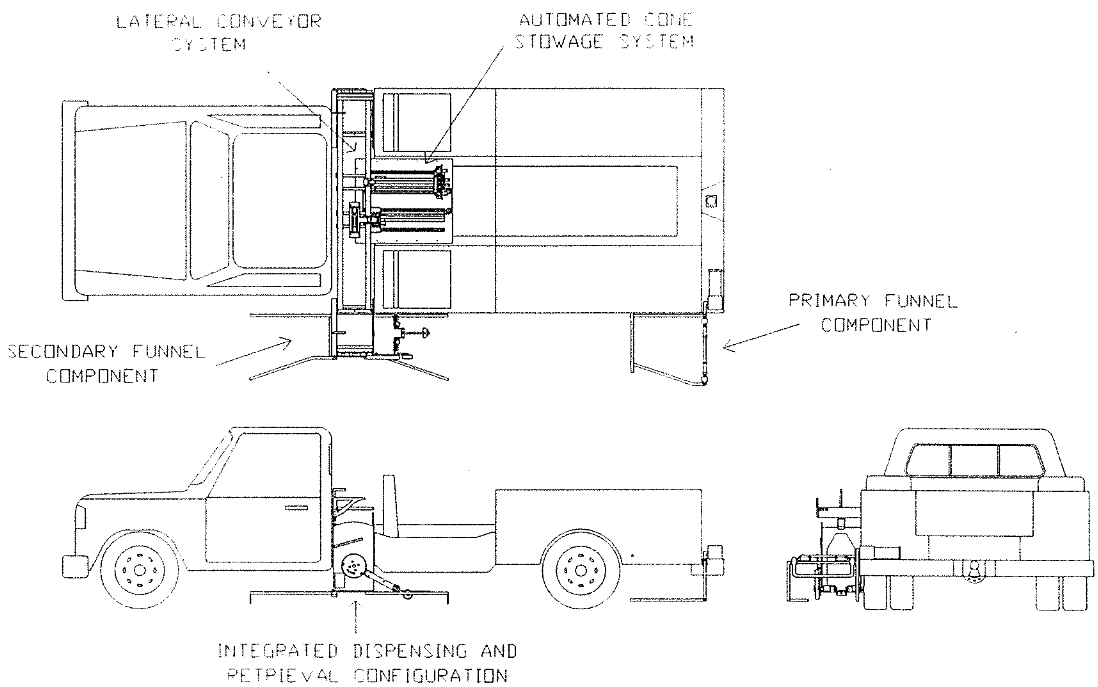

Figure 2.1 The Automated Cone Machine

2.7 General Description of the Automated Cone Machine

2.7.1 The Funnel System

The Funnel System is used by the driver to properly orient deployed traffic cones for pickup. The system consists of two components: the Primary Funnel Component and the Secondary Funnel Component. The Primary Funnel Component is modular and can be placed in one of four mounts located at each of the corners of the ACM. It consists of a frame that extends laterally, a hydraulic motor, and a tipping bar. The frame holds a swinging door that can become either free or rigid by action of a solenoid. Both the frame and the tipping bar can be stowed efficiently within the width of the vehicle by activation of the hydraulic motor. The Secondary Funnel Component consists of two simple rods positioned at specific angles from each other. Fixed to the bottom of each drop box, these rods serve to funnel any deployed traffic cones to a designated area for pick up. Vertically positioned extensions placed at the ends of the rods prevent traffic cones from getting jammed between the rods and the road.

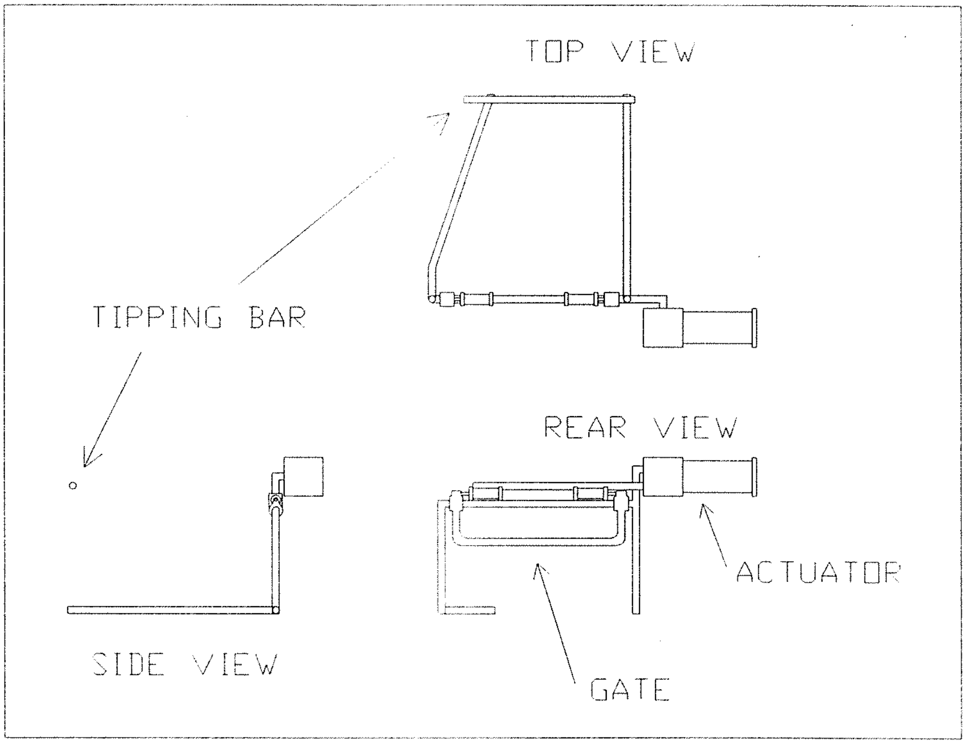

Figure 2.2 The Primary Funnel Component of the Funnel System

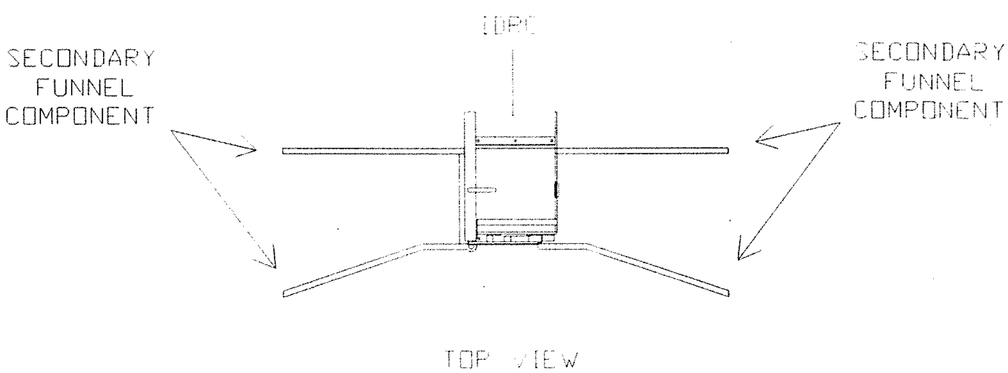

Figure 2.3 The Secondary Funnel Component of the Funnel System

2.7.2 The Integrated Dispensing and Retrieval Configuration

The Integrated Dispensing and Retrieval Configuration (IDRC) represents the means to transfer traffic cones between the road surface and the ACM. This configuration consists of five main components used for both retrieval and deployment of traffic cones. The first component is the collapsible arm that is used to pick up previously deployed traffic cones. Since all traffic cones are knocked over before being picked up, the arm serves to enter the exposed hollow end of the cone and to simply lift it upward. Once particular sensors are activated, the arm is set into a circular motion by a hydraulic actuator. The cone and the arm continue to move until the second component, the Advanced Timing System is engaged. A roller located on the arm contacts the smooth contoured surface of the Advanced Timing System causing one section of the arm to be free to rotate. While this occurs, the base of the cone presses against the stripping mechanism, the third component, and the arm begins to collapse. As the arm completes its circular motion, the cone rides up the arm until it is free to fall. The Lateral Conveyor system rests underneath the stripping mechanism and takes the traffic cone into stowage (see next section). The drop box and the angled brushes, the fourth and fifth components respectively, are used primarily for traffic cone deployment procedures. After being released from the LCS, the traffic cone falls through the specially designed drop box that restrains the cone from rotating. Prior to reaching the ground, the cone base falls through two angled brushes that help place the base of the cone with significant stability and accuracy.

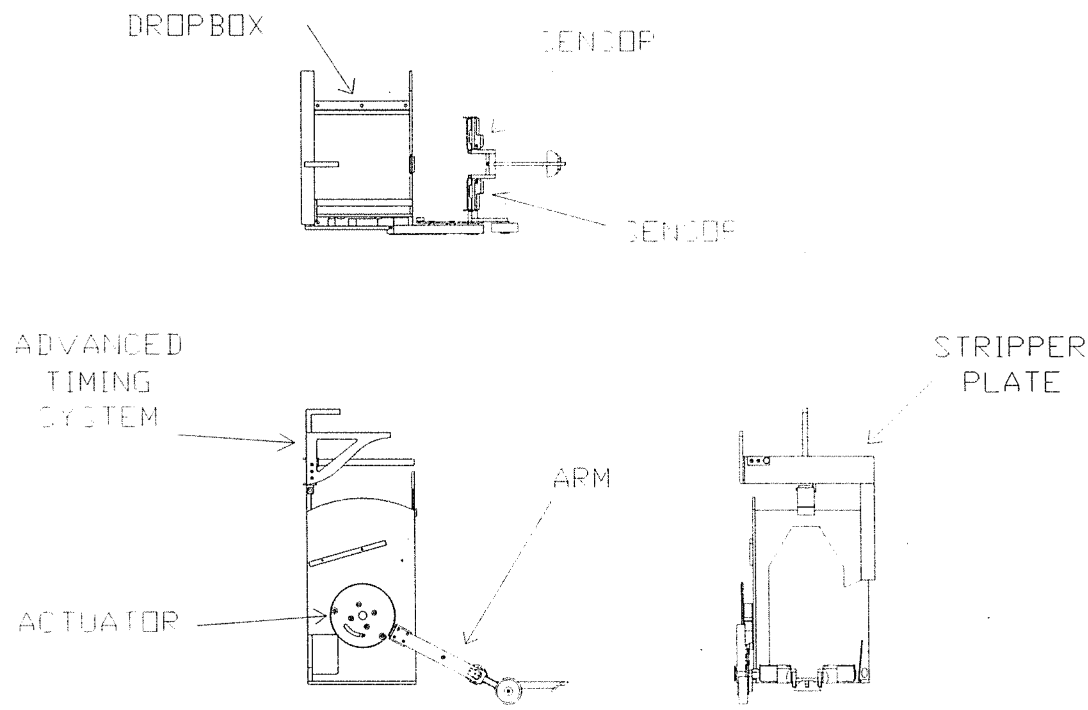

Figure 2.4 The Integrated Dispensing and Retrieval Configuration

2.7.3 The Lateral Conveyor System

The Lateral Conveyor System (LCS) serves to transfer recently picked cones to stowage and previously stowed cones to the drop box. The LCS consists of three lateral conveyor assemblies that run continuously by a hydraulic motor, a simple sensing system to signal when a cone has been retrieved, and a gate system to position cones for stowage. A large stationary conveyor assembly is located in the middle portion of the 43 cm (17 in) gap between the truck cab and modified cone body. Two 5 cm (2 in) wide drive belts serve to hold the extensions located on the bottom of the cone base and to transport the cone to the desired side of the vehicle. Attached at both ends of this stationary system are retractable conveyor wings. Deployed mechanically by the rotary action of the middle conveyor, these wings are extended when retrieving cones and lowered when dropping cones. A contact switch is positioned directly above one side of the LCS and is activated only when a cone passes towards the longitudinal centerline of the ACM. This signal is used to alert and reset the IDRC for another retrieval cycle.

In between the two narrow drive belts of the stationary assembly is a system that consists of three gates that serves to block the path of the cone and to accurately locate the position of the cone. The three gates have embedded contact switches that, once activated, produce signals to activate the stowage system. The middle gate is deployed from underneath the two belts while the left and right gates are attached to their respective drop box assemblies. By utilizing a combination of open and closed gates it is possible to properly position a retrieved cone for the Automated Cone Stowage System.

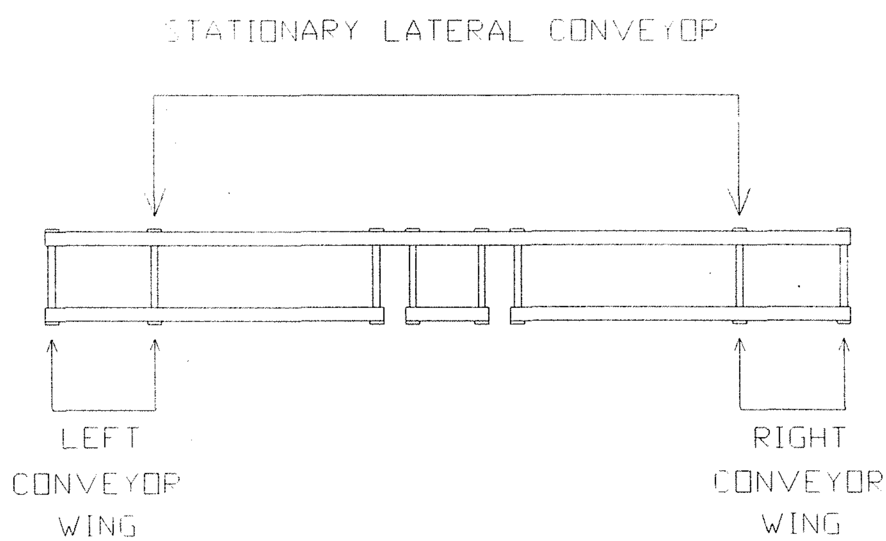

Figure 2.5 The Lateral Conveyor System

2.7.4 The Automated Cone Stowage System

The Automated Cone Stowage System (ACSS) actively moves cones between the LCS and the stowage stack. After the base of a traffic cone has contacted the gate switches of the LCS, it is ready to be placed into stowage. A signal from the gate switches activates one of the two hydraulic mechanisms that can firmly grab the cone from underneath. Two specially designed jaws open outward and prcss against thc insidc surfaccs of the hollow conical section of the cone. A belt driven pulley system moves the hydraulic gripper on a track parallel to the longitudinal centerline of the ACM. While one of the hydraulic gripper mechanisms is pulled towards the cone stack, the other is pulled closer to the LCS. As the gripper mechanism and the ensnared cone approach the stowage stack, a linkage system rotates both the gripper and cone so that the cone is horizontal instead of vertical. The tip of the cone can then enter either the hollow section of a previously stowed cone or the contoured conveyor mount that holds the first stowed cone. The stowage conveyor responds to a four sensor system that determines how far to move the conveyor to allow the proper space for a cone to be stored. This stowage operation is executed in reverse when removing cones from stowage and transporting them to the LCS. The four sensor system advances the stack of stored cones so that one end is accessible to the hydraulic grippers. After being grabbed by the jaws of one of the hydraulic grippers, the linkage mechanism will rotate a cone from a horizontal position to a vertical position so that the conveyors of the LCS can properly transport them to the desired side of the vehicle.

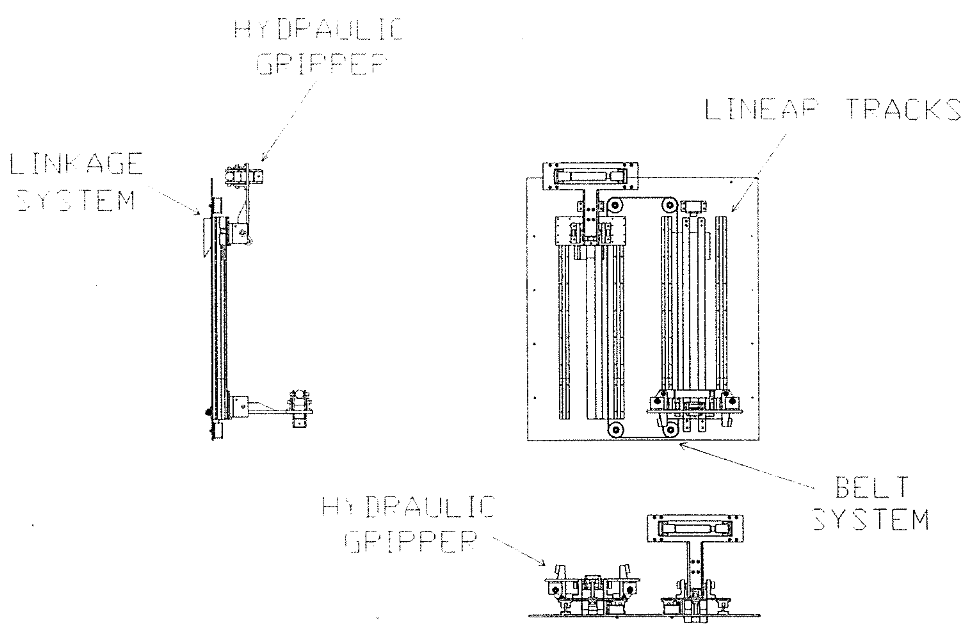

Figure 2.6 The Automated Cone Stowage System

2.7.5 The Coordinated Control Unit

The Coordinated Control Unit (CCU) is responsible for integrating all of the described systems to efficiently manipulate traffic cones during retrieval and deployment operations. By processing the signals produced by the various sensors and switches, the CCU can locate the position of the cone and prepare the crucial interfaces between these systems. A micro controller is utilized to implement a series of logical procedures that can activate particular sequences of systems. The controller allows the driver to input the characteristics of the operation so that the proper components of the ACM can be activated, deployed, or retracted. This controller can be mounted to locations both inside and outside the vehicle. During deployment and retrieval operations, the controller is placed inside the cab where the driver can access it while maneuvering the ACM. During maintenance testing, the controller can be attached to its outside mount so that the performance of the ACM components can be evaluated from a more local site. The CCU also contains several emergency switches located in numerous areas both inside and outside the vehicle that shut down all ACM systems when activated. These switches are used as safety measures when crews perform maintenance or remove damaged traffic cones from the automated components.

2.8 General Descriptions of ACM Operational Procedures

2.8.1 Pre-operational Setup

Before the ACM embarks on operational duty, several simple adjustments must be made to its components. This setup procedure can be done off-site since all components that extend from the vehicle will be stored before highway travel. The particular operation must be identified in order to properly configure the ACM's automated components. It must be established whether the operation will be occurring on the left side or the right side of the vehicle and whether the vehicle will be traveling forward or backward. Ideally, with knowledge of the site configuration, setup could occur at the equipment yard. A mount that holds the Primary Funnel Component (PFC) is located at each of the four corners of the ACM. The modular PFC will be placed at the mount where the vehicle first contacts a deployed traffic cone. Thus, if the operation occurs on the left side of the vehicle and with the ACM traveling in the reverse direction, the PFC will be attached on the rear left side mount. Prior to operational duty, the IDRC must also be properly adjusted. On the outermost side of either drop box is a rotating device that restrains the motion of the cone arm. This arm restraint must be placed in configuration A (shown in Figure 2.7) if the ACM will be operating in the forward direction. Configuration B (Figure 2.8) is necessary when operating the ACM in the backward direction.

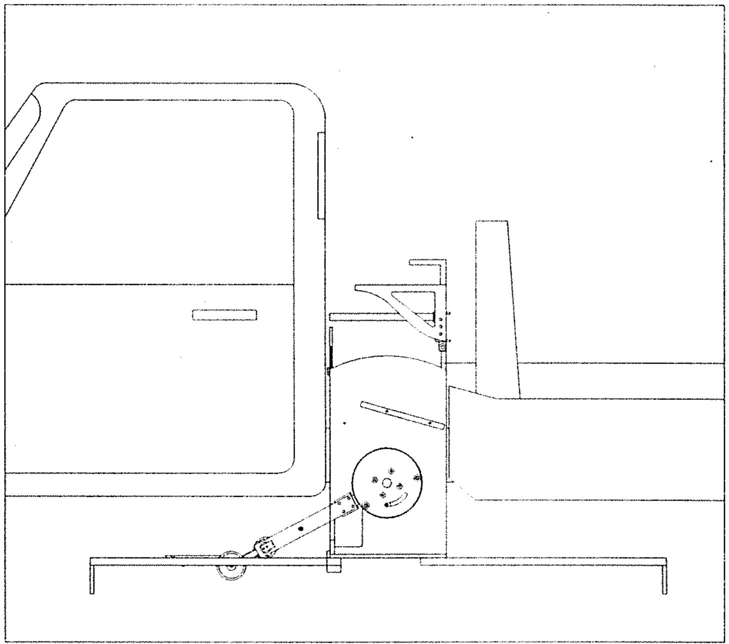

Figure 2.7 Configuration A

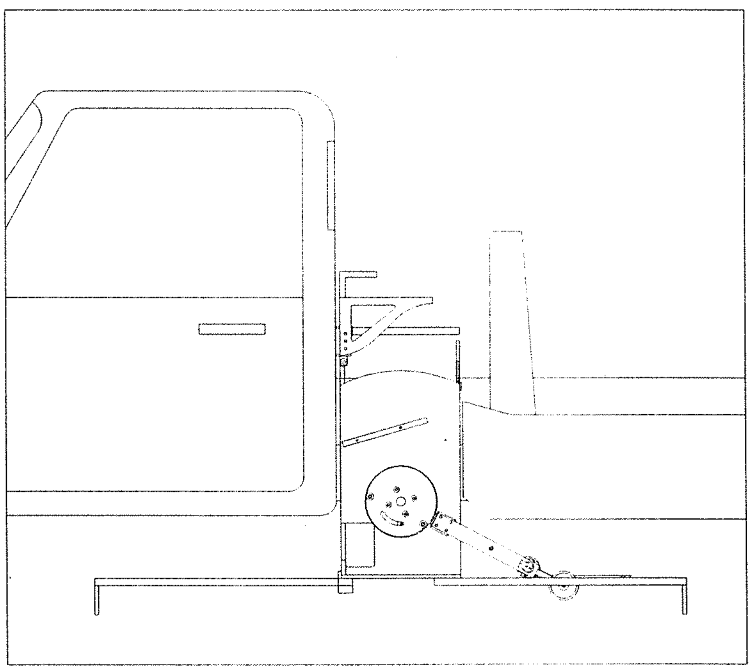

Figure 2.8 Configuration B

2.8.2 Deployment of Traffic Cones

Upon arriving at the designated work site, the driver of the ACM uses the controller located inside the cab to activate and to deploy the necessary components for this operation. For example, if this operation was to close the rightmost lane of the highway, the driver would deploy the left side IDRC and activate the LCS and ACSS. The ACM begins the traffic cone deployment operation in the same fashion as it is done currently by Caltrans. The ACM starts from the shoulder of the road and is followed by a shadow vehicle.

The driver of the ACM simply uses the single drop option on the controller to place the first four cones that constitute the Advance Warning Area. The driver and the second crew worker must also exit the cab of the ACM to set up the first four warning signs. After the crew deploys the fourth warning sign and returns to the vehicle, the driver selects the 15 m (50 ft) separation option on the controller and continues to drive slowly into the lane. The ACSS will grab available cones from storage and transport them to the LCS where it is held until the appropriate distance has been covered. When a distance counter determines that 15 m (50 ft) has passed, the cone is released from the LCS and proceeds to fall through the left drop box and land on the road surface. The driver continues the slow merge into the lane until the Transition Area is complete. After this section of the Lane Closure Configuration has been established, the crew of the ACM must again exit the cab to deploy the last warning sign.

The last portion of the Lane Closure Configuration, the Buffer and Work Area, is setup by using the 30 m (100 ft) separation option on the controller. Once this option is selected, the driver maneuvers the ACM in the desired lane to be closed while the ACSS, LCS, and IDRC work together to take traffic cones from storage and deploy them accurately on the highway. Once the Buffer and Work Area is complete the highway maintenance or construction operation can begin and the ACM may be used for utility purposes or for lane maintenance.

2.8.3 Lane Maintenance

After the Lane Closure Configuration has been established, the ACM can be used to monitor the traffic cones and to make sure that they remain standing in their designated positions. In order to perform lane closure maintenance, the Primary Funnel Component must be attached to the left or right frontal mount depending on where the lane closure is located. For example, if the right lane is closed for construction or maintenance purposes, the PFC would be placed on the left frontal mount. Since the ACM will be traveling forward during this procedure, the angle restraint of the arm would have to be adjusted to configuration A as described in the Figure 2.7. These adjustments can be made in the closed lane or at a site located off the highway. The driver would also deploy the IDRC and activate the LS and ACSS.

Two situations typically arise: the cones are knocked over by the winds generated by fast moving traffic or the cones are struck directly by the vehicles in the nearest lane. In the first situation, the cones are simply toppled over and remain in close proximity of where the cone originally stood. In the second case, however, the traffic cones are moved away from their initial positions by great distances. It is very possible that the cones end up in other lanes, along the center divide, or even off the highway.

In the first case, the ACM would be maneuvered to the fallen cone and the driver must then evaluate the orientation of the traffic cone. The desired orientation for effective pick up is to have the cone facing the vehicle base first as shown in Figure 2.9. If the cone is not oriented correctly, the driver uses components of the primary funnel to realign the cone. Figure 2.10, Figure 2.11, and Figure 2.12 show the orientations that the driver must identify to effectively use the PFC.

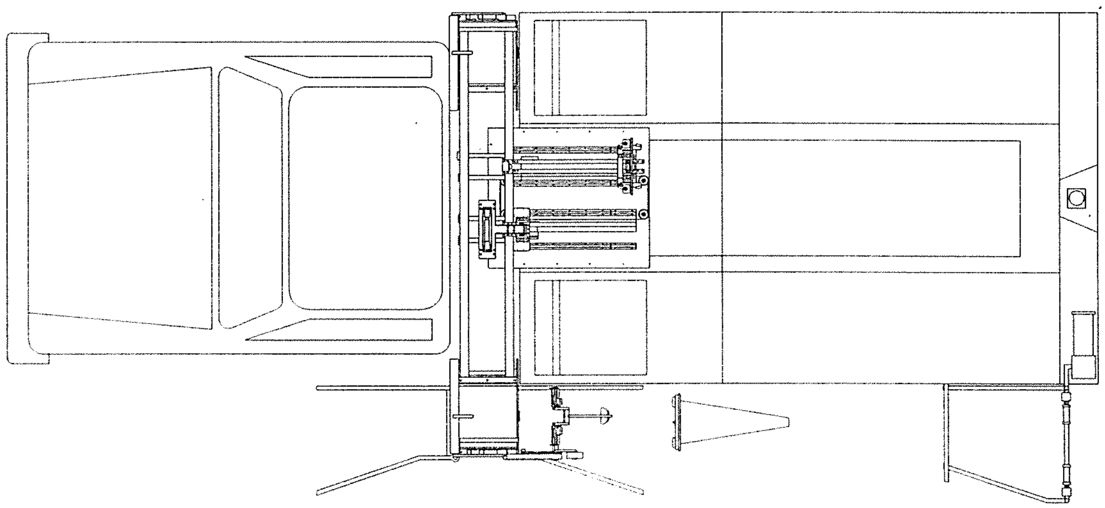

Figure 2.9 Desired orientation of traffic cone for retrieval

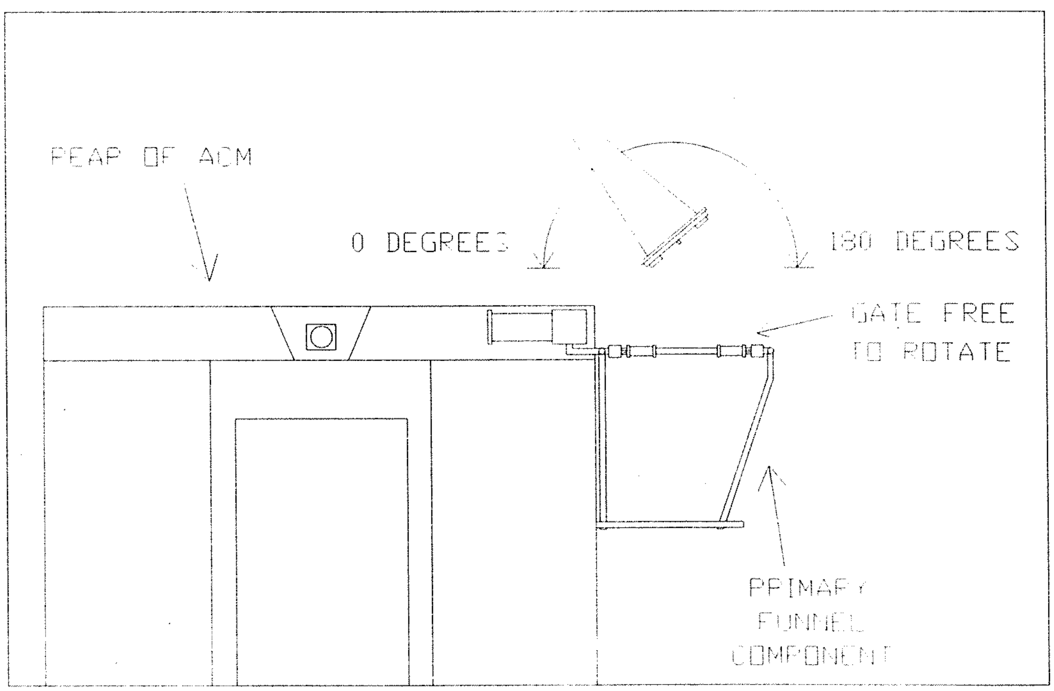

Figure 2.10 Free gate option for cones situated between 0 and 180 degrees

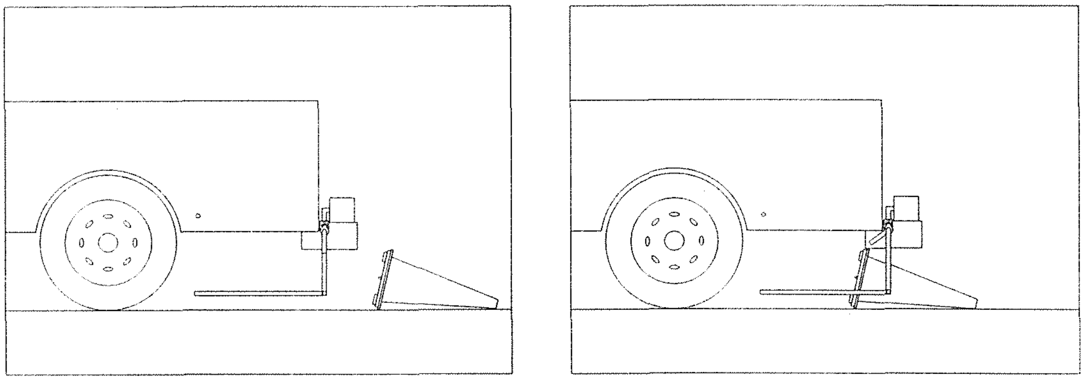

Figure 2.11 Free gate allows cone to pass underneath

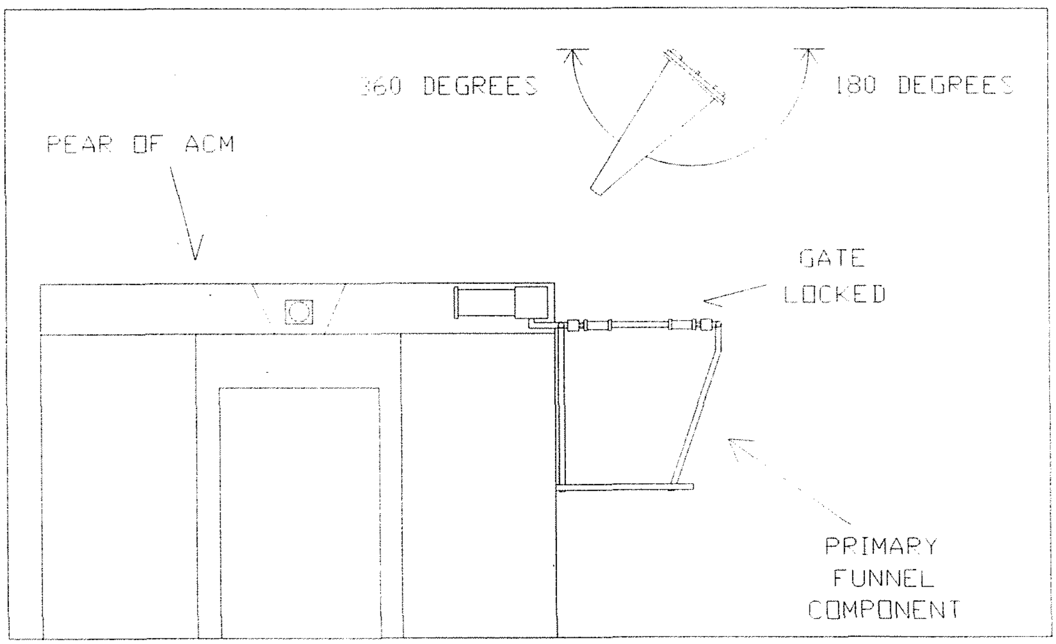

Figure 2.12 Rigid gate option for cones situated between 180 and 360 degrees

Figure 2.10 and Figure 2.11 show that if the cone is oriented between 0 and 180 degrees, the driver simply selects a free gate option and uses the PFC to straighten the cone. Since the gate is free to swing, the cone base passes underneath without obstruction. Figure 2.12 shows that when the cone is oriented between 180 and 360 degrees, the driver must select the rigid gate option. As the cone base is struck by the locked gate, the cone straightens as shown in Figure 2.12. Since the gate is locked and the ACM continues to move forward, the cone becomes upright. The tipping bar contacts the conical section of the cone, causing it to fall with the desired base first orientation. This is demonstrated in Figure 2.13. With the proper use of the PFC and some maneuvering of the ACM, any fallen traffic cone can be reoriented so that it is ready for pick up. Once the cones are aligned base first, the SFC positions the cone so that the arm of the IDRC enters the hollow conical section. After contacting a pair of switches the cone and the arm are lifted upward until the cone is stripped from the arm. The cone is taken away by the LCS and placed into the ACSS. The driver may then place a cone on the road surface in the same manner as the deployment procedure described earlier.

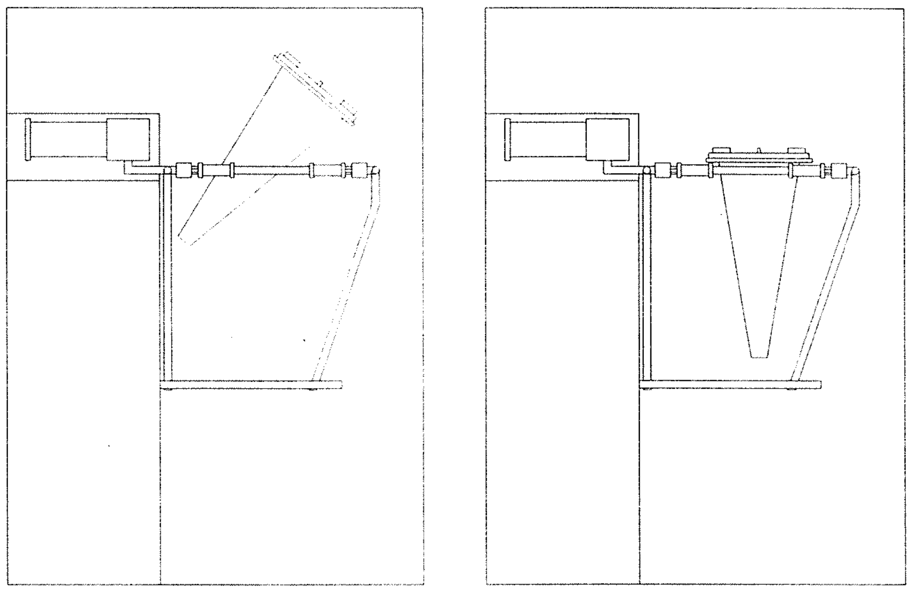

Figure 2.13 Locked gate causes traffic cones to straighten

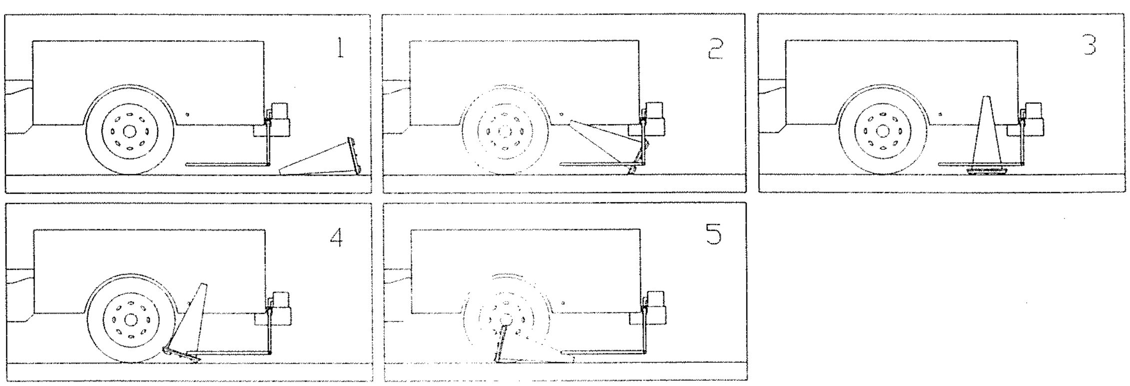

Figure 2.14 Gate stands traffic cone and tipping bar topples it into desired base first orientation

When the cone has been significantly displaced from its initial position, it is up to the driver of the ACM to evaluate the situation. If the cone has been knocked further into the lane closure, the ACM is simply driven to retrieve the fallen cone and to the site where it initial stood so that a substitute can be deployed. If the cone is far away from the lane closure, perhaps somewhere in the open traffic lanes, the crew may have no choice but to leave the cone behind. The driver must judge if it is possible to retrieve fallen cones without disturbing the open lanes of traffic and without presenting a danger to the safety of nearby drivers and highway workers.

2.8.4 Retrieval of Traffic Cones

When the ACM is used to retrieve all of the cones that constitute the Lane Closure Configuration, component changes similar to those for lane maintenance must be made. The arm restraint on the drop box of the IDRC must be adjusted so that the arm faces the rear of the vehicle. The PFC must be placed in either the left or right rearward mount depending on where the lane closure is located. If the right most lane has been closed, the PFC is fixed to the left rearward mount. Since the ACM will be operating in reverse, the left rearward mount will allow the necessary access to the long series of deployed cones.

After the highway maintenance or construction operation has been completed, the ACM and a shadow vehicle start at the end of the Buffer and Work Area and begin their slow drive in the reverse direction. Three scenarios arise as the ACM passes by the previously deployed traffic cones. The cones may be upright, fallen with the 0 to 180 degree orientation, or fallen with the 180 to 360 degree orientation. The large majority of deployed cones remain standing throughout the duration of the highway operation. In this case the driver maneuvers the ACM so that the frame of the PFC contacts the conical section of the upright cone, causing it to fall in the desired base first orientation. If the ACM encounters a fallen cone, the driver must evaluate the situation and follow one of the two scenarios described in the lane maintenance procedure. The ACM and the accompanying shadow vehicle must temporarily stop in the Buffer Area and the Advance Warning Area so that the crew can exit the ACM and retrieve the five warning signs. Once all of the traffic cones and warning signs have been stored, the driver must stow all of the ACM components by using the controller located in the cab. Once this is complete, the ACM and the shadow vehicle can carefully merge back into traffic and return to the equipment yard.

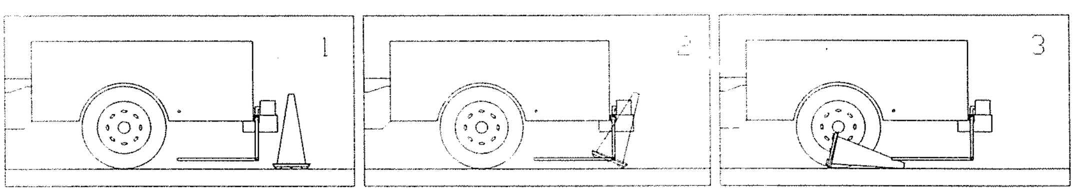

Figure 2.15 Retrieval of standing cones

3. CHAPTER THREE
DESIGN AND DEVELOPMENT
OF THE CONE RETRIEVAL AND DEPLOYMENT SYSTEM

3.1 Conceptual Development for the ACM Retrieval System

Many of the initial retrieval concepts utilize sophisticated robotic arms with multiple degrees of freedom that are able to retrieve and place 71 cm (28 in) cones, but the level of automation and the cost associated with such robotics make these concepts impractical. More basic levels of automation such as rotating arms and simple mechanical arms that rotate within a single plane dominate the later concepts. These designs also require that cones be oriented prior to retrieval with the use of funneling devices that restrict the position of the cone relative to the cone truck. The conceptual designs and their strengths and weaknesses are described in detail in the following sections.

3.1.1 Three Prong Approach

The Three Prong Approach utilizes three extended prongs mounted onto a rotating arm to pick up traffic cones from the road surface. This concept, depicted in Figures 3.1 and 3.2, requires cones to be toppled over and then oriented with a funneling device. This funnel would restrict the cone to be in either a tip first or base first orientation. Cones coming in base first would be picked up using the hinged middle prong (see Figure 3.1) which is considerably longer than the two other adjacent prongs. This middle prong is also curved to enhance its lifting ability as the arm rotates upward. For cones that are oriented tip first, the middle prong would make first contact as shown in Figure 3.2. A small collapsible wheel located at the bottom of the hinged middle prong allows it to ride along the outer surface and over the base of the cone. The tips of the two remaining prongs are positioned low enough to enclose the outer bottom surface of the cone as the arm is rotating upward. The cone is then carried upside down and repositioned at a place for removal.

Although simple and seemingly effective, this approach has some inherent problems. First of all, the two prongs that would pick up cones coming in tip first would have to be positioned very close to the ground in order to be effective. Clearly any equipment that is located this close to the ground would tend to get damaged since the vehicle that the equipment is mounted on would experience some rolling and pitching when in motion. Removal of captured cones from the prongs would be awkward due to the length of the middle prong and the interference caused by the positioning of the three prongs. The concept also relies on a method for picking up cones tip first that is very difficult to achieve reliably.

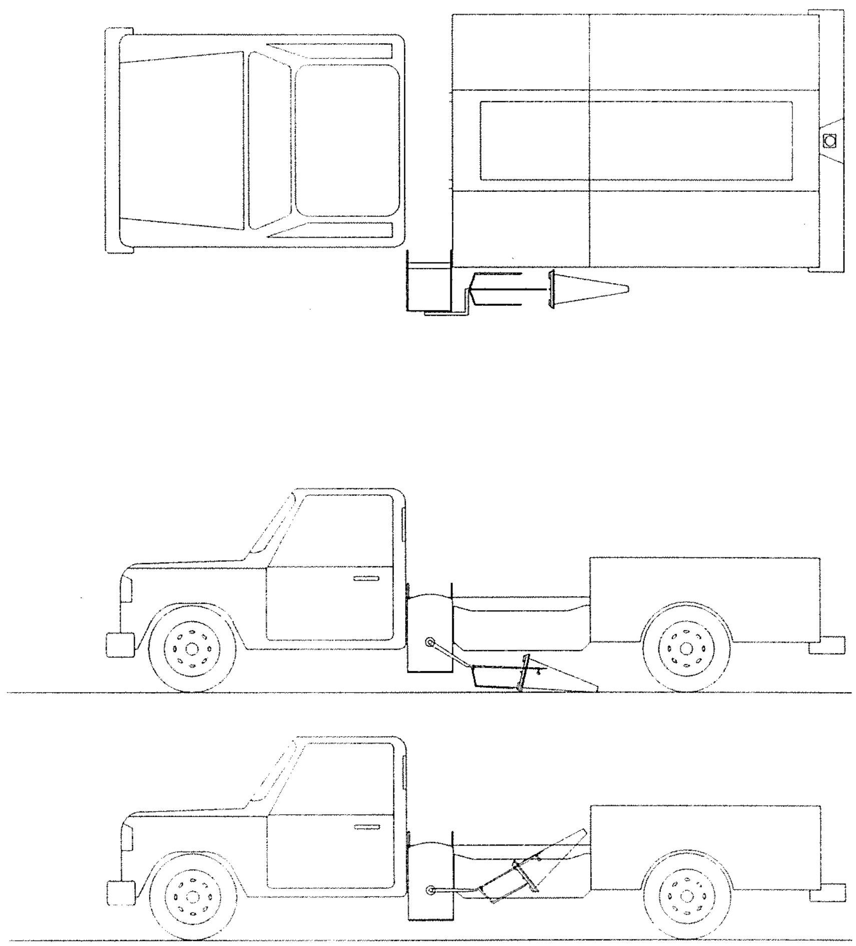

Figure 3.1 Three Prong Concept pick up sequence with cone base first

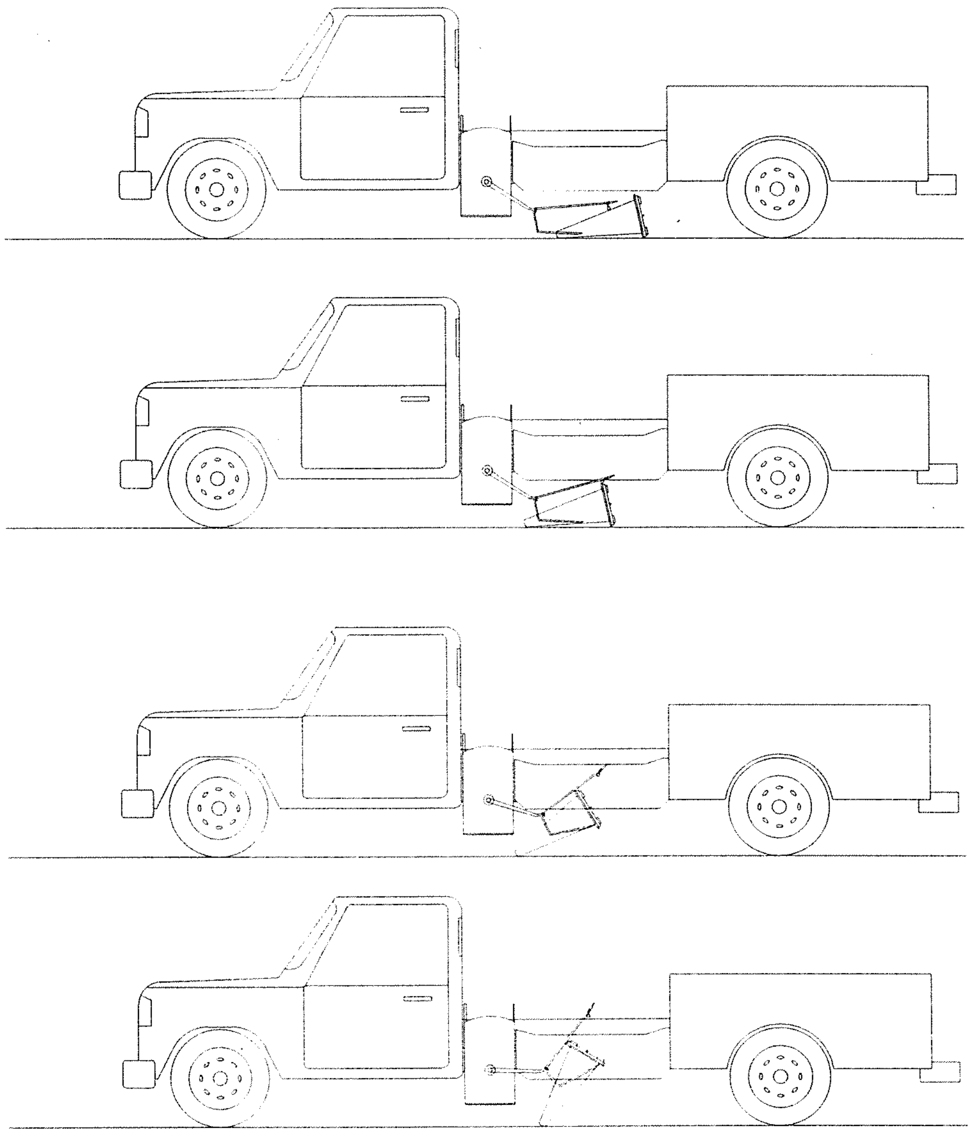

Figure 3.2 Three Prong Concept pick up sequence tip first

3.1.2 Cone Base Retriever

This retrieval system also utilizes a funnel that orients fallen cones so that either the base or the tip contacts the mechanism first. A sensing system determines the position and orientation of the cone for retrieval. This system then utilizes a set of photo-electric sensors or a pair of contact switches to locate the cones while not disturbing their alignment. After passing through the sensing system, the gripping mechanism engages the base of the cone by grabbing it between two pincers as shown at the bottom of Figure 3.3. Having the cone in its grasp, the arm that the pincers are mounted on rotates up into the storage area of the cone truck. Since the sensors can determine the orientation of the cone, the arm is able to rotate the cone and align the cone with the rest of the cone stack. This rotation is accomplished by mounting an actuator to the end of the arm. This actuator restricts the pincers to only have two set positions 180 degrees apart and allows the cone to be retrieved and stacked consistently.

This compact and simple retrieval concept is a sensible solution. The material variations of the cone due to the varying temperatures do not affect the performance of the retrieval system since the pick up of the cones relies on gripping the base. However, the timing of the pincers gripping the cone base is extremely critical. If the pincers close too early the cone would not be retrieved and the truck would pass the cone. If the pincers close too late the cones would be knocked away from the retrieval area and the cone would again be missed. Exact timing is essential for a successful retrieval. However, exact timing would be difficult to achieve since the speed of the truck and the precise orientation of the cone would have to be taken into account for a positive grip. Furthermore due to the short cycle time, the long rotating retrieval arm with the heavy pincers would have to activate very quickly demanding a significant amount of power for operation.

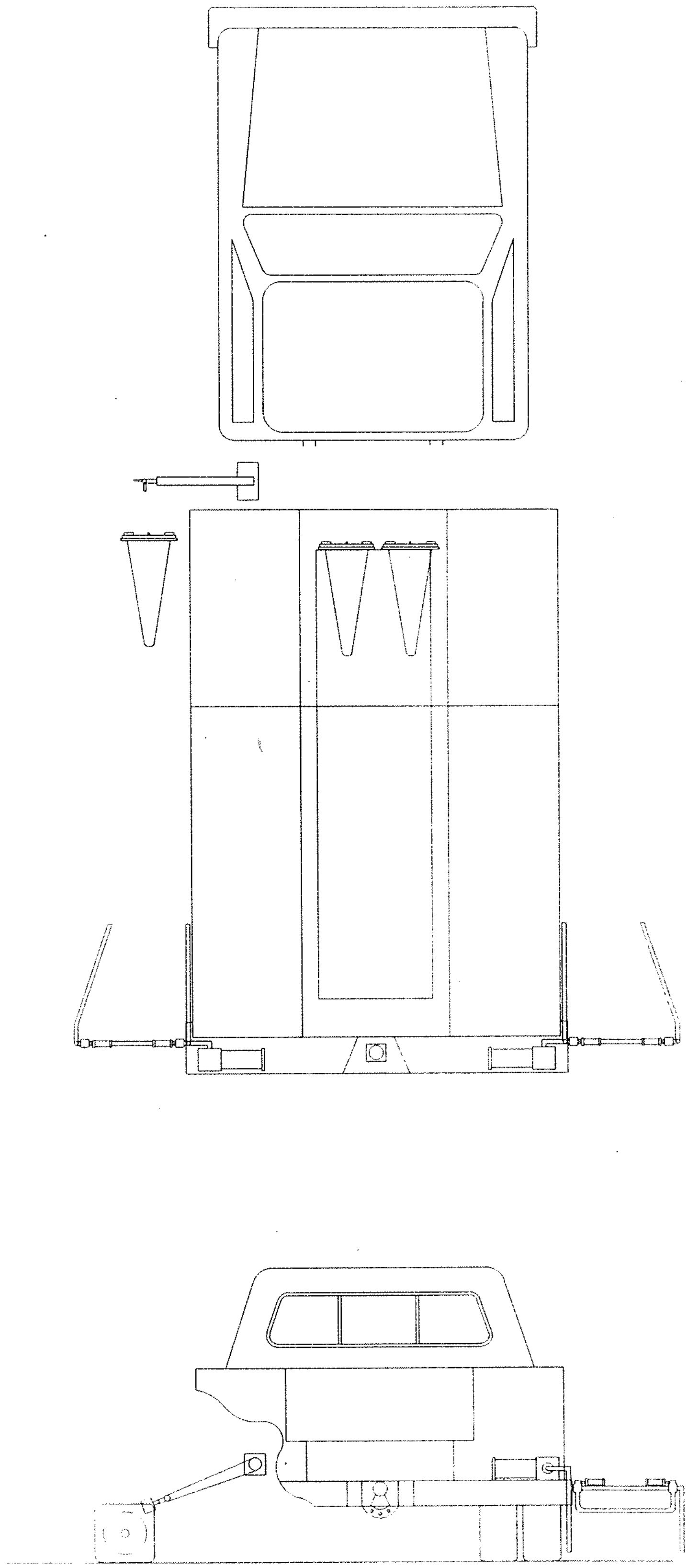

Figure 3.3 Cone Base Retrieval Concept (cut away back view)

3.1.3 Retrieval Using Contoured Surface

This contoured surface design also utilizes the usage of a funnel device to help orient cones prior to retrieval. This configuration allows for a retrieval arm to be inserted into the bottom opening of the cone. This retrieval arm protrudes from a contoured surface that the base of the cone will stop against. As the arm rotates to lift the cone, the base of the cone rides against the contoured surface (refer to Figure 3.4). As the arm completes its rotation upwards, the cone is brought up to the transfer area in its standing orientation. The transfer area is the site for the cone to be transported to the stacking mechanism. This transfer area is lower than the top of the contoured surface to allow the cone to fall into an area slightly larger that the base of the cone. The return stroke of the retrieval arm requires the arm to rotate and slide underneath the cone as it returns down to the ready position. The purpose of the lowered transfer area is to detain the cone as the arm withdraws from the base of the cone. The spring loaded arm is restricted to fold in only one direction so that withdrawal from the cone is simple and effective.

This design uses the Integrated Dispensing and Retrieval Configuration (IDRC). The IDRC is composed of a dispensing box on which the retrieval system is mounted. The box, which is referred to as the drop box, allows a traffic cone to be placed onto the ground with effective stability and consistency. During cone deployment operations, cones are dropped through the box in the standing up orientation. The cones are then firmly planted onto the roadway with the help of strategically positioned guides.

The biggest issue for this design is the fact that the contoured surface is too bulky. One of the most important design criteria for retrieval designs is the ability to retract any equipment that is deployed during operation. The bulkiness of this design makes the retraction of the contoured surface very problematic. The contoured surface has to be strong enough to handle the impact of an approaching cone and smooth enough to allow the cone to glide over it when the arm is in motion. The size of the surface is also determined by the necessary length of the retrieval arm. One option for this problem of stowage was to allow more space for this bulk. However, one requirement for the retrieval mechanism is that it must be situated in between the truck cab and the cone body because this would require minimal modifications to the existing cone truck configuration. This specification establishes a maximum space allotment of 43 cm (17 in) width wise for the retrieval mechanism. This allotment is much smaller than the necessary size of the contoured surface for effective cone retrieval.

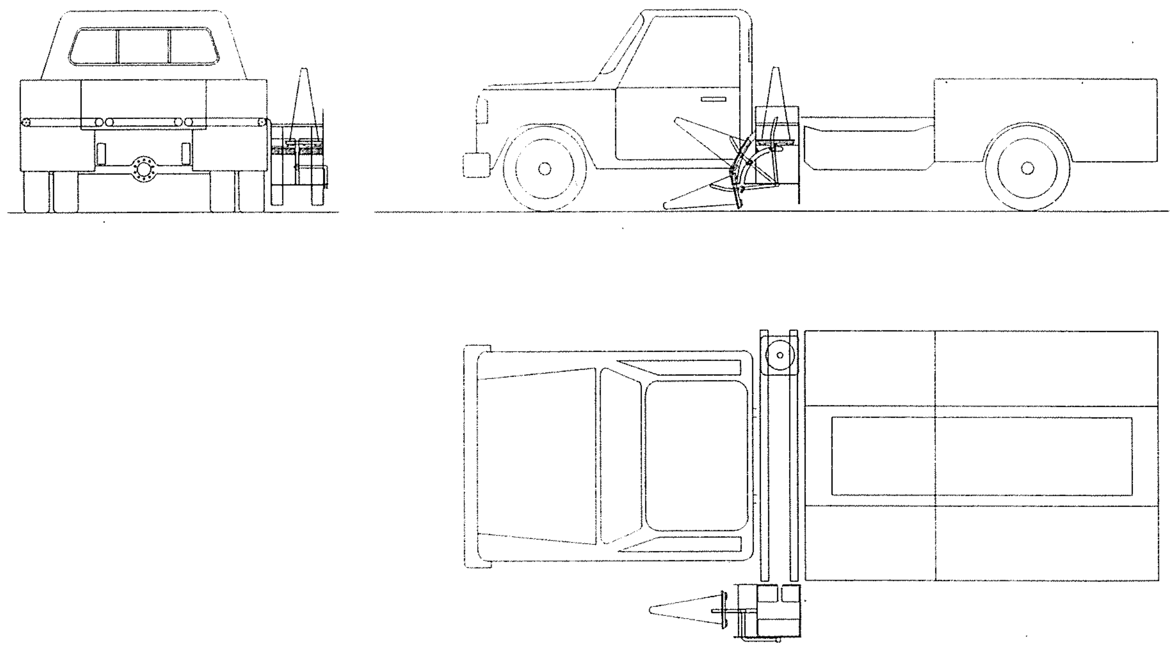

Figure 3.4 Retrieval using Contoured Surface

3.1.4 Double Retrieval Arm

The double retrieval arm design mimics the contoured surface of the previous design by utilizing a secondary arm. The secondary arm is positioned perpendicular to the retrieval arm and it supports the base of the cone during lifting. Both arms travel inline with each other so that the cone is held in place with the retrieval arm and the supporting secondary arm. As the arms reach the top of the upward rotation, the two arms begin to separate. The secondary arm remains positioned right ahead of the transfer area while the retrieval arm continues to rotate. The cone is dragged over the secondary arm and into the lowered transfer area as shown in Figure 3.5. The withdrawal of the arm from the cone remains the same as the method used in the contoured surface concept. On the return stroke however, the secondary arm travels inline with the retrieval arm into the ready position.

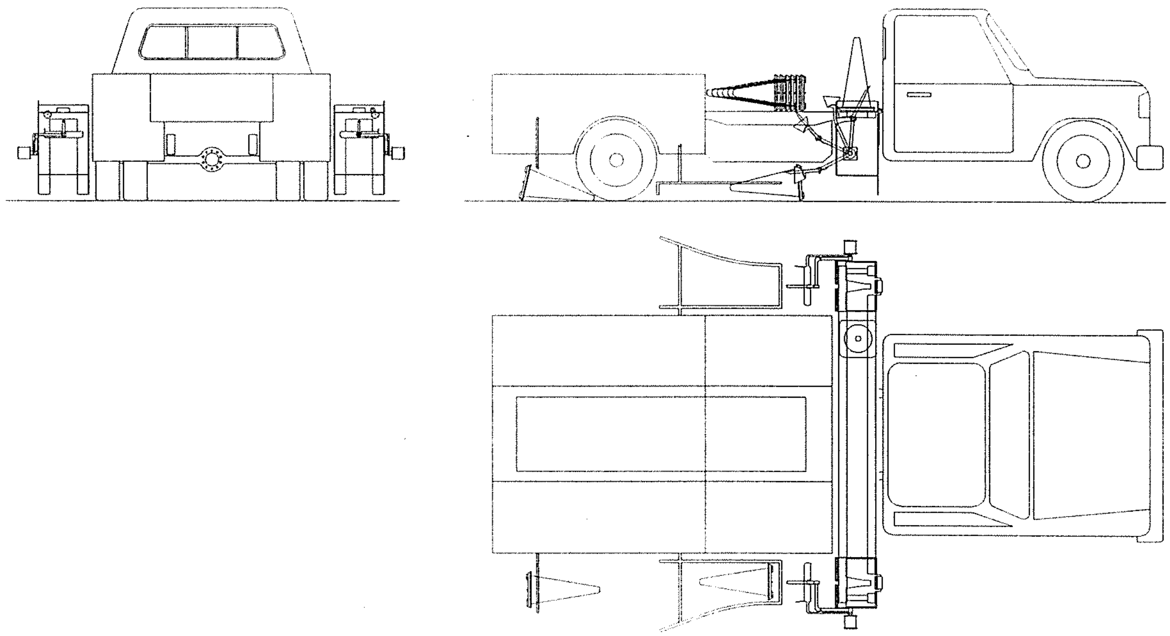

Figure 3.5 Double Retrieval Arm

The double retrieval arm has some very good features. The IDRC and funnel system are also incorporated in this concept. The double retrieval arm design is compact enough to allow for retraction of the mechanism for vehicle deployment. Furthermore, power requirements are acceptable and the simplicity of the design enhances its robustness. However, the greatest weakness of this design is the fact that the retrieval arm, by design, needs to have portions of the drop box and transfer area removed. This reduction in strength of the IDRC structure makes the transfer system more complex.

3.1.5 Break Away Arm

The break away arm functions in a similar manner as the double retrieval arm and it also incorporates the IDRC and funnel system. The retrieval arm consists of one component that enters the bottom of the fallen cone named the poker arm and another component that supports the base of the cone named the cross arm (see Figure 3.6). As the cone is lifted up on the retrieval arm, the cross arm supports the base of the cone. This cross arm is able to rotate about a pivot point on the main arm. As the cone strikes the stripping plate, the cone is removed from the retrieval arm and lands onto the cone transfer area. After the cone is transported to the stowage area, the retrieval arm returns to its ready position.

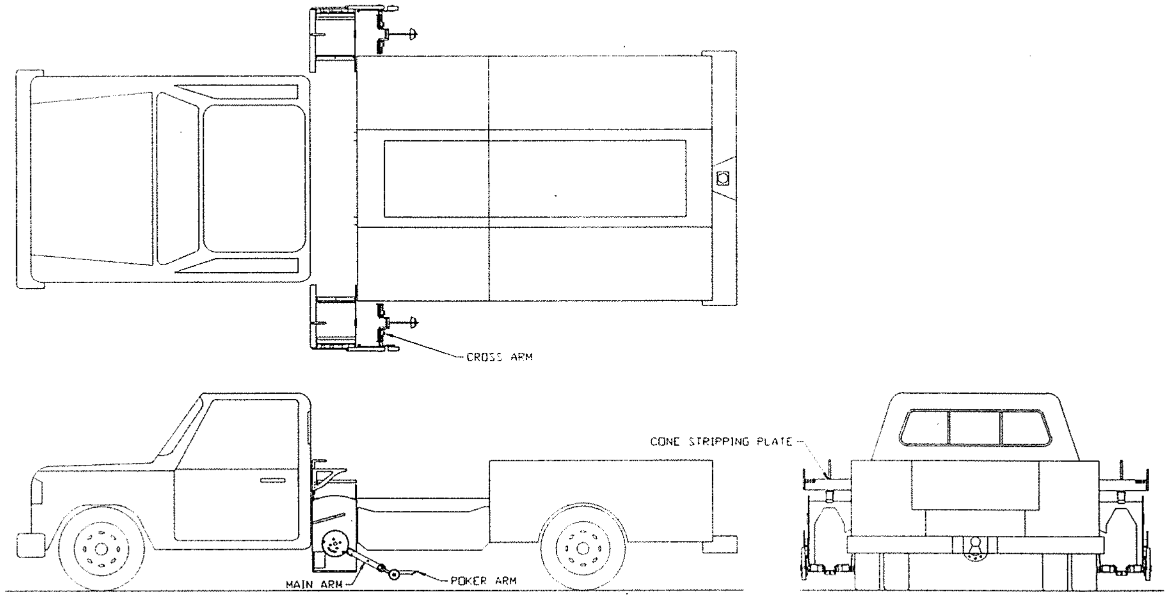

Figure 3.6 Break Away Arm

A major concern for this design is that as the cone is stripped from the poker arm and falls onto the transfer area, there is no controlled restraint of the cone. The unrestricted cone falls freely onto the transfer area that contains the moving lateral conveyor and toppling could occur. This unexpected positioning of the cone would make the handling of these cones problematic for the stowage process.

3.2 Selection of Concepts

There were many considerations when trying to select the best concept among several competent designs. First of all, there were a set of minimum requirements that needed to be satisfied before a design could even be judged. For the ACM these mandatory requirements included such factors as operating capability on either side of the truck, compatibility with Caltrans' cone truck, and cone retrieval in either direction of travel. If mandatory requirements were not satisfied, then the design was discarded for one that did satisfy these requirements. Optional capabilities demonstrated a concept's flexibility and usefulness. Examples of these were the ability to retrieve and place cones simultaneously while moving forward, operation by the driver without an additional worker, and operation at speeds of 24 km/hr (15 mph) and greater. There were also design considerations that include such factors as the durability of the machine and the safety to traffic and workers. Finally, the cost of all of the equipment had to be weighed against all of the benefits of each design.

To make the correct and unbiased decision of which design to choose and further develop, a trade-off table was constructed to create a more quantitative method for basing this decision (see Table 3.1). This trade-off table included all of the issues that needed to be addressed while utilizing a weighting factor that was given to each of the non-mandatory considerations. This weighting factor was multiplied with the individual score to come up with the total score for that individual issue. All of the mandatory requirements needed to be satisfied or the design was discarded.

Table 3.1 Trade-offs for Retrieval Designs

DESIGN CONSIDERATIONS	WEIGHTING FACTOR	Three Prong	Cone Base Retriever	Contoured Surface	Double Retrieval Arm	Break Away Arm
MANDATORY CAPABILITIES						
1. Picks up moving forward		yes	yes	yes	yes	yes
2. Picks up moving backward		yes	yes	yes	yes	yes
3. Operates on left or right side		yes	yes	yes	yes	yes
4. Operates between 3-16 km/hr (2-10 mph)		yes	yes	yes	yes	yes
5. Picks up within +/- 15 cm (6 in)		yes	yes	yes	yes	yes
6. Installs on Caltrans cone body		yes	yes	yes	yes	yes
7. Driver controlled speed		yes	yes	yes	yes	yes
8. Handles generic 71 cm (28 in) cone		yes	yes	yes	yes	yes
9. Easy to manually load		yes	yes	yes	yes	yes
10. Simple conversion to manual operations		yes	yes	yes	yes	yes
OPTIONAL CAPABILITIES						
1. Able to pick/place same side moving fwd	5	2	2	4	5	5
2. Able to pick/place opp. side moving fwd	5	2	2	4	5	5
3. Able to pick/place same side moving rev	3	2	2	4	5	5
4. Able to pick/place opp. side moving rev	3	2	2	4	5	5
5. Quick conversion for lane maintenance	1	0	1	4	5	5
6. Operates at 0-3 km/hr (0-2 mph)	4	0	4	5	5	5

7. Operates at >24 km/hr (15 mph)	2	1	1	5	3	3
8. Operated by driver only	1	1	1	1	1	1
9. Ejects defective cones	1	0	0	0	0	0
10. 80 cone carrying capacity	4	5	4	5	5	5
11. Leaves flag/storage area unmodified	1	4	4	4	4	4
SYSTEM DESIGN CONSIDERATIONS						
1. Mounts to cone body w/ no major mods.	5	2	1	2	2	2
2. Mounts with 43 cm (17 in) extension or less	3	4	5	4	4	4
3. Mounts to rear of cone body	3	0	0	0	0	0
4. Compatible with standard trucks	3	3	2	3	4	4
5. Minimal rear view obstruction	4	4	2	4	4	4
GENERAL DESIGN CONSIDERATIONS						
1. Complies with general width restrictions	5	4	4	2	4	4
2. Positive control of cone	3	0	1	4	3	3
3. Scrubbing of cone	2	2	5	3	3	3
4. Compatible w/ cone variations	5	3	5	4	4	4
5. Works in road conditions with debris	5	3	3	3	3	3
6. Durability and Maintainability	5	2	3	4	3	5
7. Rotary Joints Only	3	4	4	4	4	4
8. Minimum # of actuators	3	4	1	4	4	4
9. Minimum sensors/control	3	2	1	4	5	5
10. Quick Change to Manual Operations	3	3	4	4	4	4
11. General safety of machinery	5	3	2	4	4	4
12. Safety to traffic	5	3	1	3	4	4
13. No set up on road	5	3	3	4	4	4
14. General flexibility and modularity	4	2	3	4	4	4

15. Aesthetics	5	2	2	3	3	4
16. Anticipated costs	4	2	1	3	4	4
TOTAL SCORE		280	280	399	429	444

After all of the considerations were evaluated, the design with the best score was chosen as the concept to further develop and test. The total scores indicated that the break away arm concept was the superior design. The contoured surface and double retrieval arm nearly scored as high as the break away concept while the remaining designs had many shortcomings and scored much lower. The greatest drawback of the contoured surface design is the surface on which the cone would slide on. This surface would be very difficult to store within the spatial limitations on the truck. Furthermore, the conversion of the contoured surface to retrieve cones while traveling in either direction would be substantially more difficult than the process used with the break away arm concept. The greatest shortcoming of the double retrieval arm is its durability and maintainability. The two arms that operate in tandem greatly complicate the retrieval mechanism while they also reduce the robustness of the system.

3.3 Break Away Arm Operational Description

The Break Away Arm, as depicted in Figures 3.7-3.10, incorporates the previously mentioned IDRC and funnel system. The retrieval arm, which consists of three distinct parts, the main arm, the cross arm and the poker arm, and its actuator are secured onto the drop box as shown in Figure 3.8. The main arm is the component attached directly to the actuator and runs until it intersects with the cross arm. The cross arm supports the cone during retrieval and it houses the actuation switches and cone bumpers. The poker arm is the component that physically engages the cone during retrieval. The funnel system remains the same as the one described for the double retrieval arm design.

The Break Away Arm design is somewhat consistent with the two previous designs. However, the mechanics of retrieval is different from the other designs. The retrieval process is set into motion when the cone base contacts the cone bumpers located on the cross arm. Since these bumpers are on each side of the poker arm, as shown in Figure 3.10, activation of both switches insures that the cone is positioned squarely and is ready for pickup. While the other designs require cutting into the drop box to clear a path for the arm mechanism, the Break Away Arm concept simply carries the cone up over the entire box structure.

Positioned directly over the rear plate of the drop box is the Cone Stripping Plate (CSP). This plate is placed at the same level as the approaching cone that rides on the retrieval arm. As the cone approaches the CSP, a locking latch that holds the cross arm and poker arm rigidly in place is disengaged. The locking latch is located on the inside of the main arm, as shown in Figure 3.9, so that when the retrieval arm reaches a predetermined position, a ramp positioned on the drop box would contact the roller on the latch and cause the latch to disengage. The cross arm and the poker arm is now able to rotate with its position being restricted by a retaining spring that can be seen in Figure 3.8.

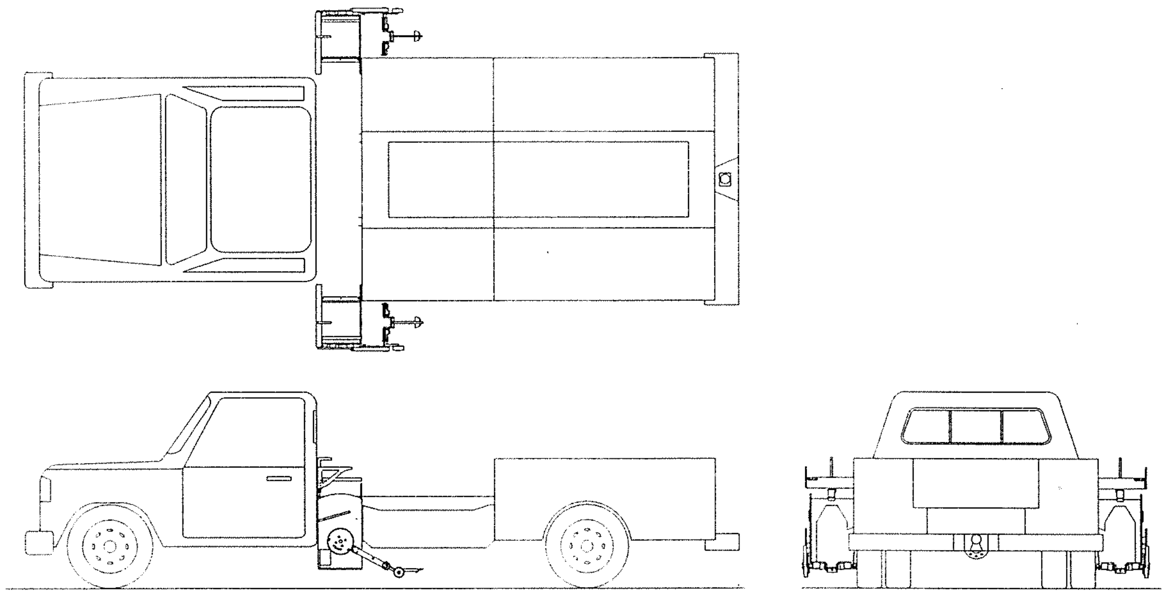

Figure 3.7 Break Away Arm Cone Retriever

With the latch disengaged the arm is ready to undergo its break away action. A simple roller mounted on the cross member of the poker arm and a timing plate mounted at the end of the CSP constitute the advanced timing element of the ACM. The advanced timing initiates the break away action of the retrieval arm. The simple roller engages the advanced timing plate and causes the poker arm along with the cone to begin to rotate about the pivot point on the main arm. The advanced timing plate is contoured so that as the retrieval arm continues through its motion, the poker arm withdraws from the bottom of the cone without rubbing against it excessively. The timing is advanced so that the breaking action of the arm is carried out without pressing against the cone and pinning it to the CSP.

Once the advanced timing is complete, the cone remains in contact with the stripper plate and cone bumpers located on the cross arm. As the main arm continues to rotate, the poker arm is forced to fold under the CSP and withdraw from the cone. At the completion of this motion, the poker arm is completely withdrawn from the cone, and the cone is restricted to fall onto the lateral conveyor. This lateral conveyor then transfers the cones to the stowage system. When the traffic cone passes a predetermined lateral position, a switch is activated and the main arm begins to rotate back. This action causes the roller on the cross arm to roll along the advanced timing plate. The poker arm then unfolds and returns to its extended position. Once the latch ramp disengages the latch, the poker arm is forced to return to its ready position by the retaining spring. The poker arm is then rigidly locked by the latch and the retrieval arm is primed to pick up another cone.

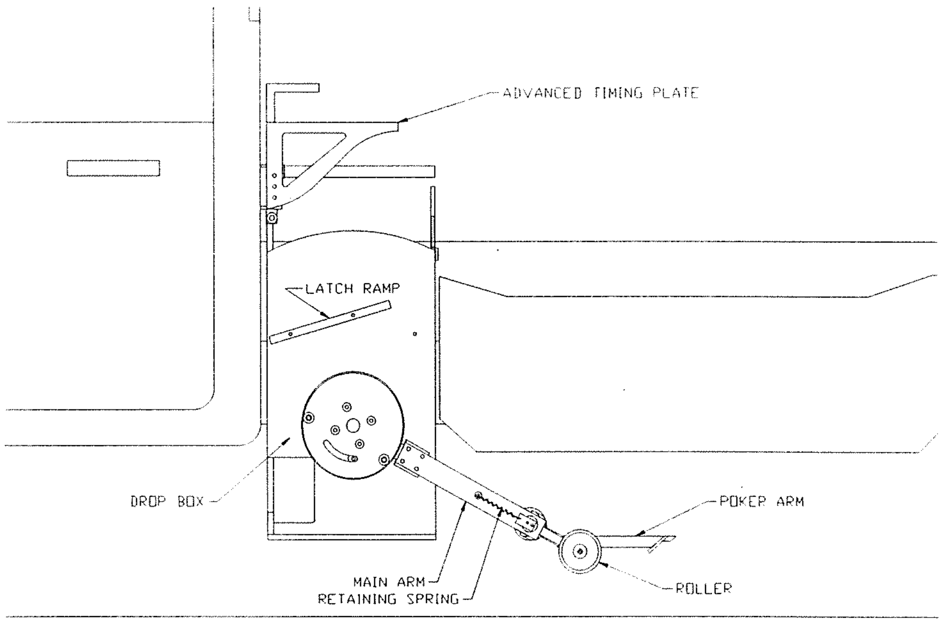

Figure 3.8 Side View of Break Away Concept

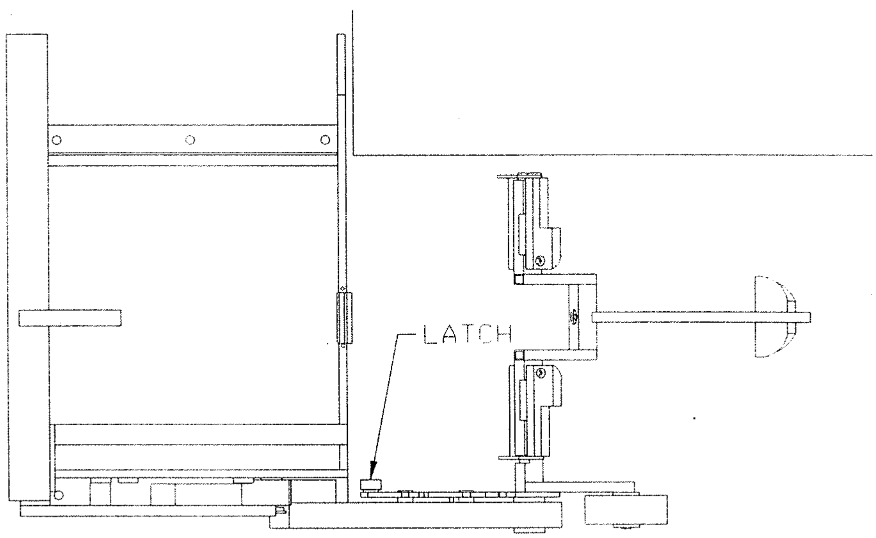

Figure 3.9 Top View of Break Away Concept

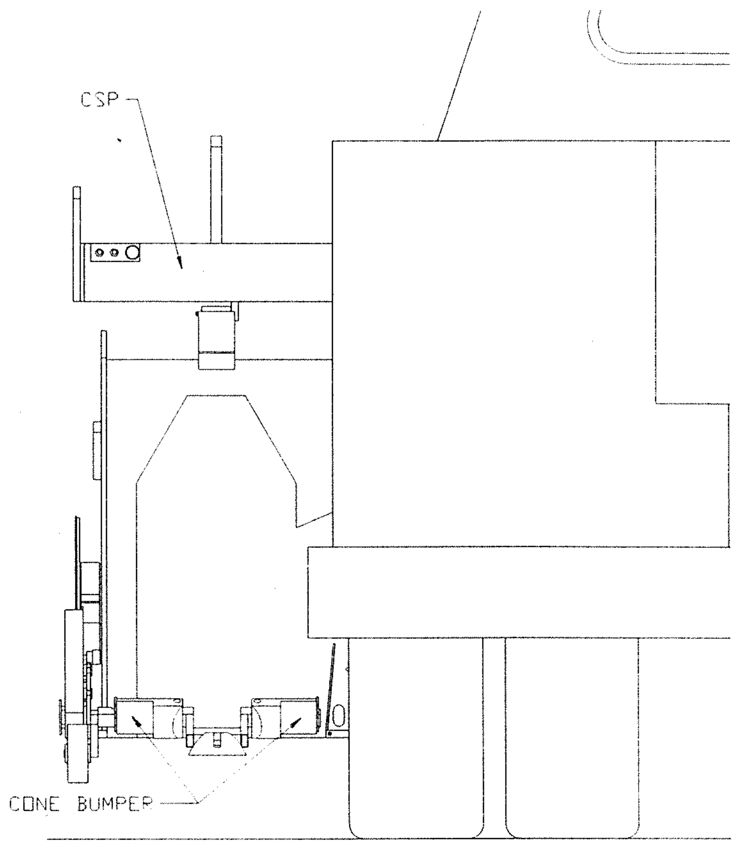

Figure 3.10 Rear View of Break Away Concept

3.4 Initial Designs for the Dispensing of Cones

Many of the initial designs for dispensing cones revolve around the idea of utilizing large vehicles with tremendous cone carrying capacities. Later designs adhere to the utilization of the Caltrans cone body vehicle and the spatial constraints imposed by the its standardized structure. Some of these designs use modified technology from earlier developed concepts and adapt them for use on the cone body configuration.

3.4.1 Sliding Plate Concept

The Sliding Plate Concept is a preliminary design for dispensing cones onto the road surface. From a stowage area, a traffic cone would be released onto a smooth plate angled toward the ground. Two positioning bars are mounted to the plate and rotate in the same manner as windshield wipers move across a windshield as shown in Figure 3.11. The plate is situated such that when a cone is placed onto the plate, the cone slides controllably down the plate and to the ground. The positioning bars laterally place the cone behind the truck so that the problems of creating a traffic lane taper would be solved without human interaction. This plate is mounted off the rear of the truck to maximize its placement capability.

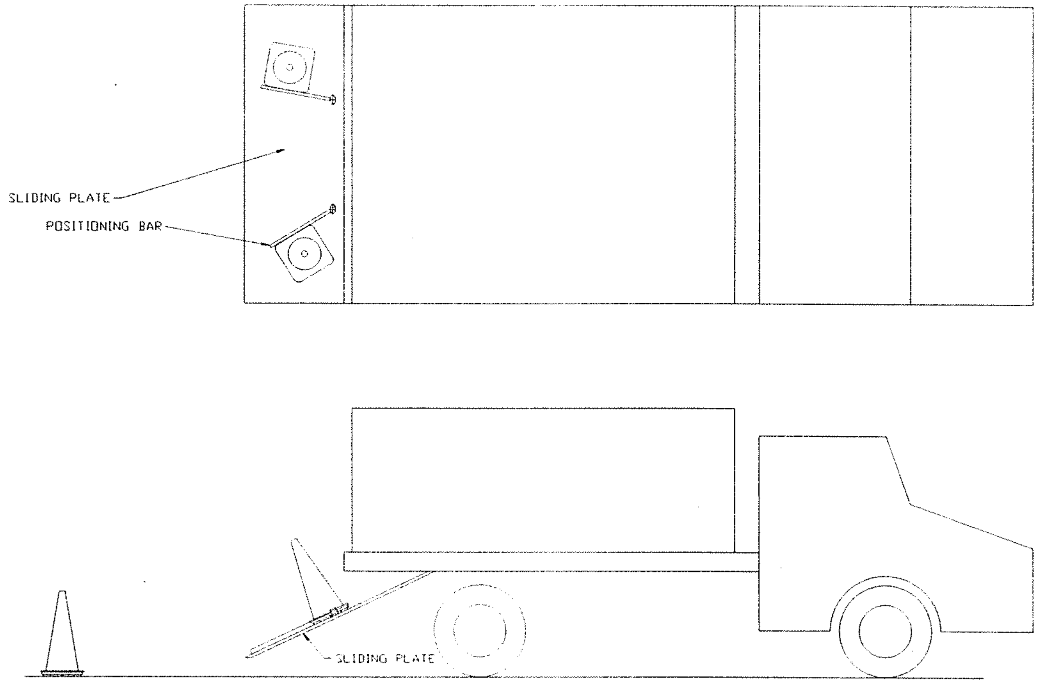

Figure 3.11 Sliding Plate Concept

The biggest problem with this concept is that it is not easily adaptable to the cone body configuration. Due to its immense size and weight, the Sliding Plate Concept is not able to extend from a cone body frame. In addition, the plate and the positioning bars need to be extremely smooth and virtually frictionless so that the cones could properly slide on them. In order to properly space the traffic cones during deployment, the cones need to be dispensed consistently. This is a difficult objective when considering varying weather conditions. In the winter, the cone would be rigid and slide quite easily on a smooth and maybe even wet surface. In the summer, the cone would become soft and would likely stick to the plate and positioning bars. At best, in the summer, the cone would slide much more slowly than in the winter. This meant that consistent spacing between cones would be virtually impossible since deployment cycle time would vary. The final problem with this design is the fact that the plate must also remain quite low to the ground for the cone to remain upright during dispensing. No plate can remain this low to the ground without being damaged because of road debris and vehicle pitching and rolling.

3.4.2 Conveyor Chute Dispenser

The Conveyor Chute, similar to the sliding plate, is mounted at the rear of the truck. As in the previous design, a reliable method of picking a single cone out of the stack and placing it onto the dispensing unit is essential. Figure 3.12 shows that the Conveyor Chute that is comprised of a conveyor slightly greater than the width of the cone base and a cone guide that insures that the cone remain on the conveyor during dispensing. The chute is mounted so that it can swivel and place cones at different lateral positions in the lane. Furthermore, the conveyor is driven by a wheel rolling on the ground and, if geared properly, can place cones with a zero velocity to the ground.

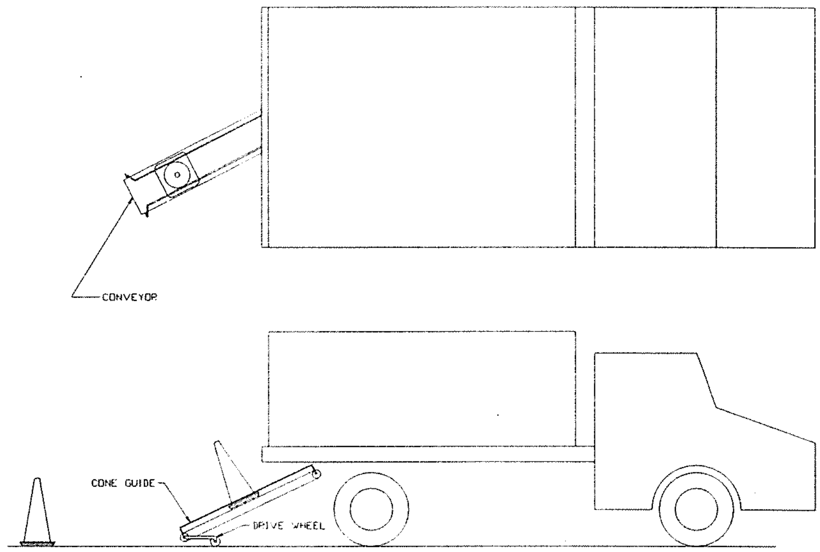

Figure 3.12 Conveyor Chute Dispenser

This design has some good improvements over the sliding plate. First, the cone deployment uses a conveyor to dependably place cones onto the road rather than relying on an unpredictable sliding surface. However, there are several problems in the design. Primarily, this design relies on a large sized truck for mounting purposes. Adaptation of this design to the cone body configuration is highly improbable due to spatial requirements. Furthermore, this concept can not place cones close enough to the ground to assure a reliable deployment. The rollers located at the end of the conveyor limits how close to the ground the cone can be dispensed.

3.4.3 Drop Chute with Wheels

This concept marks the beginning of cone dispensing designs that can mount onto the standard Caltrans cone truck. As Figure 3.13 reveals, dispensing is most easily accomplished at the rear of the truck and off to the side. This concept utilizes a small mechanical arm that picks a cone from the rear of the centrally located cone stack and swings it over to the side of the truck and directly above a drop chute. At this point, the cone is oriented such that the tip points directly to the rear of the truck.

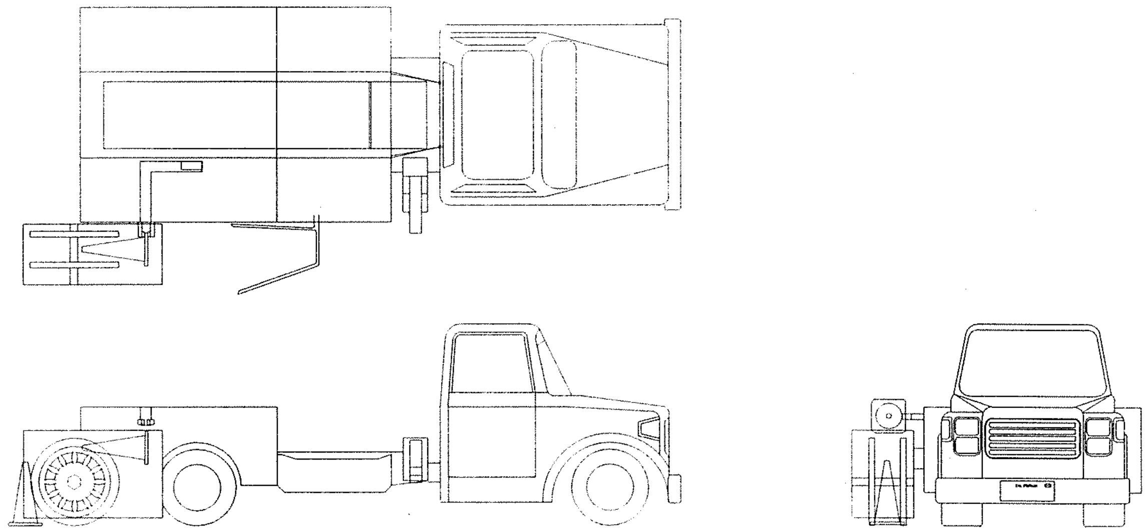

Figure 3.13 Drop Chute with Wheels

When the cone is released, it falls into the chute sideways and lands just ahead of a pair of wheels. These wheels are set wide enough apart to allow the conical section of the cone to pass between them but narrow enough to run over the base of the cone. The axle of the wheels is either high enough so that the standing cone could pass underneath it or it is separated so that the axles are mounted on the sides of the box.

The primary problem with this method of dispensing cones is the bulk of the chute and wheels. Such a unit would prove to be quite heavy and awkward to handle. Storage of such a large unit is troublesome if done manually and would require a significant amount of power if done by automation. Another problem of this concept is finding the adequate space for the mechanical arm that handles the cones during dispensing. The space immediately to the sides of the cones in the cone body is occupied by signs, sandbags and other items and modifications to this configuration can only be minimal. Also this mechanical arm adds significant complexity to the system while not adding considerable effectiveness to the design.

3.4.4 Integrated Dispensing and Retrieval Configuration

Initial IDRC designs utilize wheels to stabilize cones that have been dropped down the box (see Figure 3.14). These wheels are much smaller than the wheels in the Drop Chute concept since they are mounted on the sides of the box. These wheels are spaced apart far enough to allow the clear passage of the conical section of the cone but narrow and low enough to run over the base of the cones and properly plant it onto the pavement during dispensing. This design is also advantageous in that if the wheels inadvertently touch the road surface, they would roll instead of destructively scraping against the ground. The biggest problem with this preliminary design occurs during stowage since the wheels are unable to retract or fold without the use of additional actuators.

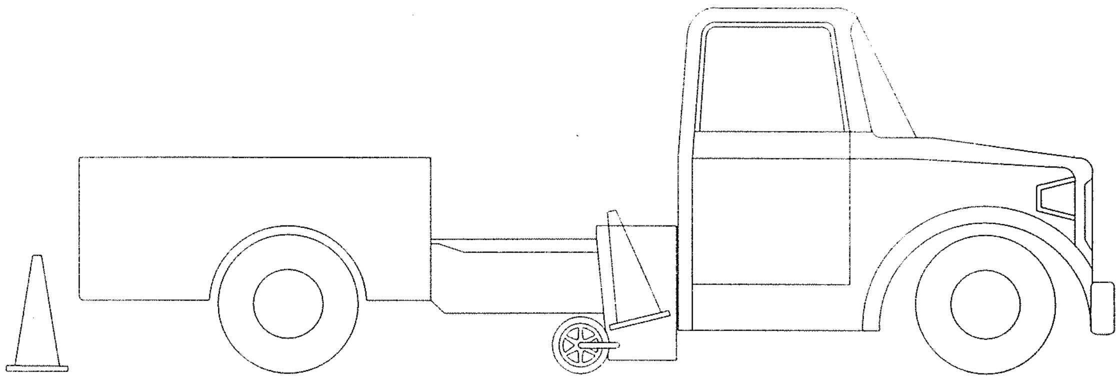

Figure 3.14 Drop Box with Stabilizing Wheels

3.5 Selection of the Dispensing Method

Similar to the method employed for concept selection of the retrieval system, the selection for the dispensing method utilizes a detailed trade-off analysis. There are mandatory capabilities, optional capabilities, design considerations and estimated cost considerations. In this manner, a quantitative method is used for choosing the best dispensing concept. Weighting factors are assigned to optional capabilities and design considerations.

Table 3.2 Trade-off Table for Dispensing Concepts

DESIGN CONSIDERATIONS	WEIGHTING FACTOR	Sliding Plate	Conveyor Chute	Drop Chute	IDRC Drop Box
MANDATORY CAPABILITIES					
1. Places moving forward		yes	yes	yes	yes
2. Operates on left or right sides		yes	yes	yes	yes
3. Spaces cones automatically		yes	yes	yes	yes
4. Compatible with Caltrans cone truck		yes	yes	yes	yes
5. Handles generic 71 cm (28 in) cones		yes	yes	yes	yes
6. Simple conversion to manual operations		no	no	yes	yes
OPTIONAL CAPABILITIES					
1. Pick/Place same side fwd	5	3	3	4	5
2. Pick/Place opposite side fwd	5	3	3	4	5
3. Pick/Place same side moving bkwrd	3	0	0	0	0

4. Pick/Place opposite side moving bkwrd	3	0	0	0	0
5. Operates 0-24 km/hr (0-15 mph)	4	1	2	3	5
6. Cone placement laterally adjustable	2	5	5	0	0
7. Leaves flags/storage area unmodified	1	0	0	1	5
SYSTEM DESIGN CONSIDERATIONS					
1. Mounts to cone truck w/ no major mods	5	1	1	2	2
2. Mounts to cone truck w/ 43 cm (17 in) extension	3	1	1	5	5
3. Mounts to rear of cone truck	3	4	4	2	0
4. Compatible with standard trucks	3	1	1	2	5
5. Minimum rear view obstruction	4	1	1	3	4
6. Compatible with stacking methods	5	1	1	3	5
GENERAL DESIGN CONSIDERATIONS					
1. Within width required limits	5	1	1	2	5
2. Scrubbing of cone	2	4	4	3	3
3. Compatible with cone variations	5	0	2	5	5
4. Compatible with road debris	5	1	1	4	5
5. Durability and maintainability	5	1	1	4	5
6. Minimum of actuators	3	2	1	3	5
7. Minimum of sensors	3	3	3	1	4
8. Quick change to manual operations	3	2	2	3	5
9. General safety of machinery	5	4	4	3	5
10. Safety to traffic	5	4	4	4	4
11. No set up on road	5	3	3	2	5
12. Aesthetics	5	1	1	2	3
13. Anticipated costs	4	1	1	3	5
TOTAL SCORE		184	195	286	409

The sliding plate and conveyor chute concepts do not satisfy all of the mandatory capabilities and are then not considered to be viable designs. Their scores are also substantially inferior to that of the IDRC/Drop Box and are subsequently discarded in favor of the IDRC. The score of the drop chute is closer to that of the IDRC than the first two concepts but is still much lower. The IDRC/Drop Box is clearly the most superior design chosen and it also has the most potential in terms of modularity and next generation adaptability.

One of the greatest advantages that the IDRC had is its simplicity. There are no actuators on the box to assist in dispensing and it does not depend on sensors to monitor the position of orientation of the cone. Another advantage of the IDRC is its easy compatibility with the current cone truck and cone operations. The drop box can fit in between the cab and the cone body and if manual operations are required, the components of the IDRC will not interfere with the operator. This concept is simple, robust and effective.

3.6 Drop Box Redesigns

Several variations of the drop box concept incorporate modifications to maximize reliability and simplify designs. Newer designs utilize rubber flaps instead of wheels to minimize space. In Figure 3.15 the flaps can be seen located close to the ground. They firmly stabilize deployed cones just as effectively as using the wheel method and they are compliant enough to avoid being significantly damaged when contacting the road surface. These rubber flaps are somewhat effective when used as shown in the figure above with the flaps hanging straight down. However, these flaps prove to be more reliable if they are given a slight rearward bend as shown in Figure 3.16.

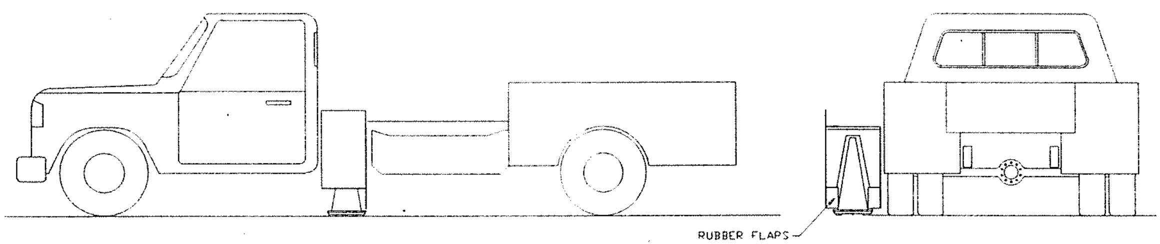

Figure 3.15 Rubber Flaps Used for Dispensing Cones

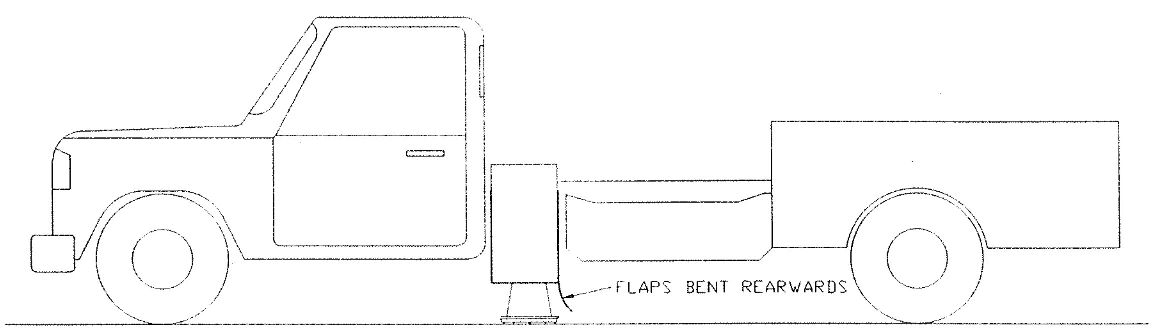

Figure 3.16 Rubber Flaps Bent Rearward

There are some concerns regarding awkward storage of the flaps on the drop box. First of all, in order for the flaps to work with the greatest reliability, they must be mounted very close to the ground and curved slightly to the rear. As stated earlier the low mounting is not a problem. However, for storage purposes, the flaps need to be straightened out so that it would fit in between the cone body and truck cab. Another issue that creates some concern is the fact that when the cone is dropped through the box, the cone strikes the pavement with considerable impact, causing it to bounce unpredictably. Even though the cones are dispensed fairly reliably, the unstable nature of this dispensing method can be potentially problematic.

Subsequent IDRC designs use stiff brushes on the bottom of the drop box to help stabilize the cones during deployment. The 8 cm (3 in) long brushes line three of the four sides of the of the drop box, omitting the side of the box facing the rear of the truck. These brushes would be slightly angled inward towards the box and are used to withstand damage if incidental contact with the pavement occurs. The brushes are somewhat ineffective due to their compliance and their inability to correctly guide the cones.

The next IDRC designs employ nylon strips rather than brushes to assist in holding cones. The nylon strips are much more rigid than the brush mechanisms. Unfortunately, the usage of these strips fails to achieve the robustness and the reliability that is established when using the rubber flaps. The cone has a tendency to fall down the drop box, hit one or both of the nylon buffers, remain teetered when striking the ground. The cone is unstable when it hits the ground and sometimes topples onto its side.

In the final IDRC designs, the nylon strips are positioned strategically along the secondary funnel. As the cones are dropped through the drop box, they fall through the nylon buffers at the bottom of the drop box. The spacing of the nylon strips on the secondary funnel slows the fall of the cone insures that the cone base remains planted on the ground. These nylon buffers are rigidly mounted on the three sides of the bottom of the box and on the secondary funnel as shown in Figure 3.17. The inward positioning of the buffers proves to be highly effective in placing traffic cones with consistent stability. A few test runs, shown in Table 3.3, demonstrate the effectiveness of using the reconfigured buffers.

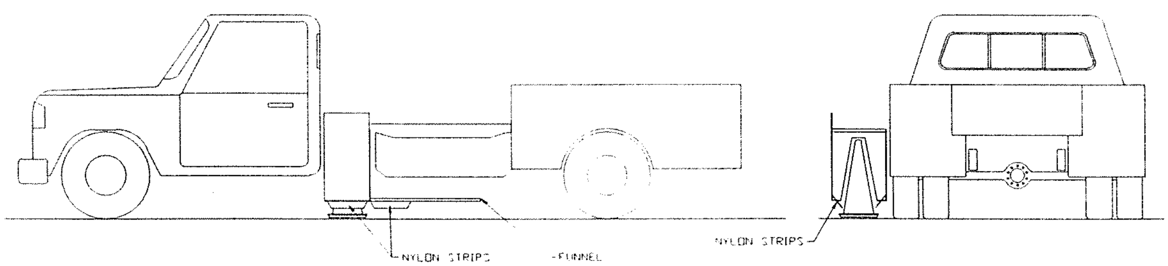

Figure 3.17 IDRC Using Nylon Buffers

Table 3.3 Test Results of Dispensing

Test Run	Number of Attempts	Number of Successful Drops	Percentage
1	8	8	100%
2	6	5	83.3%
3	8	8	100%

4. CHAPTER FOUR
TESTING AND MODIFICATION OF THE CONE RETRIEVAL SYSTEM

4.1 Introduction

There are many factors that must be examined when designing mechanical components. The most important consideration is to give proper care when analyzing components and the forces exerted on them. Attention must also be given to such factors as equipment wear, manufacturing and maintenance costs, and operator safety. Longevity, efficiency, aesthetics, and ergonomics must be correctly addressed for any equipment to be considered successful. The main focus of this chapter is the stress analysis of the critical components of the retrieval system. Stress analysis is necessary to insure that the designed components do not fail when operating under normal circumstances. The stress on each component should be substantially less than the yield strength of the components' materials to avoid failure. The major components in the retrieval system that would be susceptible to these operational variations are the poker arm, the cross member, the main arm and the arm mount.

4.2 Strength Analysis

4.2.1 Design of Components

The ACM is a prototype that is designed mainly for testing and if needed, modification. The design of components are primarily concerned with fulfilling geometric constraints. Each of the components must properly assemble with other components. These parts are designed to handled much greater loads than anticipated to ensure that failure does not occur due to incorrect assumptions or uncertainty of forces. The critical geometries of components have been developed for this early prototype to meet the anticipated loads with a high factor of safety.

The selection of materials for each of the components follows the same approach as the geometric design of components. Aluminum is used to reduce the weight, while some components are conservatively designed to guarantee strength. Steel is used in some of the components where the higher forces are expected but design efforts still favor conservative estimates. Future iterations of the ACM will emphasize more efficiently designed components by optimizing size, weight, and material.

4.2.2 Poker Arm

The poker arm is the component of the retrieval system that physically engages the cone for retrieval (refer to Figures 3.8 and 3.9). The anticipated loads for the arm take into account the mass of the cone and the acceleration of the arm during retrieval. These loads are greatest just as the cone lifts off the ground and are applied at both the tip of the arm and at the base of the arm. These loads create a maximum bending stress of only 4.94 MPa (716 psi) making nearly any material suitable for use. The material selected for this component is Aluminum 6061-T6 and has a yield strength of 276 MPa (40 ksi), proving very strong for its intended purpose. There are no applicable torques or side loads on this component.

4.2.3 Cross Member

The cross member encounters a more complex load than the poker arm. Also, this component of the retrieval system has a complex geometry. The impact of the cone coming in at 16 km/hr (10 mph) must be withstood by the cross member as well as the torque and bending caused by the lifting of the cone. A proper strength analysis can be carried out within the part of the cross member that houses the switches that trigger the lifting of the arm. The cross member is at its weakest in this area. There are two 6-32 coarse threaded holes through the beam. The weakest point in the cross member lies within this section, at the threaded hole, closest to the main arm. The analysis at this point will determine if the cross member has adequate strength. Two separate strength calculations are carried out at this point. The impact of the cone coming in at 16 km/hr (10 mph) is examined, and then the torsion and bending caused by the lifting of the cone is determined.

The impact of the cone striking the cross member generates a force that can be estimated by assuming the cross member will act like a spring. The cross member will then deflect a certain amount and the force can be estimated. The energy the cone delivers to the cross member is found by knowing the kinetic energy of the cone and estimating the energy absorption of the cone. The remaining energy is transmitted to the cross member. The cross member is subject to a calculated 797 N (179 lbf) force from a cone impacting on it at 16 km/hr (10 mph). This value matches the number obtained from testing. The test consists of a cone that is dropped from a predetermined height and strikes a rigidly supported beam. The deflection of the beam is measured and the force is determined.

At the weakest section of the cross member, this force translates into a bending stress of 62 MPa and 76 MPa (9 ksi and 11 ksi) in the directions perpendicular and parallel to this piece, respectively. This component is made of 1018 steel with a yield strength of 248 MPa (36 ksi) making it strong enough to withstand the impact of the cone. After the cone impacts on the cross member, the retrieval arm rotates upwards which puts both bending and torsional stresses on the cross member. These stresses act upon the cross member simultaneously and thus the member is in a complex state of stress. The principal stress is calculated to be 13.7 MPa (1.98 ksi), giving this component a factor of safety greater than 18.

4.2.4 Main Arm

The main arm is a rectangular beam that, similar to the cross member, experiences both torsion and bending. The mass of the cross member is not trivial and must be taken into account. The maximum stress that this main arm will have to withstand is 2.5 MPa (370 psi). The arm is made of aluminum 6061-T6. As stated earlier the yield strength is 276 MPa (40 ksi) proving that the main arm can withstand all the forces anticipated during normal operations as well as many excessive forces possibly generated in the misuse of equipment.

4.2.5 Arm Mount

The arm mount is made of 1018 steel. This component is mounted directly to the rotary actuator that powers the retrieval arm. The mount will easily be able to withstand the 3.9 MPa (568 psi) of stress that normal operations will place on its weakest point. This stress is caused from the same torsion and bending that the main arm must withstand. The increase in stress is caused by the mass of the main arm and the increased bending moment due to the increase in distance to the loads.

4.3 Improvements Of Current Design

The current retrieval system has several improvements over the original design. Before these improvements can be understood, the shortcomings of the original design must first be clarified. The three main problems with the original design were the high distance that the cone must fall to the transfer area, the instability of the cone in the transfer area and the cone's tendency to jam under the cone stripping plate (CSP).

4.3.1 Reduced Length of Main Arm

One of the most significant problems of the original retrieval design is that as the cone is stripped off the poker arm, the cone would land hard on a portion of the Lateral Conveyor System (LCS) called the transfer area and bounce unpredictably. Most of the time the cone could still be successfully retrieved, but on occasion, it would fall off the conveyors. To eliminate this problem, the current design reduces the length of the main arm. This means that the distance that the cone drops from the arm to the table is minimized. The bounce of the cone is also minimized, increasing the reliability of retrieval.

4.3.2 Side Bar and Retaining Door

Another issue that requires some attention is the cone's instability in the transfer area after it is stripped off the poker arm. The reduction of the length of the main arm helps, but the cone needs to be controlled further. The original designs do not have anything on either side of the transfer area that keeps the cone from falling. This problem is solved with the addition of two simple yet effective components, the side bar and the retaining door. The side bar is mounted on the CSP and keeps the cone from falling off the side of the transfer area. The retaining door is a small aluminum component that swings in only one direction and is mounted on the opposite side of the CSP as shown in Figures 4.1 and 4.2. This door is able to swing into the transfer area but is locked rigidly in the other direction. This allows the cones to pass through the door as it is lifted and become consistently held in the transfer area.

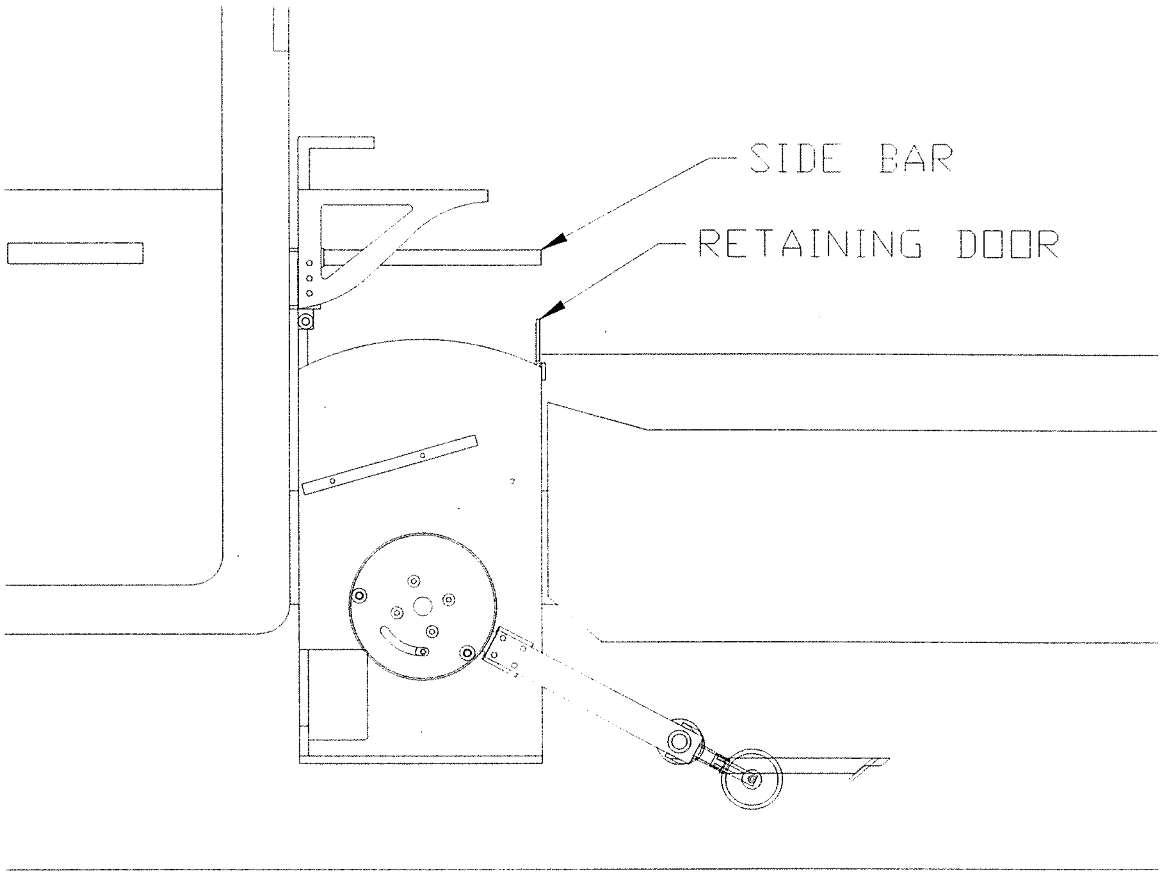

Figure 4.1 Side View of Side Bar and Retaining Door

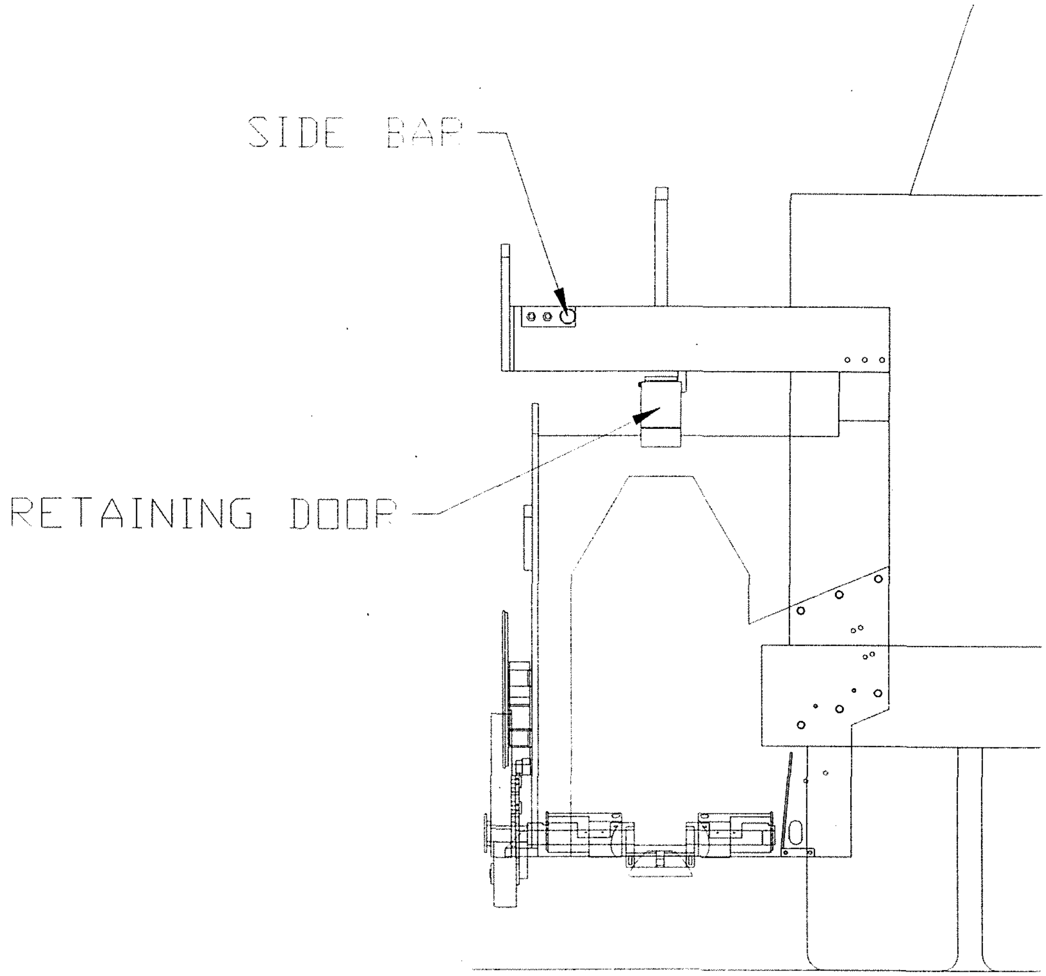

Figure 4.2 End View of Side Bar and Retaining Door

4.3.3 Advanced Timing

The final problem with the original retrieval design is that the cone sometimes gets pinned in between the CSP and the retrieval arm. This occurs when the cone, as it approaches the CSP, is tilted towards the CSP. As a result, the base of the cone is able to slide underneath the CSP. Once this happens, there is no way for the cone to strip off the poker arm. Instead the arm rubs against the cone until the cone is hopelessly caught in the mechanism. The advanced timing feature of the current retrieval system corrects this problem.

The advanced timing consists of the advanced timing plate, the advanced timing roller and an improvement to the CSP (see Figure 4.3). The advanced timing plate is mounted on the CSP. This plate guides the roller and forces the poker arm and cone to rotate and expose the bottom of the base of the cone to the CSP. The improvement to the CSP is an extension that ensures that the cone rotates to expose the bottom of the base to the CSP. With the cone base exposed, the cone can easily be extracted off the poker arm. There is no way for the cone to become pinned in between the CSP and the poker arm.

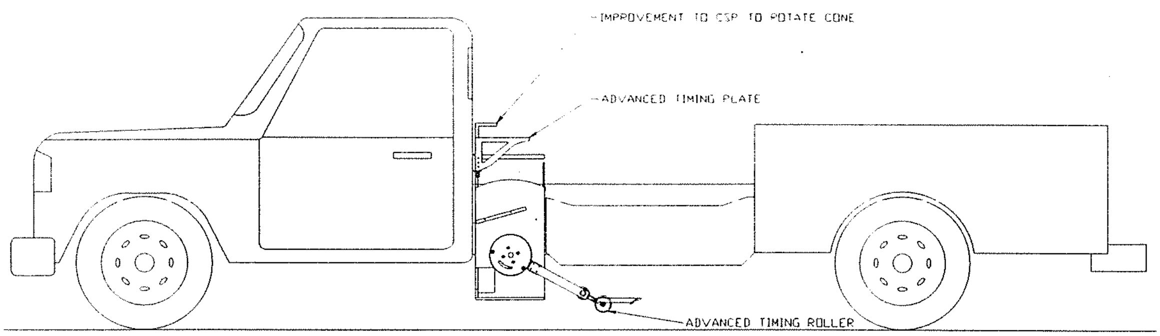

Figure 4.3 Advanced Timing Elements

4.4 Testing of the Retrieval System

Initial testing of the retrieval system identified a geometric problem in the poker arm and cross member. The cross member has a complex shape since it needs to clear the retaining door on the return stroke of retrieval. This shape also causes the cone to seat incorrectly as the arm is lifted. Since the cone can seat improperly, it has a tendency to ride towards the tip of the poker arm and cause problems as the cone reaches the CSP. The cone does not strip cleanly off the poker arm and retrieval is inconsistent since the cone struck the CSP higher than anticipated.

Another problem arises in the placement of the side bar. The side bar is positioned too low and causes the base of the cone to remain parallel to the ground instead of rotating to expose the bottom of the base of the cone. This does not cause any jams in the mechanism but the cone is not extracted cleanly off the poker arm.

A minor problem can also be seen in the design of the retaining door. This component is designed to be positioned vertically. The cone base occasionally catches on the top of this door, causing it to seat incorrectly in the transfer area. The initial test results are tabulated in Table 4.1. These first tests do not incorporate any of the described modifications. These initial tests are not promising, especially considering the redesign effort. Each issue is addressed separately in hope that the reliability can be increased.

Table 4.1 Test Results of Retrieval

Test Run	Number of Attempts	Successful Retrievals	Percentage
1	8	3	37.5%
2	8	2	25%
3	8	2	25%

The problem of the cone riding too far towards the tip of the poker arm is solved with a simple addition of a nylon component. This small component, best described as a small block, is attached at the base of the poker arm where it joins with the cross member, as Figure 4.4 shows. Here, the block allows the cone base to ride on the cone bumper as designed. The block keeps the cone base from getting caught on the cross member as the retrieval arm rotates upward. Another solution to this problem is to reshape the cross member to allow the cone to seat better on the cone bumpers. This solution is extremely complex and much more difficult to realistically implement.

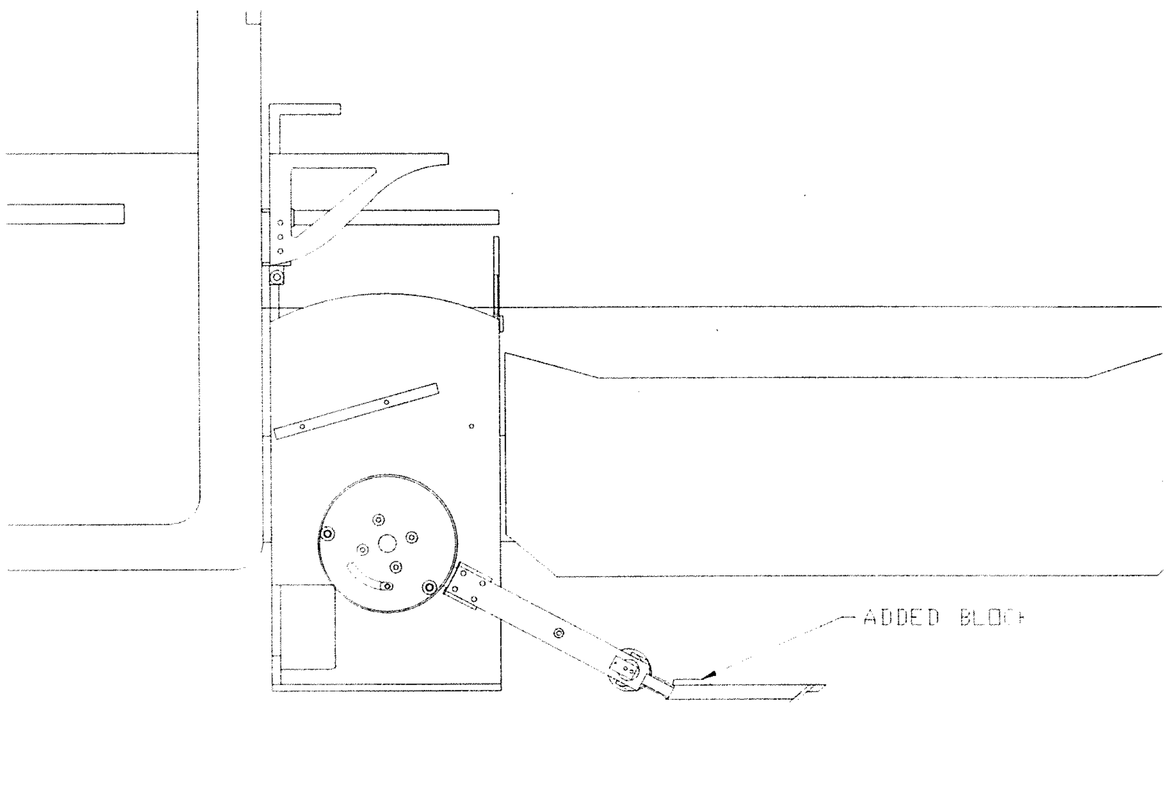

Figure 4.4 Test Results of Retrieval

As stated previously, the location of the side bar does not allow the cone to properly strip off the poker arm. The obvious solution is to reposition this bar. This gives the cone more freedom to rotate and strip while, at the same time, its position is maintained within the transfer area. The lateral position of the side bar is maintained, but the vertical position is increased by about 3.8 cm (1.5 in).

Preliminary concept development showed that the retaining door should not have been a problem. However, as the cone rebounds off the CSP, it sometimes falls on the retaining door. Repositioning the door further from the CSP is not practical since space is already limited. Instead, the door is altered to allow the cones to fall onto the conveyors unimpeded. Rather than having the door stand vertically, the door is given a slight bend in it to insure that the cone does not get caught on it. This bend can be seen in Figure 4.5. These three improvements, although minor, significantly enhanced the operation of the retrieval mechanism. Laboratory testing showed impressive results. These results are tabulated below in Table 4.2. Although further field testing will be necessary to support these initial findings, indications for this system are quite promising.

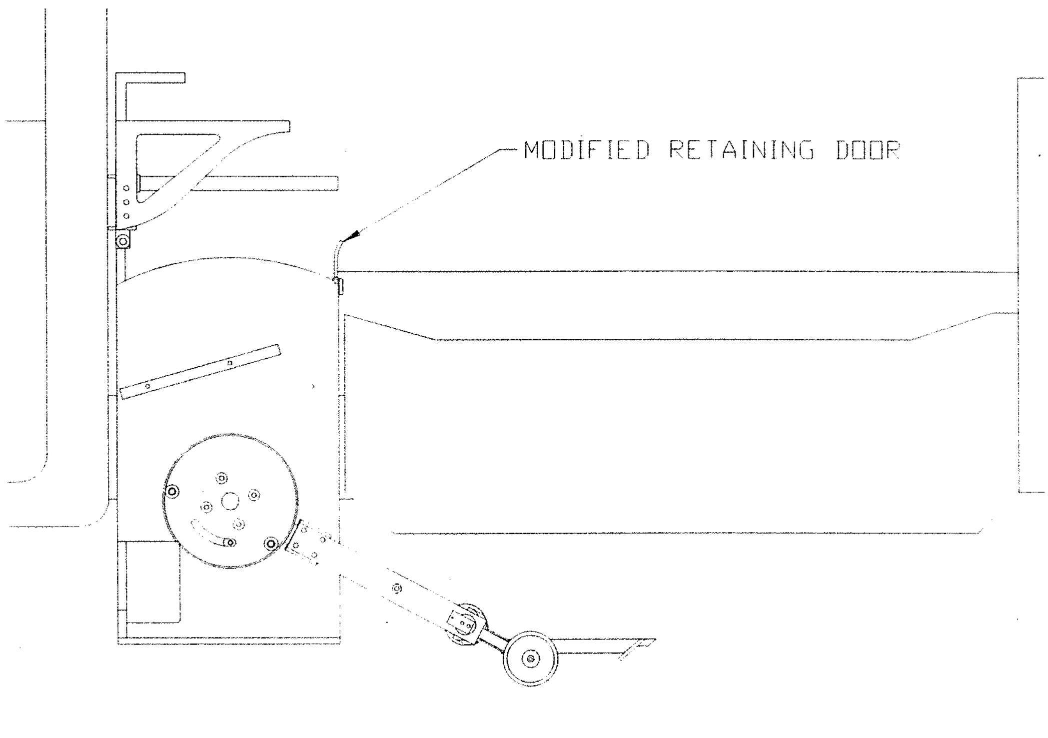

Figure 4.5 Modified Retaining Door

Table 4.2 Laboratory Test Results of Retrieval

Test Run	Number of Attempts	Successful Retrievals	Percentage
1	10	10	100%
2	10	10	100%
3	10	10	100%
4	10	10	100%
5	10	10	100%

The following figures show the retrieval components just before the laboratory testing. Figure 4.6 shows the retrieval arm in the down position ready to pick up cones. Figure 4.7 is a picture of the retrieval arm in the position under the CSP after stripping the cone off the poker arm.

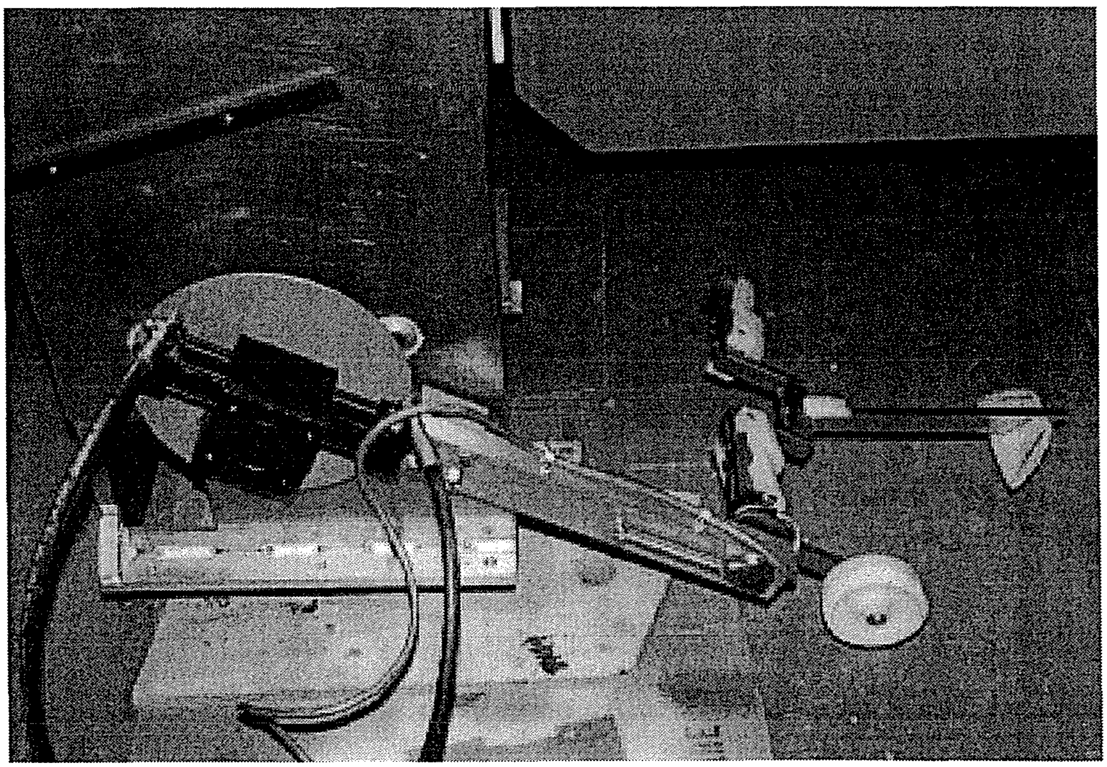

Figure 4.6 Retrieval Arm in Ready Position

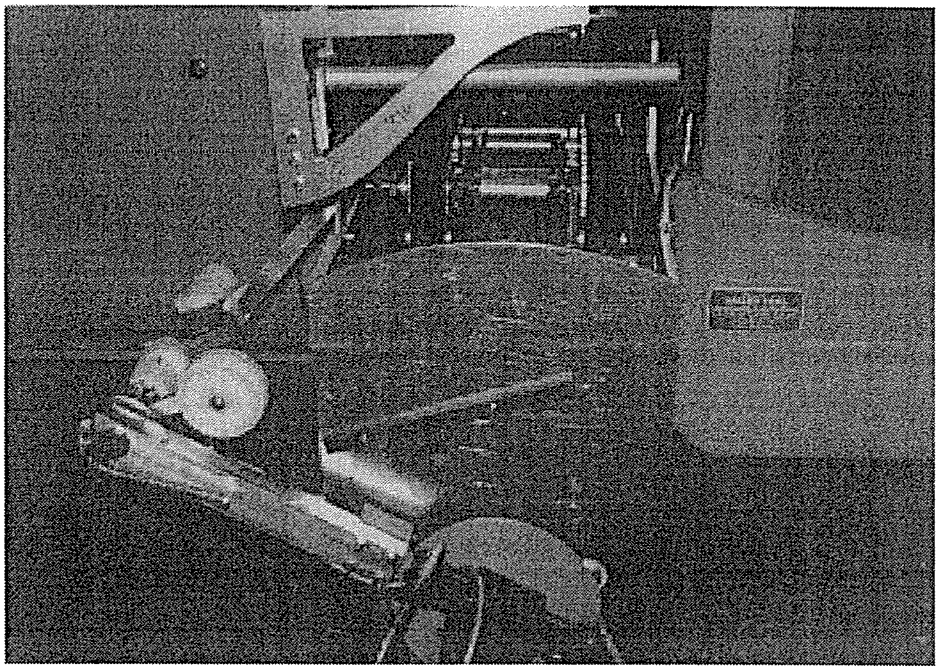

Figure 4.7 Retrieval Arm After Stripping Cone

5. CHAPTER FIVE
THE DESIGN AND DEVELOPMENT OF THE FUNNEL SYSTEM

5.1 Funnel Description

The funnel system is used by the driver to manipulate all deployed cones, standing or fallen, into a single orientation and to reposition them to a place where retrieval can occur. Initial tests show that by placing guides and bars along strategic points on the sides of the Automated Cone Machine (ACM), it is possible to effectively control deployed cones. The funnel system is composed of two main components: the Primary Funnel Component (PFC) and the Secondary Funnel Component (SFC). The PFC is a movable, modular unit that can be mounted to any of the four corners of the ACM depending on which operation is chosen. The SFC is a fixed unit mounted on the bottom of the drop box located within the Integrated Dispensing and Retrieval Configuration (IDRC). The use of this two funnel arrangement optimizes the handling of cones while avoiding overly complex hardware.

5.2 The Primary Funnel Component

The Primary Funnel Component (PFC) uses a laterally extendible frame to manipulate all deployed cones into a single base first orientation. The initial portion of this frame is used to force all fallen cones, with the exception of tip first cones, into the desired orientation. It is up to the driver of the ACM to maneuver the vehicle and the funnel to correctly orient each cone. A lock on the gate of this initial portion is activated by the driver to contact cones that come in tip first and to rotate them into an upright position. The secondary portion of this frame is a simple tipping bar that topples these upright cones into the base first orientation. Fallen cones simply travel beneath the tipping bar and remain unaltered. Once the cones pass through the PFC, they proceed to the SFC for final repositioning and retrieval.

Deployment and retraction of the PFC is accomplished with the use of a hydraulic actuator. The tipping bar and its attachments are connected to the gate portion by a spring loaded hinge. As the hydraulic actuator rotates, the gate portion deploys outward and the spring loaded hinge is released to allow the tipping bar to extend and deploy. The PFC is now ready for orienting cones. When retracting the PFC, the actuator is activated to rotate the gate inwards. As it is moving to its stow position, the tipping bar automatically folds itself at its spring loaded hinge.

5.3 The Secondary Funnel Component

The Secondary Funnel Component (SFC) is composed of two simple rods that are positioned at specific angles from one another. This unit is attached underneath the IDRC and serves to direct all of the cones oriented by the PFC to a specified area for pickup. Non sparking cables are vertically mounted at the ends of the rods to prevent cones from getting jammed between the rods and the road surface. The SFC also prevents cones from going underneath the truck. Figures 5.1, 5.2, and 5.3 show the location of both the PFC and the SFC. Detailed procedures of how the funnels are used during different operations are located in Sections 2.3.3 and 2.3.4.

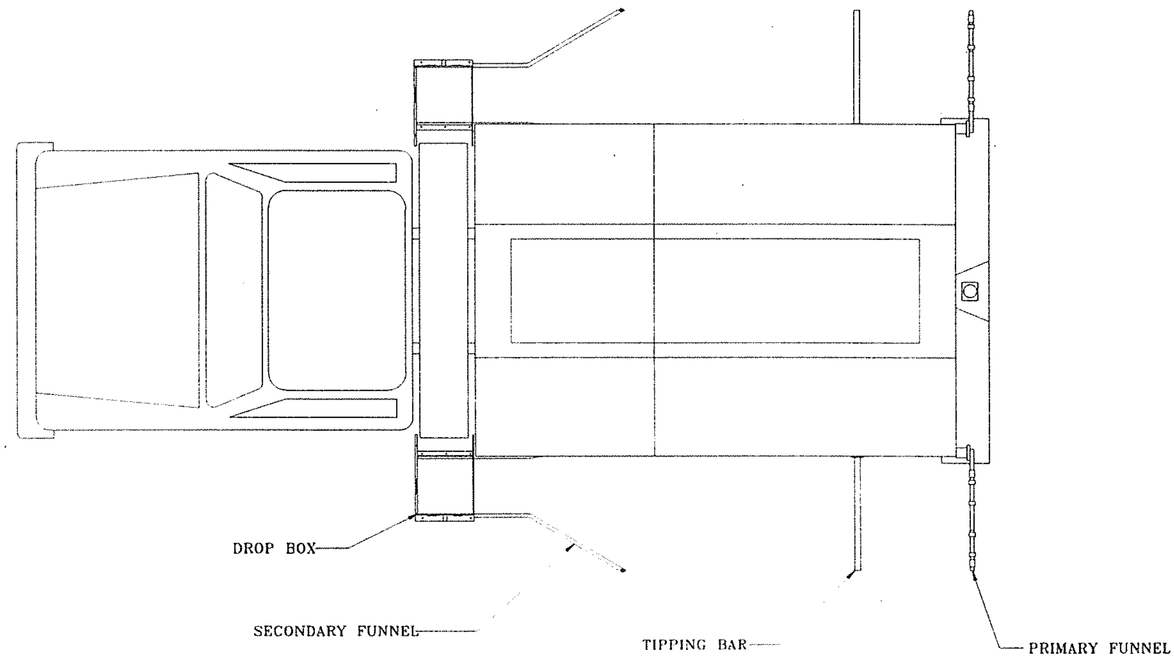

Figure 5.1 Top view of Cone Truck with Funnel System

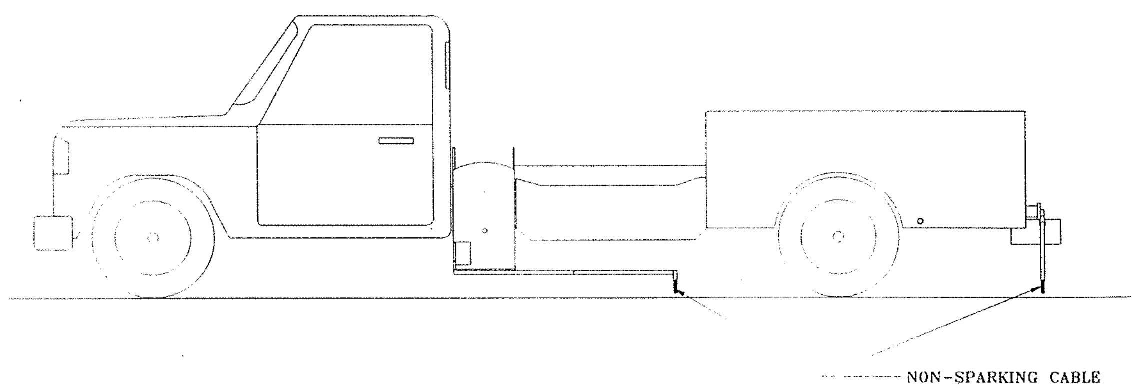

Figure 5.2 Side view of Cone Truck with Funnel System

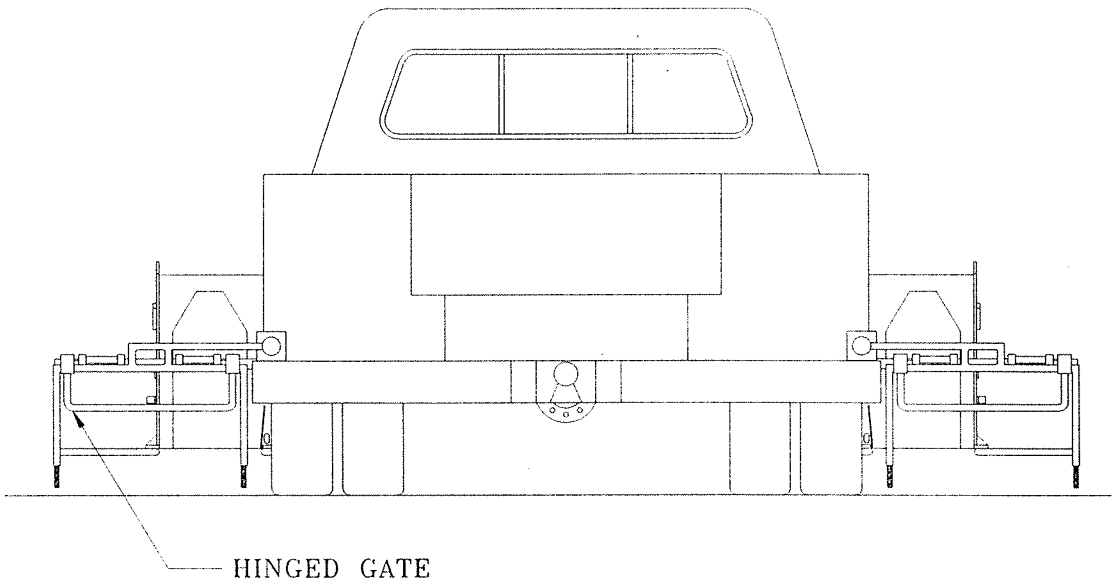

Figure 5.3 Back view of Cone Truck with Funnel System

5.4 Testing of the Funnel System

Extensive preliminary testing of the funnel system was conducted to determine the proper angles, heights, and spacing required for effective funneling. Since the majority of early funnel devices consist of simple mechanical devices, it was possible to quickly fabricate them and test them for robustness and consistency. A large conveyor unit was used to simulate the road surface and to recreate the operating speeds that ACM would travel at during deployment and retrieval procedures.

After a vehicle was obtained, it was possible to take these designs and test them on the road. A prototypical IDRC unit was also fabricated and installed so that the complete retrieval process could be examined. The initial test was done without the use of the tipping bar. The results are shown in Table 5.1

Table 5.1 Funnel Test Results on First Run

Test Run	Number of Attempts	Number of Successful Catches	Percentage
1	12	7	58.3%
2	13	6	46.1%
3	12	6	50.0%
4	11	5	45.5%
5	13	7	53.8%
6	12	7	58.3%

Much of the trouble of the funnel system could be found in the alignment of the primary funnel with the secondary funnel. Proper adjustment was critical here so that cones could be effectively handled. Further problems could be attributed to the fact that the cones that came in tip first were not struck with enough force to cause them to tumble over completely in order to expose the base for retrieval. This system made the success rate of the ACM very speed dependent. It was decided that this was an unacceptable configuration since reliability and robustness would be compromised. The tipping bar would need to be added to the funnel system. This bar would be placed after the primary funnel and came into play when cones that came in tip first were stood up by the gate. The addition of the tipping bar greatly aided in increasing the effectiveness of the funnel system. Some minor alterations to the geometry were needed to properly tune the system to work at its best. Some parameters that were adjusted were the height of the primary funnel, the width of the primary funnel, the height of the gate, the position of the tipping bar, the angle of the secondary funnel and the alignment of the primary and secondary funnel (see Figure 5.1). All of these parameters were varied until the desired effect was achieved, the proper funneling of cones to the retrieval arm. Table 5.2 shows the results after the second trial.

Table 5.2 Funnel Test Results On Second Run

Test Run	Number of Attempts	Number of Successful Catches	Percentage
1	8	4	50.0%
2	9	4	44.4%
3	8	7	87.5%

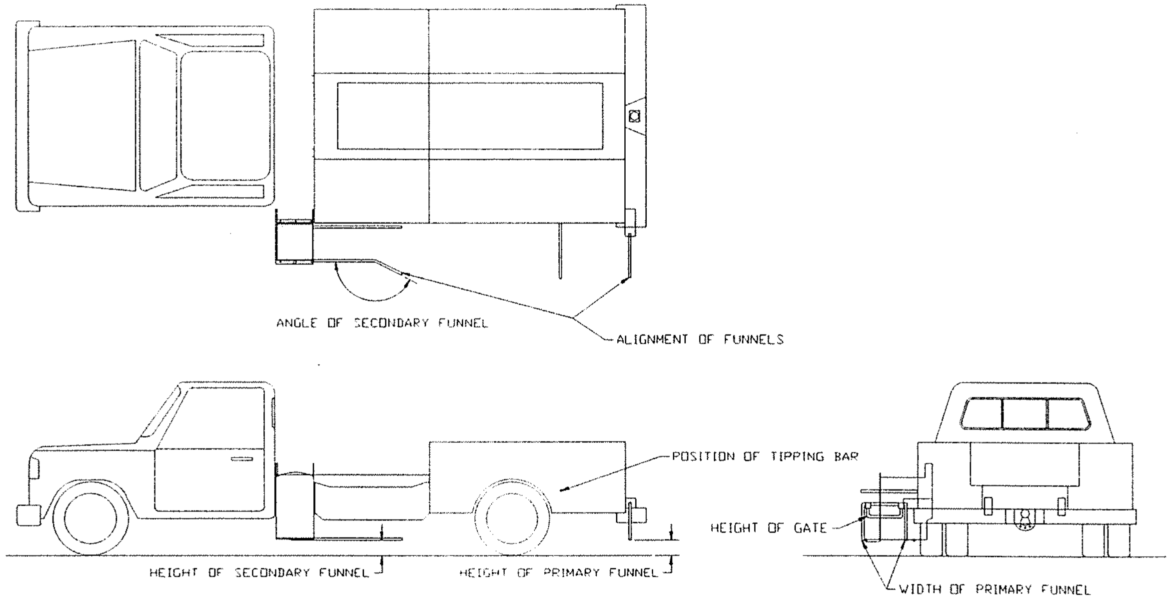

Figure 5.4 Adjustable Funnel Parameters

No funnel modifications were added from the previous tests but the test was performed because of modifications to the retrieval arm. Test run number 3 shows a high success percentage due mainly to the fact that proper alignment of the primary and secondary funnels had finally been achieved. In these tests, no tipping bar had yet been incorporated. Table 5.3 below shows the results of subsequent test runs.

Table 5.3 Funnel Test Results on Following Run with Addition of Tipping Bar

Test Run	Number of Attempts	Number of Successful Catches	Percentage
1	12	11	91.7%
2*	11	10	90.9%
3*	12	9	75.0%
4	12	12	100%
5*	12	12	100%
6	11	11	100%

This table shows a marked improvement over previous tests. Proper alignment between the funnels had been achieved as well as finding the proper funnel widths and angle. The tipping bar was mounted for the tests above, making the retrieval of fallen cones that come in tip first, a simple matter. For the previous tests, along with tests shown above, funneling of cones was achieved with the gate unlocked therefore not taking into account cones that approached the ACM tip first. Without the tipping bar, it quickly became obvious that cones coming in tip first would not be reliably retrieved. The test results for those cones in the tip first orientation have been omitted until the tests in Table 5.3. The test runs marked with an asterisk in Table 5.3 indicate runs where the gate on the primary funnel was manually locked to prove the concept of retrieving either standing cones or cones that have fallen and were pointed tip first. The use of a tipping bar helped achieve the reliability and the robustness needed for consistent retrieval.

6. CHAPTER SIX
PRIMARY FUNNEL AND TIPPING BAR ASSEMBLY DESIGN AND ANALYSIS

6.1 Development of the Primary Funnel

Once the concepts from Chapter 2 were developed, several new critical components were required to be designed and integrated into the system. The first of these was the Primary Funnel and Tipping Bar System. This system was required since the retrieval arm can only pick-up cones that are oriented on their sides with the cone base facing the retrieval poker arm. The Primary Funnel and Tipping Bar System's sole purpose was to reposition the cones on the highway so they can be picked up by the retrieval arm via the secondary funnel which directed the cone onto the retrieval arm's poker arm. The development of the Center and Outboard Stopping Gates are also discussed in this Chapter. The Stowage System required these components to stop the cones on the Lateral Conveyor System for pick-up operation. This chapter will discuss the individual design and analysis of each of these three components.

Each of these components underwent a three stage design process. The first stage consisted of defining the functional specifications and then developing conceptual designs that satisfied these specifications. In stage two, these designs were then rated in the following two categories: (1) required specifications and (2) secondary specifications. Finally in stage 3, the design with the highest overall rating was designed in detail and tested.

6.2 Primary Funnel and Tipping Bar System

The Primary Funnel and Tipping Bar System (PFTBS) was only used on the pick-up operations of the ACM. It was the first subsystem of the ACM to come into contact with the cone on the pickup operation. Its main purpose was to reorient the cones onto their sides with the cone base facing the secondary funnel system. The PFTBS was required to reorient the cone from any possible cone configuration. The two main scenarios were the following: (1) the cones were either standing up or (2) they had fallen over onto their sides. When a cone was on its side, it could be oriented anywhere in a 0-360 degree pattern. Figures 6.1 illustrates this pattern.

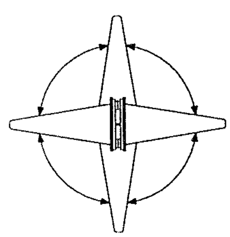

Figure 6.1 Top View of a Fallen Cone's Possible Positions

Once the cone left the PFTBS, it was to be correctly oriented for the secondary funnel system (SFS). The SFS was the final system to correctly position the cone for the retrieval arm. The output operating range of the PFTBS is shown in Figure 6.2. This range was solely dependent upon the input operating range of the SFS.

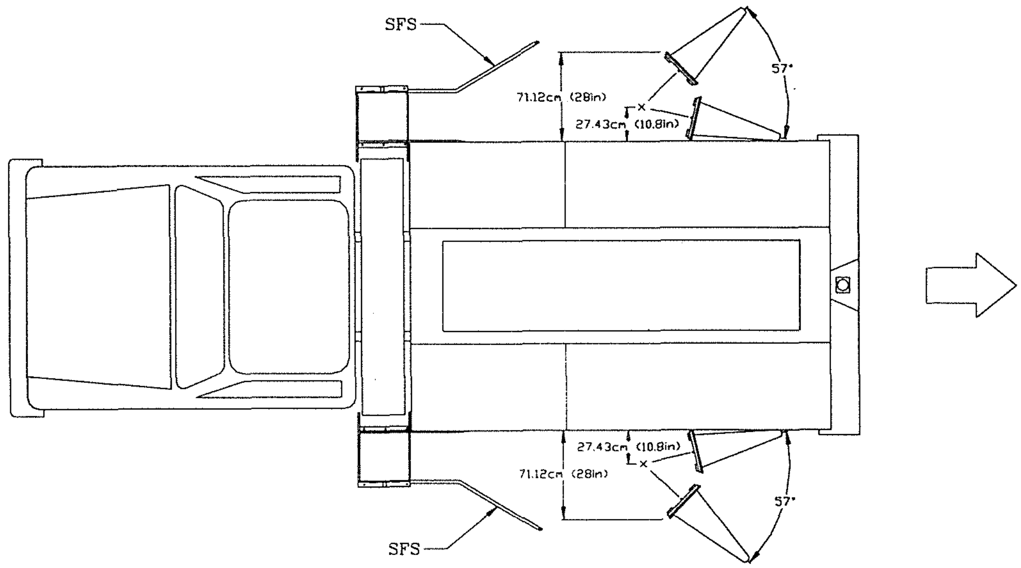

Figure 6.2 SFS Input Operating Range

6.2.1 Functional Specifications

In addition to repositioning the cones, the PFTBS had two other design constraints. First, it was required to be mounted to any of the four corners of the ACM since the ACM was capable of retrieving cones from each of these sides. The mounting was to be done by one worker and should take minimal time and effort. Only one PFTBS was being considered for the ACM, since only one was required for the pickup operations. By using only one PFTBS, both the complexity of the system and the overall system cost were reduced.

The PFTBS also needed to retract from its deployed position from where it was used during the pick-up operation. There were two main reasons for this. First, during the drop-off operation, the cones were placed on the roadway standing up. If the funnel was in its deployed position, it would have knocked down the cones onto their sides. Second, the retracted position was to fit within the envelope of the ACM for safety issues. This enabled the ACM to move freely down the highway with all of the components safely stowed.

6.2.2 Conceptual Design

A major consideration for the PFTBS was to keep the design as simple but robust as possible. Since it was going to be in direct contact with the cones, its structure was also to be very rigid.

The first evaluation was to break down and analyze each of the possible cone configurations that the PFTBS was to handle. First, the simplest cone configuration, as shown in Figure 6.3, was for the cone to be on its side with the base facing first. This position required no cone repositioning to be performed by the PFTBS, and therefore, allowed the cone to pass through untouched.

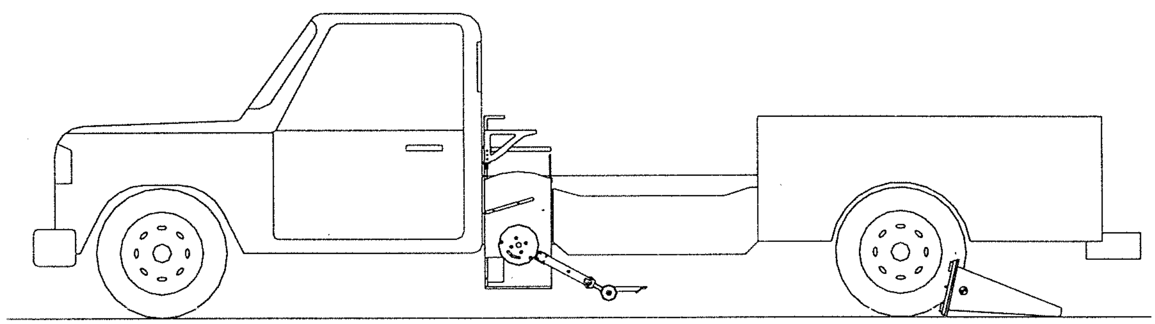

Figure 6.3 Simplest Cone Configuration

The next scenario to evaluate was an upright cone that stood in the same position as the deployed cones already placed on the highway (see Figure 6.4). In this position, the cone was knocked over by hitting the cone above the center of gravity as the truck moves past it. This performed two functions: (1) positioned the cone on its side and (2) oriented the cone base facing the retrieval arm.

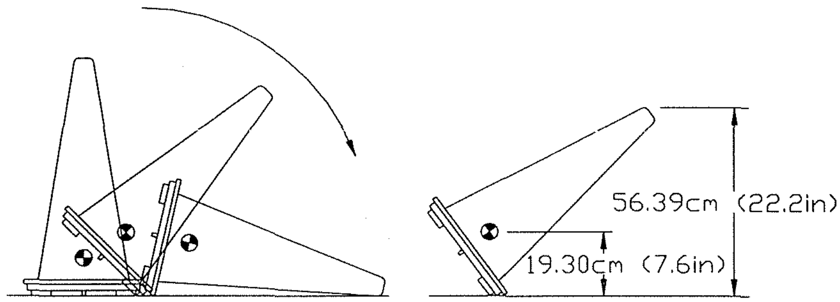

Figure 6.4 Standing Cone's Unstable Position

Now at this point, with the two possible conditions described, the PFTBS was to allow a correctly positioned cone to pass through without contact, as well as knock down a standing cone with an arm hitting the cone above the center of gravity. Combining these two functions was relatively simple because the total vertical height of a cone on its side was 34.54 cm (13.6 in), and a standing cone could be effectively knocked over at a maximum height of 56.39 cm (22.2 in). Therefore, the arm could be anywhere in the vertical range of 34.54 cm (13.6 in) to 56.39 cm (22.2 in) (see Figure 6.5).

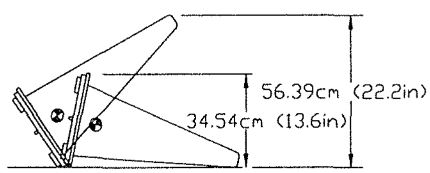

Figure 6.5 Vertical Height Range for PFTBS

Since the PFTBS was to be capable of handling cones in any possible combination of positions, other scenarios were to be evaluated. Another possibility was for a cone to be on its side and perpendicular to the direction of travel of the ACM. This required the PFTBS to reposition the cone 90 degrees. This was performed by integrating two vertical arms on each side of the PFTBS (see Figure 6.6). As the ACM moved toward these cones, the vertical arms hit the cone above the base area, and forced it to the correct position.

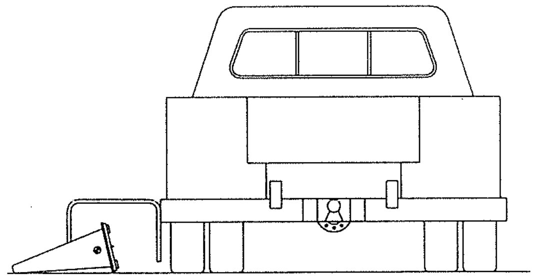

Figure 6.6 PFTBS Vertical Bars

The last scenario, and possibly the hardest, was when the cone was positioned on its side with the tip of the cone facing the PFTBS. Three possible avenues to perform the cone repositioning were as follows: (1) The cone could be forced 180 degrees in the horizontal plane, (2) The cone could be forced 180 degrees in the vertical plane, or (3) A combination of both of these. Since the two vertical arms were required on the sides of the funnel, it would be very difficult to rotate the cone 180 degrees in the horizontal plane. Therefore, the most logical avenue to pursue was to rotate the cone 180 degrees in the vertical plane. This was performed by incorporating a mechanism, such as a gate, that activated down to the edge of the cone. Then as the cone tip passed under it, the upper edge of the cone made contact. Upon contact, the cone began to tilt back to the upright position, which is illustrated in Figure 6.7.

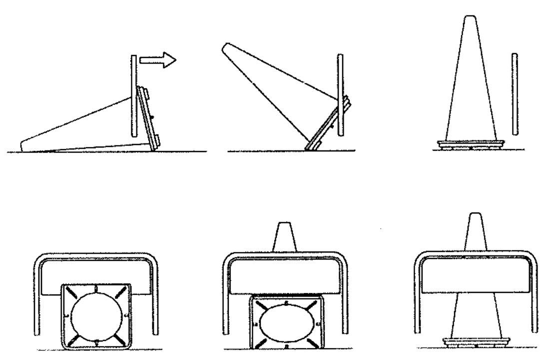

Figure 6.7 PFTBS Gate Mechanism

Once the cone was standing, a new mechanism was needed to tip the cone over, so that the base was facing the retrieval arm. This new mechanism was called the tipping bar. Its sole purpose was to tip the standing cones over after they were positioned upright by the gate assembly, as shown in Figure 6.8. Based on the range of motion of the cone being forced in the standing position, the tipping bar was to remain at least 68.58 cm (27 in) from the primary funnel.

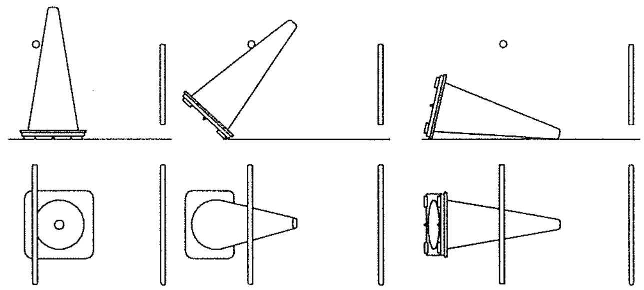

Figure 6.8 PFTBS Tipping Bar

6.2.3 Prototype Testing

With the concepts developed as previously described, a prototype PFTBS was constructed. The preliminary tests conducted on a conveyor belt system were setup in the laboratory to simulate actual road conditions. The results helped fine-tune the correct height and width for the PFTBS in relation to the cones. From this point, a prototype was mounted onto the left side at the rear of the ACM Test Bed, as shown in Figure 6.9, and testing was then conducted in a highway environment. The results proved to be similar to conveyor belt testing, and this gave way to the shape and location of the primary funnel and tipping bar.

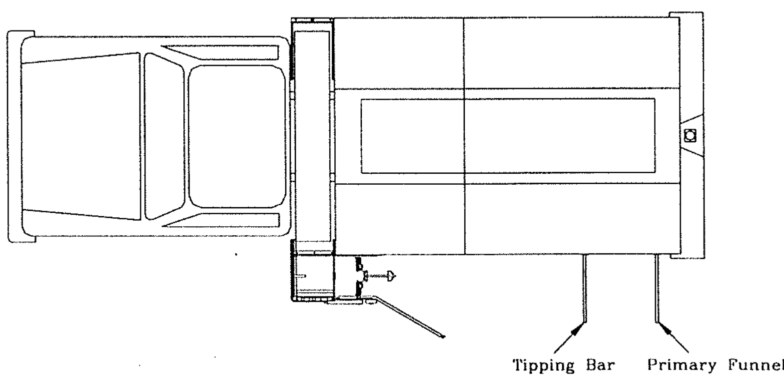

Figure 6.9 Location of PFTBS

6.2.4 Deployment and Retraction

The next step was to improve the ease of use of this system. Since the goal of this project was to take the operators out of the unsafe conditions and keep them in the safe zone of the cab of the ACM, it would have been considered unreasonable to have an operator manually operate the PFTBS. Therefore, it was of utmost priority that this system be fully automated by allowing it to be capable of automatic deployment and retraction.

The location for the PFTBS was evaluated in terms of the location and distance from the secondary funnel. The results showed the tipping bar could be no less than 40.64 cm (16 in) to the end of the secondary funnel. The maximum distance from the SFS was considered and determined to be limited to the end of the ACM's rear bumper. Since the rear bumper was considered to be within the envelope of the ACM, it was determined that the best place to mount the PFTBS was to the bumper. This allowed the primary funnel to be stowed at the rear of the ACM with plenty of room for stowage. This was selected in contrast to the mounting of the PFTBS to the side which required penetration into the side of the ACM for stowage.

With the Primary Funnel mounted on the bumper, the tipping bar was still needed to be mounted to the side of the ACM which required penetration into the side for stowage. This developed a new set of constraints. How could the tipping bar and primary funnel be incorporated together to reduce the complexity of the system? The main focus was to only have one actuator linked to both the primary funnel and tipping bar for deployment and retraction. The first consideration was a cable system . However, this consideration was short lived due to the development of the second design, as shown in Figure 6.10.

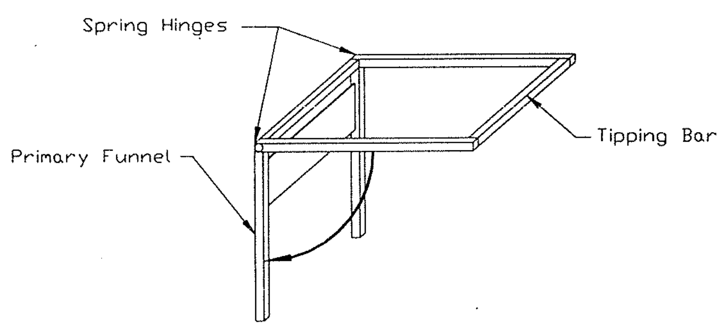

Figure 6.10 PFTBS Final Concept

This design eliminated the tipping bar attachment to the side of the ACM machine, and instead attached it to the top of the primary funnel with the use of hinged springs. By this method, only one actuator was attached to the primary funnel through which the tipping bar was controlled. During stowage of this system, the tipping bar rotated 90 degrees toward the primary funnel, and during deployment, the tipping bar repositioned for the pick-up mode by means of the spring hinge attachments.

With this new PFTBS design, several types of methods for retraction and deployment were considered. Figure 6.11 shows the possible arrangements for such methods.

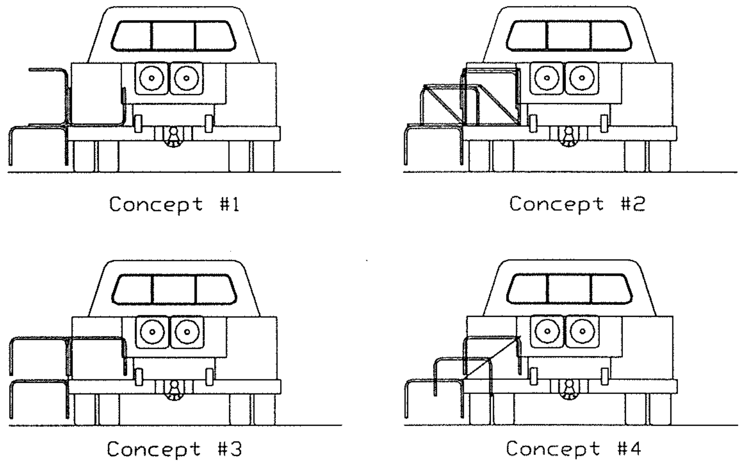

Figure 6.11 PFTBS Path Projection Concepts

Since each method was determined to be a viable solution, it was next a matter of determining which method would be the best overall. To determine this, a trade-off table was constructed with the following two criteria (see Table 6.1): (1) Required, and (2) Secondary. The "Required" criteria included specifications that were to be satisfied by the system, and any concept that did not meet them were rejected. The "Secondary" criteria included specifications that were considered to be a compliment to the system, but not mandatory. They were rated by assigning a weighting factor for each specification required in the design. The most critical specifications were assigned a five and the least critical specifications were assigned a one. Then for each design, rating factors were assigned corresponding to how close each one met the given specifications. Again, five was the highest and one was the lowest. Then the specification weighting factors were multiplied by each design/specification rating factor. Finally for each design, these values were summed together and the design with the highest overall rating was taken as the final concept.

Table 6.1 PFTBS Path Projections Trade-off Table

Design Considerations	Weighting Factors	Concept #1	Concept #2	Concept #3	Concept #4
(REQUIRED)					
Stow within truck envelope		Yes	Yes	Yes	Yes
Deploy in line with Secondary funnel		Yes	Yes	Yes	Yes
Compatible w/ existing cone body		Yes	Yes	Yes	Yes
(SECONDARY)					
Compatible with tipping bar design.	5	5	3	2	4
Degrees of Freedom	4	5	5	3	5
Stable in Stow position	3	5	2	4	3
Stable in Deployed position	3	5	5	4	3
Durability	5	5	3	3	4
Maintainability	5	5	4	3	4
Total Score		125	91	76	98

The results from Table 6.1 showed that Concept #1 received the highest number of possible points available on the trade-off-table. It was clearly the most dominant concept of the four described. It received the highest possible points available in each of the specifications listed, while the other concepts were deficient in the majority of these specifications. As a result, Concept #1 was taken to the next step of analysis and detailed design.

6.2.5 Operator Relocation

Since only one PFTBS was going to be installed on the ACM and it was going to be used on all four corners, it needed to have the capablity of being relocated to each of these corners manually. Figure 6.12 illustrates the correct locations and positions of the PFTBS.

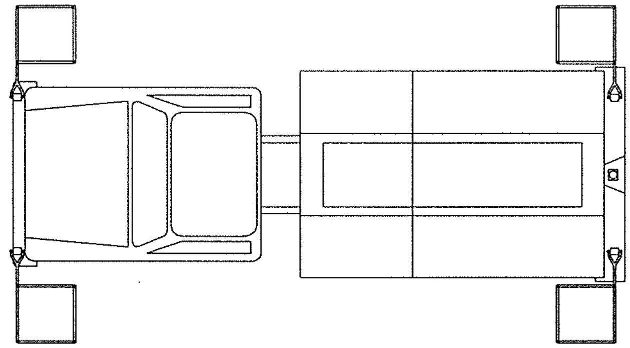

Figure 6.12 Correct Locating of the PFTBS

The potential problem that arose by relocating the PFTBS to all the corners was the orientation of the primary funnel with the tipping bar. For example, if the PFTBS was located at the left rear of the ACM, it could only be relocated to the forward right corner and still be in the correct orientation. Locating it to the other two corners would have the tipping bar leading the primary funnel, which would not allow the system to work correctly (see Figure 6.13).

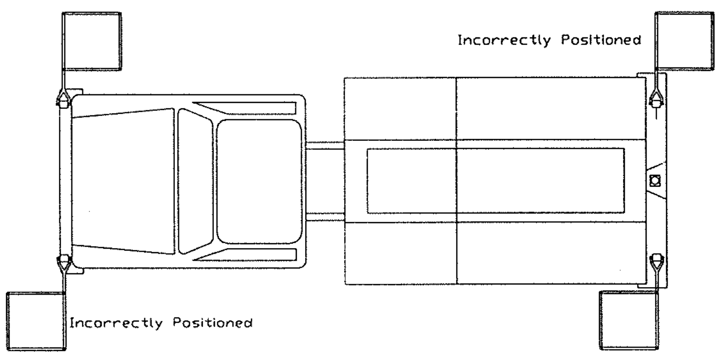

Figure 6.13 Incorrect Locating of the PFTBS

To correct this problem, the primary funnel needed to have the added versatility to manually change to two select orientations which were 180 degrees different from each other. This could be incorporated in the design by adding the following two changes: (1) a quick disconnect on the primary funnel which detached it from the actuator mount assembly, and (2) a location on both ends of the primary funnel for attaching to the actuator mount assembly. Figure 6.14 illustrates both of these concepts.

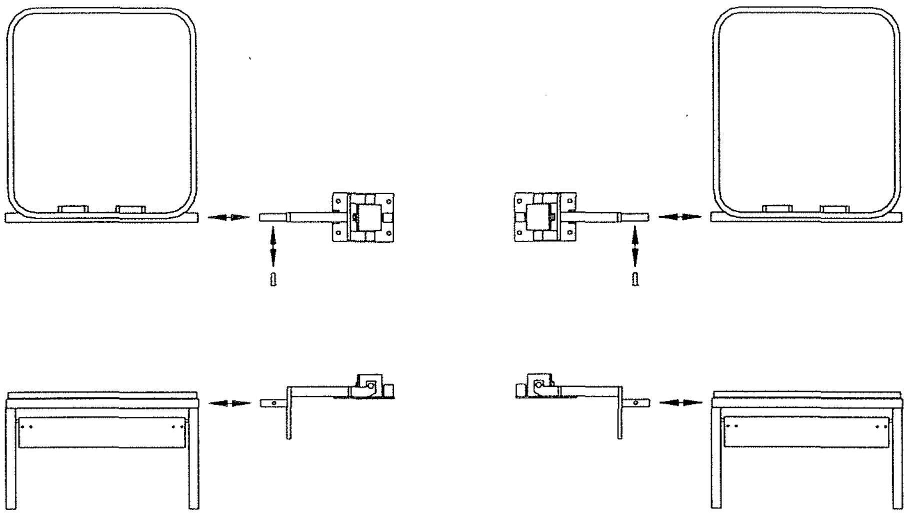

Figure 6.14 Primary Funnel Re-Orientation

The method for attaching the PFTBS to the ACM corners was performed by locating a permanent base plate assembly at each corner. On the top of each of these assembles, a pattern of bolt studs were permanently welded into place. The PFTBS was attached to this assembly by placing it on top and lining up the corresponding holes with the bolt studs on the base plate assembly. Quick disconnects were then placed on the bolt studs which securely fasten the PFTBS to the base plate assembly.

6.2.6 Gate Latching

The Gate on the Primary Funnel served only the purpose of assisting to stand cones that were positioned on their sides with the tip facing first. However, for all other cone configurations, this gate was not required and therefore was not to interfere with their operation. To incorporate these considerations, a manual switch mechanism was added within reach of the driver in the cab of the ACM, which allowed the driver easy access to activate. When the switch was off, all cones passed by the gate with no interference, and when the gate was activated, the gate was locked into place (see Figure 6.15), which enabled the cones to be flipped over.

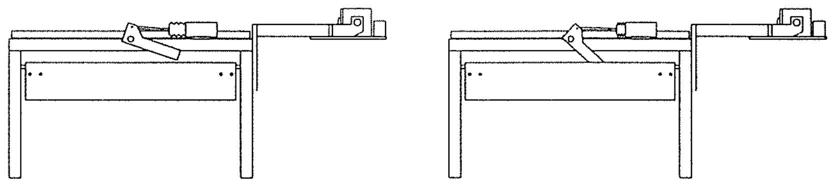

Figure 6.15 Gate Locking Mechanism

6.2.7 Detailed Analysis and Design

Now that all the concepts for all of the components of the PFTBS were developed, the next steps to perform were material selection, stress analysis, sizing of parts, detailed assembly/machining drawings, and hardware selection for commercially purchased items. Factors that were considered for each of these steps were allowable weight, applied loads, longevity/wear, and aesthetics. Listed below is a description of these steps for each of the five components that comprised the PFTBS. Detailed drawings are shown in Appendix D.

6.2.7.1 Tipping Bar

The Tipping Bar experienced relatively low impact loads during stowing of the system. This maximum moment was calculated to be 16.26 N·m (143.9 lbf·in), and was based on the system being stowed at a rate of 2 rev/sec. The maximum bending stress was calculated to 6.65 $x10^7$ N/m^2 ($9.64x10^3$ psi).

The greatest impacts that the Tipping Bar received was from the cone impact during the pick-up operation. Although the primary funnel system was designed to be subjected to an impact load of 797 N (179 lbf) at 4.5 m/s (10 mph) as calculated in chapter 4, the impact load on the tipping bar is minimal. Cones are stood up by the locked gate of the primary funnel prior to being knocked over by the tipping bar. The relative speed of the cone with respect to the tipping bar will be minimal and the loads low. The Tipping Bar material selected was 1.27 cm (1/2 in) steel conduit with a wall thickness of 0.25 cm (0.1 in), which was relatively light and easy to work into the desired position.

Based on the total length and geometry of the Tipping Bar, the total moment created at the top of the Primary Funnel was calculated to be 8.13 N-m (6 lbf-ft). This was the moment that the spring hinges were required to exert to keep the Tipping Bar in the deployed position. By multiplying this number by a factor of safety of 2, this insured that the Tipping Bar was rigid enough for operation, but not too difficult to stow. The spring hinges selected were McMaster Carr 7.62 cm (3 in) single acting hinge springs.

6.2.7.2 Primary Funnel

Several design considerations were necessary for the Primary Funnel. They were as follows: (1) the tipping bar spring hinges and actuator for the gate were to be mounted to the top, (2) the gate assembly was to be easily attached to the vertical sides, and (3) both ends of the primary funnel were to have identical attachment points for mounting to the actuator assembly. Evaluating each of these considerations for the best material shape to be incorporated into the system resulted in the use of square tubing for the Primary Funnel's main body. This allowed a planar surface for easy attachment of components verses a curved surface if round tubing was used. Also with the use of square tubing, the attachment point at both ends of the funnel allowed a smaller square tubing to be mounted within, which prevented rotation between the two pieces. This was not possible with the use of round tubing (see Figure 6.16).

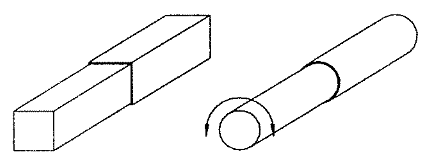

Figure 6.16 Primary Funnel Attachment Ends

The loads the primary funnel received were dependent upon the orientation of the cones contacting it and the speed of the impact. For purposes of the calculations, a load of 797 N (179 lbf) was used as a worse-case-load. There were two orientations to analyze. The first case was an upright cone which made contact with the horizontal bar of the Primary Funnel. Since the mid section of the cone is very pliable and the center of gravity low, the impact loads on the horizontal bar are less than the loads on the vertical arms which are subjected to impacting the heavier cone base. Evaluated as a worse-case scenario, the impact load was applied to the tip of the outer vertical arm. In this case, the maximum stress experienced was calculated to be 1.31×10^8 N/m^2 (19.0×10^3 psi).

The final design of the primary funnel used 3.18 cm (1.25 in) steel square tubing, with a wall thickness of 0.53 cm (0.12 in) to form the funnel. The two vertical arms of the funnel were attached to the horizontal cross arm via fillet welds. This allowed the horizontal cross arm end holes to remain unobstructed which was required for attaching to the actuator assembly (see Figure 6.17).

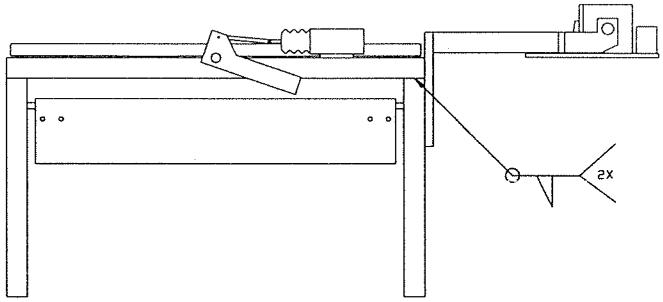

Figure 6.17 Single Vee Weld Joints

6.2.7.3 Gate and Solenoid

As previously mentioned, the Gate assembly was only activated when a cone was coming into the Primary Funnel on its side with the tip facing forward. This load was distributed between the two hinge attachments of either side of the gate and the latching lever which locked the gate into place. Based on the calculated load and a factor of safety of 2, the material selected for the entire assembly was as follows: (1) gate, .95 cm (.375 in) aluminum plate; (2) hinges, McMaster Carr 1.27 cm (.5 in) shaft; and (3) lever, 1.91cm (.75 in) aluminum plate.

The mechanism selected to activate the lever was a Tombetta Pull-In Solenoid rated for outdoor use. It was capable of 88.97 N (20 lb) pull-in and 222.4 N (50 lb) hold-in force. The calculated values required of this solenoid were 34.7 N (7.8 lb) for pull-in and 104.1 N (23.4 lb) for hold-in force which were well within the range of the solenoid's capabilities. The solenoid also had an important safety feature. It had a switching mechanism built in which reduced the current supplied to the solenoid after the solenoid was seated. This was very important because as the solenoid pulled-in, a large amount of current was required to achieve a suitable pull-in force. However, once the solenoid was seated, very little current was required to obtain a large hold-in force. Over a period of time, if only a large current was supplied, the life of the solenoid would drop severely due to burnout. Therefore, with the use of an electronic current switcher, the solenoid was manually activated by the operator and the current was automatically controlled, thereby reducing any chance of solenoid burnout.

6.2.7.4 PFTBS Mounting Assembly and Actuator

The mounting assembly consisted of the following three parts as shown in Figure 6.18: (1) two arm shaft extensions with keyways, (2) a cross brace with height adjustments, and (3) a linkage rod which fit into either end of the primary funnel.

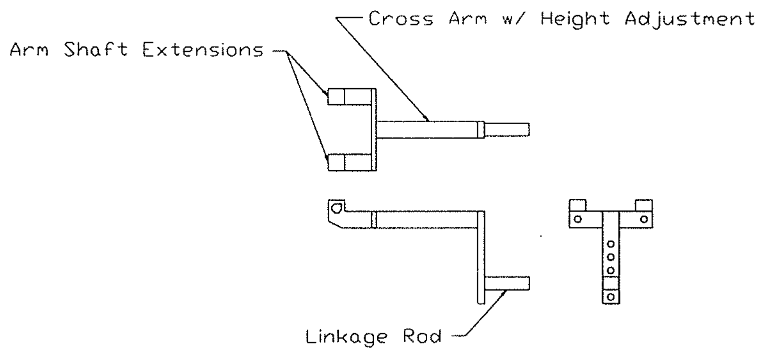

Figure 6.18 PFTBS Mounting Assembly

The stress analysis evaluation of these parts was broken into two case evaluations. First, when the PFTBS was either deployed or stowed, the system's inertia effects created significant stress on these parts by hitting the stops, which caused the system to cease rotational movement. This case was based upon an actuator rotation rate of .5rev/sec, and the primary funnel and tipping bar dead weight of 93.4N (21 lbf). The second case evaluation was during the pick-up operation with the PFTBS in the deployed position. In this operation, the primary funnel experienced cone impacts, which created a moment on these parts. A worst case scenario was considered in which a cone's center of gravity made contact with the lower tip of the outer vertical tubing on the primary funnel.

By considering these two cases and the loads experienced, the parts were sized as follows: Arm Shaft Extensions - 3.18 cm (1.25 in) solid plate steel; keyways - .95 cm (.375 in); Cross Arm - 3.18 cm (1.25 in) square steel tubing, with a wall thickness of 0.53 cm (0.12 in); and Linkage Rod - 2.54 cm (1 in) steel plate.

At this point, all the known components that the actuator was to drive were designed. Based on their combined weight, the total moment that the actuator was to supply to deploy and stow the system was 56.51 N-m (500 lbf-in). Now applying a factor of safety of 2 to this moment, the actuator was to be capable of 113 N-m (1000 lbf-in). Since two types of power were available on the ACM, two avenues were pursued for the type of actuator selected. They were as follows: (1) a 12 volt reversible motor linked to a gear box assembly, or (2) a hydraulic rotary actuator.

A trade-off table was used to evaluate the two actuators (see Table 6.2). The same design evaluation considerations were applied as were to the trade-off table used in table 6.1.

Table 6.2 PFTBS Actuator Trade-off Table

Design Considerations	Weighting Factors	12VDC Design	Hydraulic Design
(REQUIRED)			
1000 in-lb torque output		Yes	Yes
(SECONDARY)			
Rotation rate of 1 rev/sec	3	3	5
Compact Size	4	3	5
Low Weight	4	3	5
Durability	5	3	5
Maintainability	5	5	4
Total Score		73	100

Based on the final results from the trade-off table, the hydraulic powered actuator was the most superior. It was easily capable of delivering the desired rotation rate and torque, while maintaining a very compact size and low weight. Also, it was extremely robust and contained very few parts, which were all completely enclosed in a single weatherproof housing. The electric powered actuator, on the other hand, proved to lag in the majority of the design considerations. Its only strong point was that it did not require any servicing over the system's life. In comparison, the hydraulic system was limited to the quality of the fluid in the system and, therefore, was to undergo routine changes of the hydraulic fluid.

6.2.7.5 Fixture and Base Plate

Since the PFTBS was to be capable of being manually relocated by an operator to all four corners of the ACM, the quickest way to perform this was for the actuator to be mounted to a fixture which easily attached/detached to a base plate at these corners. The fixture shape and base plate are illustrated in Figure 6.19. The vertical plate on this fixture was where the actuator mounted. It was calculated to be .63 cm (.25 in) plate based on the maximum output of 113 N-m (1000 lbf-in) and with a factor of safety of 2. The vertical standing rod on this fixture was designed to be a stop for the PFTBS when the system was in the stowed position. It was calculated to be 1.27 cm (.5 in) square rod based on the PFTBS impacting it with a rotation rate of 2 rev/sec.

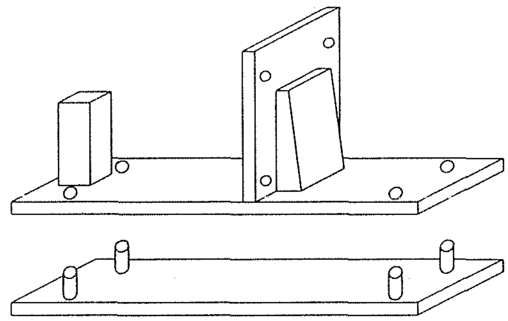

Figure 6.19 PFTBS Fixture and Base Plate

6.2.8 Prototype Assembly

The entire assembly of the PFTBS is shown in Figure 6.20. It had an overall weight of 111.2 N (25 lbf), which allowed an operator to easily relocate it to the desired corner of the ACM depending on the operation selected. This weight could have been reduced even further by replacing the carbon steel components with a more light weight alloy composite, but only at the expense of significantly increasing the overall price.

Two hydraulic lines were supplied at each corner of the ACM for the PFTBS power supply. Each of these lines contained a quick disconnect fitting that allowed the operator to quickly disconnect the actuator from the hydraulics.

All parts, with the exception of the actuator and the solenoid, were protected from the elements with a combination of a primer and double finish coat application.

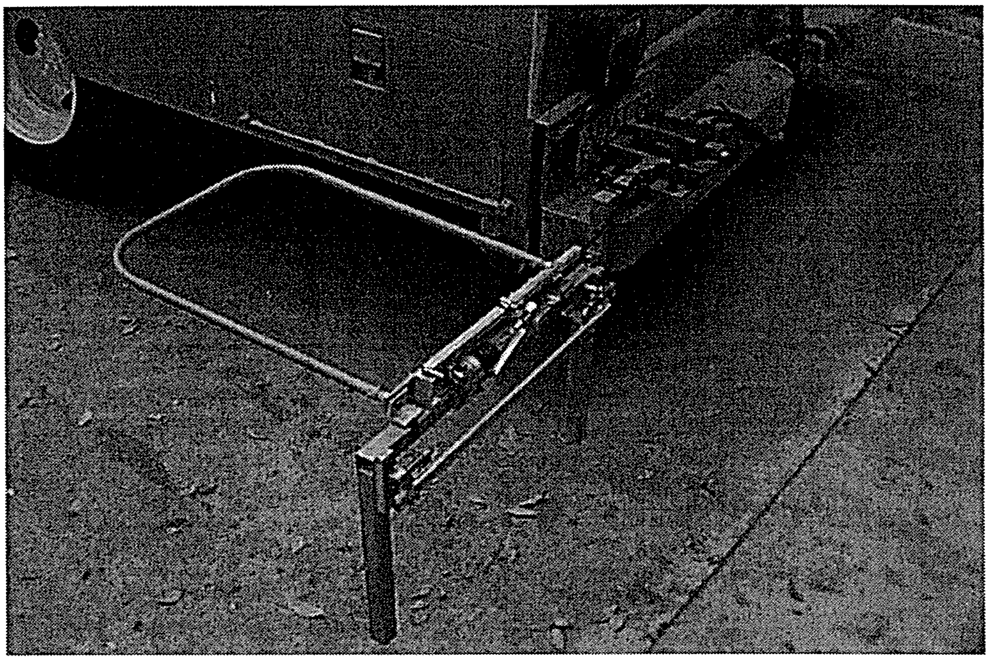

Figure 6.20 PFTBS Prototype Assembly

6.3 Stopping Gates

The design of the Stowage System during the pick-up operation was such that the cones were picked up off of the lateral belt and then placed on the main conveyor. However, for the Stowage System to correctly pick-up a cone on the lateral belt, the cones were to be completely stopped, allowing the gripper system enough time to fully engage the base of the cones before the stowage system lifted the cones off of the lateral belt. This was typical at two locations on the lateral belt, since there was a left and right stowage system. The control system determined the best side to stow the cones on the main conveyor, which will be discussed in more detail later. This then determined which side to stop the cones on the lateral belt. Figure 6.21 illustrates a top view of the two positions at which the cones were to be stopped on the lateral belt.

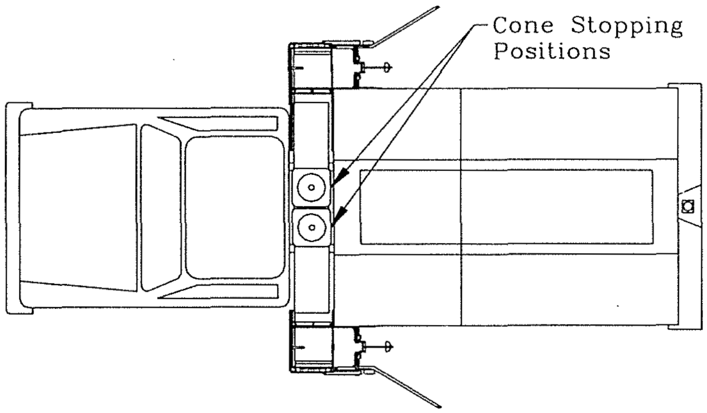

Figure 6.21 Lateral Belt Cone Stopping Locations

6.3.1 Functional Specifications

The total height required for the gate was based on the vertical height of the forward edge of cone base that made contact with the gate. This height was found to be 4.06 cm (1.6 in), which was measured from the top of the lateral belt to the top of the cone base.

6.3.2 Stopping Gate Conceptual Design

The two feasible concepts to stop cones on the lateral belt were as follows: (1) a sensor device which triggered when a cone had reached the correct position at which time the lateral belt is turned off, or (2) a gate system that activated prior to the cone arrival, and at which time was able to stop and hold a cone upon contact in the correct position with the lateral belt remaining on or off. To best evaluate both of these concepts, a trade-off table was constructed (see Table 6.3) with the same design evaluation considerations as were used in the trade-off table 6.1.

Table 6.3 Stopping Gate Mechanisms

Design Considerations	Weighting Factors	Concept #1	Concept #2
(REQUIRED)			
Complete stowage without cone interference		Yes	Yes
(SECONDARY)			
Minimal stopping error	5	2	5
Cone alignment correction	4	2	5
Compact Size	3	5	3
Simple design	4	5	4
Durability	5	3	5
Maintainability	5	5	5
Total Score		93	120

Concept 2 proved to be the best concept to pursue. It added the versatility of stopping the cone via the gate in the exact location each time required by the stowage system, as well as, correctly positioned any cone which had become misaligned while traveling on the lateral belt. In addition, it had the capability of operating with the lateral belt either on or off, which was dependent upon the power requirements of the hydraulic system. The problem with Concept 1 was its difficulty to stop the cones in the exact location repeatedly, because of several factors which effected the lateral belt system, such as the following: inertial, mechanical, and thermal. Now with this information, Concept 2 was applied to both cone stopping locations.

Depending on the side of the ACM being used for the pick-up operation, the cones could travel on the lateral belt in two possible directions. Therefore, the exact locations of the gates needed to be determined on the lateral belt. The three locations required for the cone stopping gates are shown in Figure 6.22.

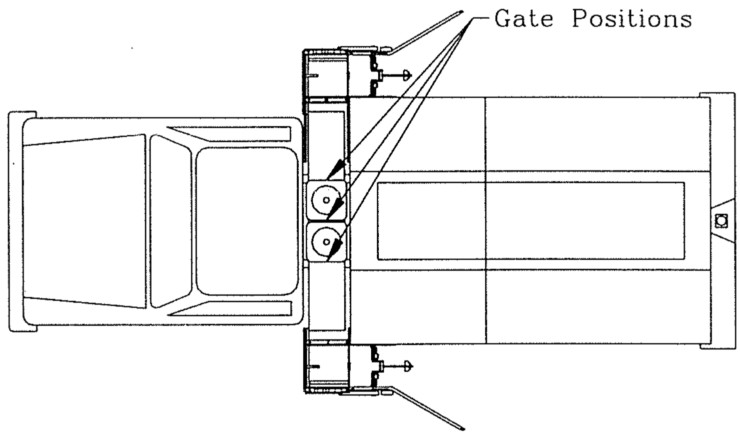

Figure 6.22 Lateral Gate Locations

With this in mind, two types of gate stopping systems were required. First, a gate system was required at the middle of the lateral belt, which was capable of stopping cones from both directions. Secondly, a gate stopping system was required at both the left and right sides of the lateral belt. Both the left and right systems were required to stop cones traveling from the opposite side of the lateral belt that they were located on. The two gate stopping systems were called the Middle Stopping Gate System and the Outboard Stopping Gate System.

6.4 Middle Stopping Gate System

6.4.1 Operating Range

The Middle Stopping Gate System (MSGS) had a very limited operating range available due to strict space constraints as shown in Figure 6.23. This range was limited to the following: (1) 2.54 cm (1 in) from the inside path of the left and right side of the Stowage System, (2) 10.16 cm (4 in) below the surface of the lateral belt to the top of the drive shaft, and (3) an unlimited vertical constraint subject to the ability to stow at or below the surface the lateral belt.

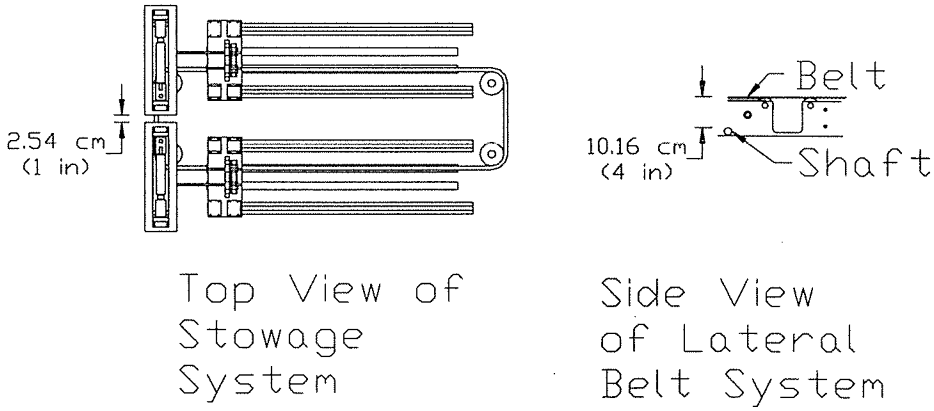

Figure 6.23 MSGS Space Constraints

The MSGS was to be capable of stowing at or below the top level of the lateral belt, because when cones were directed to the Outboard Gate Systems, they were required to move over the MSGS without interference. Depending on the side of operation, the cones could travel in two such directions. This is illustrated in Figure 6.24.

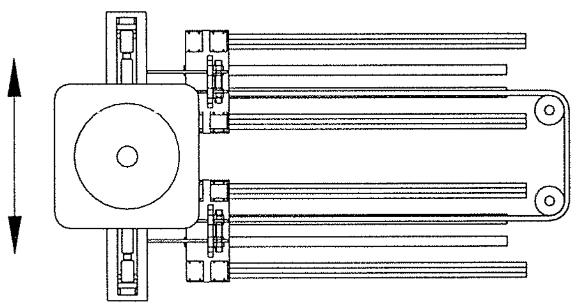

Figure 6.24 MSGS Stowage

6.4.2 Conceptual Design

Based on the conceptual design previously developed for the method of a stopping gate system, this concept was now applied to the design of the MSGS. While this concept consisted of a rigid gate assembly with a sensor attached, it was of utmost priority that the MSGS meet all the functional specifications while remaining within the limited space constraints. The first design was a single gate which deployed vertically while being guided by two linear tracks. However, due to the limited space for stowage, this design was unable to be stowed within the given confinements. The second design developed was a double gate system in which both gates deployed by rotating on two independent shafts a total of 90 degrees from the stowed to the deployed position (see Figure 6.25). This design was extremely efficient in the use of the limited space available and was therefore considered for the final design concept.

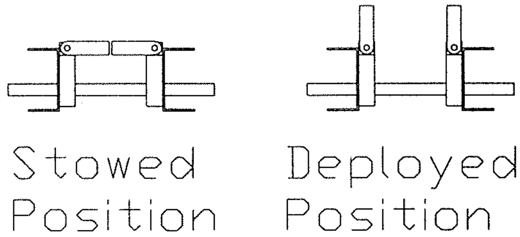

Figure 6.25 MSGS Double Arm Design

6.4.3 Detailed Analysis and Design

Each component of the MSGS was designed to withstand the impact of a cone traveling on the lateral belt and impacting the gates at an average operating speed of 0.6 m/s (2 ft/s). Calculations were based on a 969.7 N (218 lbf) load horizontally applied to either gate at a distance of 4.45 cm (1.75 in) from the top of the lateral belt. This was physically far greater than any loads the system would receive under normal operating conditions, but was required to ensure a very robust system.

6.4.3.1 Base Fixture

Each gate of the MSGS needed to have an attachment point to the existing cone machine. This was best incorporated by utilizing the existing drive shaft housing blocks of the lateral belt. They were located in the exact location where each gate attachment was required. With a simple modification (see Figure 6.26), these aluminum housing blocks were redesigned to include shaft supports for the gates while still maintaining their original design requirements.

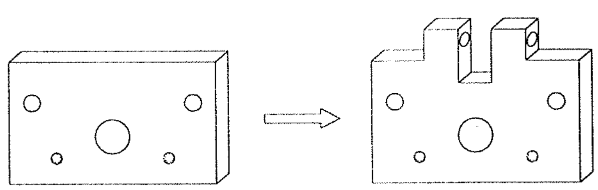

Figure 6.26 MSGS Base Fixture

Based on a maximum static load of a 969.7 N (218 lbf) applied at each gate, the material and size of each shaft support was within the allowable range. The stress was calculated to be 1.43×10^7 N/m^2 (2.08×10^3 psi), which was considerably less than the yield strength of the material.

6.4.3.2 Shaft

Since the shaft was permitting the gate to rotate 90 degrees, a problem might have existed with the wires that attached to the sensor on the gate. Because these wires were also attached to the ACM control system, they also needed to rotate 90 degrees. This led to an important consideration, "Where and how to run the wires for the sensor attached on the gate?". By considering this potential problem in conjunction with the detailed design of the shaft, a well thought-out system resulted.

A simple option to route the wires was to fasten them on the outside of the gates and allow enough extra slack leading down the frame which permitted the rotation. However, this left the wires exposed to the elements and therefore susceptible to damage. Another option was to route the wires inside the gates, while also leaving slack in the wires for the rotation. While this option was somewhat better, the wires were still susceptible to damage. Finally, the best method was to route the wires inside the gate and then through the shaft, which was hollow. The wires were then routed out either end of the shaft. This completely enclosed the wires in protective housings, as shown in Figure 6.27, and incorporated a very simple method of allow the wires to freely rotate 90 degrees in the shaft when the gates were activated. The material selected for the hollow shaft was .64 cm (.25 in) O.D., .32 cm (.125 in) I.D., stainless steel.

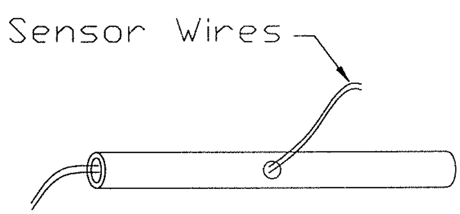

Figure 6.27 MSGS Hollow Shaft

The stress the shaft received from the cone impact was only caused from bending. This was due to the orientation and location of the shaft relative to the direction of the applied load. All other stresses, torsional and radial, were considered negligible.

Each shaft was supported at each end by oil-impregnated bearings which allowed the shaft to rotate freely. These particular bearings were maintenance free, and therefore require no lubrication.

6.4.3.3 Switches

The MSGS required a total of four switches. Two switches were mounted to each of the two gates. Since each switch performed the same function and were limited to the same space constraints, they were all identical. This allowed the switches to be interchanged, as well as, simplified the parts list.

Since each switch was located on the exterior of the gate, it was to be designed to operate in adverse environmental conditions, such as rain and excessive temperatures. It was also to be able to handle high impacts from the cones. Over the lifetime of the ACM, these impacts were estimated to be over 600,000 cycles. Therefore, the switch's design cycle life was to be substantially greater to insure a very robust system.

In addition to the above requirements, the switch was limited to very strict space confinements. The switch was to have a very sleek profile, with the following maximum dimensions: .64 cm (.25 in) x 1.91 cm (.75 in) x 6.35 cm (2.5 in).

Due to the extensive requirements for this type of switch, only one type was found that could meet all the requirements and also be purchased commercially. The switch selected was a CPI Limit Switch, Thinline Series.

Both sets of switches were wired in series on each side of the MSGS. This allowed a signal to be sent to the control system only when either side of the MSGS had both switches engaged. This ensured that the cone was fully engaged against the gates and therefore ready to be picked-up. Figure 6.28 illustrates the wire diagram

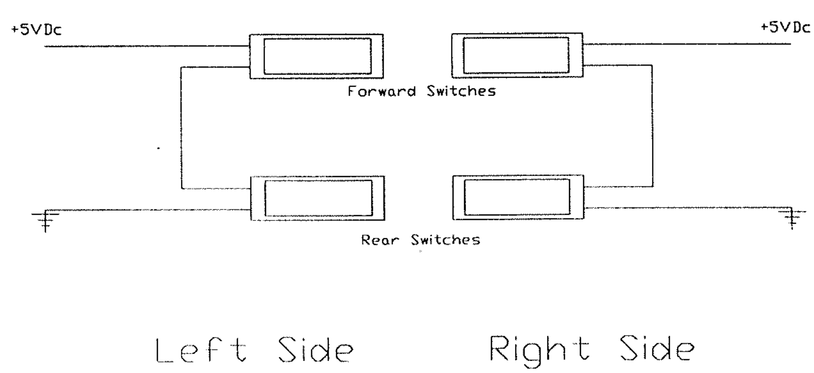

Figure 6.28 MSGS Switch Wire Diagram

6.4.3.4 Gate and Actuator

The concept for the MSGS required two independent identical gates. For clarification of referring to these gates individually and not the MSGS as a whole, they were referred to as the forward and rear gates. Both of these gates worked together to stop the cones on the lateral belt. The gates were designed to hard mount to the shafts, as detailed above, via set screws. This prevented any rotation between the shaft and gate, thus allowing the routing of the switch wires through the gate and hollow shaft without having any potential of damaging the wires.

The shape of the gate was first designed to accommodate the overall length required to stop the cones on the lateral belt, as well as, stow within the required space. The minimum height the gate needed to be above the lateral belt was 4.06 cm (1.6 in). This was the minimum distance to the forward edge of the cone. As a margin of safety, this distance was to be 5.72 cm (2.25 in) to eliminate any chance of the forward edge of the cone bouncing over the gate. Next, the maximum length of the gates was determined, so not to cause any interference between each gate when stowing them. Based on the CAD drawings for the ACM, the mid-span available between the lateral belts was determined to be 16.51 cm (6.5 in). This allowed each gate to have a maximum length of 8.26 cm (3.25 in). However, in order for the gates to open with this length from the stowed position, the lower inside edges were to be modified. By rounding these edges, any possible chance of interference was eliminated.

To examine the performance of the forward and rear gates based on these new dimensions, a preliminary test was conducted in the laboratory with the use of a conveyor belt and a prototype set of gates. The biggest problem that was watched for was a cone colliding with the gates and bouncing over the top or off-center of the gates. The results showed out of over 100 cones tested, all cones successfully stopped in the correct position on the conveyor via the deployment of the gates.

Since the gates were tested to be 100% accurate at stopping the cones, the gates were next designed to accommodate the width and depth of the switches. The actual socket, to install the switch into the gate, was designed so the switch case was flush mounted with the outside edge of the gate. Then on either side of the switch, the gate was designed to extend an extra .5 cm (.20 in) for added protection. Down the middle of the gate, a cavity was required that extended the entire length of the gate. This cavity was designed to route the switch wires through to the hollow shaft.

The material selected for the gate was 17-4 stainless steel. This material had excellent material properties to resist corrosion. Since each gate had a large percentage of its surfaces exposed to the environment and the large number of penetrations to accommodate the switches, a very corrosion resistant material was required. On the down side, this material was relatively expensive, but due to the size of the gate, the overall cost was not appreciable relative to its benefits.

With the addition of the cavity through the middle of the gate and the sockets to mount the switches, the outer walls of the gate were relatively thin. To compensate for this, strength was added to the gate after machining was complete, by applying a series of heat treatments. This ensured that the gate would be robust enough to handle the unexpected wear and tear encountered during operation.

In order for the gates to achieve the desired rotation of 90 degrees from stowage to deployment, an actuator device was required. This device was attached to a linkage which was pinned at two locations. One end of the linkage was pinned to the base plate and other end of the linkage was pinned to a slot on the bottom of the gate. This is illustrated in Figure 6.29. By attaching this device to a point on the linkage, which was 1.40 cm (0.55 in) up from the bottom pin of the linkage, only a 1.98 cm (0.78 in) horizontal pull-in stroke was required to achieve 90 degree rotation in the gate. The device was not required to push the linkage back 1.98 cm (0.78 in), since the gates could be returned to the stowed position by attaching an extension spring between the two gates. When the gates were in the deployed position, the device was to remain on because of the tension in the spring. Then when the device was turned off, the spring tension forced the gates back to the stowed position. The device selected was a McMaster Carr ,12 Vdc, 7.62 cm (3 in) Solenoid.

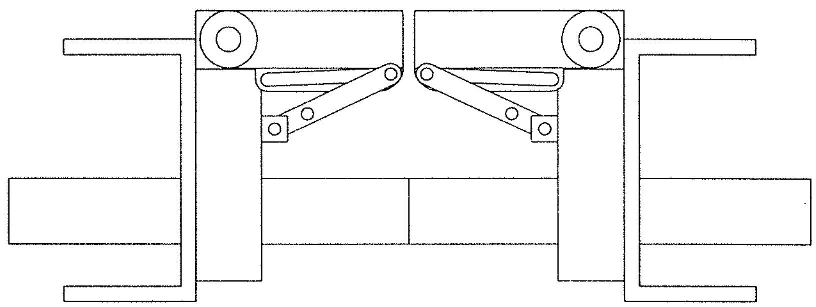

Figure 6.29 Gate Linkage

Since each gate required an independent solenoid, two solenoids were required, one for the forward gate and one for the rear gate. The location and orientation of the solenoids were very critical because they were required to drive the gate linkages a specified stroke length. The best location for the solenoids was attaching them beneath the lateral belt support C-channel. Here, they were easily attached and readily accessible, as well as, located in the correct orientation to activate each linkage. Before the solenoid was attached to the linkage, a hole was made through the C-channel and base plate, thereby allowing clearance for the connection. The two were then connected via a chain which was pinned at both ends.

<u>6.4.3.5 Prototype Assembly</u>

The final prototype assembly of the MSGS is shown in Figure 6.30. The two views show the forward and rear gates in the stowed and deployed position.

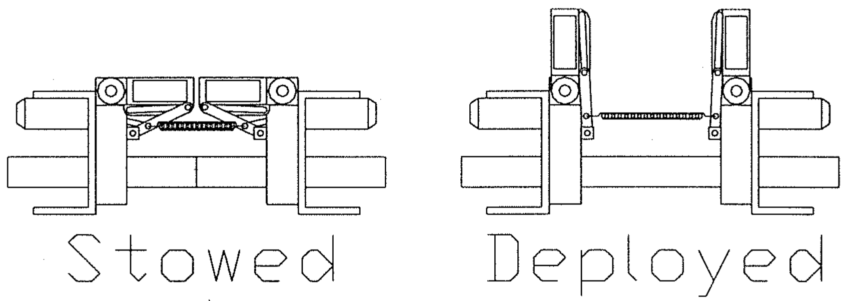

Figure 6.30 Prototype Assembly

6.5 Outboard Stopping Gate System

6.5.1 Operating Range

As previously described, the Outboard Stopping Gate System (OSGS) was required to be installed and operated at the left and right ends of the lateral belt. Unlike the MSGS though, the OSGS was not limited to the tight space constraint requirements, as was experienced with the design of the MSGS. Each side had approximately a 25.4 cm (10 in) x 16.51 cm (6.5 in) x 20.32 cm (8 in) space available below the surface of the lateral belt. This allowed plenty of space to fit the individual gates in for stowage, and room to include an actuator and supporting components.

6.5.2 Conceptual Design

The same conceptual design developed for a stopping gate system, which was applied to the MSGS, was also applied to the design of the OSGS. While this concept consisted of a rigid gate assembly with a sensor attached, the OSGS was allowed considerably more design leeway in that the available operating range was over ten times greater than that of the MSGS.

Both the left and right gates of the OSGS were to be performing the same type of function, with the differentiation of operating in complete opposite directions from each other. Therefore, based on this symmetry, the two OSGS's were to be mirror images of each other, and would only require one conceptual design.

The evaluation of the performance required of the OSGS's depended on which side of the ACM was being used for the pickup operation. The prospective OSGS's either remained in the stowed or deployed position for the duration of the operation. For example, when a left side pickup was performed, the right OSGS was required to remain up, and the left OSGS was required to remain down. This did not change unless the type or side of operation was changed. Therefore, when a pickup operation was selected, the prospective OSGS's were activated to either the stowed of deployed position, and remained there until the end of the operation. This was unlike the MSGS, in that regardless of the side used for pickup, the MSGS was required to be capable of stowing and deploying anytime during the operation.

This now led into an important consideration. What type of deployment method should be used to activate the OSGS's? To answer this question, a closer look was given to both the pick-up and drop-off operations. Evaluating in more detail the left side pickup operation, showed the left drop box was deployed and the right drop box was stowed. Then as the cones were picked up by the retrieval arm, they were placed on the lateral conveyor which was moving toward the right, at which time, they traveled over the left OSGS and came to a stop at either the MSGS or the right OSGS. At no time during this operation was the right OSGS required to be stowed.

By again analyzing a left side operation, but this time with a drop-off operation performed, the results showed the same requirements of the left drop box to be down and the right drop box to be up. Cones were then placed at either the left or right side on the lateral belt by the stowage system, at which time the cones were moved towards the left. Again, the right OSGS was able to remain in the deployed position and the left OSGS was still required to be in the stowed position. The same type of results were also seen by analyzing these operations for the right side.

Comparing both the pick-up and drop-off operations analyzed above, the results showed both operations were compatible when it came to the positions of the two OSGS's and the Drop Boxes. Therefore, when a particular side was selected on the ACM for an operation, either pick-up or drop-off, the OSGS's could be positioned at the same time the drop boxes were deployed. The OSGS's were then determined to remain in these positions until the drop box was stowed.

In conclusion, the best conceptual method to activate the left and right OSGS's was by a mechanical linkage, which connected both the corresponding OSGS's and drop boxes. Each linkage would drive the OSGS to the stowed position when the box was deployed, and then when the box was stowed, the OSGS would be driven to the deployed position. This enabled the OSGS's to indirectly connect to the drop-box actuator, thus, eliminating the need for any additional actuator devices, and simplifying the overall system.

6.5.3 Detailed Analysis and Design

Just like the MSGS, each component of the OSGS was designed to withstand a worst-case scenario of a cone traveling on the lateral belt and impacting the gates. The gates were designed to withstand a maximum load of 969.7 N (218 lbf) applied at a vertical distance of 4.45 cm (1.75 in) from the top of the lateral belt. . This was physically far greater than any loads the system would receive under normal operating conditions, but was required to ensure a very robust system.

6.5.4 Base Plate

Both the left and right gates of the OSGS needed to have an attachment point to the existing cone machine. This was best incorporated by utilizing the existing lateral belt cross braces which tied into the ACM cone body. They were located in the exact location of where each gate attachment was required. With a simple modification (see Figure 6.31), these aluminum housing blocks were redesigned to include shaft supports for the gates while still maintaining their original design requirement.

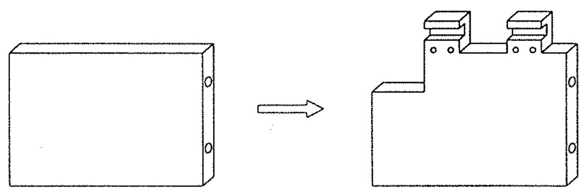

Figure 6.31 Gate Linkage

6.5.5 Shaft

Unlike the MSGS, each shaft of the OSGS was not required to be hollow in order to route the sensor wires. The wires could be routed through the back of the gates, which experienced no activity from the cones.

The stress the shaft received from the cone impact was only caused from radial stresses. This was due to the orientation and location of the shaft to the direction of the applied load. All other stresses, bending and torsional, were considered negligible. The material selected for each shaft was 0.64 cm (0.25 in) stainless steel.

Each shaft was supported by oil-impregnated bearings which allowed the shaft to rotate freely. These particular bearings were maintenance free, and therefore require no lubrication.

6.5.6 Linkage

The linkage was to be designed so as the drop box traveled from its stowed to deployed positions, the OSGS would be forced to do the same. This was best incorporated by utilizing a four bar linkage as illustrated in Figure 6.32. Each of the four links are described as follows: (1) The crank, q, is a link which is part of wing actuator mechanism which is driven by the drop box actuator. (2) The rocker, s, is a link on the gate on the OSGS. (3) The coupler link, l, attaches both the crank and the rocker links. And, (4) the ground link, p, is the distance between the ends of the crank and rocker links which have no displacement.

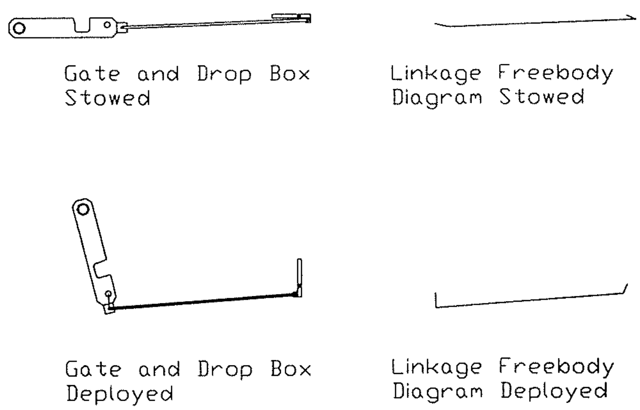

Figure 6.32 Four Bar Linkage

Based on the desired input and output rotations required, the linkage lengths were calculated to be the following: (1) the crank link (q): 2.69 m (1.06 in), (2) the rocker link (s): 3.89 cm (1.53 in), (3) the coupler link (l): 48.62 cm (19.14 in), and (4) The ground link (p): 50.04 cm (19.70 in). The link lengths satisfy Grashof's law which states $s+l \leq p+q$.

6.5.7 Gate

The height of the gate in the deployed position was first designed to accommodate the edge of the cones which made contact with the gate. The height used for the MSGS gates was designed to be 8.26 cm (6.25 in). Since space constraints were not a concern for the OSGS, a factor of safety was added by designing the height to be 9.91 cm (3.90 in).

The width of the gates was designed to be approximately the width between the lateral belt support braces. This more than adequately ensured a large enough surface area for the cones to impact. In addition, sufficient room was available for mounting the switches and securing the associated wires.

To make the gates easily detachable from the shaft hinge points, a shaft support plate was designed into the gates. As the name implies, these shaft support plates were designed to house the shaft, as well as, the bearings. With the removal of two screws on each plate, the gate was completely detachable. By attaching the gates in this method, the installation and disassembly time was significantly reduced.

An extension of the gate was the rocker link which was part of the four bar linkage. It was designed to be 0.64 cm (0.25 in) thick and 3.51cm (1.38 in) wide to withstand the loads experienced on the gate by the cone impacts. The connection link was attached to the extension link via a 0.64 cm (0.25 in) threaded eye bolt. Also, the lever link was designed with an inset from the gate body, which allowed the gate and linkage to fully stow below the surface of the lateral belt without interference. Both the left and right OSGS gates are illustrated in Figure 6.33.

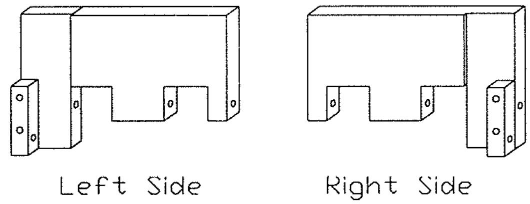

Figure 6.33 OSGS Gates

6.5.8 Prototype Assembly

The final prototype parts assembly of the OSGS, with the exception of the fasteners, is illustrated in Figure 6.34.

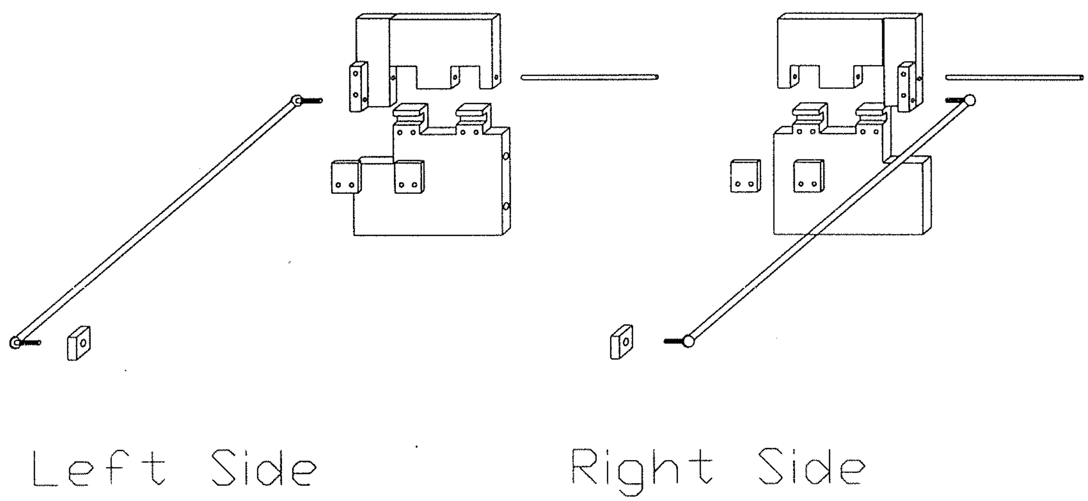

Figure 6.34 OSGS Prototype Assembly

7. CHAPTER SEVEN
CONCEPTUAL DESIGN AND DEVELOPMENT OF THE AUTOMATED CONE STOWAGE SYSTEM

7.1 Introduction

The stowage system for the Automated Cone Machine (ACM) was designed by utilizing a three step process involving brainstorming sessions, conceptual development, and evaluation of designs. Several iterations of these steps were necessary to identify all feasible methods of transporting traffic cones between the longitudinal stowage conveyor located on the bed of the cone truck and the Lateral Conveyor System (LCS) located directly behind the cab. Brainstorming sessions generated various ideas of how to grab and move the traffic cones within certain performance and spatial specifications. Once these ideas were conceived, it was possible to detail these concepts and to determine the operating capabilities of each design. With the conceptual development complete, a trade-off table was used to identify and evaluate the advantages and disadvantages for each design. The most important criteria for the design evaluations were the compatibility with existing systems, the compliance with spatial requirements, and the fulfillment of performance specifications.

7.2 Important Criterion for the Evaluation of Concepts

7.2.1 Compatibility with Existing Systems

During the multiple brainstorming sessions, it was important to identify the physical interfaces between the stowage unit and the two adjoining systems, the LCS and the longitudinal conveyor assembly. While both the LCS and the longitudinal conveyor could be altered to accommodate the stowage system, it was more desirable to keep all changes to a minimum. The LCS, described in Chapter 2, is a complex design with many intricate parts located in a narrow gap between the truck cab and the cone body. Due to its confined nature and compact design, major alterations of the LCS components would be significantly difficult. The longitudinal conveyor setup, shown in Figure 7.1, is a standard, self-contained assembly used in cone body vehicles. It features two large cylindrical drums that apply tension to the conveyor belt and a long frame of rollers that decrease the friction when the belt is in motion. Decreasing the length of the assembly was a feasible option since removing the rollers from the frame was a simple process. However, significant alteration to the rollers or to the end drums was not allowed because such changes would require considerable cost and effort. By allowing only minimal changes to these two systems, it was possible to establish the spatial requirements for the design of the traffic cone stowage system.

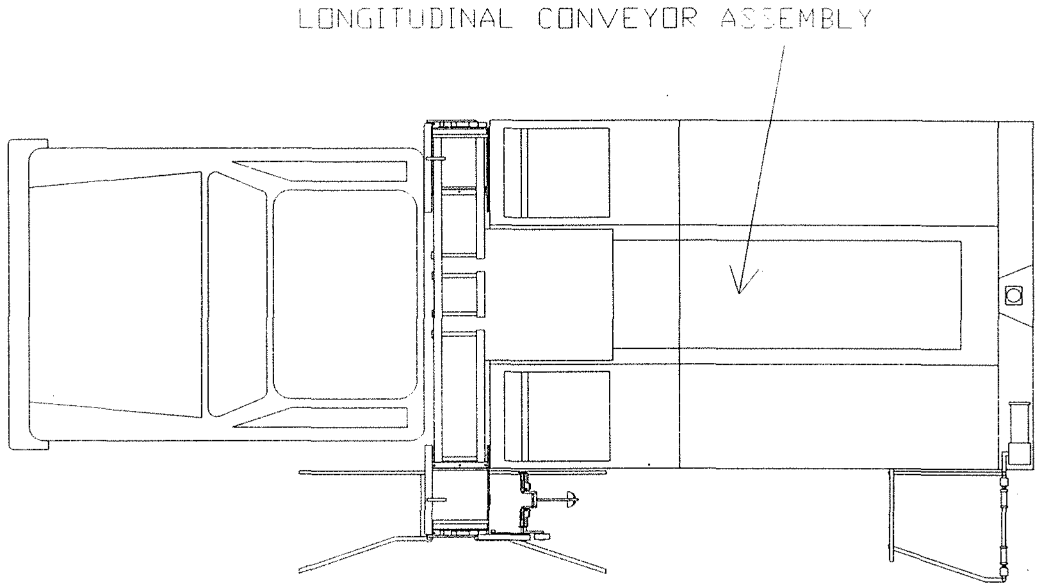

Figure 7.1 Longitudinal conveyor assembly

7.2.2 Compliance with Spatial Requirements

It was important to recognize and to consider the spatial requirements of the stowage system during the design process. The dimensions of the stowage system depends on the interface of the adjacent systems and the geometric limitations of the cone body structure. Since the components of the Automated Cone Machine (ACM) were designed around the cone body, certain dimensions could not be altered. For example, since the bucket seat areas are vital for the safety of workers and for the operations that require manual handling of the cones, these structures must remain intact and unaltered. Thus, the width of the stowage system could not exceed 51 cm (20 in), the distance between the two bucket seat areas. The length of the stowage system was restricted to the distance between the LCS and the longitudinal conveyor assembly. In order to properly access the cones from the LCS, it was possible to enter the open space located between the two narrow conveyors of the LCS as shown in Figure 7.2. This open space allows the possibility of grabbing a cone from underneath the base. The opposite end of the stowage system interfaces the longitudinal conveyor setup. The overall length of the stowage system depends on the desired amount of alteration to be performed on the longitudinal conveyor. Figure 7.3 shows the allowable space located in the LCS and the interface between the stowage system and the two adjoining systems.

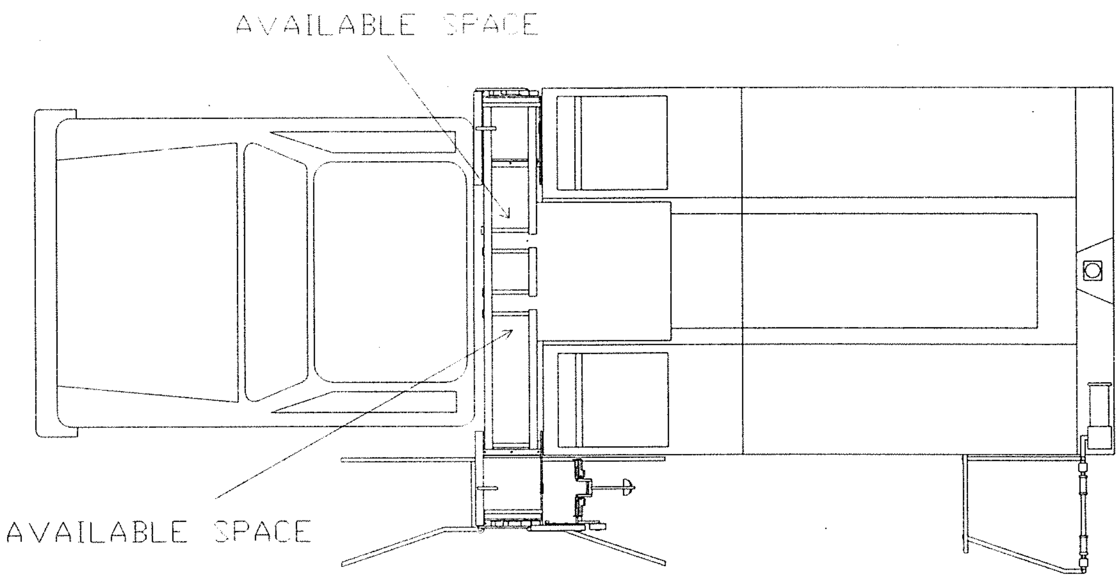

Figure 7.2 Top view of the available space in the LCS

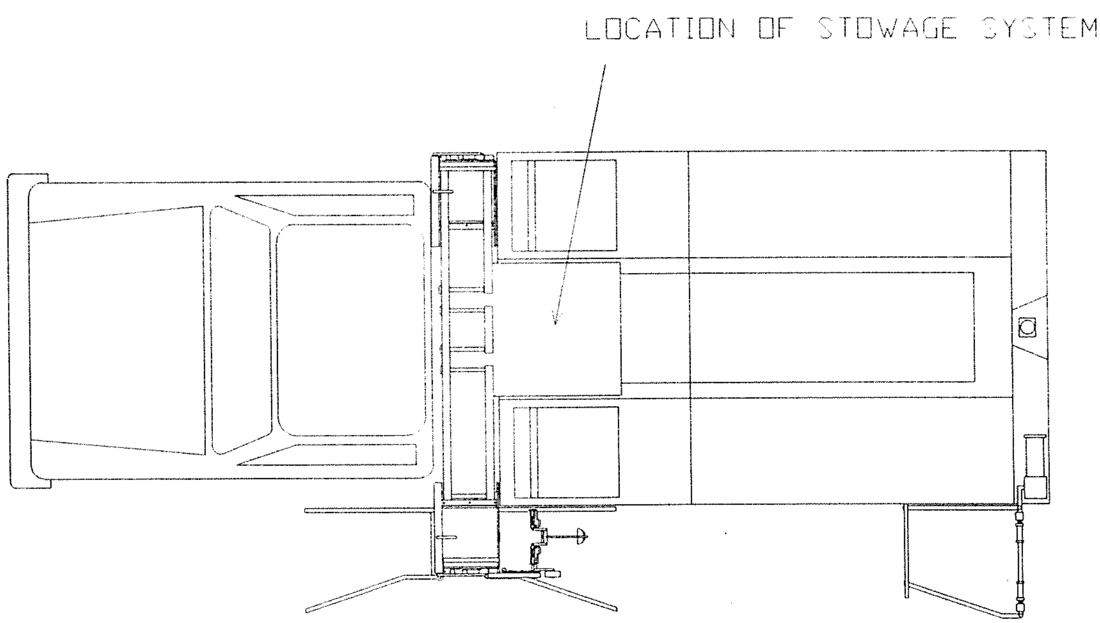

Figure 7.3 Top view of the location of the stowage system

While the cone body is a standard assembly used for all Caltrans cone trucks, various base vehicles are commonly used. Investigation of several Caltrans cone trucks revealed that the base vehicle varied in size, weight, and height. Since the allocated space for the stowage system was located directly above the frame rails, variation in the frame height of the base vehicles had to be accounted for. Assuming the vertical gap between the frame rails and the mounted cone body was smallest for large 1.5-ton trucks, it was established that the depth of the stowage system could not exceed 6 inches. A narrow 4- inch gap beneath the longitudinal conveyor and above the frame rails was also available for the design of the stowage system. Figure 7.4 shows a side view of the location for the stowage system.

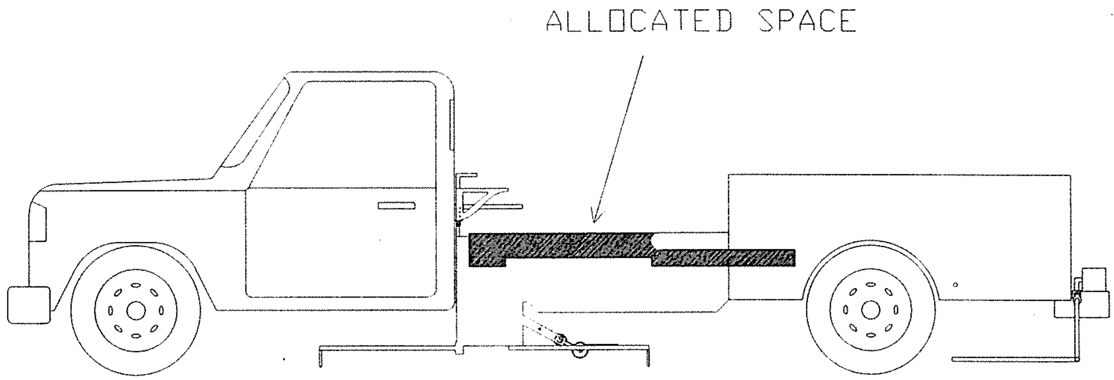

Figure 7.4 Side View of the allocated space for the traffic cone stowage system

7.2.3 Fulfillment of Performance Specifications

The stowage system is vital for both the deployment and retrieval operations because it is the means of transferring traffic cones to and from the longitudinal conveyor setup. During cone deployment operations, the stowage system had to be capable of accessing either of the two stacks of cones located on the longitudinal conveyor, transferring a previously stored cone to the LCS, and releasing a cone with steady precision on laterally moving belts. When the ACM is retrieving cones, the stowage system must be able to remove a cone from the belts of the LCS, transport the cone to either of the stowage stacks, and place it inside the hollowed base end of the last stored cone. Since the two stacks of stored traffic cones rest horizontally on the longitudinal conveyor and the LCS requires the cones to be situated in an upright orientation, the stowage system must be able to rotate the cones as they are moved between these two systems.

The grasping of traffic cones can become difficult since the compliance of the cone is dependent on the temperature. The compliance of the bases of the traffic cones remain fairly constant under various temperatures since they are bulky and solid. The hollow conical section, however, becomes very soft and bendable as temperatures rise. Since the temperatures on the road surface can become considerably high, it appears that grasping the cone base would be far more reliable than gripping the conical section during stowage.

The operating speeds of the ACM and its various systems dictate the speed at which the cone stowage system must transport cones between the LCS and the longitudinal conveyor. Since the ACM travels at 16 km/hr (10 mph) and traffic cones must be placed at 50 feet intervals in the Transition Area, the Integrated Dispensing and Retrieval Configuration (IDRC), the LCS, the stowage system, and the stowage conveyor setup are required to collectively cycle one traffic cone through deployment or retrieval procedures in approximately 3.5 seconds. Due to the limitations of the IDRC and the LCS, it was determined that the stowage system must perform its operation in approximately 1 to 1.5 seconds.

7.3 The Automated Cone Stowage System

7.3.1 General Description

The Automated Cone Stowage System (ACSS) is a very compact design that transports traffic cones between the Lateral Conveyor System (LCS) and the longitudinal conveyor assembly while adhering to all required specifications and spatial limitations. The ACSS is also fully compatible with the moving mechanisms of the two adjoining systems. The ACSS is a modular mechanism that mounts to a portable base plate that can be attached and adjusted on the frame rails of most large trucks. Actuation of the ACSS mechanisms is primarily done by using a simple motor driven belt system, small hydraulic cylinders, and a sliding linear track system as shown in Figure 7.5.

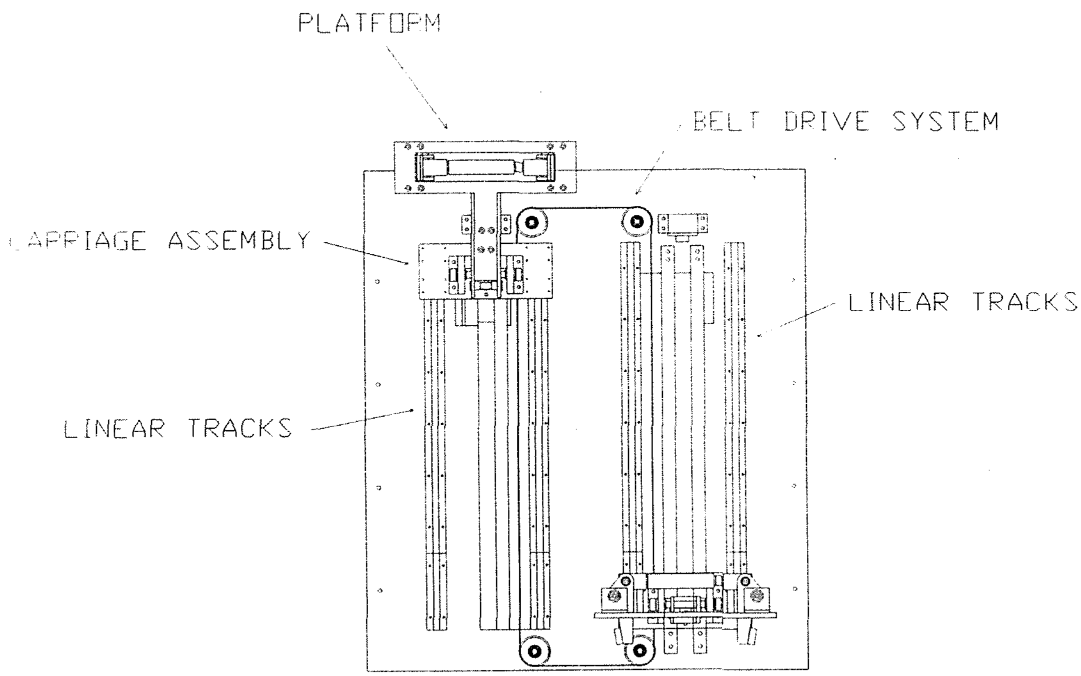

Figure 7.5 Top view of the Automated Cone Stowage System

The ACSS has two pairs of linear tracks that run parallel to the centerline of the Automated Cone Machine (ACM). These tracks serve as the means to transport traffic cones between the LCS and the longitudinal conveyor assembly. A carriage assembly, mounted on a set of four bearing blocks, slides smoothly on each pair of tracks. The two carriages are actuated by a hydraulic motor and a simple belt and pulley system. The four pulleys and the hydraulic motor are mounted on the base plate and allow the belt system to run in either the clockwise or counterclockwise direction. Since the belt is connected to both of the carriage assemblies, actuation of the hydraulic motor will simultaneously cause one assembly to move toward the LCS and the other to move toward the longitudinal conveyor. Small spring loaded blocks are mounted to the base plate and serve to reduce the speed of the carriages as they reach the ends of the tracks.

The ACSS utilizes the approach of grabbing and holding traffic cones from below the cone bases. A T-shaped platform is attached to both of the carriage assemblies and serves to extend into the adjoining systems. A small hydraulic cylinder and a pair of rotating grippers are mounted beneath each platform as shown in Figure 7.6. When the cylinder is fully extended, the grippers remain beneath the top surface of the platform. However, when the cylinder is completely retracted, the pair of grippers extend outward and to the sides of the platform. When the platform is properly positioned beneath the base of a traffic cone, the grippers can press outwardly against the inside walls of the hollow exposed section of the cone base. Once activated the cone is firmly held and ready for transport between the two adjacent systems.

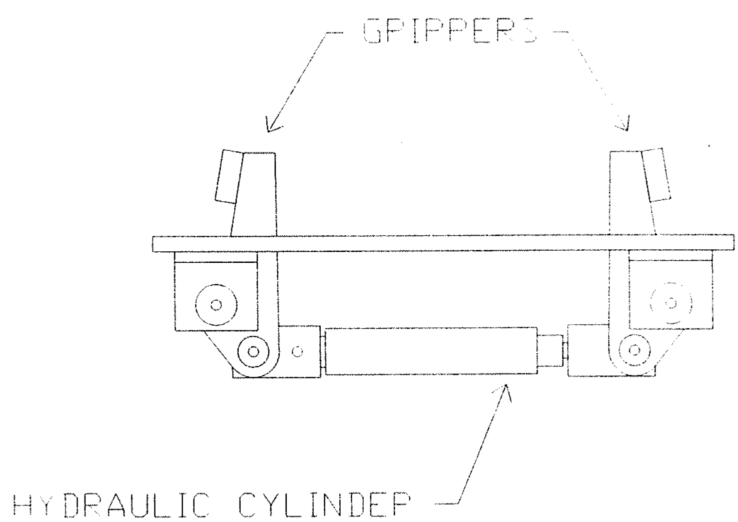

Figure 7.6 Gripper mechanisms on the ACSS

Since the traffic cones are in the upright orientation when traveling on the LCS and in the horizontal orientation when resting on the longitudinal conveyor, it is necessary to rotate the cone during transport between these two systems. A linkage system, located at the base of each carriage assembly, forces the T-shaped platform to rotate when the carriage passes by a certain position on the linear tracks. A rail system lies beneath the base plate and is designed to slope upward at the point where rotation should occur. A rod with attached rollers follows along the rail system and when it reaches the sloped portion, the rod is forced upward. This action of the rod, shown in Figure 7.7, engages the T-shaped platform and causes the necessary rotational motion. Thus, when the carriage is located at the end interfacing the LCS, the platform is in the down position. As the carriage moves toward the longitudinal conveyor, the platform rotates and remain in an upright position. The rod is placed under considerable stress as the carriage assembly is pulled into the sloped rail section. Using basic stress equations, it was determined that the maximum stress, 7.9 ksi (54.4 MPa), would occur at the top of the rod when the T-shaped platform has been lifted approximately 22 degrees from the horizontal position. The linkage system and the T-shaped platform are joined by a slotted frame that restrains the lifting motion. Simple force calculations were done on this frame and the results showed that the maximum force, 222 lbf (988 N), would occur against the slotted surface when the platform was raised 22 degrees. Proper bearings and materials were selected to alleviate this considerable load.

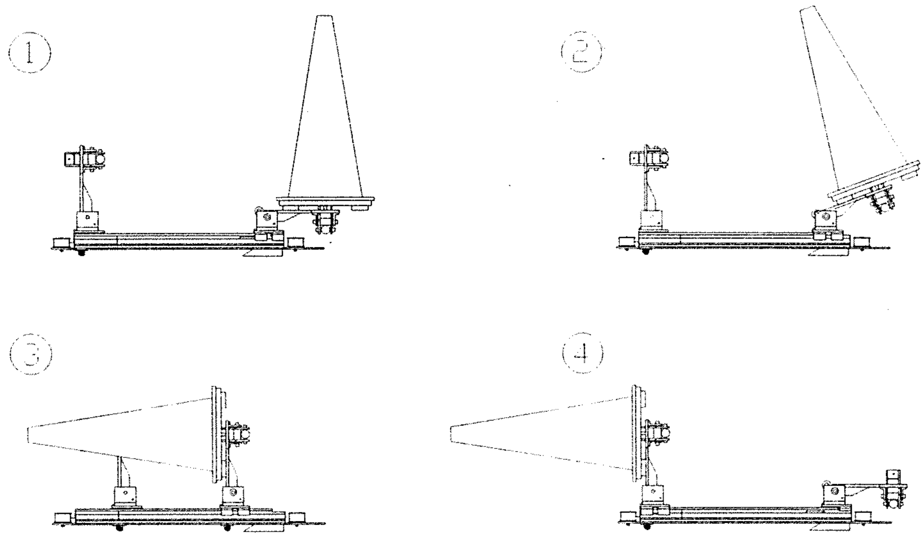

Figure 7.7 Rotational motion caused by the linkage system

7.3.2 Operation of the ACSS

Different configurations of the carriage assemblies are necessary to properly remove and store traffic cones from the longitudinal conveyor. The operation of the ACSS relies on a number of sensors to identify the number of traffic cones in each stowage stack. Depending on how the identified cones are situated on the longitudinal conveyor, the ACSS can determine which direction the belt should travel and when to extend and retract the cylinders that actuate the gripping mechanisms.

During deployment operations, the ACSS removes cones from the longitudinal conveyor and transports them to the LCS. Due to their attachment to a common belt, one carriage assembly will always be traveling in the opposite direction of the other. Furthermore, when one carriage is positioned at the LCS, the other will be positioned at the longitudinal conveyor. Four sensors mounted to the longitudinal conveyor assembly will determine whether a cone is at the edge of the conveyor and ready for transport. If the sensor locates a cone in the left stack, the left carriage will be moved to the longitudinal conveyor. Likewise, if the sensor locates a cone in the right stack, the right carriage will be moved to the longitudinal conveyor. If two cones are located by the sensors, the left carriage will be sent to the longitudinal conveyor. Finally, if no cones are located by the sensors, the longitudinal conveyor will advance the stored stacks until a cone activates the sensors. Once this occurs, the sensors will be reevaluated to determine which scenario needs to be set into motion. After a carriage is moved into a ready position, the gripper mechanism will activate and grab the inside walls of the cone base. The cone is pulled from the stack, rotated to the upright position, and held above the moving conveyors of the LCS. After the grippers close, the cone drops onto the LCS and is taken away to the Integrated Dispensing and Retrieval Configuration.

During retrieval operations, the carriage assemblies must be reset in order to determine the necessary configuration for proper cone stowage. By using the four sensor group on the longitudinal conveyor, it is possible to identify open spaces at the front end of the stored stacks of cones. If the sensors identify an empty space in the either left or right stack only, the respective carriage assembly will be moved to the LCS. When the sensors identify end spaces in the left and right stacks, the left carriage assembly will be sent to the LCS. In the case when no end spaces are located by the sensors, the longitudinal conveyor will advance the stacks until the sensors are activated. Once this occurs, the scenarios will be reevaluated. Once the correct carriage assembly is positioned at the LCS, the cones are ready to be stored. After a cone is picked up by the Integrated Dispensing and Retrieval Configuration, it is placed on to the moving conveyors of the LCS. By knowing which carriage is positioned at the LCS, it is possible to utilize the proper gate and stop the cone directly above the waiting carriage assembly. The cylinder that activates the grippers extends and the cone is firmly held. The cone is then rotated to the horizontal orientation as it travels to the stowage stacks. Once the hollow portion of the cone is placed into one that was previously stored, the grippers are released and the entire retrieval and stowage procedure is repeated.

7.4 Other Trade-Off Concepts

7.4.1 Rotating Stowage Assembly

The Rotating Stowage Assembly (RSA) is a simple and compact design that transports cones between the longitudinal conveyor stack and the Lateral Conveyor System (LCS) by means of a rotating linkage and a hydraulic cylinder. Similar to the ACSS, the RSA features two small carriage assemblies that slide on two parallel sets of tracks as shown in Figure 7.8. A rotating slotted rod connects the assemblies so that when one assembly is positioned at the LCS, the other assembly is positioned at the longitudinal conveyor. The slots located on the rod allow the carriages to move linearly on the tracks as the rod rotates. The motion of the slotted rod is actuated by a hydraulic cylinder located a short distance from the centerline of the ACM. The two carriage assemblies have platforms that are used to grab and rotate the cones during transport. The rotation of these platforms is accomplished by using small actuators mounted on the carriage assemblies.

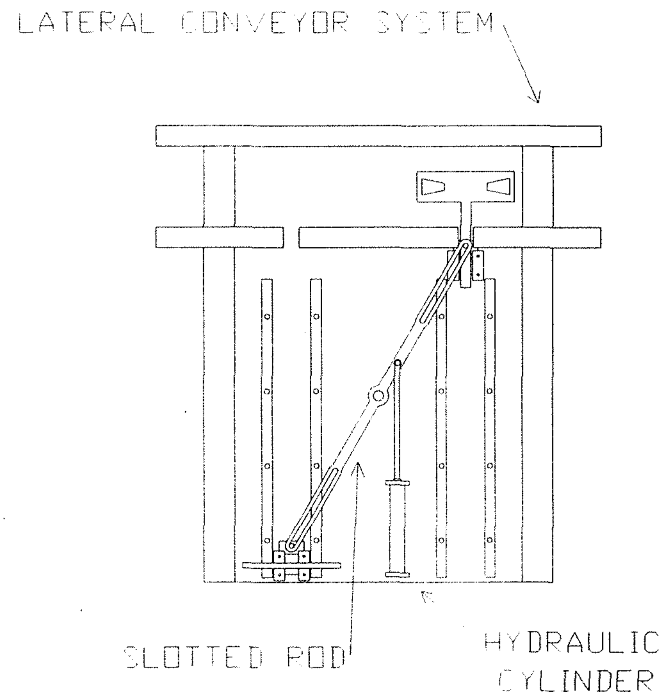

Figure 7.8 The Rotating Stowage Assembly

During the deployment and the retrieval of traffic cones, the RSA operates in a similar fashion as the ACSS. When operating in retrieval mode, the RSA sends one of the two carriage assemblies to the LCS depending on which stack has an open space. The cones are stopped in one of two positions on the LCS and a group of sensors are activated to begin the transfer procedure. The grippers located below the platform open so that the cone is held and the entire platform is rotated once the actuators are set into motion. As the hydraulic cylinder activates and travels through its stroke, the slotted rod rotates about its center, causing the carriage assembly to slide along the parallel tracks. Once the carriage assembly is positioned at the longitudinal conveyor, the cone is released and the retrieval cycle is repeated. During deployment operations, the RSA utilizes the sensors to locate which of the two stowage stacks has a readily available cone. Once the cone is identified, the hydraulic cylinder pushes or pulls the rotating rod to position the appropriate carriage assembly at the longitudinal conveyor. The grippers are activated and the carriage assembly is moved towards the LCS. During transport, the actuators rotate the platform to set the cone in the upright orientation on to the moving conveyors of the LCS.

7.4.2 Swivel Stowage Unit

The Swivel Stowage Unit (SSU) utilizes two hydraulic cylinders and a hinged conveyor platform to transport cones between the LCS and the longitudinal conveyor. The hinged platform contains two sets of small conveyor belts that take the place of the middle section of the

LCS. The conveyors are spaced apart so that an upright cone can easily ride on top of them. Instead of having two alternating platforms beneath the LCS conveyors as seen in the ACSS and the RSA, the SSU, shown in Figure 7.9, simply uses the conveyor assembly itself to rotate and to transport two cones at a time.

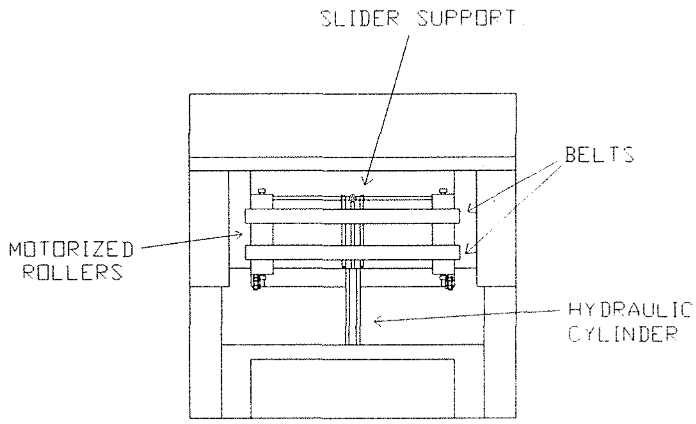

Figure 7.9 The Swivel Stowage Unit

One of the hydraulic cylinders is mounted vertically on the edge of the conveyor assembly closest to the truck cab. When the cylinder is fully retracted, the conveyor assembly is situated horizontally and is ready to accept cones that are in the upright orientation. When the cylinder is fully extended, the conveyor assembly moves to a vertical orientation since it has a hinge and slider mechanism attached on one side. This cylinder is also mounted to a track system that is positioned along the centerline of the ACM. When activated, a horizontally mounted hydraulic cylinder pushes and pulls the first cylinder and its rotating conveyor assembly between the LCS and the longitudinal conveyor.

During deployment operations, the conveyor assembly is positioned at the longitudinal conveyor. A pair of gripper mechanisms, similar to those of the ACSS, are activated to grab the two cones at the ends of the stowage stacks. The horizontal conveyor fully extends and pushes the sliding components to the LCS. The vertically mounted cylinder retracts, causing the small conveyor assembly to rotate from a vertical position to a horizontal position. The conveyor assembly activates one set belts to send one of the two upright traffic cones to the adjacent conveyors of the LCS. Both belts are then activated to send the second cone to the LCS.

During retrieval operations, the conveyor assembly is sent to the LCS and set into the horizontal position. The conveyors are activated so that when a cone travels on the LCS, it proceeds to move onto the conveyor assembly. After two cones have been positioned on the assembly, the gripper mechanisms open to capture the cones and the vertically mounted hydraulic cylinder extends to rotate the cones into the horizontal orientation. The other cylinder activates to slide the two cones toward the longitudinal conveyor as described in Figure 7.10. Once properly placed into the two stowage stacks, the grippers are closed and the traffic cones are released.

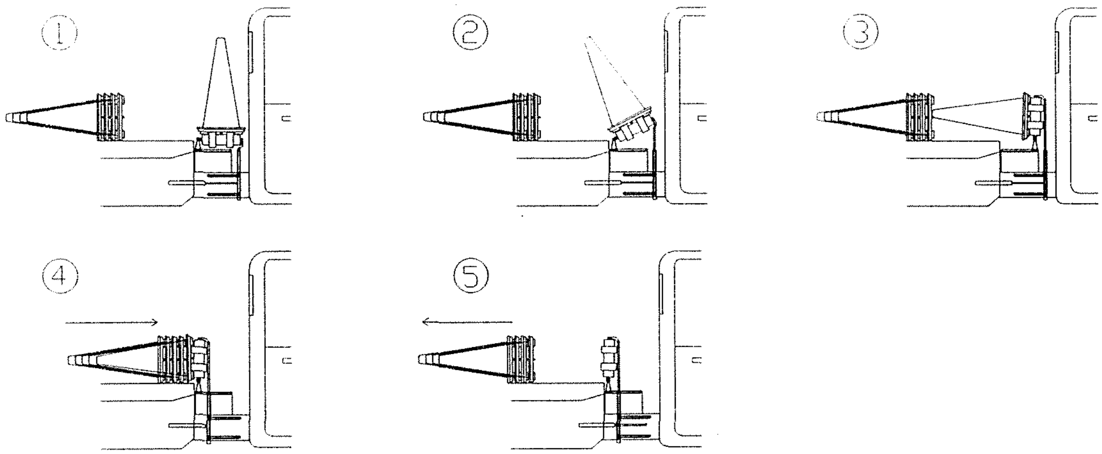

Figure 7.10 The Rotating Swivel System in retrieval mode

7.5 Evaluation of Conceptual Designs

While the three designs for traffic cone stowage systems used reasonably similar methods to transport the cones between the neighboring systems, each design had to be evaluated for the special needs of the ACM. The most critical consideration was that different base vehicles were used with the cone body frames to constitute the Caltrans cone trucks. This variability increased the need for a more modular design that could be both flexible and adaptable to different frame rail heights. In addition, the stowage system must be durable and robust under extended cyclical use and constant weathering. A trade off table, shown in Table 7.1, was used to compare the specific and cumulative advantages and disadvantages for each of the three designs. The mandatory design considerations were verified for each concept while the system and general considerations were given a weight factor. This factor ranged between 1 and 5 with 5 being the most important. A value of 1, 2, or 3 times the weight factor was given to each concept depending on how well the design considerations were satisfied. By comparing the point totals for each concept, it was possible to identify the most optimal design.

While the Rotating Stowage Assembly is a compact and modular design, its strength and durability are in question. The rotating slotted rod that allows the necessary linear motion of the carriage assemblies would be subject to large loads. Due to the confined width available and the required radius of movement, it would be difficult to provide the adequate support to keep this part from bending and rotating unevenly. Furthermore, the actuators that rotate the gripper platforms and the hydraulic cylinder that drives the carriage assemblies are not cost effective and lend to control complexities.

The Swivel Stowage Unit (SSU) design is simply too bulky for the spatial requirements of the desired stowage system. The SSU requires two hydraulic cylinders to provide the motion for its components with one of them entering the space between the frame rails of the base vehicle. While this space was available for some vehicles that were inspected, it cannot be certain whether all vehicles will have this area unobstructed. With the usage of two large hydraulic cylinders, a significant amount of hosing, and a set of linear tracks, the problem of finding adequate space would be compounded.

Since all of its components are mounted onto a single base plate, the Automated Cone Stowage System (ACSS) is simply the most modular of the three designs. The usage of a stationary hydraulic motor minimizes the necessary amount of hydraulic hosing and makes the entire assembly easier to mount. The linkage system that rotates the gripper platforms minimizes the number of actuators needed while the belt drive system that runs the ACSS is both simple and efficient. The ACSS fulfills both the spatial and performance requirements for the desired stowage system of the ACM.

Table 7.1 Trade-off Table for Conceptual Designs

DESIGN CONSIDERATION	Factor	Concept 1 ACSS	Concept 2 RSA	Concept 3 SSU
1. MANDATORY CAPABILITIES				
a. Accesses both stacks of stored cones		Yes	Yes	Yes
b. Transports cones between LCS and stowage		Yes	Yes	Yes
c. Rotates cones between horizontal and vertical orientation		Yes	Yes	Yes
d. Cycle cone within 1.5 seconds		Yes	Yes	Yes
e. Places cones steadily on LCS		Yes	Yes	Yes
f. Compatible with LCS design and longitudinal conveyor assembly		Yes	Yes	Yes
g. Handles generic 710 mm (28 in), 4.5 kg (10lb) traffic cone		Yes	Yes	Yes
h. Does not affect safety of workers seated in bucket seat areas		Yes	Yes	Yes
i. Compatible with horizontal stacking		Yes	Yes	Yes
j. Compatible with dual stowage stacks		Yes	Yes	Yes
2. SYSTEM CONSIDERATIONS				
a. Width of system less than 51 cm (20 in)	5	10	10	10
b. Minimal alterations to bucket seat areas	5	10	10	10
c. Minimal alterations to longitudinal conveyor	5	10	10	10
d. Minimal alterations to LCS	5	10	10	5

e. Stays above frame rails with minimum distance 12 cm (6 in)	5	5	5	0
f. Compatible with standard trucks	5	10	10	10
3. GENERAL DESIGN CONSIDERATIONS				
a. Durability	3	6	3	3
b. Maintainability	3	6	6	3
c. Rotary joints only	3	6	6	6
d. Compatible w/ variations in cone geometry and material properties	5	10	10	10
e. Compatible with debris (water, sand, tar) on road surface	5	10	10	10
f. Minimum of actuators	3	6	3	6
g. Minimum of sensors	3	3	3	6
h. DC electric power only	3	3	3	3
i. General safety of machinery	3	10	10	10
j. General safety of worker in bucket seat area	5	5	5	5
k. Minimal setup of equipment	5	10	10	10
l. General flexibility and modularity	4	8	4	4
m. Aesthetics	4	8	8	8
n. No patent infringement issues	5	10	10	10
o. Minimum of cylinders	3	6	3	3
POINT TOTAL	87	162	148	142

8. CHAPTER EIGHT
THE ACM POWER DELIVERY SYSTEM

8.1 Design Considerations

The operation of the Automated Cone Machine can be powered with the use of electricity, pneumatics or hydraulics. Using electricity has the advantage of easy accessibility onboard the vehicle and easy routing of lines. Furthermore, in general, electric motors and actuators operate quietly. Pneumatics, although noisier than electric power, offer some distinct advantages. With pneumatics, it is possible to pressurize the tank and use it to run specified hardware. This gives an advantage of operating equipment without taxing a vehicle's engine or bringing along an extra generator to run an onboard compressor. Hydraulics run quietly and offer compact power unmatched by either electricity or pneumatics. However, leaks are common with hydraulics, and the power needed to run the pump can sometimes cause problems. Choosing the most effective method for powering the ACM requires weighing all of the factors and selecting the most suitable candidate.

8.2 Selection of Power Delivery System

The Automated Cone Machine (ACM) requires a power source to operate the many subsystems used during cone deployment and retrieval operations. Electric and hydraulic motors are used to operate the Automated Cone Stowage System (ACSS) and the Lateral Conveyor System (LCS) while rotary actuators are used to rotate the retrieval arm and to deploy the funnel system. These individual systems must all be supplied with power for the ACM to operate a single integrated system.

As with previous decisions, a detailed trade-off analysis is performed so that an unbiased, logical judgment can be made. The different factors are weighted to emphasize the importance of each. The results are shown in Table 8.1.

Table 8.1 Trade-Off Table of Power Delivery

FACTORS	WEIGHTING FACTOR	POWER TYPES		
		HYDRAULC	ELECTRIC	PNEUMATIC
1. POWER REQUIREMENTS	5	5	3	2
2. NOISE	3	3	5	1
3. EASY INSTALLATION	3	3	4	3
4. EASY MAINTENANCE	4	3	4	3
5. WEATHERPROOF	5	5	3	4
6. BULKINESS	4	5	4	2
7. WEIGHT	3	2	3	3
8. SAFETY	5	3	3	4
9. MINIMUM EQUIPMENT	3	3	2	3
10. COST	3	3	2	3
11. LONGEVITY OF EQUIPMENT	3	5	3	4
12. SENSITIVITY OF EQUIPMENT	2	3	4	3
13. ROBUSTNESS/RELIABILITY	3	4	3	4
14. CONSISTENCY OF POWER DELIVERY	2	2	4	3
15. LEAKS	2	1	5	4
TOTALS		178	169	153

The greatest advantage that hydraulic power has over electricity or pneumatics is that hydraulics easily satisfy the power requirements of the retrieval arm. Power estimates using hydraulics have been calculated at 1400 Watts (1.9 horsepower) or greater (see Calculation 8.1). Electricity and pneumatics have difficulty delivering this power. Hydraulic systems have more than enough power to operate the ACM and are well suited for the hardware from each of the subsystems. A pump unit that delivers up to 6500 Watts (8.75 horsepower) is used to power the retrieval arm.

8.3 Design Evolution of the Hydraulics

The design of the hydraulic circuit begins with the selection of hydraulic components. This selection must take into account the torque and force requirements of the subsystems of the ACM. At the same time, the hydraulic schematic must deliver the necessary amount of flow and pressure to ensure that the actuators, motors and cylinders all perform as needed. The first design incorporates a constant flow, constant pressure pump. This preliminary design utilizes a three way rotary flow divider with an internal relief valve as shown in Figure 8.1. This schematic, although sound in design, can not be constructed with conventional components. There are no rotary flow dividers available that can handle such small flows. Conventional flow dividers create extraneous heat and the rotary flow dividers are more desirable.

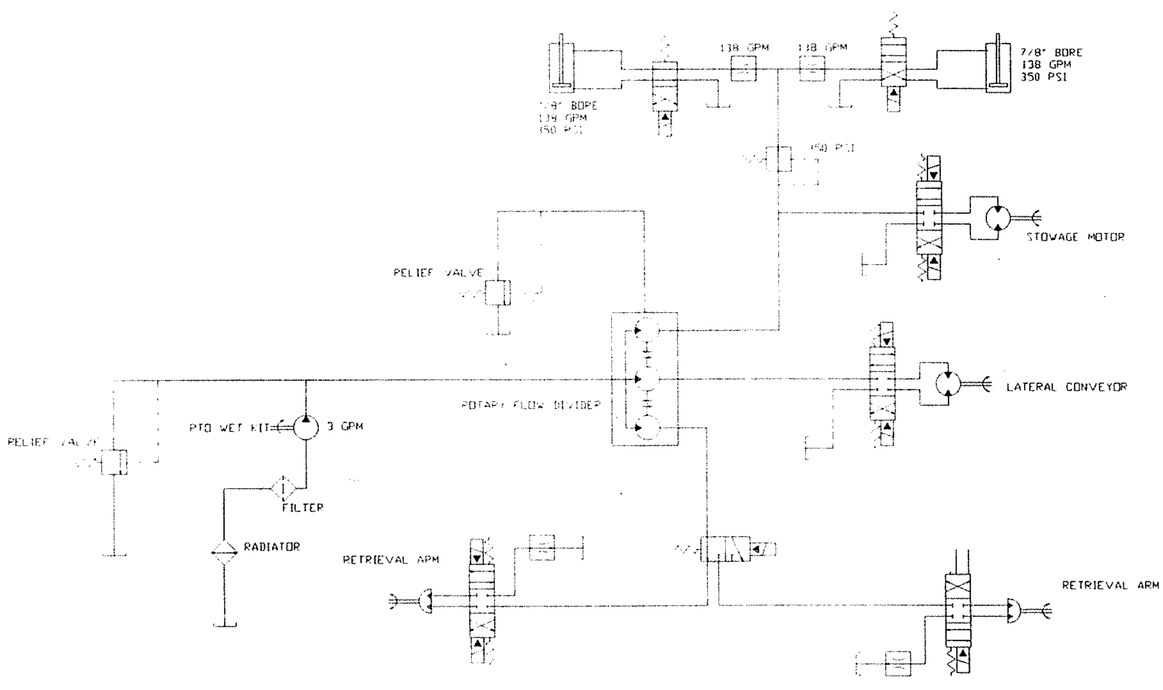

Figure 8.1 First Hydraulic Schematic

The next design uses conventional flow dividers (see Figure 8.2). In order to ensure that there are no heat generation problems in the circuit, a smaller, constant flow pump was used. This pump delivers only .13 liters per second (2 gallons per minute) versus the .19 liters (3 gallons per minute) put out in the previous design. This means that there would be no extra available power in the circuit if more would be needed. Also, there is no certainty that the design would actually be free from heat generation problems, especially considering that the oil reservoir would be housed in the engine compartment of the truck. A radiator would be required to dissipate the heat. Furthermore, many extra components would be needed to make this hydraulic circuit design work effectively.

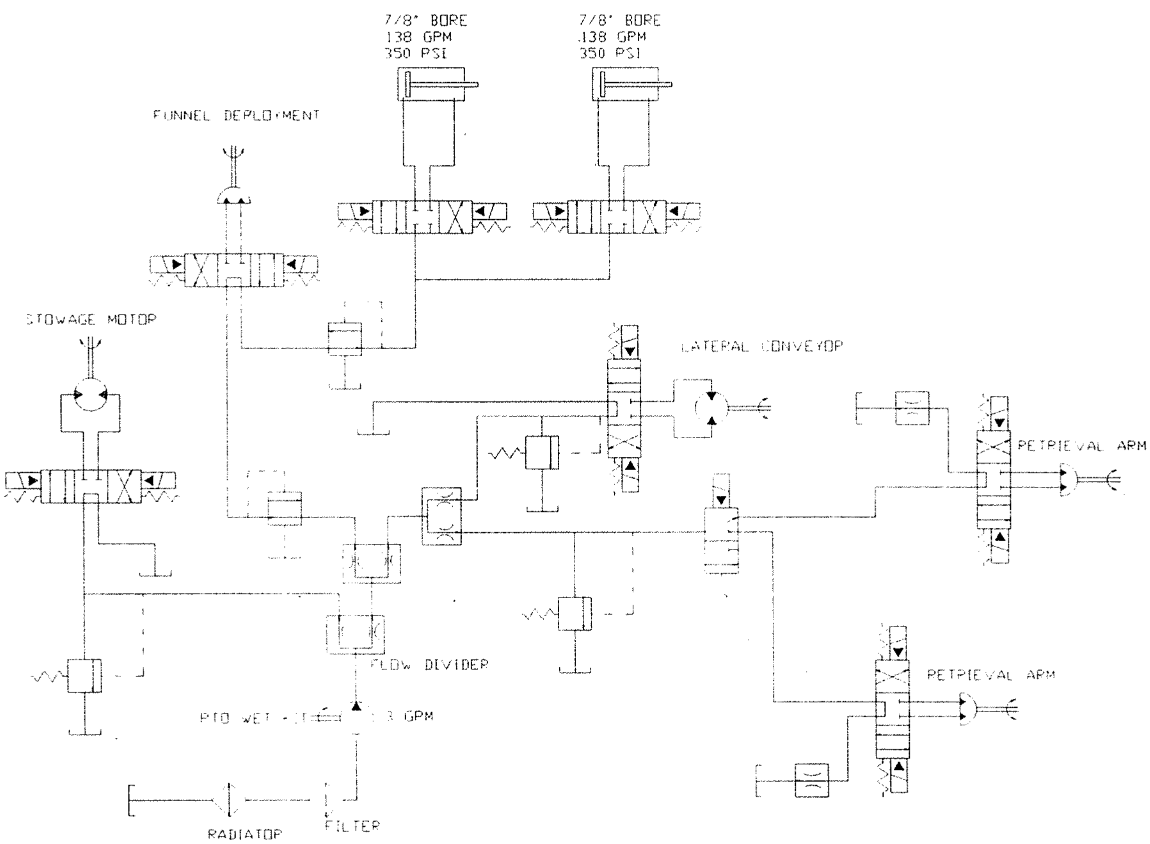

Figure 8.2 Second Hydraulic Schematic

The next hydraulic circuit design utilizes a variable displacement pump. This represents a major change in the flow of circuit designs. With a variable displacement pump, there is no excess heat generated from flow over a relief valve which occurs in the previous two designs. The pump delivers only as much flow as is demanded by the circuit. Also, the pump can be slightly oversized to ensure that there is enough power transmitted to all the components of the circuit. The circuit design is greatly simplified as shown in Figure 8.3.

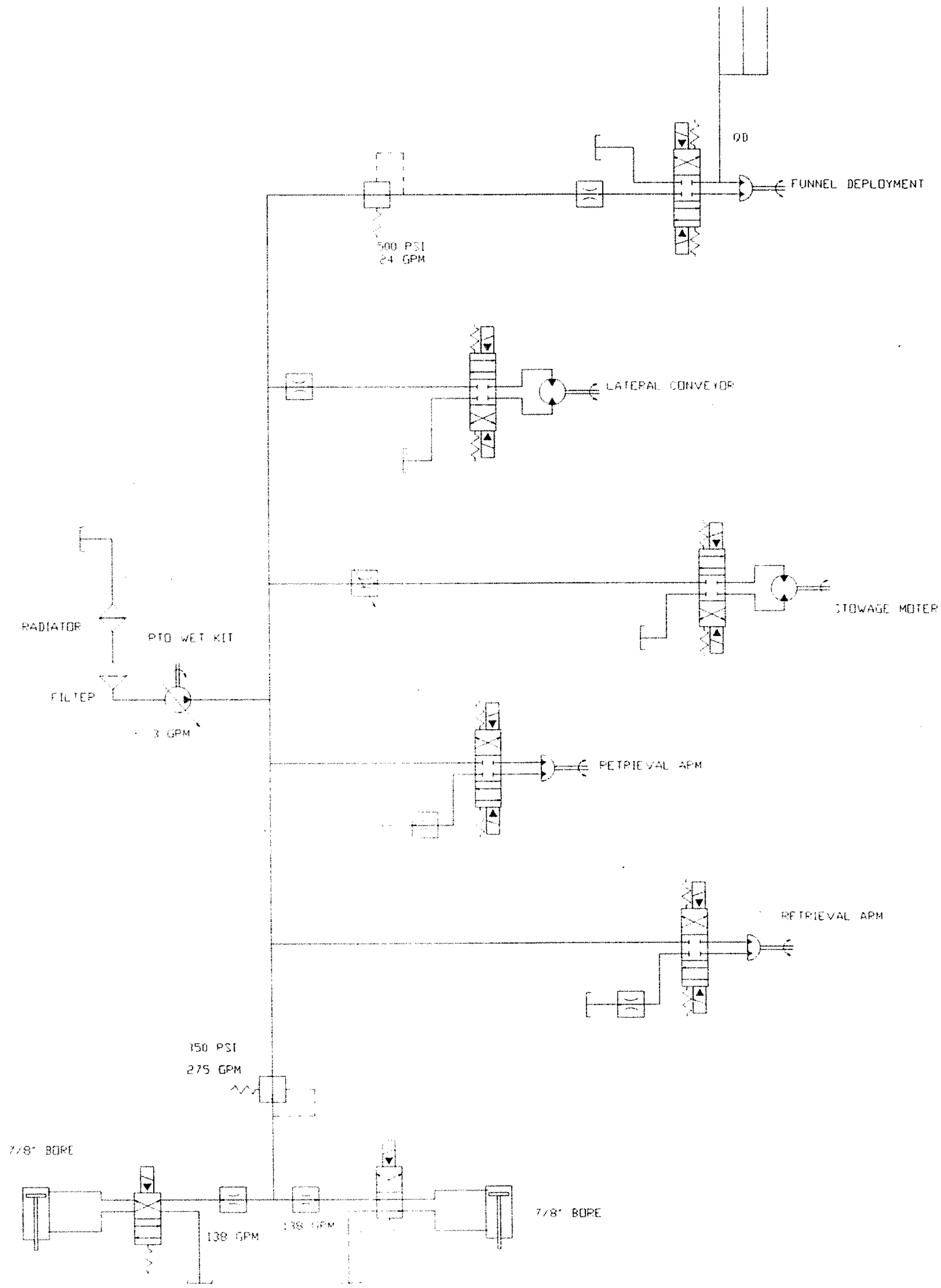

Figure 8.3 Current Hydraulic Schematic

The only drawback of a variable displacement pump is its cost. This type of pump, a piston pump, is substantially more expensive than the gear pumps of the previous two designs.

However, due to the simplification of the circuit, fewer components are needed to build the circuit. The use of the variable displacement pump circuit costs less than building a circuit with a constant flow pump. These cost savings and simplification of the circuit are the main factors in the decision to adopt this design. Figure 8.4 below shows the distribution box for all of the hydraulic valves of the circuit.

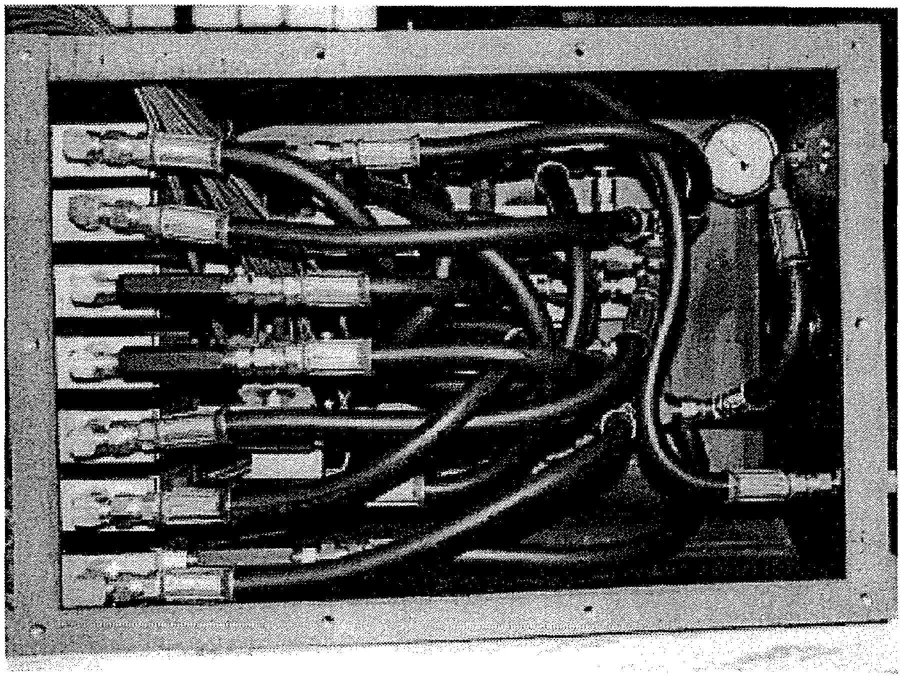

Figure 8.4 Hydraulic Distribution Box

Although there should be no heat generation problems caused by excess flow over a relief valve, there can still be some heat generation caused by losses in the circuit. Each of the valves, the fittings and even the hoses themselves can cause some heat in the circuit. Also, the reservoir is housed in the engine compartment having a capacity of only 19 liters (five gallons). This small amount of oil in this hot environment means that even minor increases in the temperature can cause some problems. In order to avoid these situations, a radiator is added to guarantee reliable operation.

9. CHAPTER NINE
COORDINATED CONTROL UNIT

9.1 Control Requirements

The Coordinated Control Unit (CCU) is responsible for the complete automation of the Automated Cone Machine (ACM). It is the vital link to each of the mechanical components and supporting power systems described in the pervious chapters. By way of a single operator interface, a worker is able to run all cone retrieval and deployment operations via the CCU while seated in the cab of the ACM. In addition, the CCU is capable of controlling each sub-system independently for maintenance and testing purposes.

The CCU consists of multiple computer software routines loaded on two separate miniature controllers, each with added hardware support components. Through vital input sensors located throughout the ACM and linked to one of the controllers, the software is designed to locate and control the exact position of the cones.

9.2 Hardware Selection and Setup

The hardware selected for the CCU consists of the following Z-World Engineering products: (1) two, Little Giant C-Programmable Miniature Controllers; (2) four, Relay6 Expansion Boards; (3) one, IOE-DBL96 Expansion Board; and (4) one, Keyboard Display Module. By purchasing each of these components directly from Z-World Engineering, compatibility between the components is insured. Figure 9.1 illustrates a block diagram of each of the CCU's components.

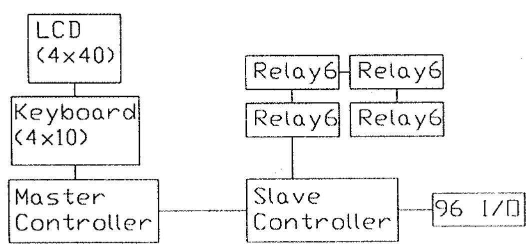

Figure 9.1 CCU Block Diagram

9.2.1 Little Giant C-Programmable Miniature Controllers

The Little Giant is an extremely versatile C-Programmable Miniature Controller. Based with a Z180 microprocessor, it includes such features as a 16-bit parallel port and four serial ports capable of asynchronous and synchronous communications at 57,600 baud. For the user interface, a standard (Hitachi) 8-bit LCD interface is included which will support both character and graphic displays. Seven analog inputs are also included which are capable of 10,000 samples per second for continuous sampling of one channel, and an eighth analog channel is setup to read the board temperature. All eight analog input channels have an operational amplifier for signal conditioning within, which the associated gain and feedback resistors can be changed to adjust the signal gain and type of interface. In addition, the Little Giant includes programmable timers, EPROM, lithium battery, SRAM, EEPROM, time/date clock, watch-dog timer, and power failure detection. Figure 9.2 illustrates the exact location of each of these features on the Little Giant Controller.

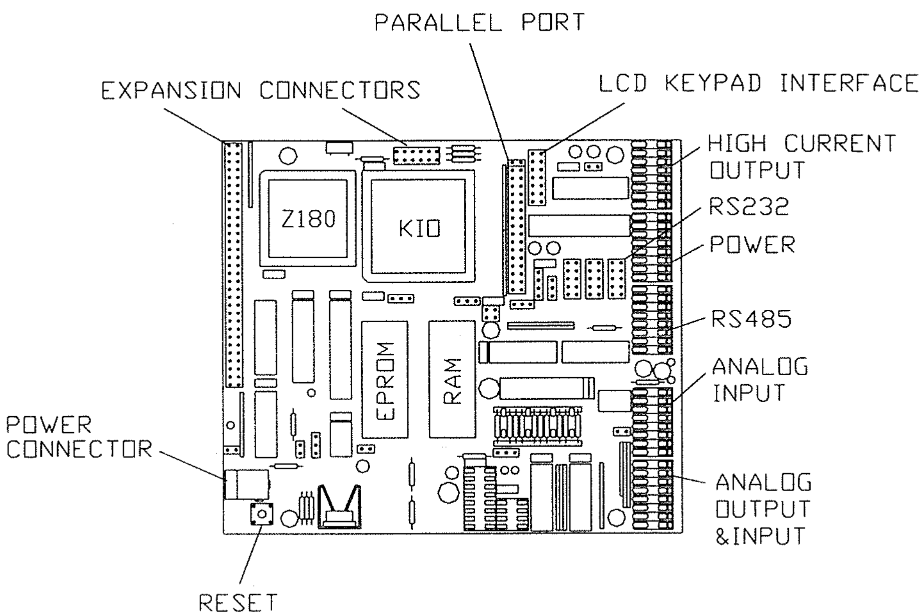

Figure 9.2 Little Giant

The CCU utilizes two Little Giant Controllers connected by RS485 serial communication interface. Although only one Little Giant is actually required based on the demands of the CCU, the limiting factor is the location of the hardware components. The user interface, referred to as the Key Board Display module, is required in the cab of the ACM, but the remaining hardware components are required to be mounted on the exterior of the ACM within a storage compartment. The distance to route a cable between these two locations is approximately 2.4 m (8 ft). The problem that exists is that the Keyboard Display Module cable can be a maximum of 15.2 cm (6 in) because it is connected directly to the data bus on the Little Giant. In order to resolve this problem, two Little Giants are utilized. The first, referred to as the Master Controller, is installed with Keyboard Display Module in the cab of the ACM. The second, referred to as the Slave Controller, is installed with the remaining hardware components. The two controllers are then linked together via a serial communication interface. RS485 was chosen as the interface of choice, since it is much more noise-resistant and reliable over large distances than RS232.

9.2.2 Relay6 Expansion Boards and Relay Outputs

A total of four Relay6 expansion Boards are daisy-chained to the Slave Controller. As the name implies, each Relay6 Expansion Board has 6 relays installed which are individually controlled through software. Accordingly, a total of 24 individual relays are available for use by the CCU. Each relay is protected from transients by a metal oxide varistor and a 10-amp fuse. Figure 9.3 illustrates the layout of a Relay6 Expansion Board.

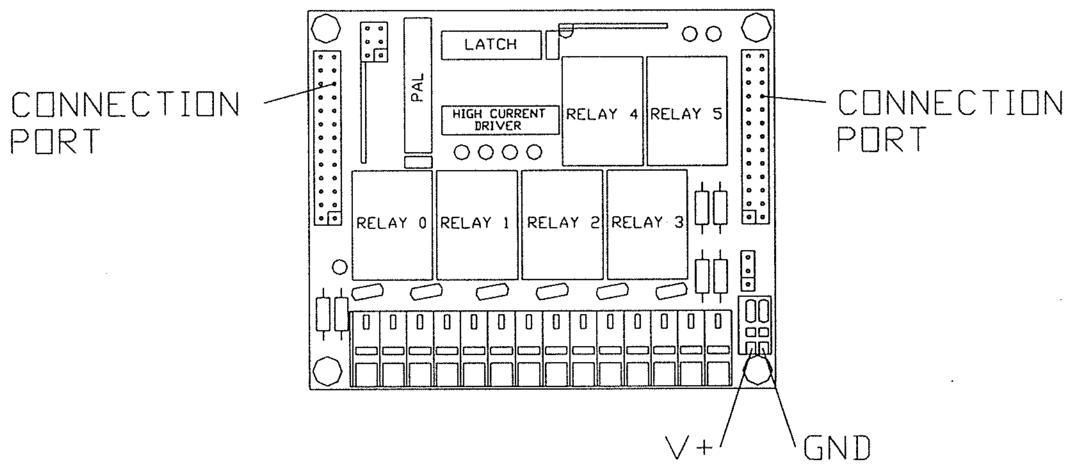

Figure 9.3 Relay6 Expansion Board

Based on the number of outputs required by the CCU, a total of 23 relays are required. Table 9.1 lists each output and the corresponding relay. Each relay in use is connected to either a 12 Vdc motor or a solenoid.

Table 9.1 Relay Identification List

	Description	Relay Board	Relay number
1	Left Gripper	6	3
2	Right Gripper	7	0
3	Lateral Conveyor Left to Right	7	1
4	Lateral Conveyor Right to Left	7	2
5	Left Stowage Arm Forward	7	4
6	Right Stowage Arm Forward	7	3
7	Left Retrieval Arm Down	6	0
8	Left Retrieval Arm Up	7	5
9	Middle Gates	5	0
10	Main Conveyor Forward	5	1
11	Main Conveyor Reverse	5	2
12	Left Box Down	5	3
13	Left Box Up	5	4

14	Back Left Primary Funnel Up	6	5
15	Back Left Primary Funnel Down	6	4
16	Cooler On/Off	6	2

Due to the negative effect of inductive voltage spikes created by solenoids, all solenoids controlled by the CCU are supplied with a diode for suppression. The electrical circuit is illustrated in Figure 9.4. Diode suppression is used to prevent the build-up of emf from discharging back toward ground, and thus creating a large voltage spike across the power lines. In the case of the CCU, this could potentially have severe adverse affects to any of the computer hardware components, and in particular, the relays, since they are directly attached.

The Drop Box Systems (DBS) is the only system of the ACM that requires extra relays to be used in conjunction with the CCU relays. In this system, two double position relays are connected together to produce a circuit capable of controlling the direction of the current through the electric drive motor for either forward or reverse directions. The wire schematic is illustrated in Figure 9.5 with both relays in their normal state. Both of these relays are forced to change from their normal positions by the activation of single CCU relays.

By varying the status of the two relays, the circuit in Figure 9.5 has a total of four possible states. In the first state, relays 1 and 2 are not energized. Consequently, both relays 1 and 2 remain in their normal state, and therefore the motor is not energized since leads AE and BF are connected to +12 volts. In the Second state, relay 1 is energized while relay 2 remains unenergized. As a result, the motor is powered in the forward direction allowing the DBS to deploy. This is possible since lead CE is connected to ground and lead DF is connected to +12 volts. In the Third state, relay 1 remains unenergized while relay 2 is energized. Just like in state 2, the motor is powered, but this time the motor turns in the opposite direction. This is possible since lead AE is connected to +12 volts and lead DF is connected to ground. In the final state, both relays are energized, but no power is delivered to the motor since both leads are connected to ground.

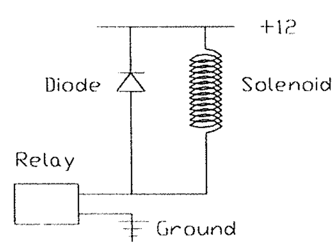

Figure 9.4 Diode Suppression on Solenoids

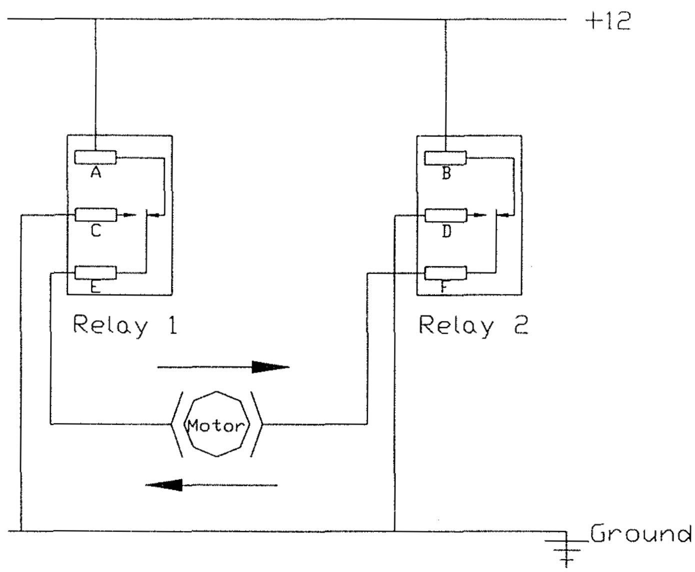

Figure 9.5 Relay Lockout System

9.2.3 IOE-DGL96 Expansion Board and Sensor Inputs

The IOE-DGL96 Expansion Board (see Figure 9.6) connects directly to the Little Giant Controller via a 64-pin connection. Each board is capable of handling 96 individual digital lines with a TTL signal used as input or output (I/O). A maximum of four boards may be mounted in series to the Little Giant resulting in a total of 384 digital I/O lines.

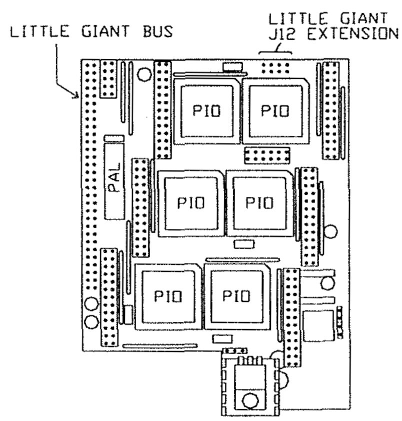

Figure 9.6 IOE-DGL96 Expansion Board

The CCU requires one IOE-DGL96 Expansion Board attached to the Slave Controller. A total of 20 lines are used as inputs that attach to various types of sensors located throughout the

ACM. Table 9.2 classifies each digital I/O attached and their associated address on the Board. Each switch is connected between ground and 5 volts positive, with a normal open state.

Table 9.2 Digital I/O Identification List

	Description	I/O Address	Bit
1	Stowage Left Arm Down	0xB800	0x01
2	Stowage Right Arm Down	0xB800	0x02
3	Photo-sensor Forward Left	0xB800	0x04
4	Photo-sensor Forward Right	0xB800	0x08
5	Photo-sensor Rear Left	0xB800	0x10
6	Photo-sensor Rear Right	0xB800	0x20
7	Dropbox Left Side Up	0xB800	0x40
8	Dropbox Left Side Down	0xB801	0x80
9	Dropbox Right Side Up	0xB801	0x02
10	Dropbox Right Side Down	0xB801	0x20
11	Bumper Switch Left Ret. Arm	0xB801	0x04
12	Bumper Switch Right Ret. Arm	0xB801	0x01
13	Retrieval Arm Left Stow	0xB801	0x40
14	Retrieval Arm Right Stow	0xB600	0x02
15	Platform Switch Left Side	0xB600	0x01
16	Platform Switch Right Side	0xB600	0x04
17	Outboard Gate Left Side	0xB600	0x08
18	Outboard Gate Right Side	0xB600	0x10
19	Middle Gates	0xB600	0x40
20	Abort	0xB601	0x04

9.2.4 Keyboard Display Module

The Keyboard Display Module (KDM) consists of the following three components: (1) KDM Controller Board, (2) Liquid Crystal Display (LCD), and (3) Keyboard Panel. Figure 9.7 illustrates each of these components assembled on the KDM. The Controller Board is capable of handling both character and graphic LCD displays with maximum display sizes of 4x40 and 240x128, respectively. Also, two standard size Keyboard Panels are available which are compatible with the Controller Board in either 4x6 or 4x10 sizes.

Based on the requirements of the CCU, a single KDM is attached to the Master Controller to supply the user interface. A 4x40 character display was selected with a 4x10 keyboard panel to supply maximum capability for input and output to the operator. The KDM is housed in a single hand held enclosure that can be relocated to one of two connectors located on the ACM. In either of the two locations, the KDM is connected directly to the Master Controller.

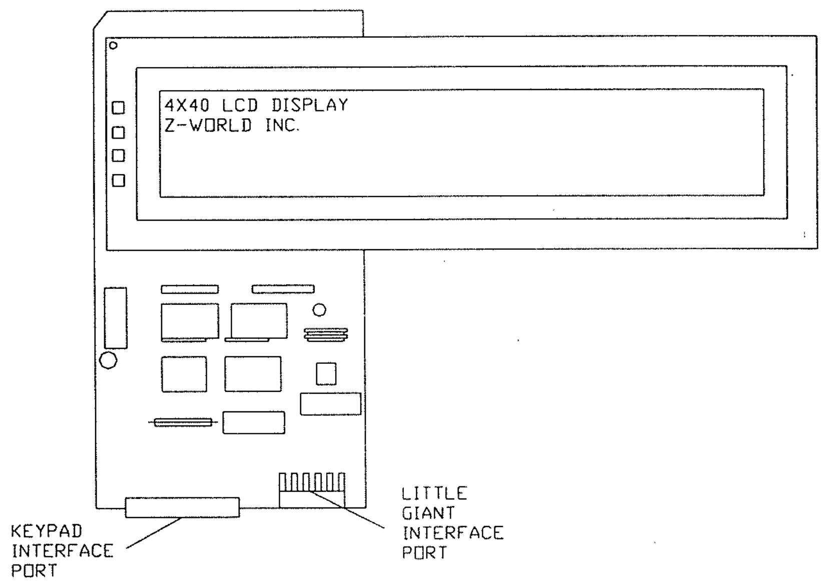

Figure 9.7 Keyboard Display Module

9.3 Software Design

The software language used to program the Z-world controllers is Z-world's own Dynamic C. This language is based around the standard C software language, but has added features to accommodate their hardware components. Dynamic C includes such features as a fast floating point math library, a real-time kernel, and a utility program for creating EPROM files.

Through an IBM compatible PC connected to the Little Giant Controller via RS232 communication, Dynamic C programs are developed and tested. Once complete, the programs are loaded onto the Controllers in one of two ways. For temporary use, the program is loaded into EPROM and held in place by battery backup. For permanent use, as in a stand alone unit, the program is burned in EPROM.

For this test bed application of the ACM, both the Master and Slave Controllers each have Dynamic C programs loaded into EPROM with battery backup. Listed below are detailed descriptions of both programs, which are each listed in Appendix C.

9.3.1 Master Program

The Dynamic C Master Program coordinates all input from the user and sends the appropriate commands to the Slave Controller for execution. The Master Program is divided into several functions which display various menus on the LCD. The operator creates an execution by pressing the appropriate key on the keyboard corresponding to the desired action listed on the LCD. The software then responds to a correct keypad input by sending a corresponding coded message to the Slave Controller and then displaying on the LCD which action was executed. During this time, the Master Controller waits in standby mode until the Slave Controller signals back to the Master Controller that the execution is complete.

9.3.2 Slave Program

The Slave Program is substantially larger than the Master Program since it is responsible for complete control of the ACM. It is directly responsible for reading all sensors connected to the digital I/O's and for controlling all relays connected to the motors and solenoids. Through select Dynamic C commands and the corresponding addresses, the Slave Program is capable of accessing all I/O and relays.

With such a large number of addresses and commands to keep track of, individual functions were created in the Slave Program for each sensor reading and relay action required. This serves two purposes. First, it greatly reduces the amount of code required in the Slave Program, since these actions can now be performed by an execution of a single function name. Because these functions are used numerous times throughout the Program, this eliminates having to list the additional lines of code established in each function every time the operation is desired. Second, to make the program easy to follow, each function was named corresponding to the type of function executed. For example, the function name for reading the right outboard gate sensor is the following: right_gate_sensor( ). Now each time the right_gate_sensor() function is listed within the Program, it is apparent which action is taking place, and therefore it is not necessary to decipher the individual addresses.

To make the Slave Program as robust as possible, sensor readings are taken multiple times within a 10 ms period to ensure the accurate status readings of the sensors. Since it is very difficult to eliminate all possible electrical transients within the system, it is not uncommon to experience a random false sensor reading. Therefore, by taking several readings within a given time sample, false readings are averaged out and integrity of the CCU is maintained.

During startup, the Slave Program remains in standby mode until the Master Program sends a coded operational signal for execution. Once received, the Slave Program deciphers the code and executes either of 10 operational functions available. Of the ten, the two most common operations are used for the complete deployment and retrieval of the cones. The remaining eight functions are used to control individual systems for setup or testing. Once complete, the Slave Program goes back into standby mode and sends a signal back to the Master Program to notify that the execution is completed. Listed in the next two sections are detailed descriptions of the program logic for Deployment and Retrieval Operations.

9.3.2.1 Deployment Operation

At the beginning of the execution of the Deployment Operation, the Slave Program stows the following nonessential systems: the Primary Funnel Tipping Bar System (PFTBS), Retrieval System, and the Wing Actuator of the Lateral Conveyor System (LCS). Unlike other Systems not utilized during the Deployment Operation, these Systems would potentially interfere with the cones path if allowed to remain in any other orientation than stowed. Consequently, these systems are required to be kept stowed entirely throughout the duration of the Deployment operation.

The next progression of the Program is to align the forward most cone or cones on the Main Conveyor Belt System (MCBS) with the forward photo sensors. Figure 9.8 and 9.9 illustrate the flow chart and pseudo code progression of this operation, respectively. The flow chart consists of symbols used to illustrate the top view of the cones on the MCBS in relation to the photo sensors. The larger boxes symbolize the area between the photo sensors, whereas, the smaller boxes located within the larger boxes symbolize the cone bases. Cone bases positioned in the top portion of the photo sensor area are used to illustrate the triggering of the forward photo sensors. Cone bases positioned in the bottom of the photo sensor area are used to illustrate the triggering of the rear photo sensors. For consistency between the Deployment and Retrieval operation, the rear photo sensors are shown even though they are not used during the Deployment operation.

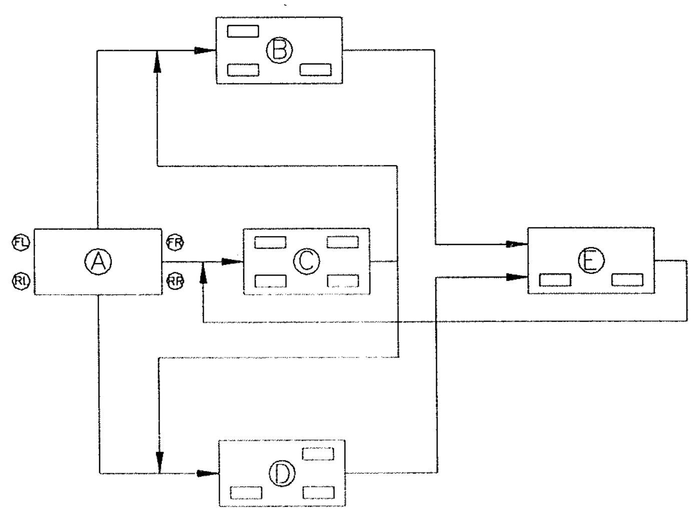

Figure 9.8 Deployment Flow Chart Using Photo Sensors

```
if A    ┌ if B
        │     then E
        │ else if C   ┌ if B
        │             │     then E
        │             │ else D
        │             └     then E
        │ else D
        └     then E

else if C   ┌ if B
            │     then E
            │ else D
            └     then E

else if B
      then E

else if D
      then E

else E
      then E
```

Figure 9.9 Deployment Control Logic Using Photo Sensors

Following the setup procedures, the Stowage System requires the Slave Program to determine if any cone bases are correctly aligned on the MCBS for the Deployment Operation. Without the correct alignment of the cone bases, the Stowage System is unable to effectively grasp a cone base with the grippers. Then once the correct alignment has been determined to exist, the Program coordinates with the Stowage System by instructing which side of the Stowage System to engage for a cone deployment. A total of four possible case scenarios exist, which are each required to be handled by the Program.

In the first case, the Stowage System is unable to successfully engage a cone base from either the left or right stack since neither of the two forward photo sensors are triggered. Consequently, the MCBS is powered in the forward direction until one of the two forward photo sensors are triggered by the presence of a cone base. Immediately following the triggering of the sensor, the power is deactivated and the cone base(s) are halted within 3 mm (0.125 in) of the triggered position. This stopping range is determined to be within the operating range of the Stowage System which is designed to handle a cone base deviation of plus or minus 6 mm (0.25 in).

The remaining three cases involve making a decision on which side of the Stowage System to activate since the left, right, or both cone stack(s) have a correctly positioned cone base. The forward photo sensors are again used as input for these decisions, but this time the MCBS is not required to be activated. For the two cases involving only a single correctly positioned cone base, the program has no choice but to activate the Stowage System to the corresponding side the cone is located. However, when two cone bases are correctly positioned, the Program is required to select a side since the Stowage System is limited to transporting only one cone at a time. To simplify this decision, the Program is designed to default to a left stowage deployment when deciding between which of the two cone bases to engage.

After a cone has been placed on the LCS by the Stowage System, the Program activates the LCS in the direction of the selected deployment side and then monitors the corresponding platform switch. Upon complete deployment of the cone, the platform switch is triggered by the cone, thereby signaling to the Slave Program to perform the next cone deployment. The program continues with the cone deployments until both of the cone stacks are exhausted on the MCBS or until the program is halted by the activation of the manual escape key located on the operator interface.

9.3.2.2 Retrieval Operation

Contrary to the Deployment Operation, the Retrieval Operation requires the use of the PFTBS, the Retrieval System, and the Wing Actuator of the LCS. As a result, the beginning of the Retrieval Operation consists of the deployment of each of these systems. Of the three, the Retrieval System is the only system not constrained to the deployed position for the duration of the Retrieval Operation.

Following the setup procedure, the Retrieval Program prepares the MCBS for cone placement for use by the Stowage System. A flow chart and pseudo code progression for this execution are illustrated in Figures 9.10 and 9.11, respectively. The symbols used in the flow chart are the same as those described for Figure 9.8 in the Deployment Operation.

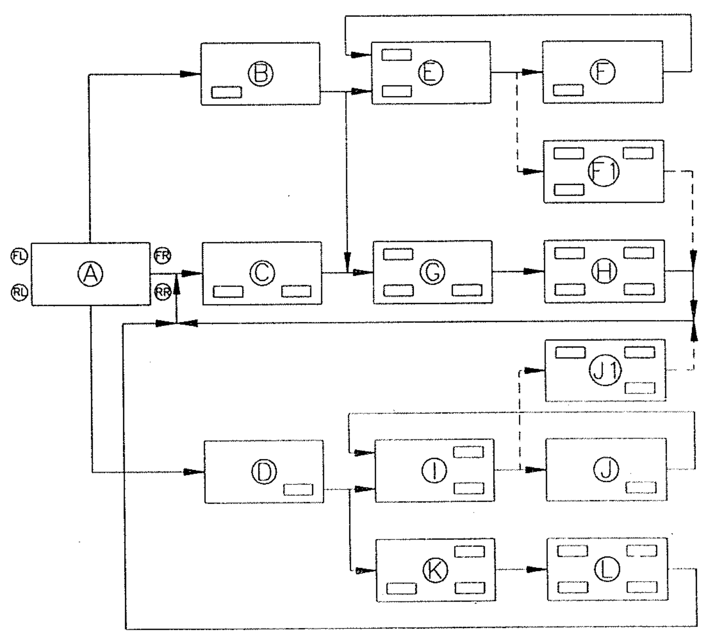

Figure 9.10 Retrieval Flow Chart Using Photo Sensors

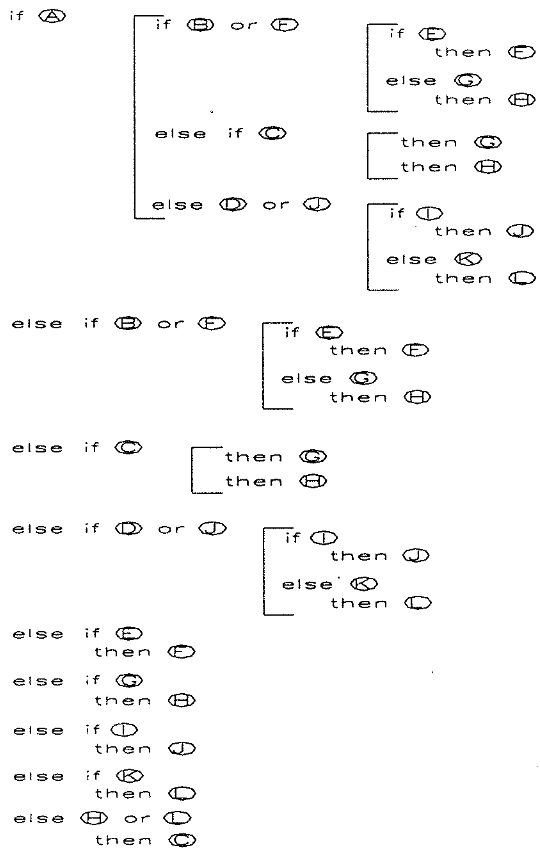

Figure 9.11 Retrieval Control Logic Using Photo Sensors

Through the use of both sets of the photo sensors, forward and rear, the Retrieval Program is capable of correctly locating and positioning the cone stacks accordingly on the MCBS. The Program is designed to handle a total of five possible case scenarios involving the location of the cones on the MCBS. In all of the cases, the outcome required is for either of the cone stacks to have the last cone aligned with the rear photo sensors. As a result, the corresponding forward photo sensor area is left empty, thus, allowing the correct amount of room for the Stowage System to place a cone into the stack.

Due to the limitations of the MCBS, the Program is also designed to stagger the placement of the cones onto the MCBS. In other words, the cones must be placed in any of the two stacks, so there is no more than a cones difference in length between the stacks. Therefore, it is very important that the cones are initially setup on the MCBS correctly before the ACM is operated.

In the first case, no cones are aligned with any of the four photo sensors. Consequently, the MCBS is powered forward until one of the two rear photo sensors triggers from a cone base. From this point, the program evaluates the new input results of the rear photo sensors and determines the next course of action which is described by the other possible case evaluations.

In the second case, the last cone of each stack on the MCBS is positioned triggering the rear photo sensors. This permits the Stowage System to successfully place a cone onto either side of the MCBS without having to reposition the Stacks. However, to maintain consistency within the control process, the Program is setup to default to the left side, as in the Deployment Program, for cone placement on the MCBS by the Stowage System when this situation arises.

The next two cases also involve no activation of the MCBS. They contain one cone stack completely forward to the corresponding sides forward photo sensor, and the other stack to the corresponding rear photo sensor. In either case, only one side is able to handle a cone for stowage since that side's forward photo sensor is not triggered. Consequently, the Stowage System is activated to stow a cone on the only available side.

In case five, both cone stacks are completely forward to the forward photo sensors, thus preventing the Stowage System from stowing a cone onto either side. To correct this situation, the Program activates the MCBS in reverse until both of the forward photo sensors un-trigger. Upon deactivation of the MCBS, the cone stacks are stopped so the end of both cone stacks are aligned with the rear photo sensors, thus forcing both forward photo sensor areas to be free for cone stowage. These actions now result in the cones being positioned in the same orientation as that of the previously described case two. The Program is designed to link back to the logic of case two, when it reaches this situation.

The remaining two cases are considered optional since they should not occur unless the cone stacks were incorrectly setup before the operation. These two cases are shown in Figure 9.10 with a dashed line. The cone stacks are considered incorrectly setup if more then one cone's distance exists between the two stacks. If this situation exists, the Stowage System will be unable to correctly stow a cone up against the last cone in the short stack, thus allowing this cone to drift from the required placement. The program is designed to handle these two cases by vacating the shorter stack and only allowing cones to be placed in the larger stack.

Once the Retrieval Program has prepared the MCBS for cone stowage based on the above case evaluations, it must next prepare the Stowage System for cone pickup from the LCS. Either the left or right arm of the Stowage System is activated forward depending on the cone stack chosen for stowage. From this point, the Retrieval System is enabled to pick-up a cone from the highway once the bumper switches are triggered. Once the Retrieval System places the cone on the LCS, the cone is transported to the Stowage System. After the Stowage System stows a cone on the MCBS, the Retrieval Program loops back to the beginning of the program and prepares the MCBS for the next cone Retrieval Operation. The Retrieval Program remains in this operation until halted by the activation of the manual escape key, located on the operator interface.

10. CHAPTER TEN
CONCLUSIONS AND RECOMMENDATIONS

10.1 Evaluation of the ACM Concept as Developed

The Automated Cone Machine concept design as described in this report and represented by the machines fabricated and tested during the project meets the requirements of an automated cone handling machine. Prior to development of machine concepts, a thorough attempt to understand the requirements of the cone laying operation was made and the resulting design has incorporated these requirements. This conclusion is based on the results of testing, design reviews, and feedback from persons directly involved in Caltrans cone laying operations. As intended, the workers will be sitting within the cab of the vehicle while the cones are placed and retrieved. The objective of having the worker protected from the hazards of the passing traffic and the potentially injurious work is achieved without excessively complicated machinery. The method of funneling the cones during cone retrieval is very reliable and will easily pick up cones that the vehicle can be brought alongside to. It is very compatible with existing cones and the methods of laying and retrieving cones. The system will drop cones in the forward direction and retrieve in both directions. Feedback from Caltrans representatives during demonstrations of the machine and in design presentations has been very positive. Input from individuals directly involved in the cone laying operations continues to be sought as the machine is refined during deployment in various districts.

By developing the machine around a platform that allows manual operation in case of equipment failure or in situations in which the machine cannot be used, the versatility of the machine is greatly enhanced. This feature is desirable in the initial development of a new machine such as the cone machine and when crews are asked to consider the addition of an automated mechanism to their equipment list. Even in a refined cone machine in which high reliability has been achieved, the cone laying operation, because of its nature, may always require this feature. An example of this was observed on the San Francisco Bay Bridge which requires very long closures on a regular basis and for which the need of an automated system is readily apparent. The road has no shoulder and the first cones used to begin the transition were placed on a 20 cm (8 inch) high curb at the edge of the roadway. By allowing manual operation for a short distance, the machine's value to the operation is increased. It is not possible to anticipate all the situations that workers deal with and maintaining the option of manual operation at this time is considered very important.

10.2 Status of Specific Systems and Components

Development of the components that make up the ACM have been tested and operated in various configurations. Details of this work is included in the body of this report and a summary of the status of these designs is discussed in the following paragraphs

The Primary and Secondary Funnels used to funnel the cones on the road into the retrieval mechanism worked well. Although the effectiveness of the system is dependent on the operator, its operation is simple and intuitive. The operator is only required to maneuver the truck alongside the cone and activate a switch once in a while for some knocked over cones which have to be stood up before being oriented base first. Successful cone funneling is speed dependent and some cones may be knocked out of the funnel system at speeds of 16 km/h (10 mph) or higher. Additional modifications could be implemented to improve high speed funneling but the system is very effective and simple in its present configuration and no changes are recommended at this time. At the suggestion of some operators, it is recommended that a Primary funnel be placed at each corner of the truck to avoid the need for any mechanical setup of the funnel system prior to operation. The less desirable option would be to use one or two units that could be mounted in any corner with a movable mount and quick connections to hydraulic and electrical lines. Another issue identified is the overall width of the funnel which some operators say could be reduced to minimize the width of the truck when deployed. At this time the design of the funnels is being refined only to implement a retraction system, minimize parts and increase robustness. Other changes can be readily implemented once the input from crews is obtained when the ACM is deployed in the field

The Retrieval System which lifts the cones that have been funneled to it and places it onto the Lateral Conveyor System was simple and effective but improving the reliability of the system was difficult. During testing the system reliability was increased to over 95% but slight variations in cone configuration and other variables continued to cause problems with the stripping action causing the cones to be misaligned when dropping onto the Lateral Conveyor System. Since the ACM must be very robust, the stripping action mechanism was eliminated and the Retrieval Arm was redesigned to include a positive gripping mechanism which releases the cone onto the Lateral Conveyor System more precisely.

Placing cones using the Drop Box system proved to be very effective. By using this method of placing cones, the mechanisms involved in this aspect of the machine operation are minimized. The method is very robust and the reliability of correct cone placement is very high. Relatively simple modifications continue to be tested to improve its reliability, reduce wear on the base of the cones and accommodate varying road heights

The Stowage System operated as designed but improvements to the system continue to be implemented to improve the operation and optimize the design. A major design change being implemented is the decision to rotate the gripper action 90 degrees to maximize the effectiveness of the gripping forces when rotating the cones between the vertical and horizontal orientations. This longitudinal orientation has been proven to be much more effective in grasping the cones but is more difficult to package. Design improvements to improve the gripper action and general reliability are being implemented.

The Lateral Conveyor System which uses a system of belts to convey the cones across the width of the truck between the Stowage system and the Retrieval System is effective. Although other methods of moving the cones back and forth were considered the belt system is adequate and relatively simple. Modifications to the layout of the belts are relatively easy and are being implemented to accommodate changes to the Stowage system and methods of Drop Box retraction.

Development of the Coordinated Control Unit is continually evolving. Initial concepts of the ACM attempted to minimize the number of actuators and inputs driven by the control system. During development several problems were solved by adding components operated by the control system rather than incorporating added mechanisms. On the road programmability of the controller has also permitted quick improvements to the machine operation. A significant improvement is the addition of a hand held control pad operated by a few toggle switches which eliminates the need to interface with the control system through a keypad. By using a few switches to define the operating modes and directions of the machine, the control system has become much more user friendly.

10.3 Continuing Work

Added work required to implement the automated machine concept into the fleet includes support of the field testing of the prototype machine, refinement of the design details for reliability and producibility, and implementation of a design modification to increase the cone carrying capacity of the machine for special operations requiring more than 80 cones. These tasks are occurring concurrently in the next phase of the project.

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APPENDIX A

CALCULATIONS

Conversion Factors: US Customary to SI

Length:	1 in = 0.0254 m	Speed:	1 mi/hr = 1.61 km/hr
Force:	1 lbf = 4.44 N	Mass:	1 lb = 0.454 kg
Stress:	1 psi = .006894 Mpa	1 hp = 746 W	

Calculation 4.1

velocity of vehicle	$v := 10\cdot mph$	
distance between cones	$d := 50\cdot ft$	
cycle time interval	$t := \frac{d}{v}$	$t = 3.409\cdot sec$
mass of cone	$mc := 10\cdot lb$	
angular velocity of arm	$\omega := 3.14159\cdot\frac{rad}{scc}$	
angular accel of arm	$\alpha := 3.14159\cdot\frac{rad}{sec^2}$	
radius	$r := 25.8\cdot in$	
accel	$a := \alpha\cdot r$	$a = 81.053\cdot\frac{in}{sec^2}$

Poker Arm

length of poker arm	$l := 10.75\cdot in$	
width of poker arm	$w := .5\cdot in$	
heightof poker arm	$h := 1.0\cdot in$	
θ–angle between vertical and instantaneous direction of travel of the center of mass of cone	$\theta := 22\cdot deg$	
	$ay := a\cdot\cos(\theta)$	$ay = 1.909\cdot m\cdot sec^{-2}$

Calculation 4.1 (Cont.)

find reaction forces Ra and Rb

sum of vertical forces $$Ra + Rb := mc \cdot \left(9.81 \cdot \frac{m}{sec^2} + ay\right)$$

sum of moments about point Force Ra is exerted

$$-(Ra + Rb) \cdot (4.97 \cdot in) + Rb \cdot (4.97 \cdot in + 7.91 \cdot in) := 0$$

$$-mc \cdot \left[\left(9.81 \cdot \frac{m}{sec^2}\right) + ay\right] \cdot (4.97 \cdot in) + Rb \cdot (4.97 \cdot in + 7.91 \cdot in) := 0$$

$$-(11.95 \cdot lbf) \cdot (4.97 \cdot in) + Rb \cdot (4.97 \cdot in + 7.91 \cdot in) := 0$$

$$Rb := \frac{(11.95 \cdot lbf) \cdot (4.97 \cdot in)}{(4.97 \cdot in + 7.91 \cdot in)}$$

$$Rb = 4.611 \cdot lbf$$

$$-(Ra + Rb) \cdot (4.97 \cdot in) + Rb \cdot (4.97 \cdot in + 7.91 \cdot in) = 0$$

$$Ra := \left[\frac{Rb \cdot (4.97 \cdot in + 7.91 \cdot in)}{4.97 \cdot in}\right] - Rb$$

$$Ra = 7.339 \cdot lbf$$

Calculation 4.1 (Cont.)

Strength of Poker Arm

Moment of Inertia $I := \frac{1}{12} \cdot w \cdot h^3$ $I = 0.042 \cdot in^4$

distance from neutral axis to farthest fibers of component $c := \frac{h}{2}$ $c = 0.5 \cdot in$

due to symmetry

angle between horizontal and poker arm orientation $\tau := 98 \cdot deg$

Moment on Poker Arm $M := l \cdot Rb \cdot \sin(\tau)$

$M = 49.087 \cdot in \cdot lbf$

Calculation 4.1 (Cont.)

Treating Poker arm as a simple beam

$$\sigma := \frac{M \cdot c}{I} \qquad \text{flexural formula}$$

$$\sigma = 589.048 \cdot psi$$

To calculate the strength of Poker Arm close to tip where it is weakest

length of thinner tip piece of poker arm $\quad l := 1.634 \cdot in$

Height of thinner thinner piece of poker arm $\quad h := .5 \cdot in$

Moment of inertia of thinner piece of poker arm $\quad I := \frac{1}{12} \cdot w \cdot h^3 \qquad I = 0.005 \cdot in^4$

Moment of thinner piece of poker arm $\quad M := l \cdot Rb \cdot \sin(\tau)$

$$\sigma := \frac{M \cdot c}{I} \qquad \text{flexural formula}$$

$$\sigma = 716.283 \cdot psi$$

Drawing for Calculation 4.1

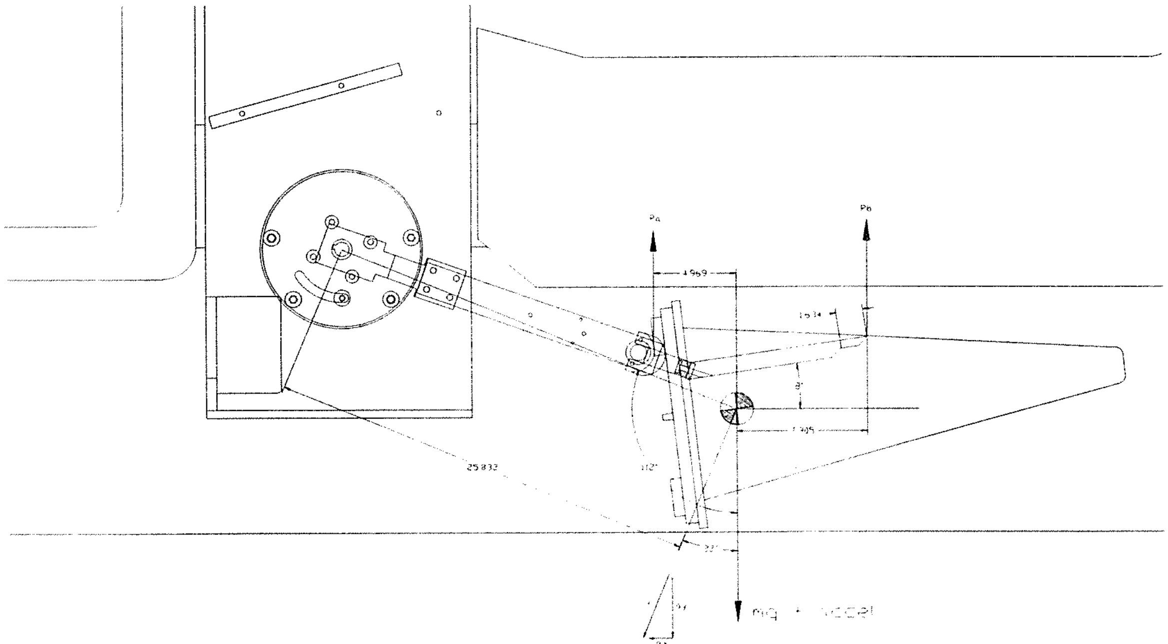


Figure A.1 *Reference Drawing for Calculation 4.1*

Calculation 4.2

velocity of vehicle	$v := 10 \cdot mph$
distance between cones	$d := 50 \cdot ft$
cycle time interval	$t := \frac{d}{v}$ $\quad t = 3.4091 \cdot sec$
mass of cone	$mc := 10 \cdot lb$
angular velocity of arm	$\omega := 3.14159 \cdot \frac{rad}{sec}$
angular accel of arm	$\alpha := 3.14159 \cdot \frac{rad}{sec^2}$
radius	$r := 25.8 \cdot in$
accel	$a := \alpha \cdot r$ $\quad a = 81.053 \cdot \frac{in}{sec^2}$

Cross Member Calculations

Impact of Cone Onto Cross Member at 10 MPH

relative velocity of cone to truck $\quad v := 10 \cdot mph$

kinetic energy $\quad T := \frac{1}{2} \cdot mc \cdot v^2 \quad T = 45.324 \cdot kg \cdot m^2 \cdot sec^{-2}$

observed energy absorption of cone $\quad EA := \frac{82}{84}$

amount of energy transmitted to cross arm as cone hits it

$$En := (1 - EA) \cdot T$$

$$En = 1.0791 \cdot kg \cdot m^2 \cdot sec^{-2}$$

Calculation 4.2 (Cont.)

assuming cross arm acts like a spring

potentiall energy of arm=energy transitted by cone

$PE := En$

x =displacement of cross member

k =equivalent spring constant of cross member

E =elastic modulus

I =moment of inertia

F =force on cross member

to find the force that the cone generates onto cross member

for mild steel $E := 29 \cdot 10^{6} \cdot psi$

assume rectangular cross section with length $L := 8.875 \cdot in$

At weak point: hole has diameter $d := .138 \cdot in$

width $w := 1 \cdot in$

thickness $h := .5 \cdot in$

θ angle that cross arm lies with respect to ground $\theta := 28 \cdot deg$

At weak point of cross member

1-direction along cross member
2-direction perpendicular to cross member

$$I1 := 2 \cdot \left(\frac{1}{12} \cdot \frac{w-d}{2} \cdot h^{3} \right) \qquad I1 = 0.009 \cdot in^{4}$$

$$I2 := 2 \cdot \left[\left[\frac{1}{12} \cdot h \cdot \left(\frac{w-d}{2} \right)^{3} \right] + h \cdot \left(\frac{w-d}{2} \right) \cdot \left[\left(\frac{w-d}{4} \right) + \frac{1}{2} \cdot d \right]^{2} \right]$$

Calculation 4.2 (Cont.)

$$I2 = 0.0416 \cdot in^4$$

$$I12 := 0 \cdot in^4$$

$$I := -\frac{I1 - I2}{2} \cdot \sin(2 \cdot \theta) + I12 \cdot \cos(2 \cdot \theta)$$

$$I = 0.0135 \cdot in^4$$

loading of a cantilever beam states: $x := \frac{F \cdot L^3}{3 \cdot E \cdot I}$

$$F := \frac{3 \cdot E \cdot I}{L^3} \cdot x$$

$$PE := \left(\frac{1}{2} \cdot k \cdot x^2\right)$$

$$x := \sqrt{2 \cdot \frac{PE}{k}} \qquad k := \frac{3 \cdot E \cdot I}{L^3}$$

$$F := \frac{3 \cdot E \cdot I}{L^3} \cdot x \qquad F = 179.1785 \cdot lbf$$

$$x = 0.1066 \cdot in$$

$$F1 := F \cdot \cos(\theta) \qquad F1 = 158.2052 \cdot lbf$$

$$F2 := F \cdot \sin(\theta) \qquad F2 = 84.1192 \cdot lbf$$

Distance from cone CM to weak point on cross member $X := 4.70 \cdot in$

Calculation 4.2 (Cont.)

The bending moment about the 2-direction

$M2 := F1 \cdot X$ $\qquad$ $M2 = 18.8865 \cdot m \cdot lbf$

$M1 := F2 \cdot X$ $\qquad$ $M1 = 10.0422 \cdot m \cdot lbf$

Bending stress

$$\sigma 1 := \frac{M1 \cdot \frac{h}{2}}{I1} \qquad \sigma 1 = 1.1008 \cdot 10^{4} \cdot psi$$

$$\sigma 2 := \frac{M2 \cdot \frac{w}{2}}{I2} \qquad \sigma 2 = 8.9463 \cdot 10^{3} \cdot psi$$

Drawing for Calculation 4.2

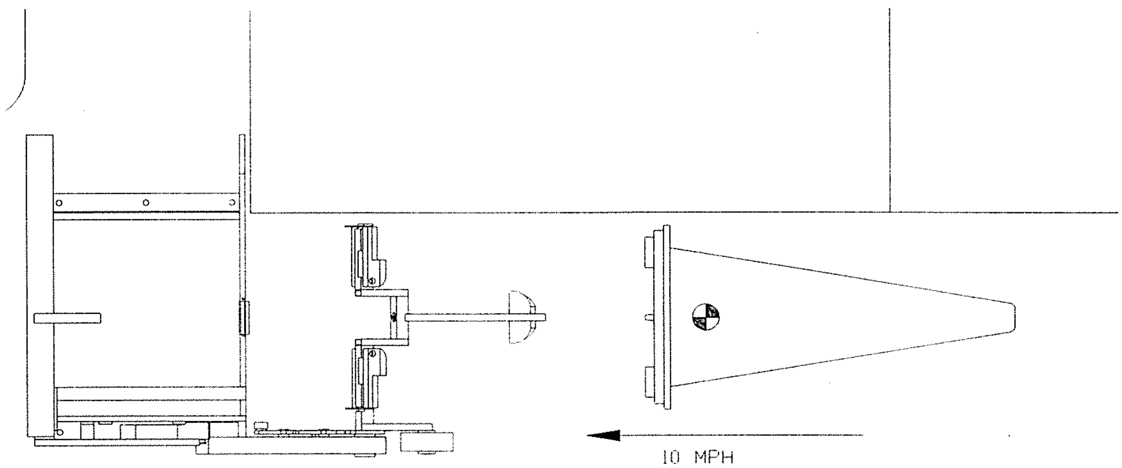


Figure A.2 *Reference Drawing for Calculation 4.2*

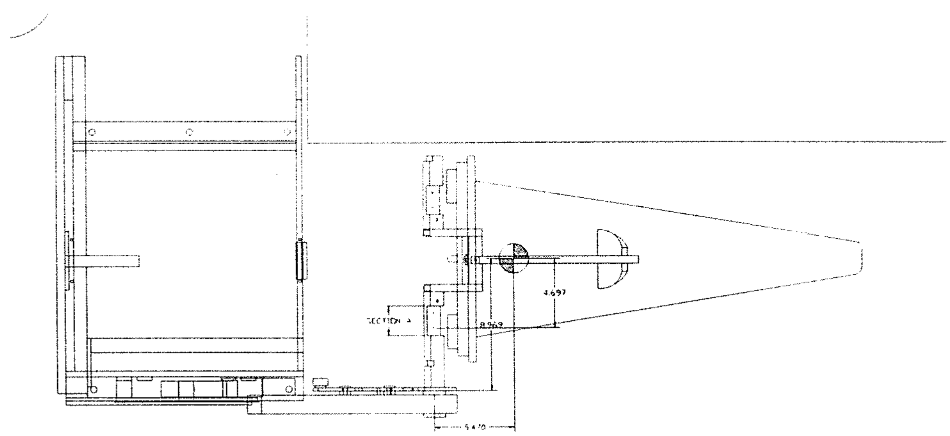


Figure A.3 *Reference Drawing for Calculation 4.2*

Drawing for Calculation 4.2

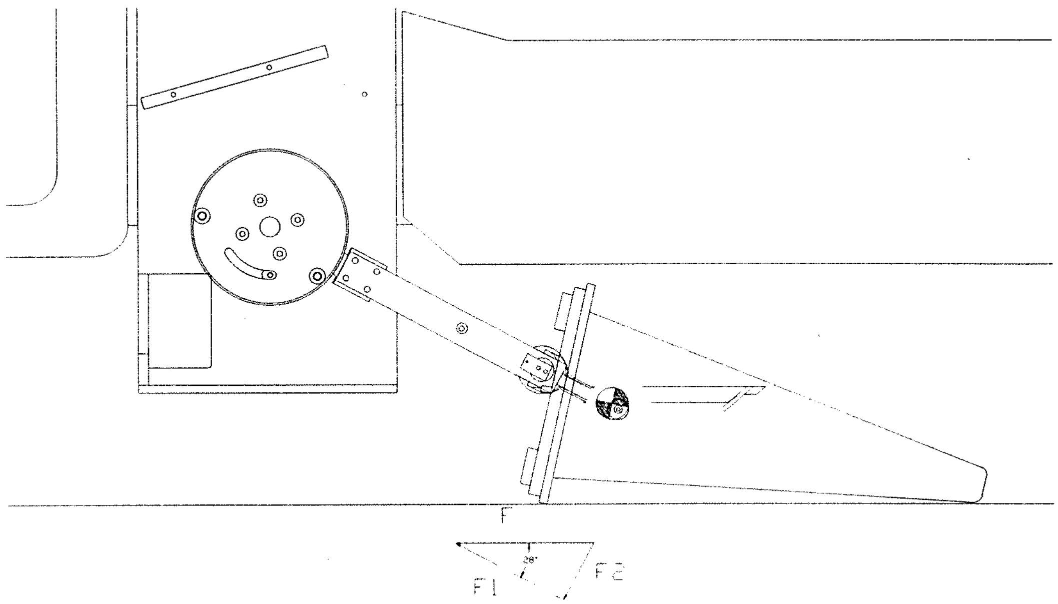


Figure A.4 *Reference Drawing for Calculation 4.2*

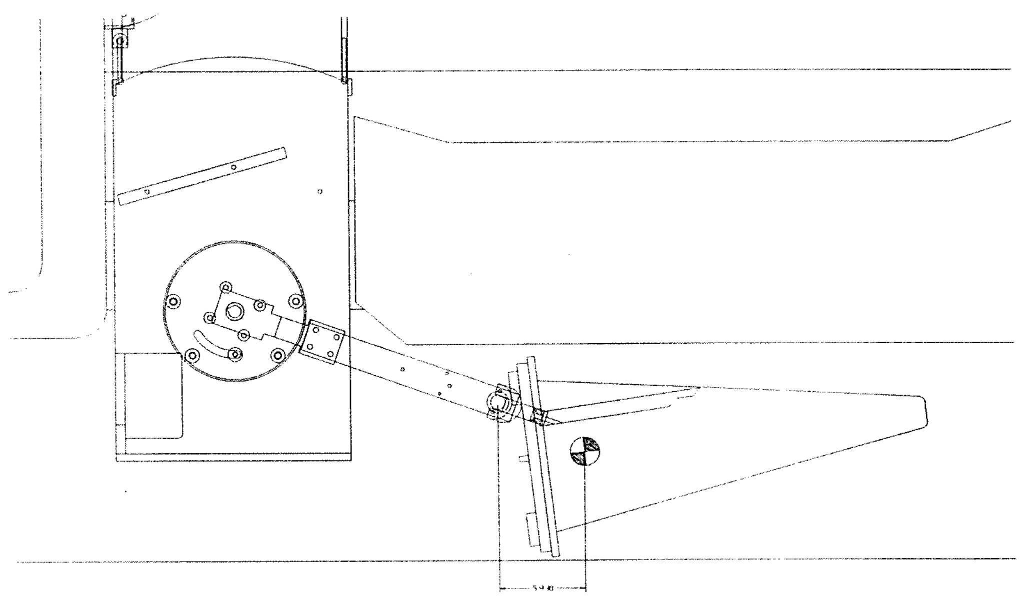


Figure A.5 *Reference Drawing for Calculation 4.2*

Calculation 4.3

velocity of vehicle	$v := 10 \cdot mph$	
distance between cones	$d := 50 \cdot ft$	
cycle time interval	$t := \frac{d}{v}$	$t = 3.409 \cdot sec$
mass of cone	$mc := 10 \cdot lb$	
angular velocity of arm	$\omega := 3.14159 \cdot \frac{rad}{sec}$	
angular accel of arm	$\alpha := 3.14159 \cdot \frac{rad}{sec^2}$	
radius from actuator to C.M. of cone	$r := 25.8 \cdot in$	
accel of cone	$a := \alpha \cdot r$	$a = 81.053 \cdot \frac{in}{sec^2}$

Calculations for cross member during lifting of cone

Define X-direction to run along long side of cross member
Define Y-direction to run perpendicular to long side of cross mem

angle of cross member to ground	$\theta := 28 \cdot deg$	
thickness at weak point	$th := .5 \cdot in$	
base at weak point	$b := 1 \cdot in$	
constant for torsion calculation	$\psi := .246$	(p.208, Popov, 1990)
distance to C.M. of cone from pivot point	$dc := 5 \cdot in$	

distance from poker arm to weak point	dp=4.7 in	
from Calc3-20	$Ix := .00898 \cdot in^4$	$Iy := .0416 \cdot in^4$

Calculation 4.3 (Cont.)

Force generated from lifting cone

$$F := mc\cdot(a+g) \qquad F = 12.099\cdot lbf$$

Force in X-direction $\quad Fx := F\cdot\sin(\theta) \quad Fx = 5.68\cdot lbf$

Force in Y-direction $\quad Fy := F\cdot\cos(\theta) \quad Fy = 10.683\cdot lbf$

Torsion on cross member

$$Mt := F\cdot dc \qquad Mt = 60.497\cdot in\cdot lbf$$

Shear stress due to torsion (Popov, 1990)

$$\tau := \frac{Mt}{\psi\cdot b\cdot th^2} \qquad \tau = 983.686\cdot psi$$

Bending stresses due to lifting

$$Mx := Fx\cdot dp \qquad Mx = 26.697\cdot in\cdot lbf$$

$$My := Fy\cdot dp \qquad My = 50.21\cdot in\cdot lbf$$

distance from neutral axis to point of interest in y-dir $\quad cy=.25$ in

distance from neutral axis to point of interest in x-dir $\quad cx=.5$ in

$$\sigma x := \frac{My\cdot cy}{Ix} \qquad \sigma x = 1.398\cdot 10^3\ \cdot psi$$

$$\sigma y := \frac{Mx\cdot cx}{Iy} \qquad \sigma y = 320.882\cdot psi$$

Superposition Principle states that all stress can be added together

Due to torsion:	$\sigma x=0$	Due to bending:	$\sigma x=1398$ psi
	$\sigma y=0$		$\sigma y=321$ psi
	$\tau=984$ psi		$\tau=0$

maximum stress

$$\sigma max := \frac{\sigma x+\sigma y}{2} + \sqrt{\left(\frac{\sigma x-\sigma y}{2}\right)^2+\tau^2}$$

$$\sigma max = 1.981\cdot 10^3\ \cdot psi$$

Calculation 4.4

velocity of vehicle	$v := 10 \cdot mph$	
distance between cones	$d := 50 \cdot ft$	
cycle time interval	$t := \frac{d}{v}$	$t = 3.409 \cdot sec$
mass of cone	$mc := 10 \cdot lb$	
angular velocity of arm	$\omega := 3.14159 \cdot \frac{rad}{sec}$	
angular accel of arm	$\alpha := 3.14159 \cdot \frac{rad}{sec^2}$	
radius from actuator to C.M. of cone	$rc := 25.8 \cdot in$	
radius from actuator to cross member	$rcm := 19 \cdot in$	
length of main arm	$l := 15 \cdot in$	
accel of cone	$ac := \alpha \cdot rc$	$ac = 81.053 \cdot \frac{in}{sec^2}$
accel of cross member	$acm := \alpha \cdot rcm$	$acm = 59.69 \cdot \frac{in}{sec^2}$

approximate mass of cross member

volume of cross member	$Vol := 1 \cdot in \cdot 1 \cdot in \cdot 16 \cdot in$	
	$Vol = 16 \cdot in^3$	
density of steel	$\rho := .283 \cdot \frac{lb}{in^3}$	
mass of cross member	$mcm := Vol \cdot \rho$	$mcm = 4.528 \cdot lb$

Calculation 4.4 (Cont.)

Static load of cross member and cone on main arm

$$Ps := g \cdot (mcm + mc)$$
$$Ps = 14.528 \cdot lbf$$

Dynamic loads of cross member and cone arm

$$Pd := ac \cdot mc + acm \cdot mcm$$
$$Pd = 2.799 \cdot lbf$$

Total load, static and dynamic

$$P := Ps + Pd$$
$$P = 17.327 \cdot lbf$$

Bending on main arm

maximum load when arm is parallel to ground

bending moment $Mb := P \cdot l$

$$Mb = 259.911 \cdot in \cdot lbf$$

Torsion on arm

distance from C.M. of cone and cross member to main arm pivot $dc := 8 \cdot in$

$$Mt := P \cdot dc$$
$$Mt = 138.619 \cdot in \cdot lbf$$

Calculation 4.4 (Cont.)

height of beam $hb := 2 \cdot in$

thickness of beam $tb := 1.25 \cdot in$

Moment of inertia $I := \frac{1}{12} \cdot tb \cdot hb^3$ $\quad I = 0.833 \cdot in^4$

Bending stress on main arm

$$\sigma b := \frac{Mb \cdot \frac{hb}{2}}{I} \qquad \sigma b = 311.893 \cdot psi$$

Torsional stress on main arm

coeff for rectangular bars (Popov, 1990) $\psi := .19$

$$\tau := \frac{Mt}{\psi \cdot tb \cdot hb^2}$$

$$\tau = 145.915 \cdot psi$$

Calculation 4.4 (Cont.)

Stresses from bending

σb=395 psi

σx=0 psi

τ=0 psi

Stresses from torsion

σb= 0 psi

σx= 0 psi

τ=146 psi

Superposition Principal allows for the addition of stresses

total stresses

$$\sigma b = 311.893 \cdot psi$$

$$\sigma x := 0 \cdot psi$$

$$\tau = 145.915 \cdot psi$$

$$\sigma max := \frac{\sigma b + \sigma x}{2} + \sqrt{\left(\frac{\sigma b - \sigma x}{2}\right)^2 + \tau^2}$$

$$\sigma max = 369.512 \cdot psi$$

Calculation 4.5

velocity of vehicle	$v := 10 \cdot mph$	
distance between cones	$d := 50 \cdot ft$	
cycle time interval	$t := \frac{d}{v}$	$t = 3.409 \cdot sec$
mass of cone	$mc := 10 \cdot lb$	
angular velocity of arm	$\omega := 3.14159 \frac{rad}{sec}$	
angular accel of arm	$\alpha := 3.14159 \frac{rad}{sec^2}$	
radius from actuator to C.M. of cone	$rc := 25.8 \cdot in$	
radius from actuator to cross member	$rcm := 19 \cdot in$	
radius from actuator to C.M. of main arm	$rma := 12.75 \cdot in$	
radius from actuator to end of arm mount	$ram := 6.5 \cdot in$	
accel of main arm	$ama := \alpha \cdot rma$	$ama = 40.055 \cdot \frac{in}{sec^2}$
accel of cone	$ac := \alpha \cdot rc$	$ac = 81.053 \cdot \frac{in}{sec^2}$
accel of cross member	$acm := \alpha \cdot rcm$	$acm = 59.69 \cdot \frac{in}{sec^2}$

Calculation 4.5 (Cont.)

approximate mass of cross member

volume of cross member $Vol := 1\cdot in\cdot 1\cdot in\cdot 16\cdot in$

$Vol = 16\cdot in^3$

density of steel $\rho s := .283\cdot\frac{lb}{in^3}$

mass of cross member $mcm := Vol\cdot\rho s$ $mcm = 4.528\cdot lb$

approximate mass of main arm

volume of main arm $Vol := 1.25\cdot in\cdot 2\cdot in\cdot 15\cdot in$

$Vol = 37.5\cdot in^3$

density of aluminum $\rho a := .100\cdot\frac{lb}{in^3}$

mass of cross member $mma := Vol\cdot\rho a$ $mma = 3.75\cdot lb$

Calculation 4.5 (Cont.)

Static load of main arm, cross member and cone on arm mount

$$Ps := g \cdot (mma + mcm + mc)$$

$$Ps = 18.278 \cdot lbf$$

Dynamic loads of cross member and cone arm

$$Pd := ac \cdot mc + acm \cdot mcm + ama \cdot mma$$

$$Pd = 3.188 \cdot lbf$$

Total load, static and dynamic

$$P := Ps + Pd$$

$$P = 21.466 \cdot lbf$$

Bending on main arm

maximum load when arm is parallel to ground

bending moment $Mb := P \cdot ram$

$$Mb = 139.532 \cdot in \cdot lbf$$

Torsion on arm

distance from C.M. of cone and cross member to main arm pivot $dc := 8 \cdot in$

$$Mt := (P - (g \cdot mma + ama \cdot mma)) \cdot dc$$

$$Mt = 138.619 \cdot in \cdot lbf$$

Calculation 4.5 (Cont.)

height of mount $hm := 1.5 \cdot in$

thickness of mount $tm := 1.065 \cdot in$

Moment of inertia $I := \frac{1}{12} \cdot tm \cdot hm^3$ $I = 0.3 \cdot in^4$

Bending stress on main arm

$$\sigma b := \frac{Mb \cdot \frac{hm}{2}}{I} \qquad \sigma b = 349.375 \cdot psi$$

Torsional stress on main arm

coeff for rectangular bars (Popov, 1990) $\psi := .231$

$$\tau := \frac{Mt}{\psi \cdot hm \cdot tm^2}$$

$$\tau = 352.712 \cdot psi$$

Stresses from bending	Stresses from torsion
σb=349 psi	σb= 0 psi
σx=0 psi	σx= 0 psi
τ=0 psi	τ=352 psi

Superposition Principal allows for the addition of stresses
total stresses

$$\sigma b = 349.375 \cdot psi$$

$$\sigma x = 0 \cdot psi$$

$$\tau = 352.712 \cdot psi$$

$$\sigma max := \frac{\sigma b + \sigma x}{2} + \sqrt{\left(\frac{\sigma b - \sigma x}{2}\right)^2 + \tau^2}$$

$$\sigma max = 568.288 \cdot psi$$

Calculation 5.1

HYDRAULIC POWER REQUIREMENTS

Lateral conveyors

$Q := .28 \cdot \frac{gal}{min}$ $\quad$ $press := 2500 \cdot psi$

$Power1 := Q \cdot press$ $\quad$ $Power1 = 0.408 \cdot hp$

Funnel Actuator

$Q := .24 \cdot \frac{gal}{min}$ $\quad$ $press := 500 \cdot psi$

$Power2 := Q \cdot press$ $\quad$ $Power2 = 0.07 \cdot hp$

Stowage Motor

$Q := .7 \cdot \frac{gal}{min}$ $\quad$ $press := 2500 \cdot psi$

$Power3 := Q \cdot press$ $\quad$ $Power3 = 1.021 \cdot hp$

Retrieval Actuator

$Q := .235 \cdot \frac{gal}{min}$ $\quad$ $press := 2500 \cdot psi$

$Power4 := Q \cdot press$ $\quad$ $Power4 = 0.343 \cdot hp$

Stowage Cylinders

$Q := .276 \cdot \frac{gal}{min}$ $\quad$ $press := 350 \cdot psi$

$Power5 := Q \cdot press$ $\quad$ $Power5 = 0.056 \cdot hp$

Total Power

$$Power := Power1 + Power2 + Power3 + Power4 + Power5$$

$$Power = 1.898 \cdot hp$$

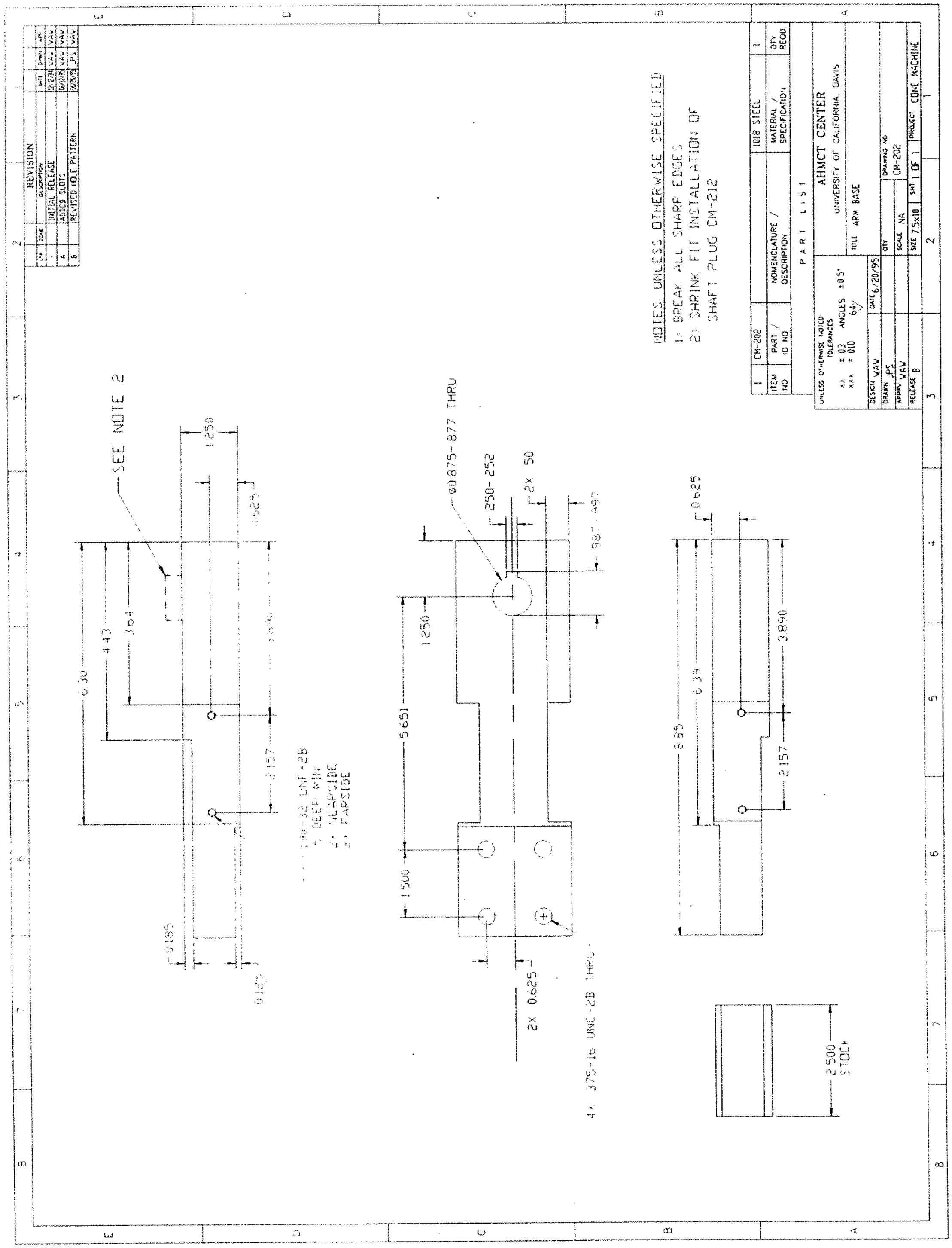
$$Power = 1.416 \cdot 10^{3} \cdot watt$$

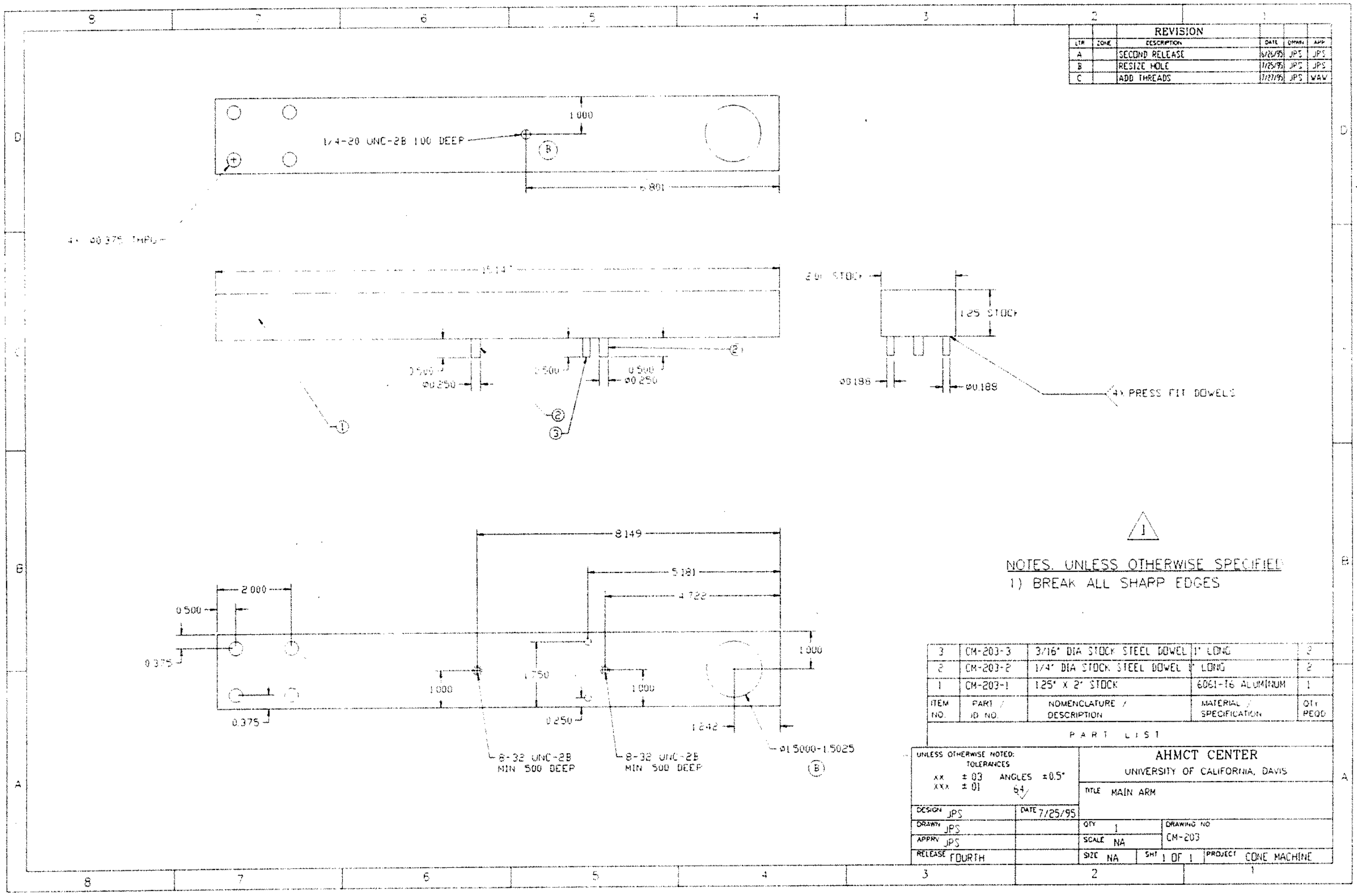
APPENDIX B

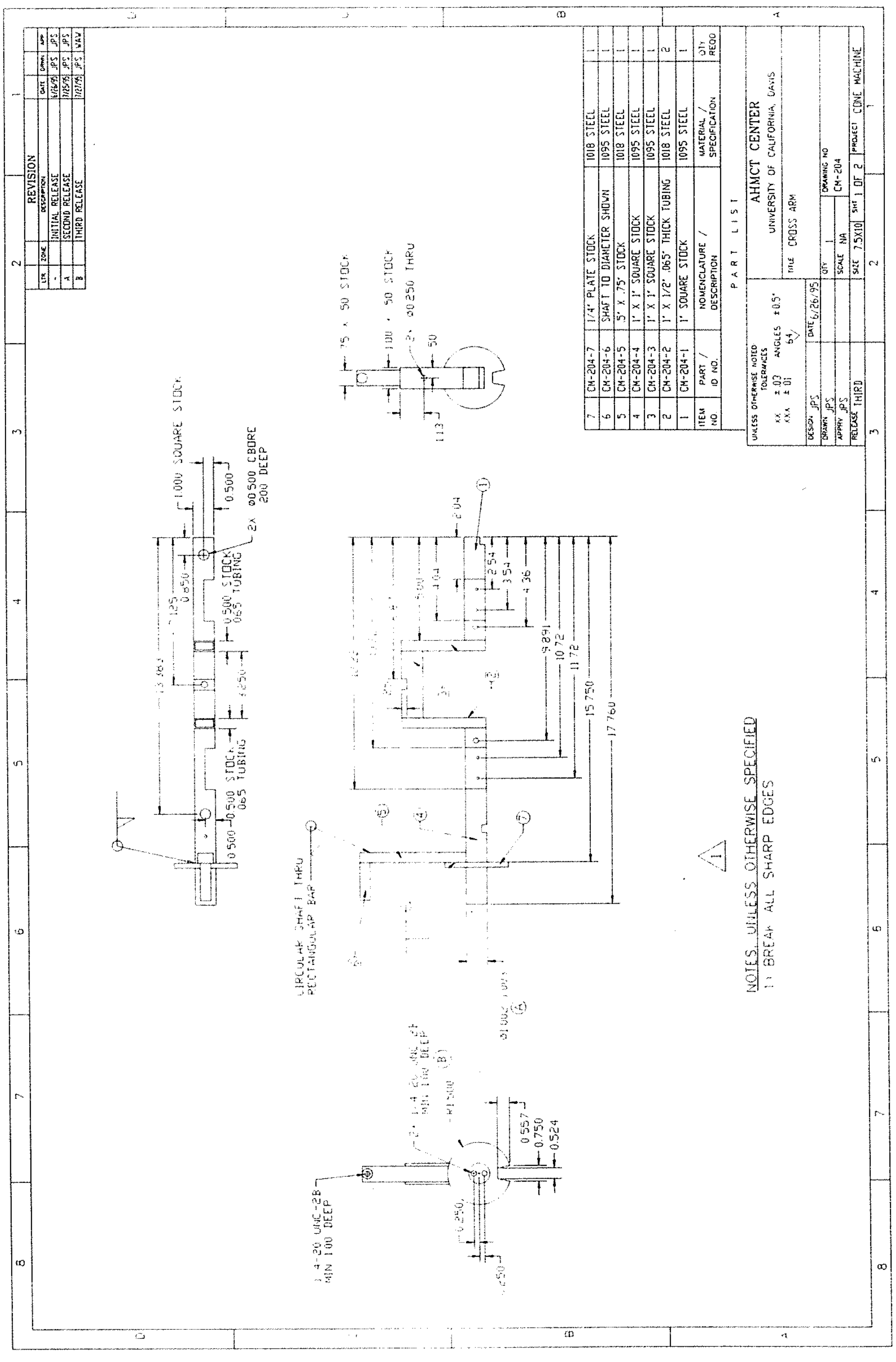
DETAILED DRAWINGS FOR RETRIEVAL SYSTEM

RETRIEVAL SYSTEM DRAWING LIST

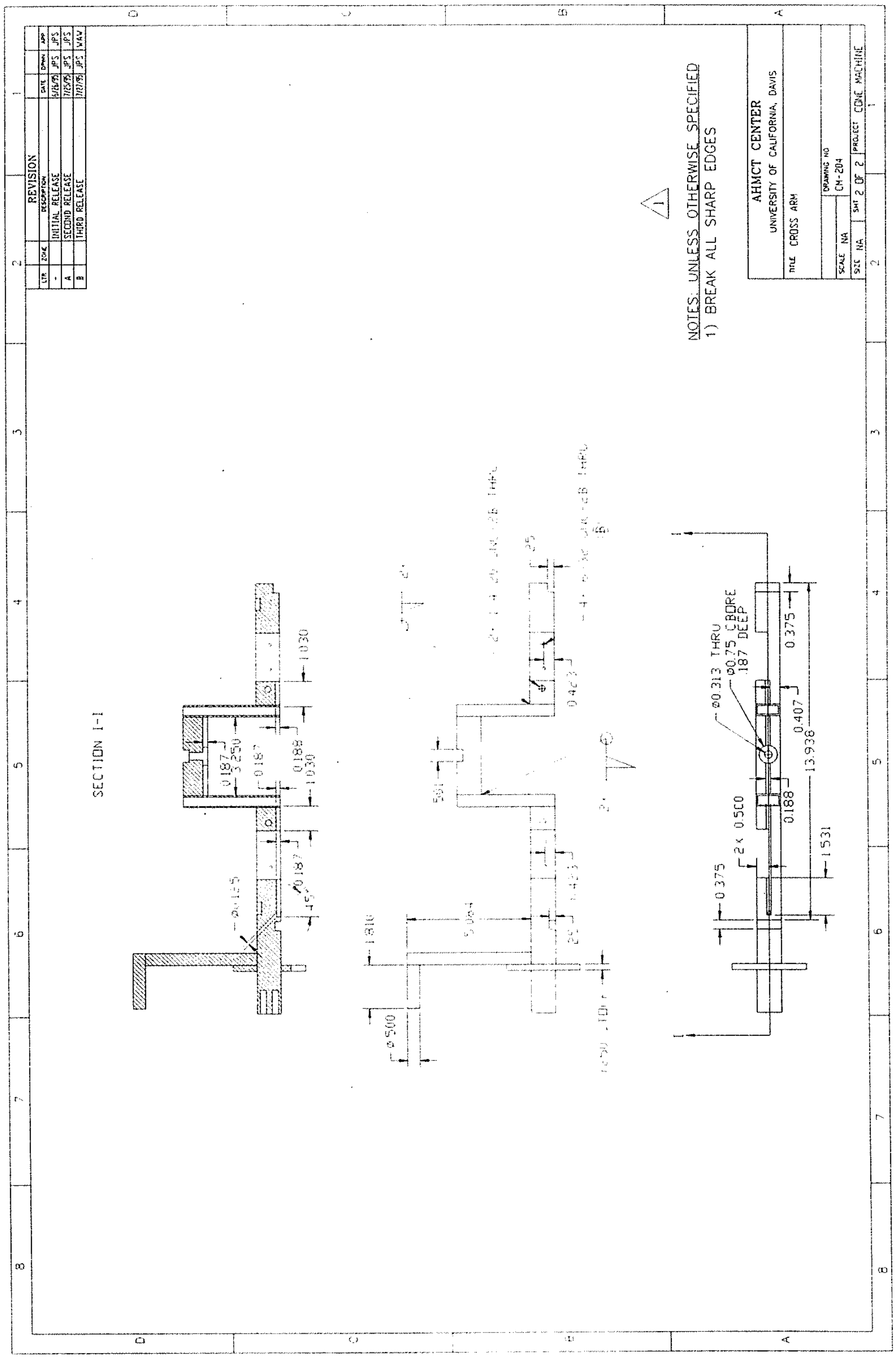
DWG NO.	DESCRIPTION
CM-202	ARM BASE
CM-203	MAIN ARM
CM-204	CROSS ARM
CM-205	LATCH
CM-206	LATCH BEARING
CM-208	SWITCH MOUNT
CM-209	BUMPER RETAINING PLATE
CM-210	CONE BUMPER
CM-211	SPRING MOUNT
CM-213	POKER ARM
CM-214	POKER ARM SEMI-CIRCLE
CM-215	LATCH ROLLER
CM-301	STRIPPER PLATE
CM-310	TIMING PLATE
CM-311	SIDE BAR
CM-405	DOOR
CM-406	DOOR SHAFT
CM-800	STORAGE TRAY
CM-801	SWITCH FRAME

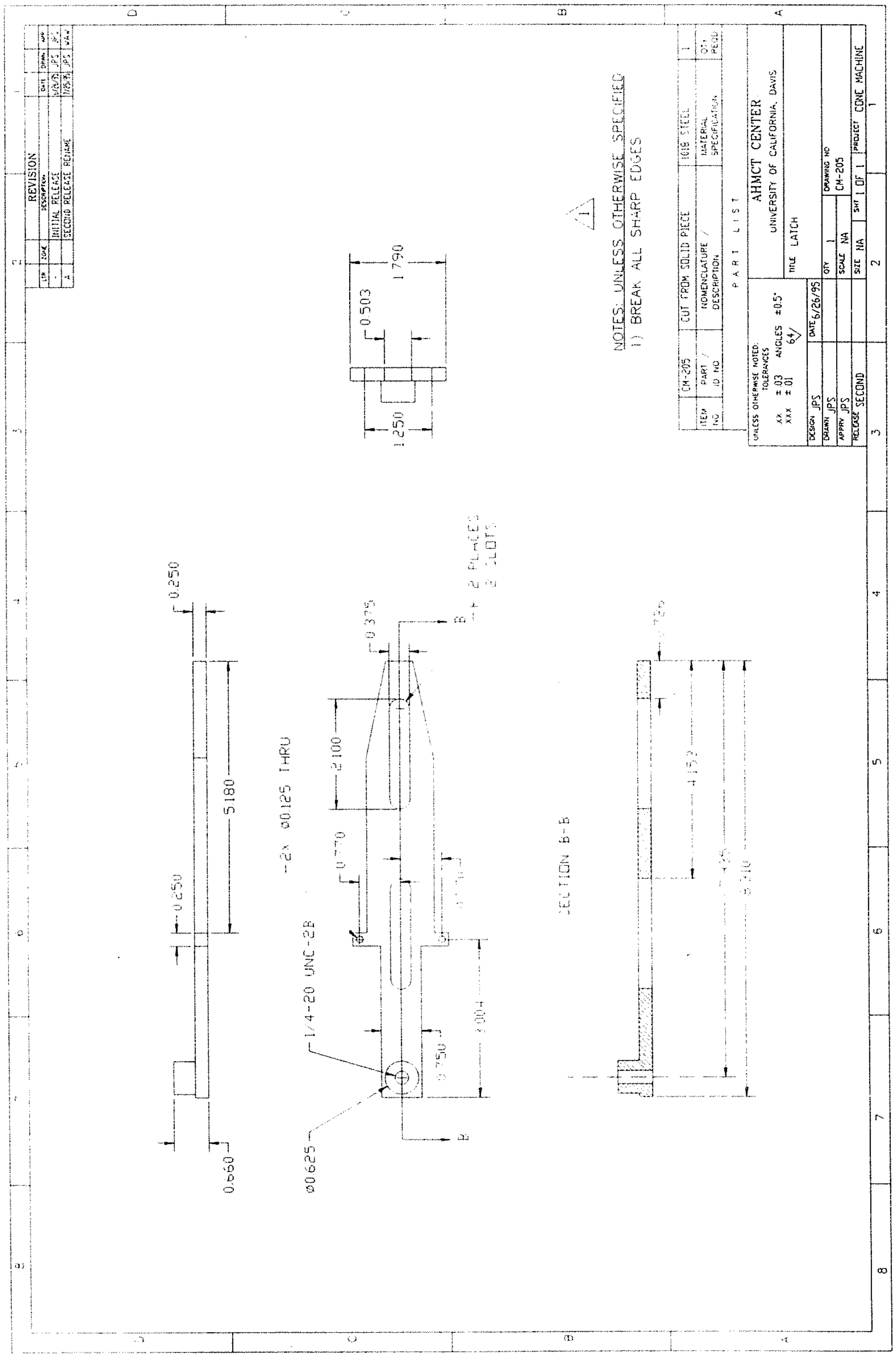

REVISION
INITIAL RELEASE
ADDED SLOTS
REVISED HOLE PATTERN
NOTES UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
2) SHRINK FIT INSTALLATION OF SHAFT PLUG CM-212
SEE NOTE 2
Ø0.875-.877 THRU
2X 0.625
4X .375-16 UNC-2B THRU
2.500 STOCK
CM-202
1018 STEEL
PART LIST
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
ARM BASE
CONE MACHINE

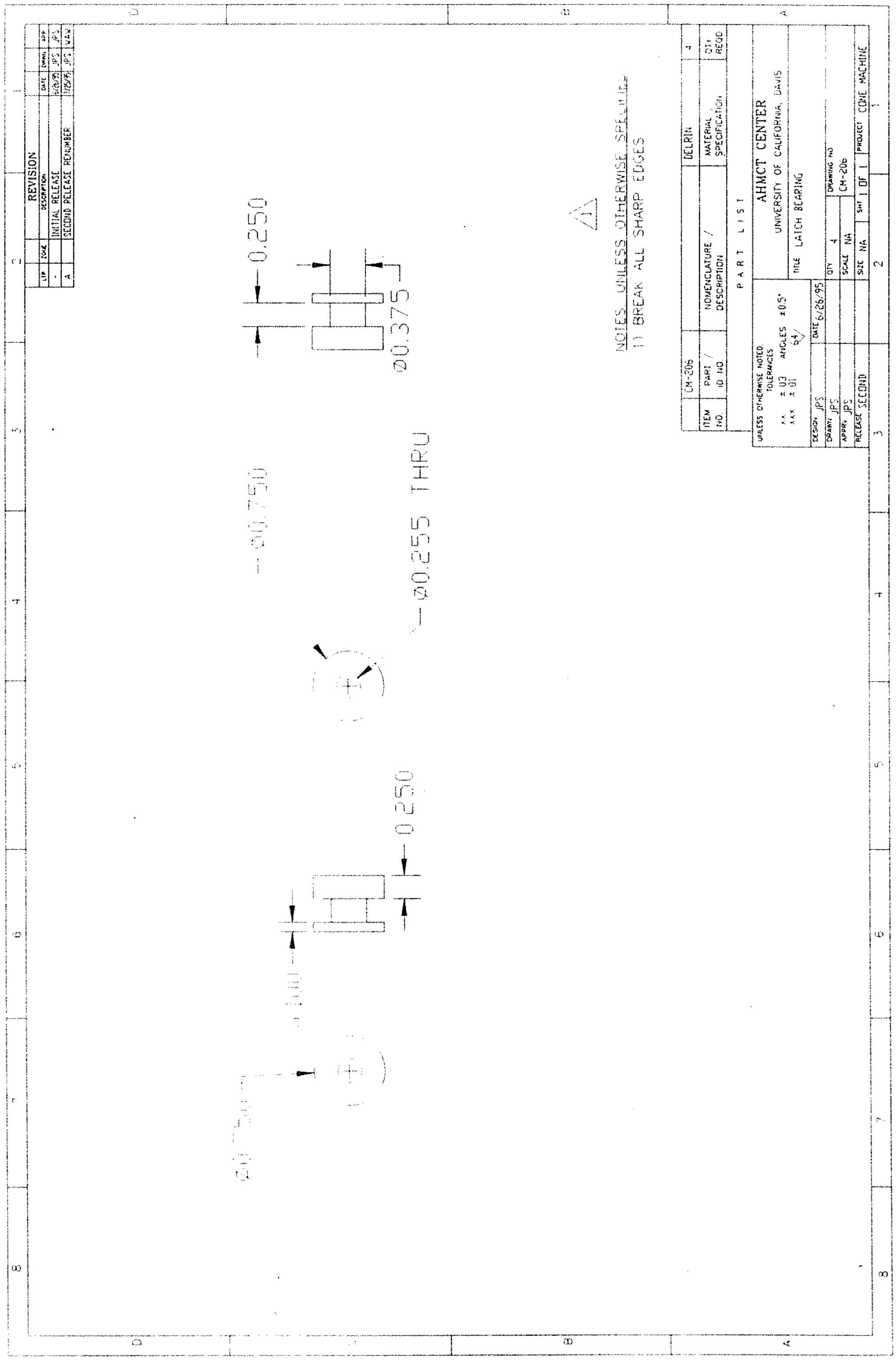

REVISION
LTR | ZONE | DESCRIPTION | DATE | DRWN | APP
A | SECOND RELEASE | JPS | JPS
B | RESIZE HOLE | JPS | JPS
C | ADD THREADS | JPS | WAV
1/4-20 UNC-2B 1.00 DEEP
1.000
6.801
4× Ø0.375 THRU
15.147
0.500
Ø0.250
2.01 STOCK
1.25 STOCK
Ø0.188
4× PRESS FIT DOWELS
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
8.149
5.181
4.722
2.000
0.500
0.375
1.750
0.250
1.242
8-32 UNC-2B MIN .500 DEEP
Ø1.5000-1.5025
3 | CM-203-3 | 3/16" DIA STOCK STEEL DOWEL 1" LONG | 2
2 | CM-203-2 | 1/4" DIA STOCK STEEL DOWEL 1" LONG | 2
1 | CM-203-1 | 1.25" X 2" STOCK | 6061-T6 ALUMINUM | 1
ITEM NO | PART / ID NO | NOMENCLATURE / DESCRIPTION | MATERIAL / SPECIFICATION | QTY REQD
PART LIST
UNLESS OTHERWISE NOTED: TOLERANCES
.XX ±.03 ANGLES ±0.5°
.XXX ±.01
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
TITLE MAIN ARM
DESIGN JPS
DATE 7/25/95
DRAWN JPS
APPRV JPS
RELEASE FOURTH
QTY 1
DRAWING NO CM-203
SCALE NA
SIZE NA
SHT 1 OF 1
PROJECT CONE MACHINE



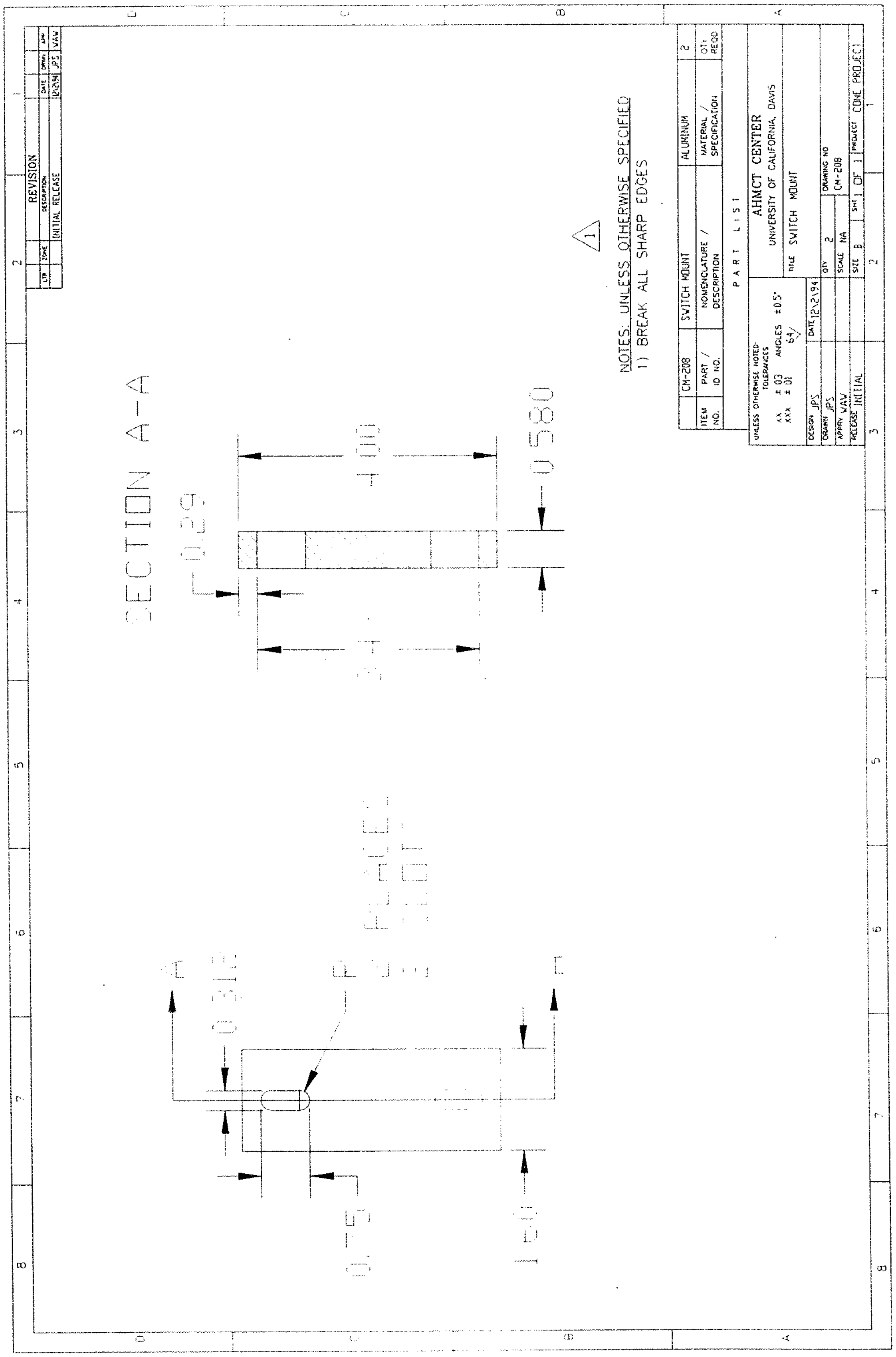
REVISION
LTR ZONE DESCRIPTION DATE DRWN APP
- INITIAL RELEASE 6/26/95 JPS JPS
A SECOND RELEASE 7/25/95 JPS JPS
B THIRD RELEASE 7/27/95 JPS VAV
7 CM-204-7 1/4" PLATE STOCK 1018 STEEL 1
6 CM-204-6 SHAFT TO DIAMETER SHOWN 1095 STEEL 1
5 CM-204-5 .5" X .75" STOCK 1018 STEEL 1
4 CM-204-4 1" X 1" SQUARE STOCK 1095 STEEL 1
3 CM-204-3 1" X 1" SQUARE STOCK 1095 STEEL 1
2 CM-204-2 1" X 1/2" .065" THICK TUBING 1018 STEEL 2
1 CM-204-1 1" SQUARE STOCK 1095 STEEL 1
ITEM NO. PART / ID NO. NOMENCLATURE / DESCRIPTION MATERIAL / SPECIFICATION QTY REQD
PART LIST
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
UNLESS OTHERWISE NOTED TOLERANCES
XX ±.03 ANGLES ±0.5°
XXX ±.01
TITLE CROSS ARM
DESIGN JPS DATE 6/26/95
DRAWN JPS
APPRV JPS
RELEASE THIRD
QTY 1
SCALE NA
SIZE 7.5X10 SHT 1 OF 2
DRAWING NO CM-204
PROJECT CONE MACHINE
1.000 SQUARE STOCK
2X ⌀0.500 CBORE .200 DEEP
0.500 STOCK .065 TUBING
CIRCULAR SHAFT THRU RECTANGULAR BAR
1/4-20 UNC-2B MIN 1.00 DEEP
0.557
0.750
0.524
9.891
10.72
11.72
15.750
17.760
NOTES, UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES

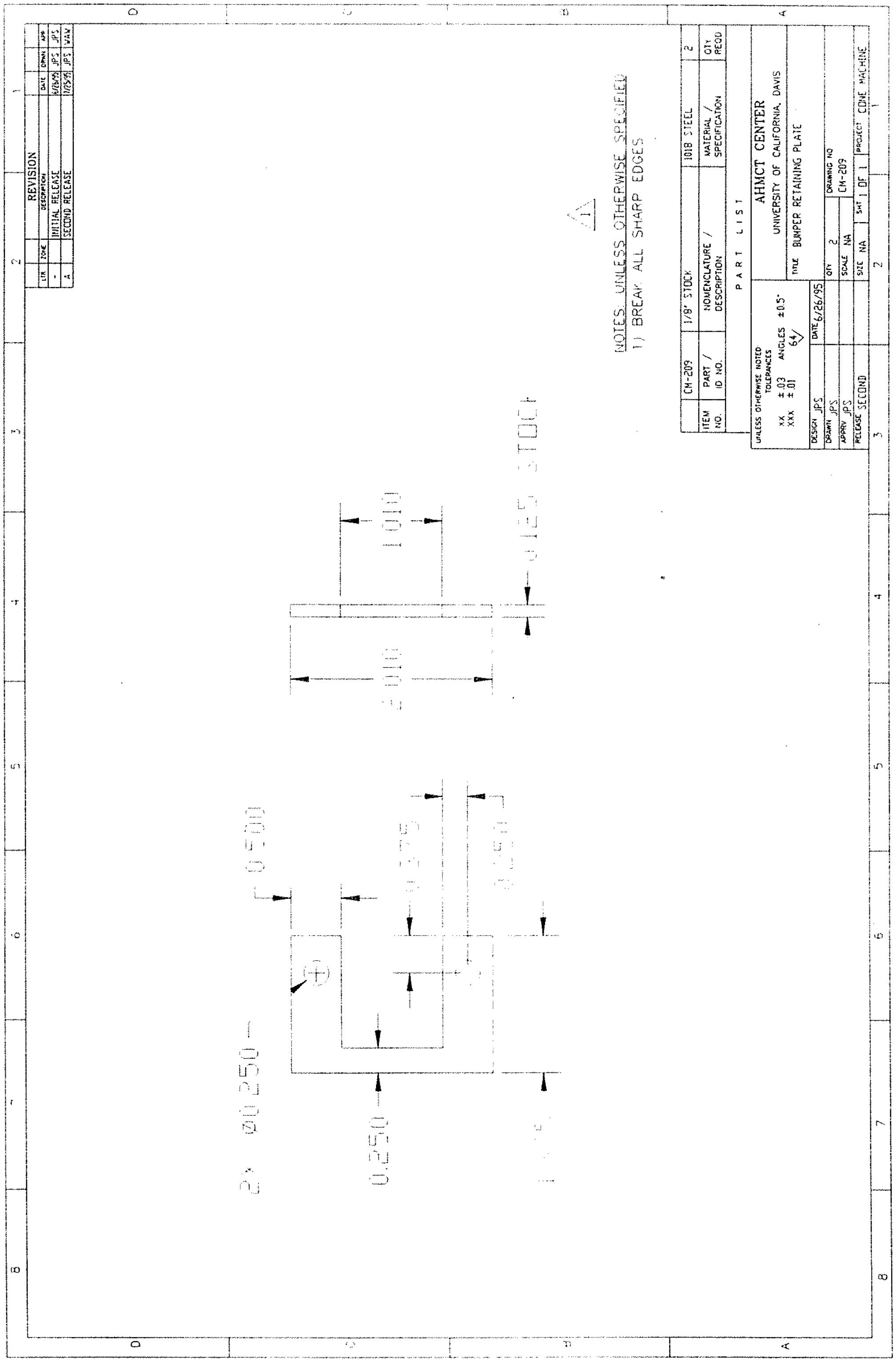

REVISION
INITIAL RELEASE
SECOND RELEASE
THIRD RELEASE
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
CROSS ARM
CM-204
CONE MACHINE
SECTION I-I

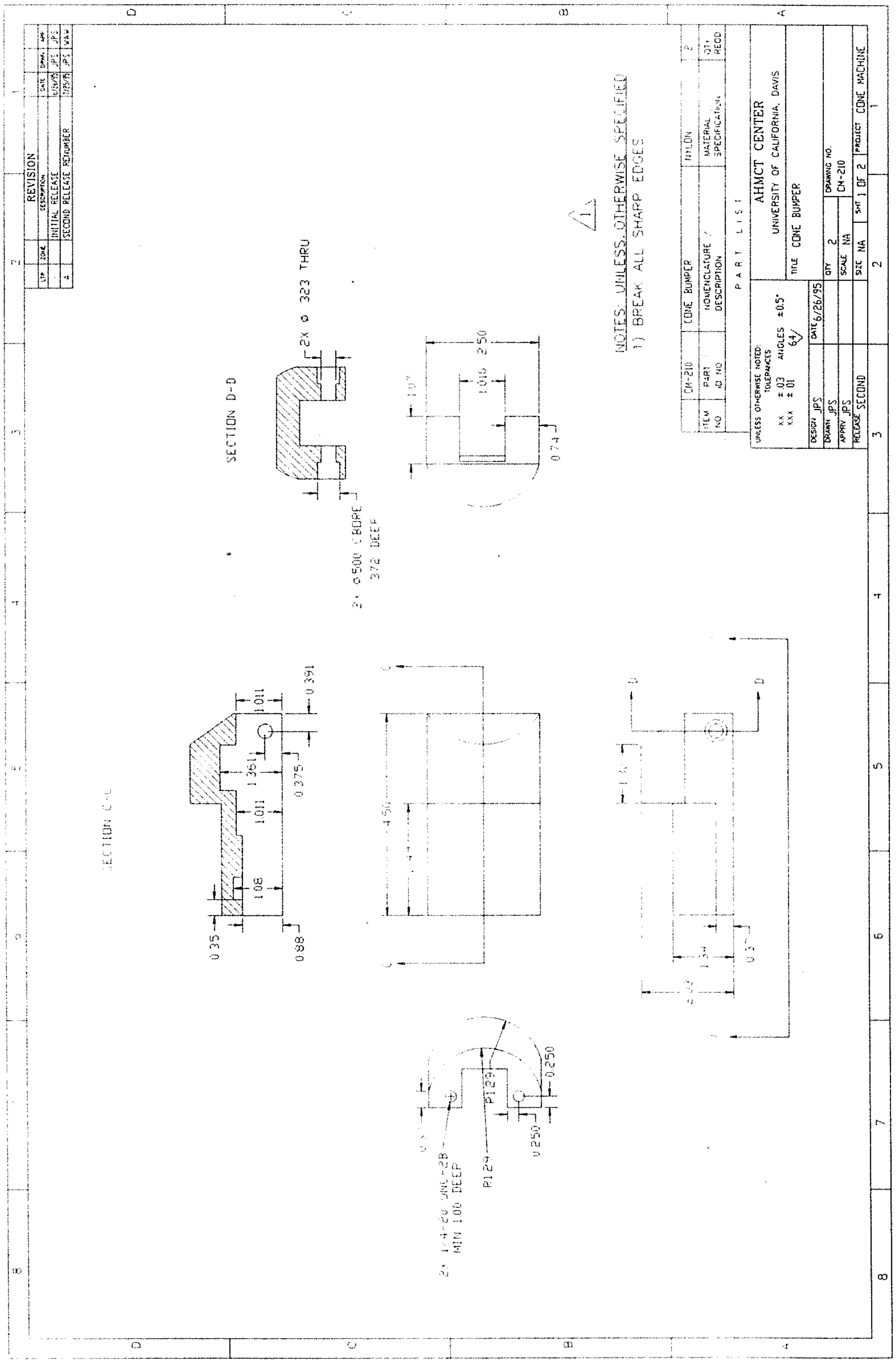

REVISION
INITIAL RELEASE
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
CM-205
CUT FROM SOLID PIECE
1018 STEEL
PART LIST
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
LATCH
DESIGN JPS
DRAWN JPS
APPRV JPS
RELEASE SECOND
PROJECT CONE MACHINE
SECTION B-B
1/4-20 UNC-2B
Ø0.625
2X Ø0.125 THRU
5.180
0.250
0.503
1.790
1.250
2.100
0.375
0.750

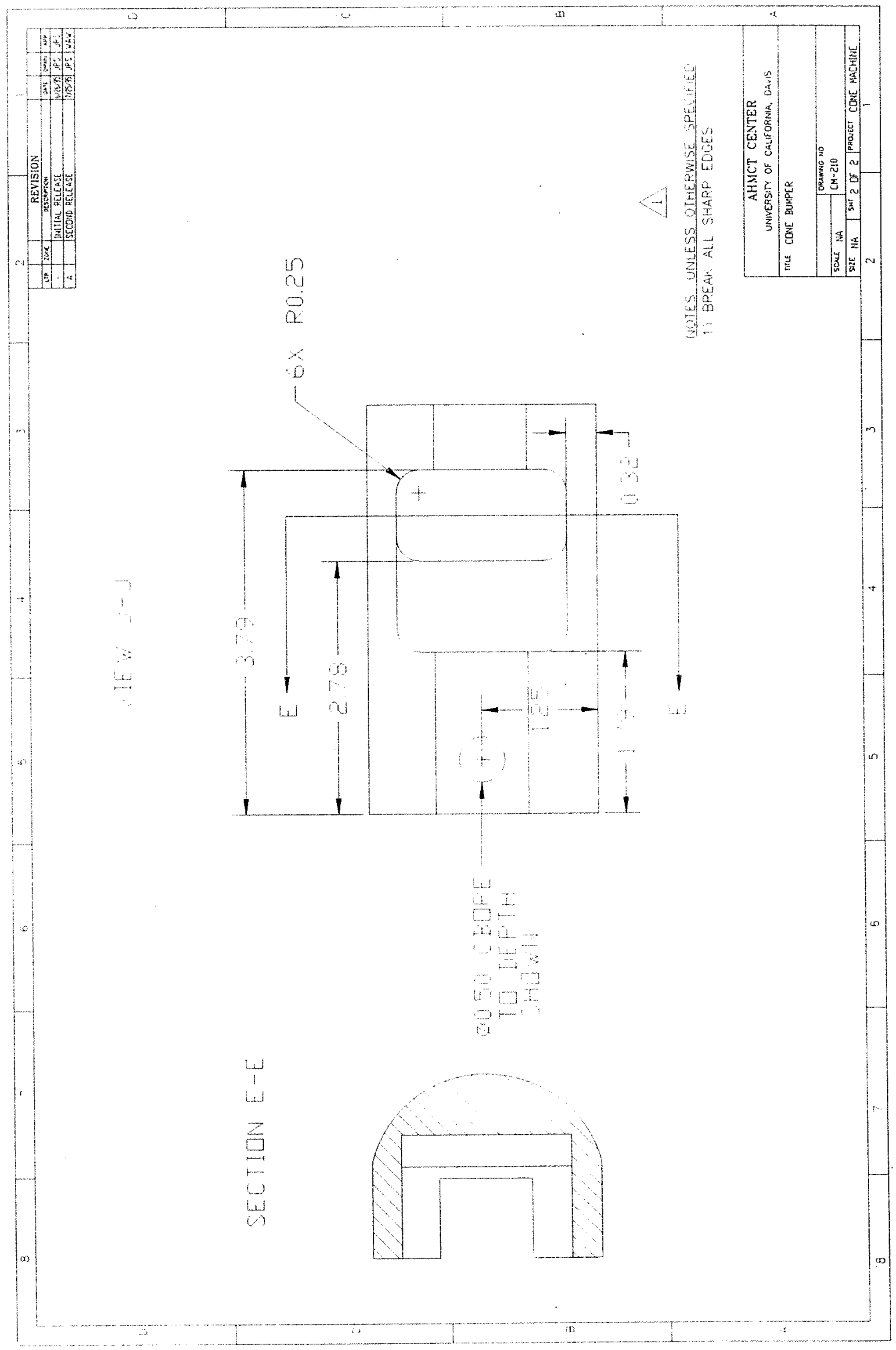


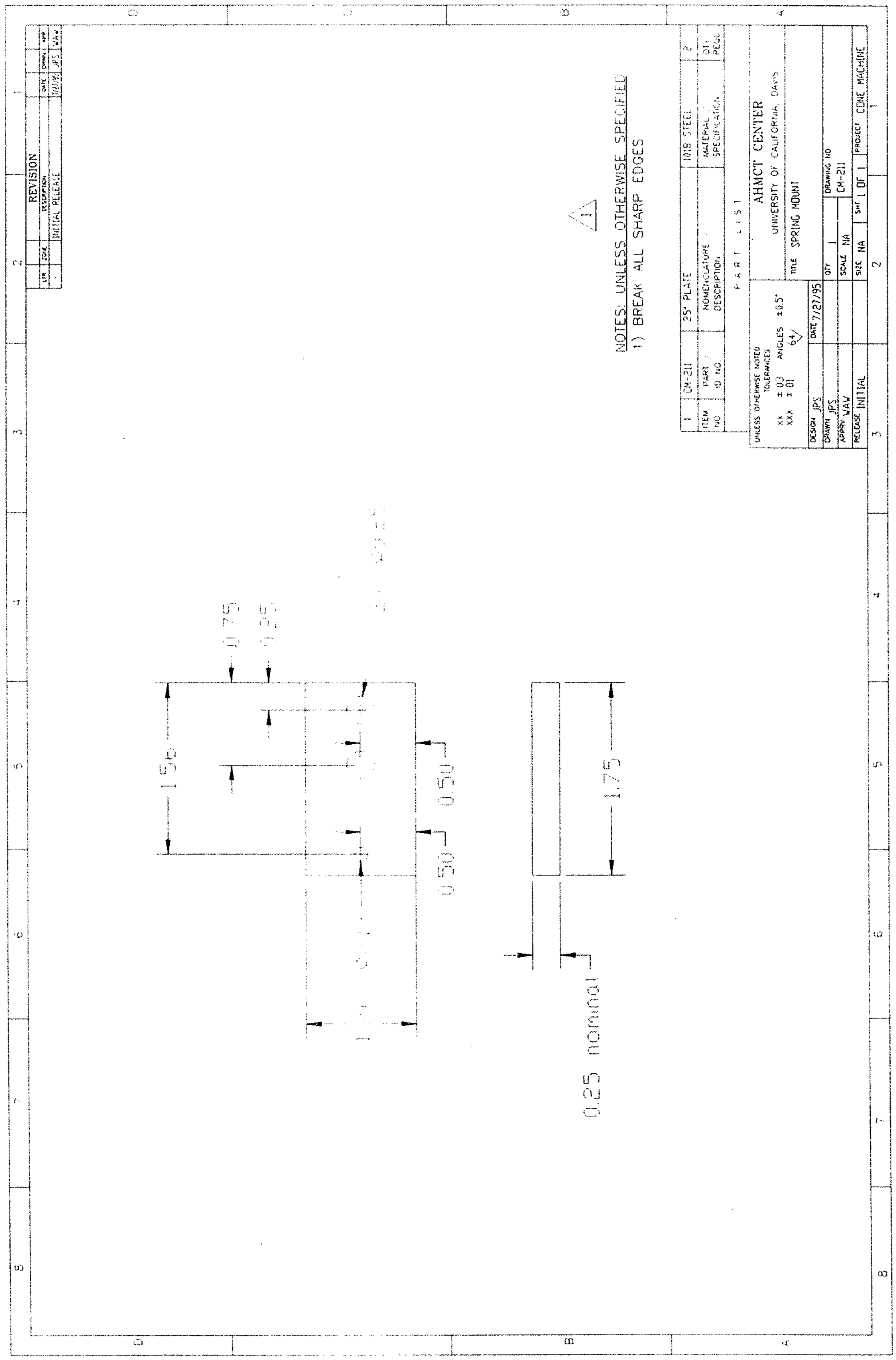
REVISION
LTR
ZONE
DESCRIPTION
DATE
DRWN
APP
INITIAL RELEASE
SECOND RELEASE RENUMBER
0.250
Ø0.375
Ø0.750
Ø0.255 THRU
NOTES UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
CM-206
DELRIN
4
ITEM NO
PART / ID NO.
NOMENCLATURE / DESCRIPTION
MATERIAL / SPECIFICATION
QTY REQD
PART LIST
UNLESS OTHERWISE NOTED TOLERANCES
.XX ±.03
.XXX ±.01
ANGLES ±0.5°
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
TITLE LATCH BEARING
DESIGN JPS
DRAWN JPS
APPR. JPS
RELEASE SECOND
DATE 6/26/95
QTY 4
SCALE NA
SIZE NA
DRAWING NO CM-206
SHT 1 OF 1
PROJECT CORE MACHINE

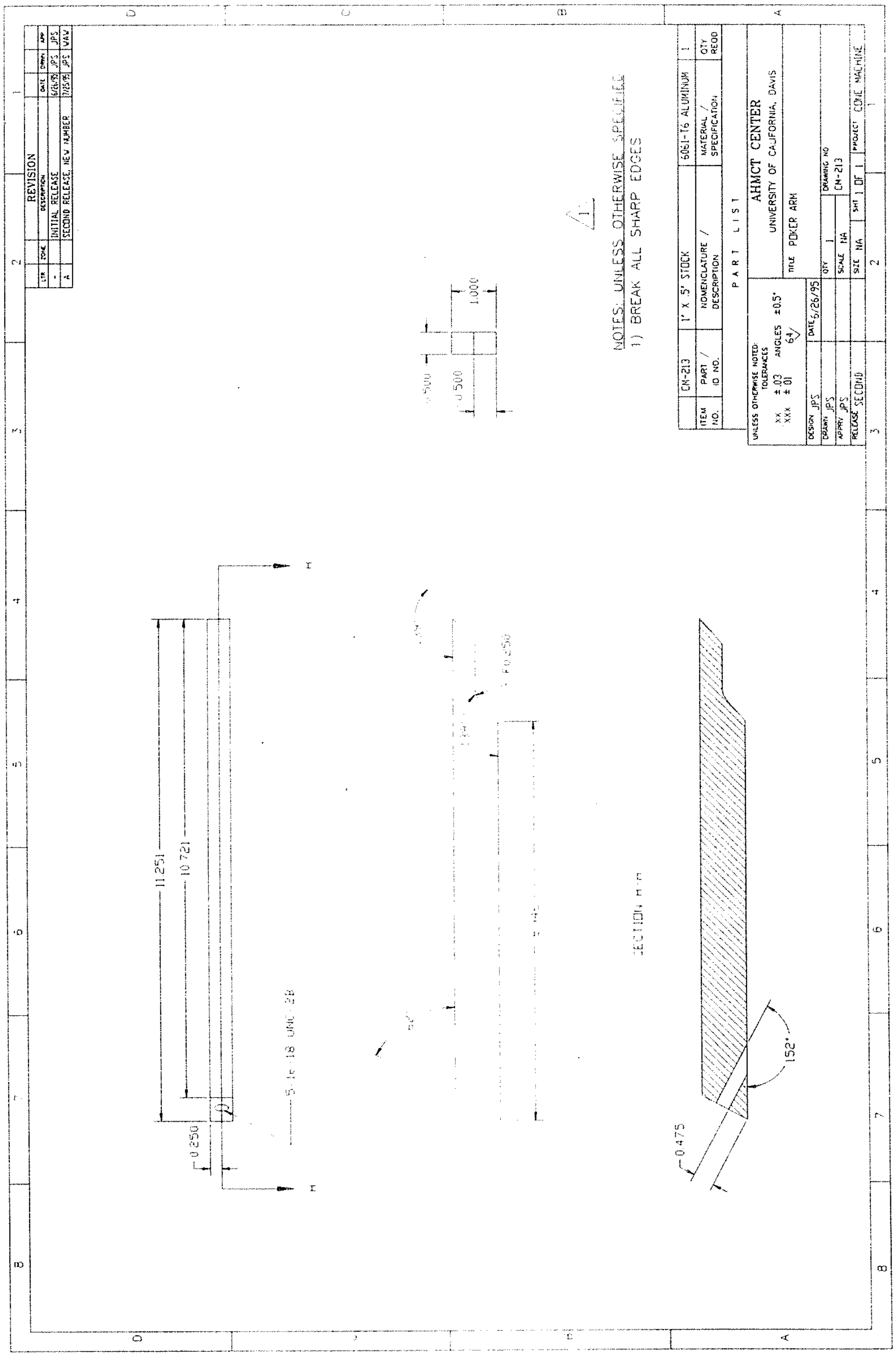

SECTION A-A
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
REVISION
INITIAL RELEASE
CM-208
SWITCH MOUNT
ALUMINUM
PART LIST
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS

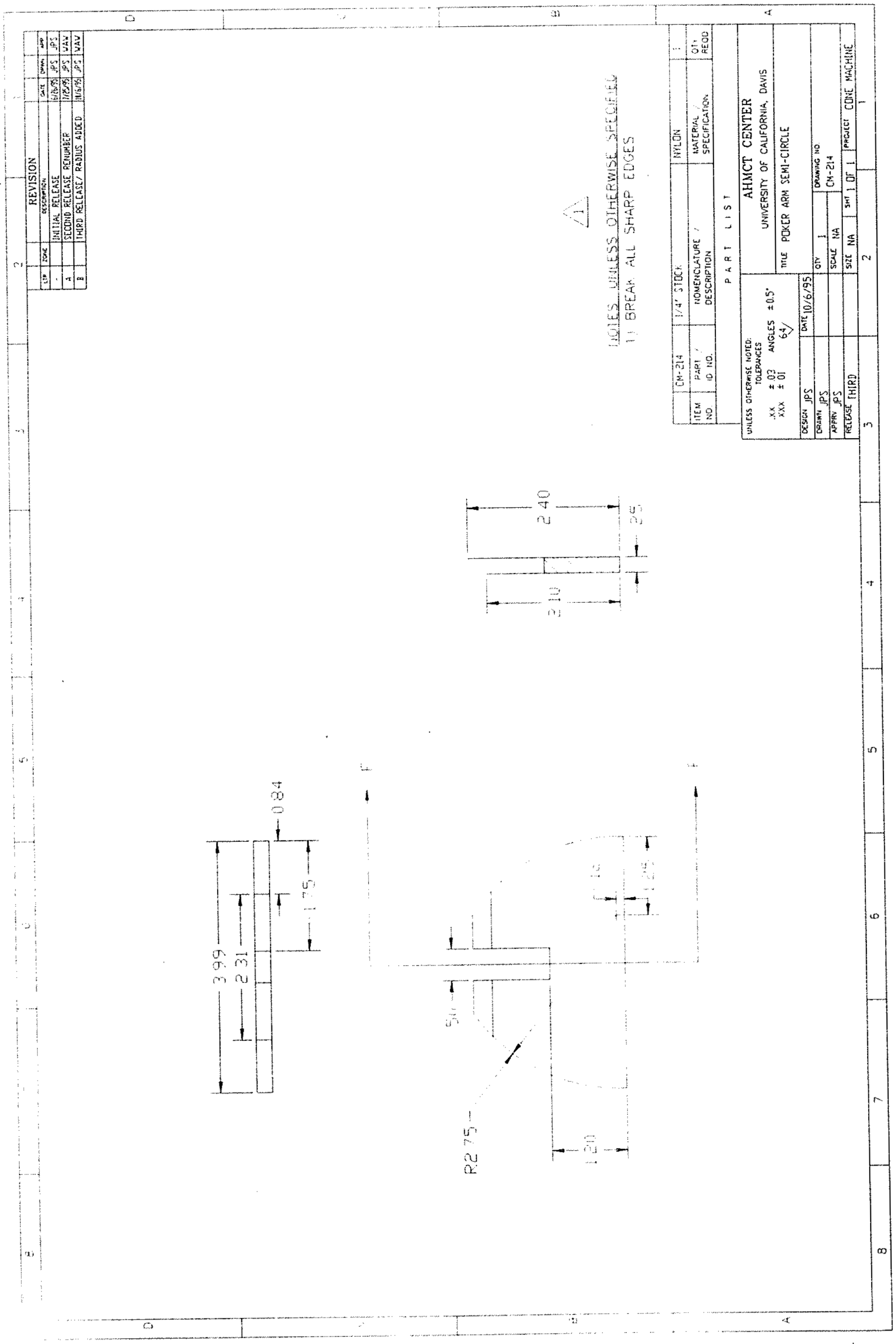

REVISION
INITIAL RELEASE
SECOND RELEASE
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
CM-209
1/8" STOCK
1018 STEEL
2
ITEM NO.
PART / ID NO.
NOMENCLATURE / DESCRIPTION
MATERIAL / SPECIFICATION
QTY REQD
PART LIST
UNLESS OTHERWISE NOTED TOLERANCES
XX ±.03
XXX ±.01
ANGLES ±0.5°
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
TITLE BUMPER RETAINING PLATE
DESIGN JPS
DRAWN JPS
APPRV JPS
RELEASE SECOND
DATE 6/26/95
QTY 2
SCALE NA
SIZE NA
SHT 1 OF 1
DRAWING NO CM-209
PROJECT CONE MACHINE
2X Ø0.250
0.250
0.500
1.000
2.000

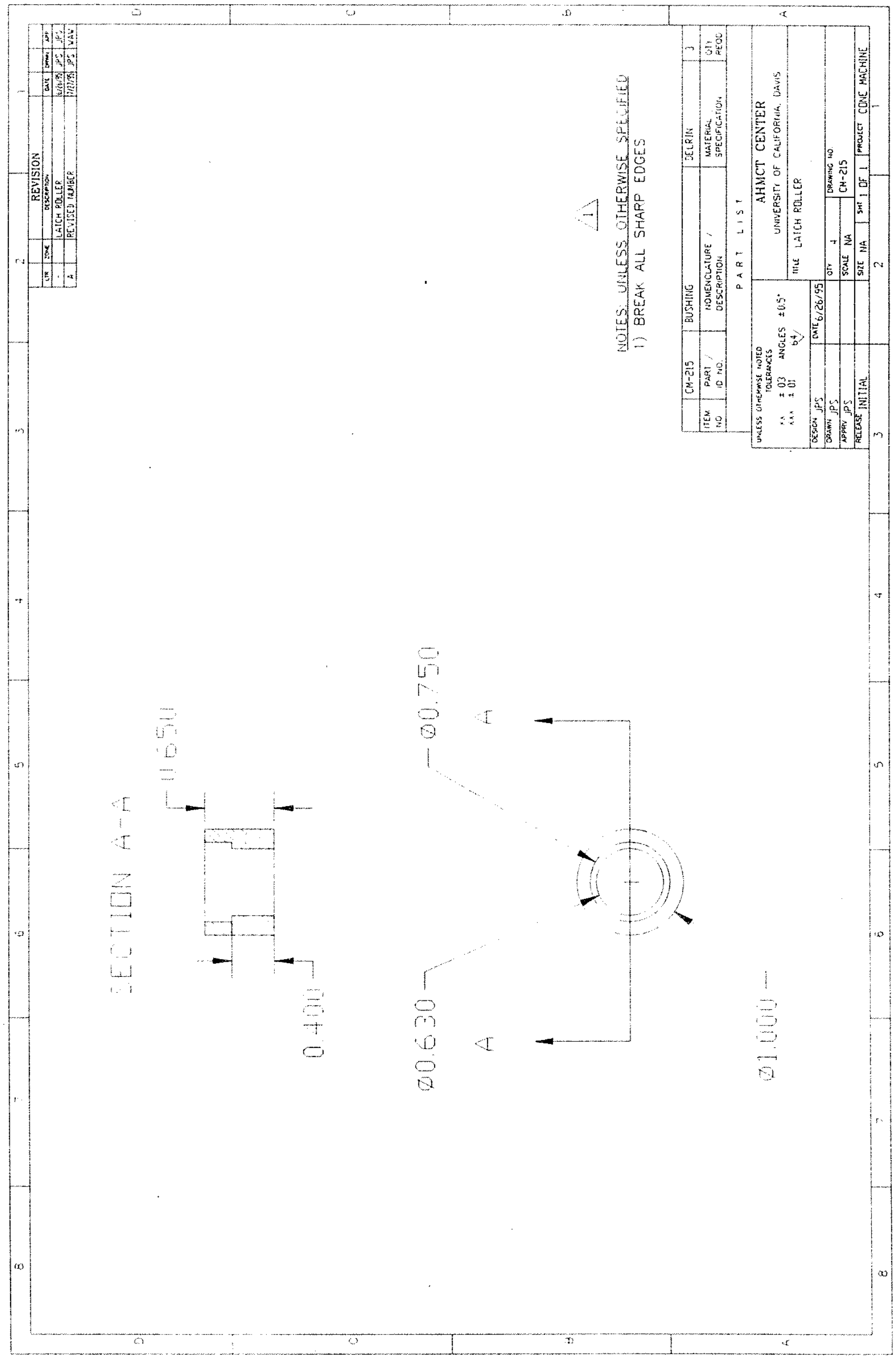

REVISION
INITIAL RELEASE
SECOND RELEASE RENUMBER
SECTION D-D
2X ⌀ .323 THRU
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
CM-210
CONE BUMPER
NYLON
PART LIST
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
TITLE CONE BUMPER
DRAWING NO. CM-210
PROJECT CONE MACHINE
DESIGN JPS
DRAWN JPS
APPRV JPS
RELEASE SECOND
DATE 6/26/95
SCALE NA
SIZE NA
SHT 1 OF 2


REVISION
INITIAL RELEASE
SECOND RELEASE
NOTES UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
CONE BUMPER
CM-210
CONE MACHINE
6X R0.25
0.32
3.79
2.78
SECTION E-E

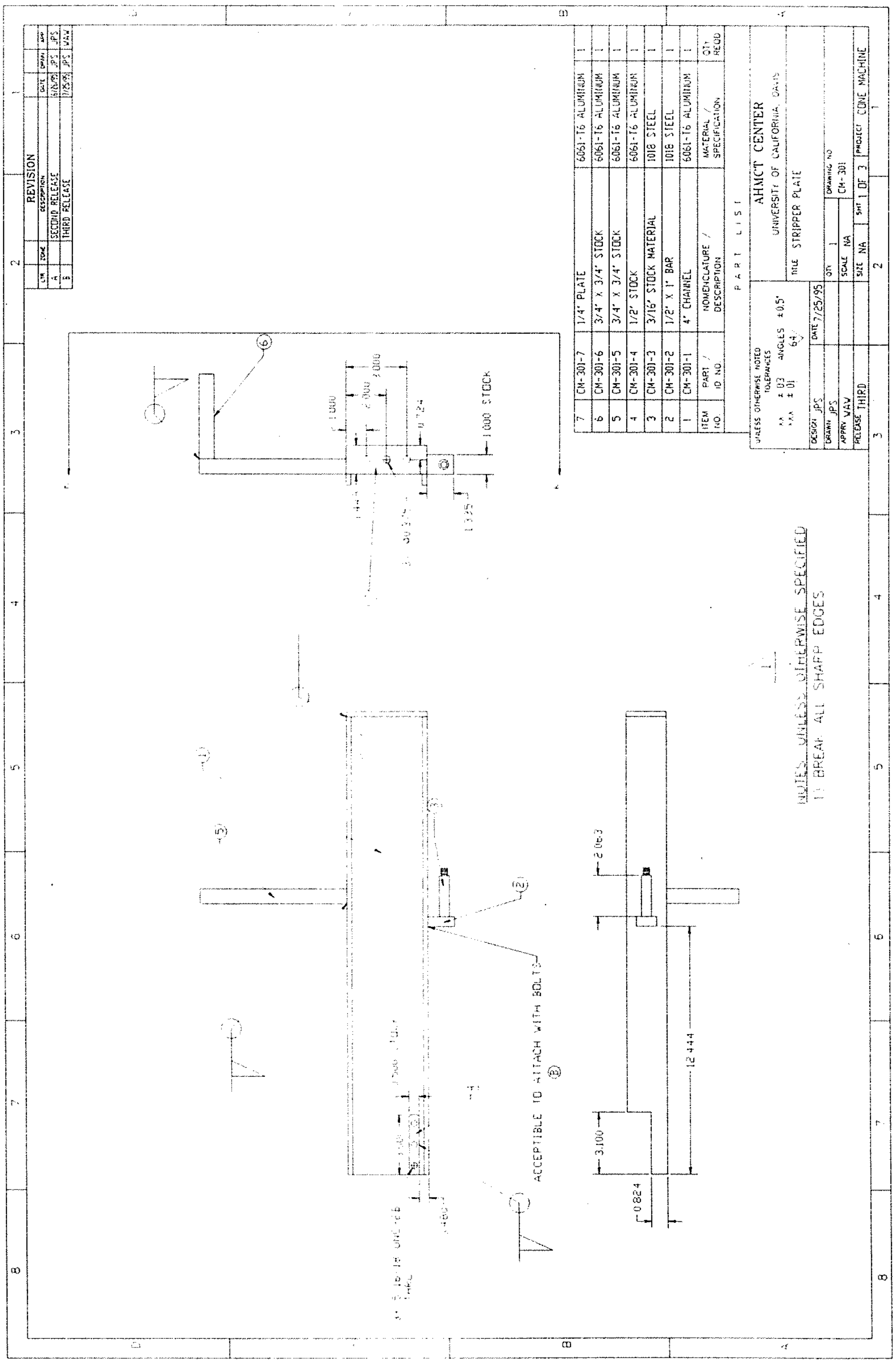

REVISION
INITIAL RELEASE
JPS
WAV
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
1
CM-211
.25" PLATE
1018 STEEL
2
ITEM NO
PART / ID NO.
NOMENCLATURE / DESCRIPTION
MATERIAL / SPECIFICATION
QTY REQD
PART LIST
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
TITLE SPRING MOUNT
UNLESS OTHERWISE NOTED TOLERANCES
XX ±.03
XXX ±.01
ANGLES ±0.5°
64
DESIGN JPS
DATE 7/27/95
DRAWN JPS
APPRV WAV
RELEASE INITIAL
QTY 1
DRAWING NO CM-211
SCALE NA
SIZE NA
SHT 1 OF 1
PROJECT CONE MACHINE
0.75
0.25
1.50
0.50
0.50
1.75
0.25 nominal


REVISION
INITIAL RELEASE
SECOND RELEASE, NEW NUMBER
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
CM-213
1" X .5" STOCK
6061-T6 ALUMINUM
PART LIST
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
POKER ARM
CONE MACHINE
11.251
10.721
0.250
0.475
152°
1.000
0.500

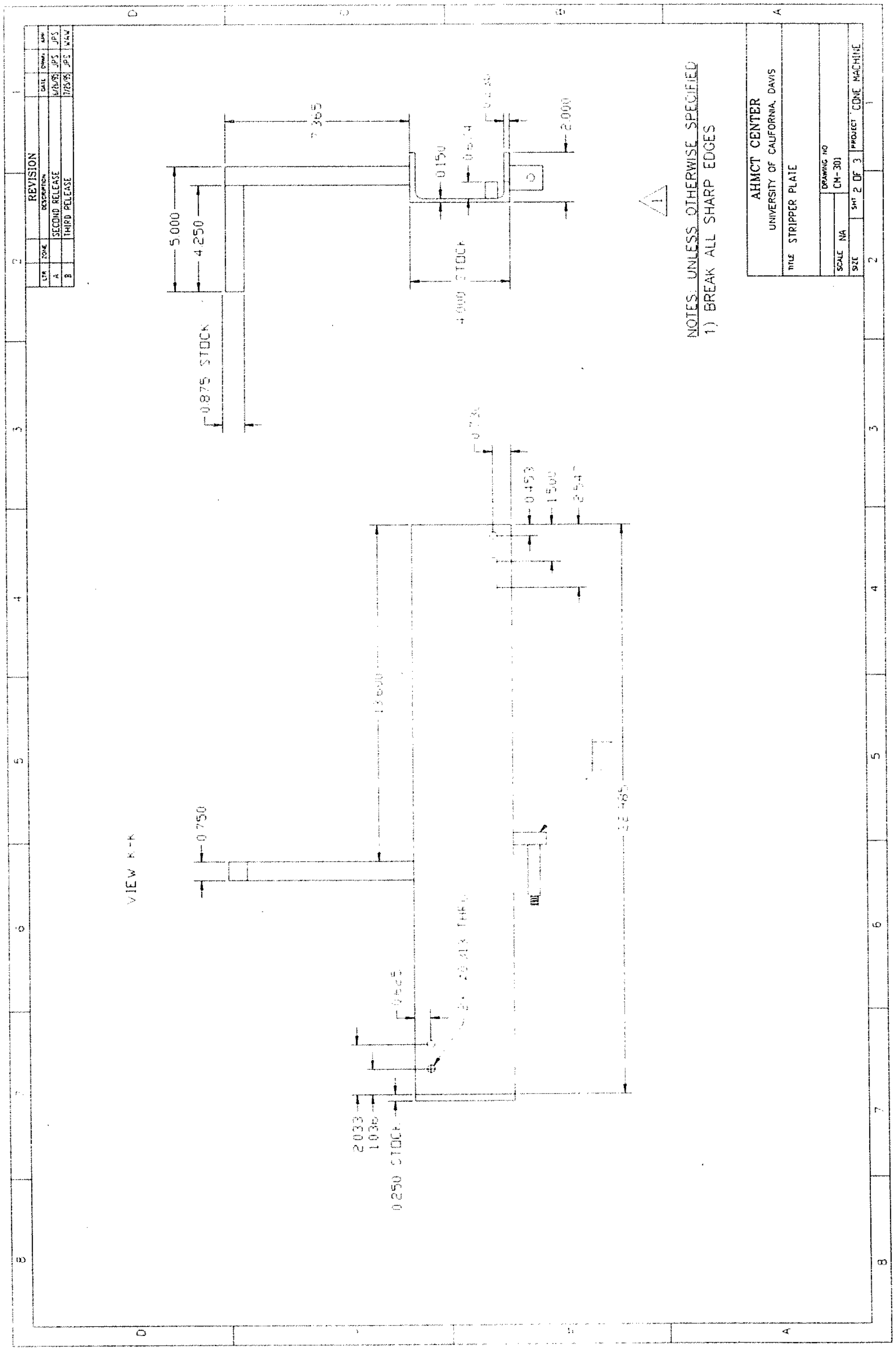

REVISION
INITIAL RELEASE
SECOND RELEASE RENUMBER
THIRD RELEASE/ RADIUS ADDED
NOTES UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
CM-214
1/4" STOCK
NYLON
PART LIST
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
POKER ARM SEMI-CIRCLE
CM-214
CORE MACHINE
2.40
.25
2.10
0.84
1.75
3.99
2.31
.50
R2.75
1.20

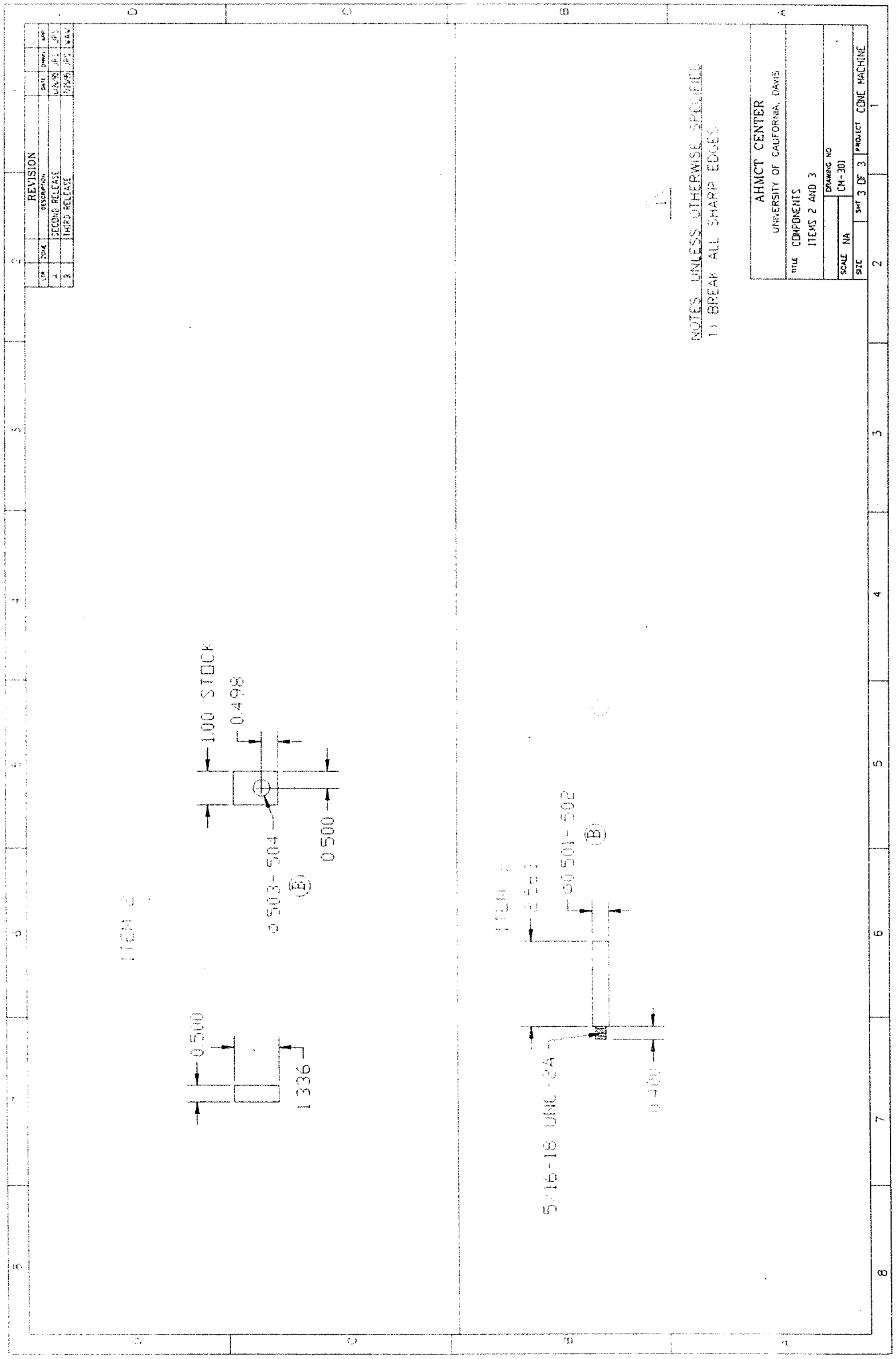


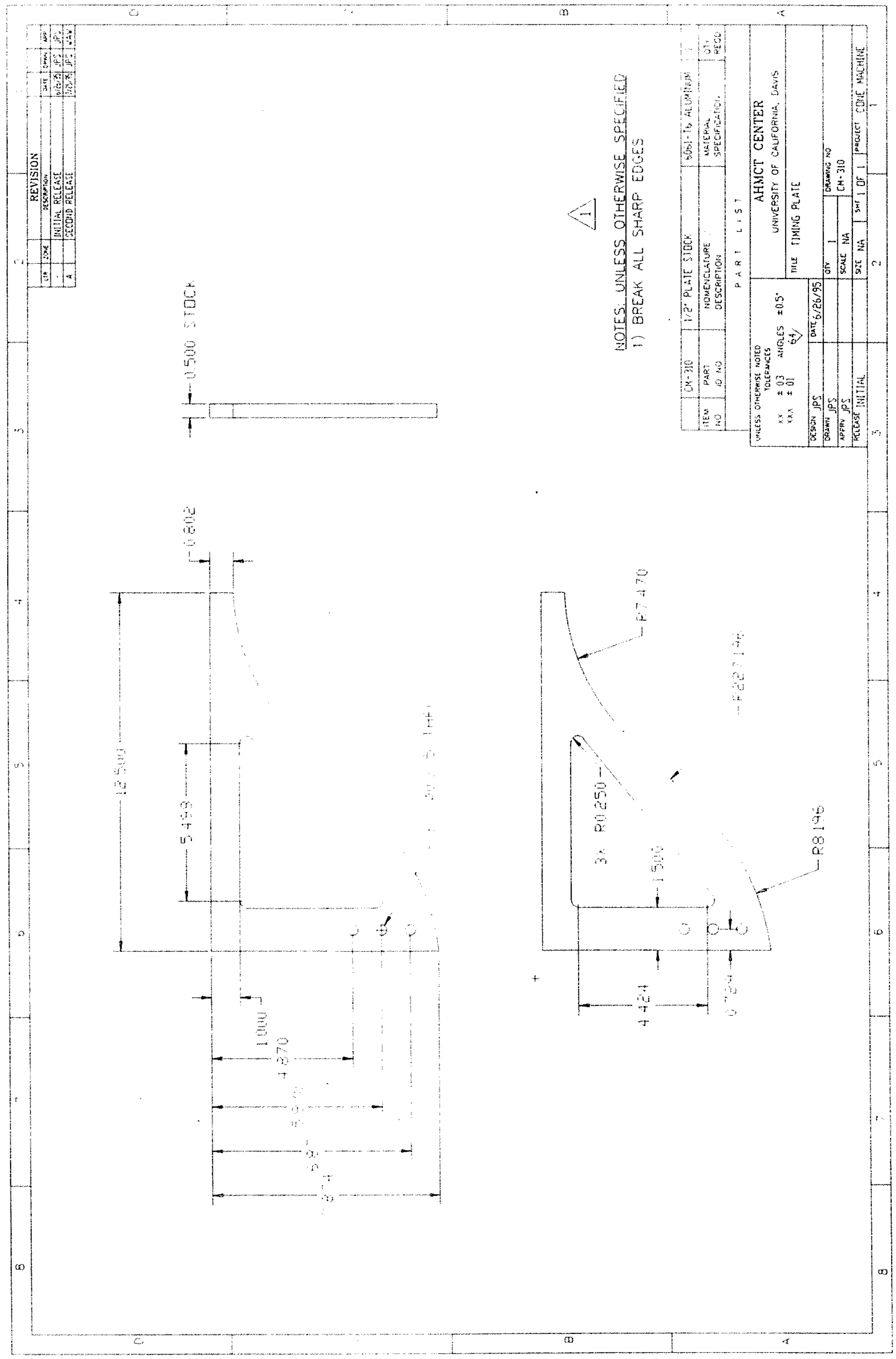
REVISION
LATCH ROLLER
REVISED NUMBER
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
CM-215
BUSHING
DELRIN
3
PART LIST
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
LATCH ROLLER
CONE MACHINE
SECTION A-A
0.400
Ø0.750
Ø0.630
Ø1.000


REVISION
A SECOND RELEASE JPS
B THIRD RELEASE JPS VAV
7 CM-301-7 1/4" PLATE 6061-T6 ALUMINUM 1
6 CM-301-6 3/4" x 3/4" STOCK 6061-T6 ALUMINUM 1
5 CM-301-5 3/4" x 3/4" STOCK 6061-T6 ALUMINUM 1
4 CM-301-4 1/2" STOCK 6061-T6 ALUMINUM 1
3 CM-301-3 3/16" STOCK MATERIAL 1018 STEEL 1
2 CM-301-2 1/2" X 1" BAR 1018 STEEL 1
1 CM-301-1 4" CHANNEL 6061-T6 ALUMINUM 1
ITEM NO PART / ID NO NOMENCLATURE / DESCRIPTION MATERIAL / SPECIFICATION QTY REQD
PART LIST
AHMCT CENTER
UNIVERSITY OF CALIFORNIA DAVIS
TITLE STRIPPER PLATE
DRAWING NO CM-301
PROJECT CONE MACHINE
SHT 1 OF 3
SCALE NA
SIZE NA
QTY 1
DESIGN JPS
DRAWN JPS
APPRV VAV
RELEASE THIRD
DATE 7/25/95
UNLESS OTHERWISE NOTED TOLERANCES ANGLES ±0.5°
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
ACCEPTABLE TO ATTACH WITH BOLTS
1.000 STOCK
12.444
3.100
0.824

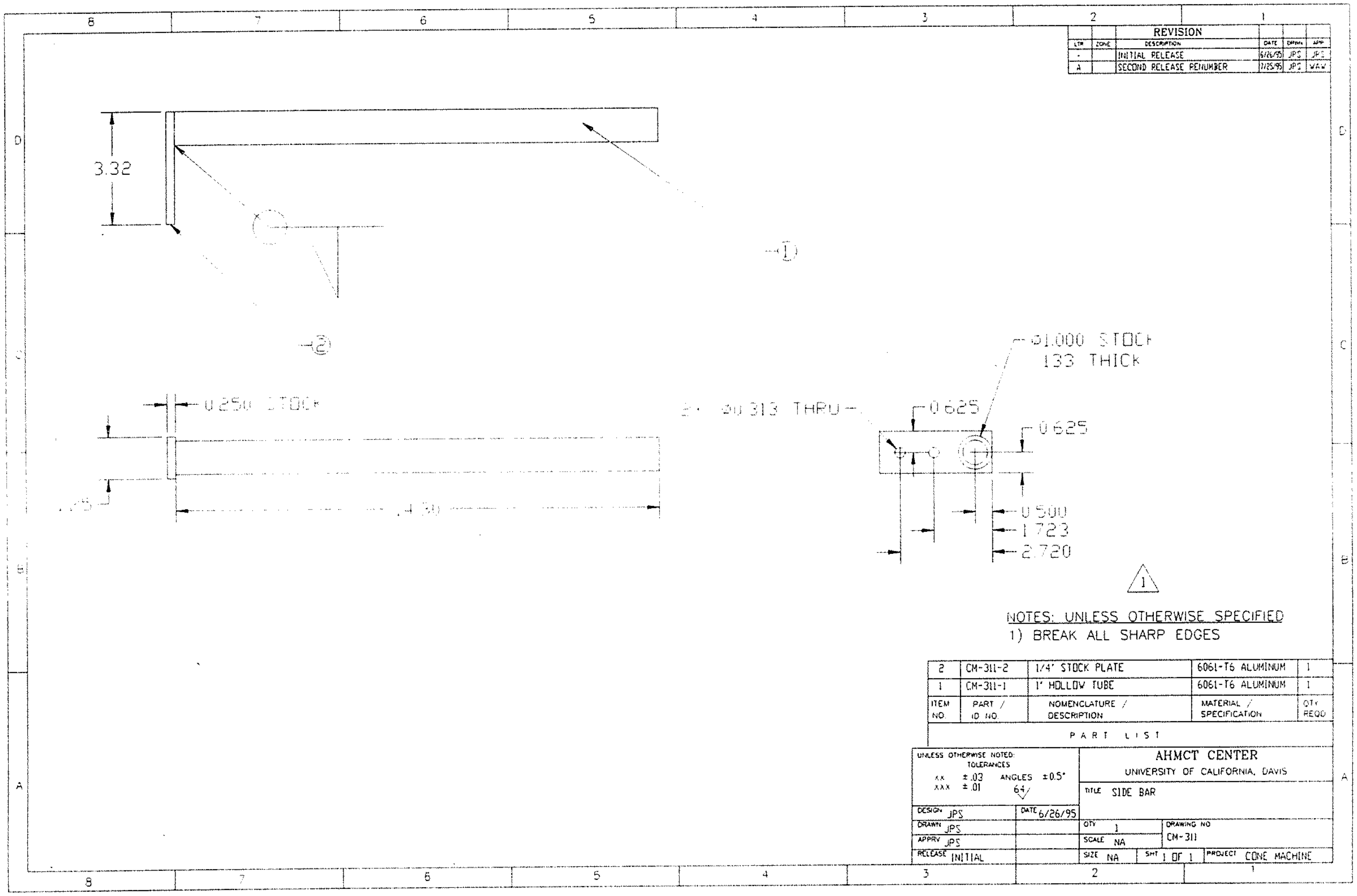
174


REVISION
SECOND RELEASE
THIRD RELEASE
5.000
4.250
0.875 STOCK
0.150
2.000
VIEW K-K
0.750
2.033
1.036
0.250 STOCK
NOTES UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
TITLE STRIPPER PLATE
DRAWING NO CM-301
SCALE NA
SHT 2 OF 3
PROJECT CONE MACHINE


REVISION
SECOND RELEASE
THIRD RELEASE
NOTES UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
COMPONENTS
ITEMS 2 AND 3
CM-301
3 OF 3
CONE MACHINE
1.00 STOCK
0.498
0.500
1.336
5/16-18 UNC-2A

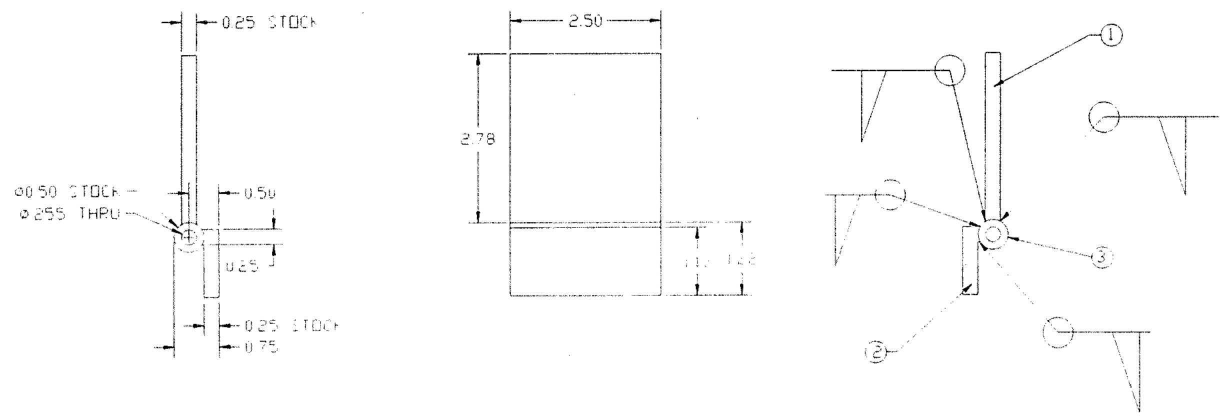


NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
REVISION
INITIAL RELEASE
SECOND RELEASE
0.500 STOCK
1/2" PLATE STOCK
6061-T6 ALUMINUM
CM-310
PART LIST
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
TIMING PLATE
6/26/95


REVISION
INITIAL RELEASE 6/26/95 JPS JPS
A SECOND RELEASE RENUMBER 7/25/95 JPS WAW
3.32
1
2
Ø1.000 STOCK
.133 THICK
0.250 STOCK
2X Ø0.313 THRU
0.625
0.625
0.500
1.723
2.720
1
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
2 CM-311-2 1/4" STOCK PLATE 6061-T6 ALUMINUM 1
1 CM-311-1 1" HOLLOW TUBE 6061-T6 ALUMINUM 1
ITEM NO. PART / ID NO. NOMENCLATURE / DESCRIPTION MATERIAL / SPECIFICATION QTY REQD
PART LIST
UNLESS OTHERWISE NOTED: TOLERANCES
.XX ±.03 ANGLES ±0.5°
.XXX ±.01
64
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
TITLE SIDE BAR
DESIGN JPS DATE 6/26/95
DRAWN JPS
APPRV JPS
RELEASE INITIAL
QTY 1
DRAWING NO CM-311
SCALE NA
SIZE NA SHT 1 OF 1 PROJECT CONE MACHINE

LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
-		INITIAL RELEASE	6/26/95	JPS	JPS

REVISION



1

NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
2) ACCEPTABLE FROM 1 PIECE

ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
3	CM-405-3	1/2" STOCK	6061-T6 ALUMINUM	1
2	CM-405-2	1/4" STOCK PLATE	6061-T6 ALUMINUM	1
1	CM-405-1	1/4" STOCK PLATE	6061-T6 ALUMINUM	1

PART LIST

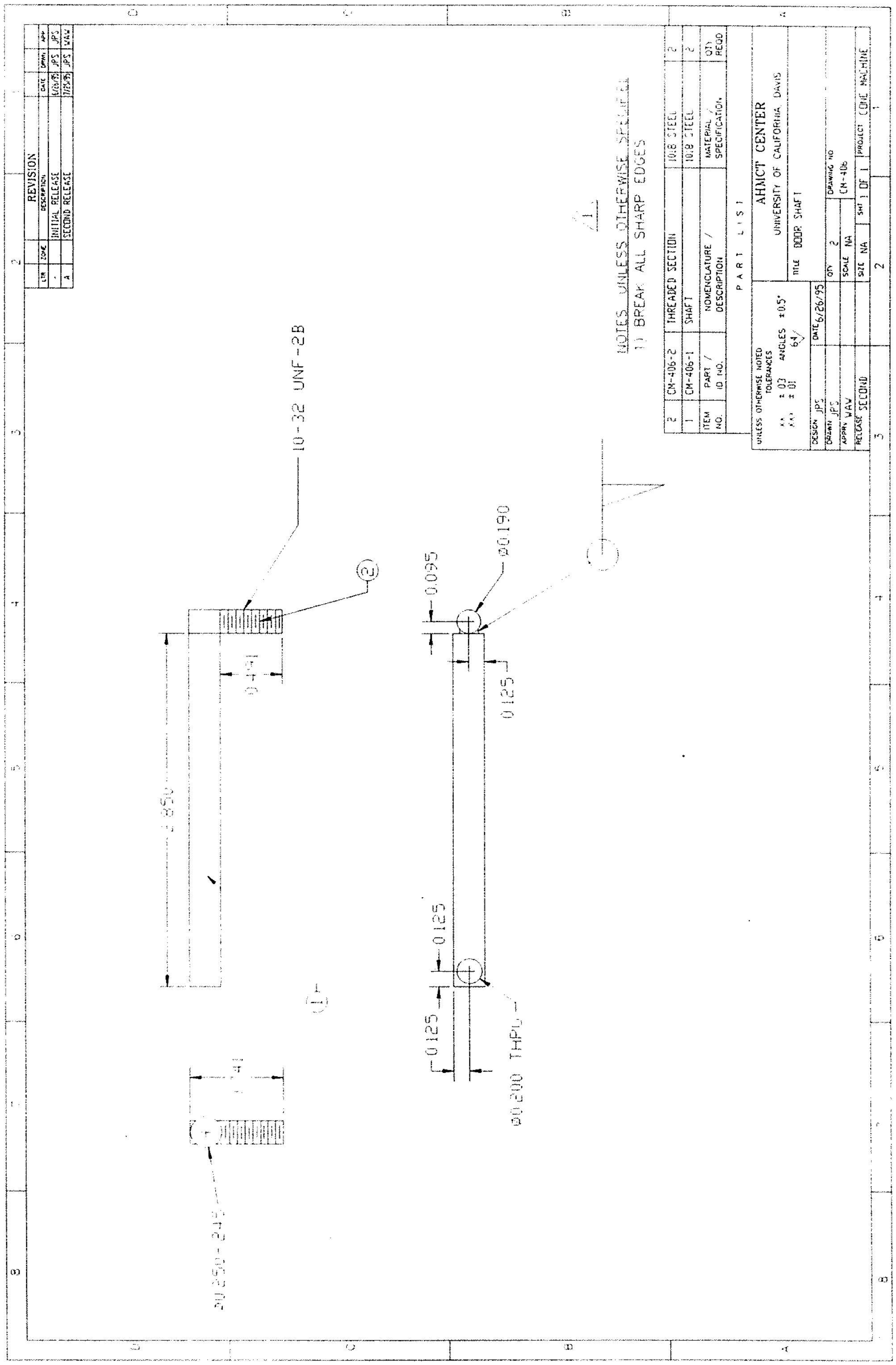
UNLESS OTHERWISE NOTED TOLERANCES
XX ±.03 ANGLES ±0.5°
XXX ±.01 64/

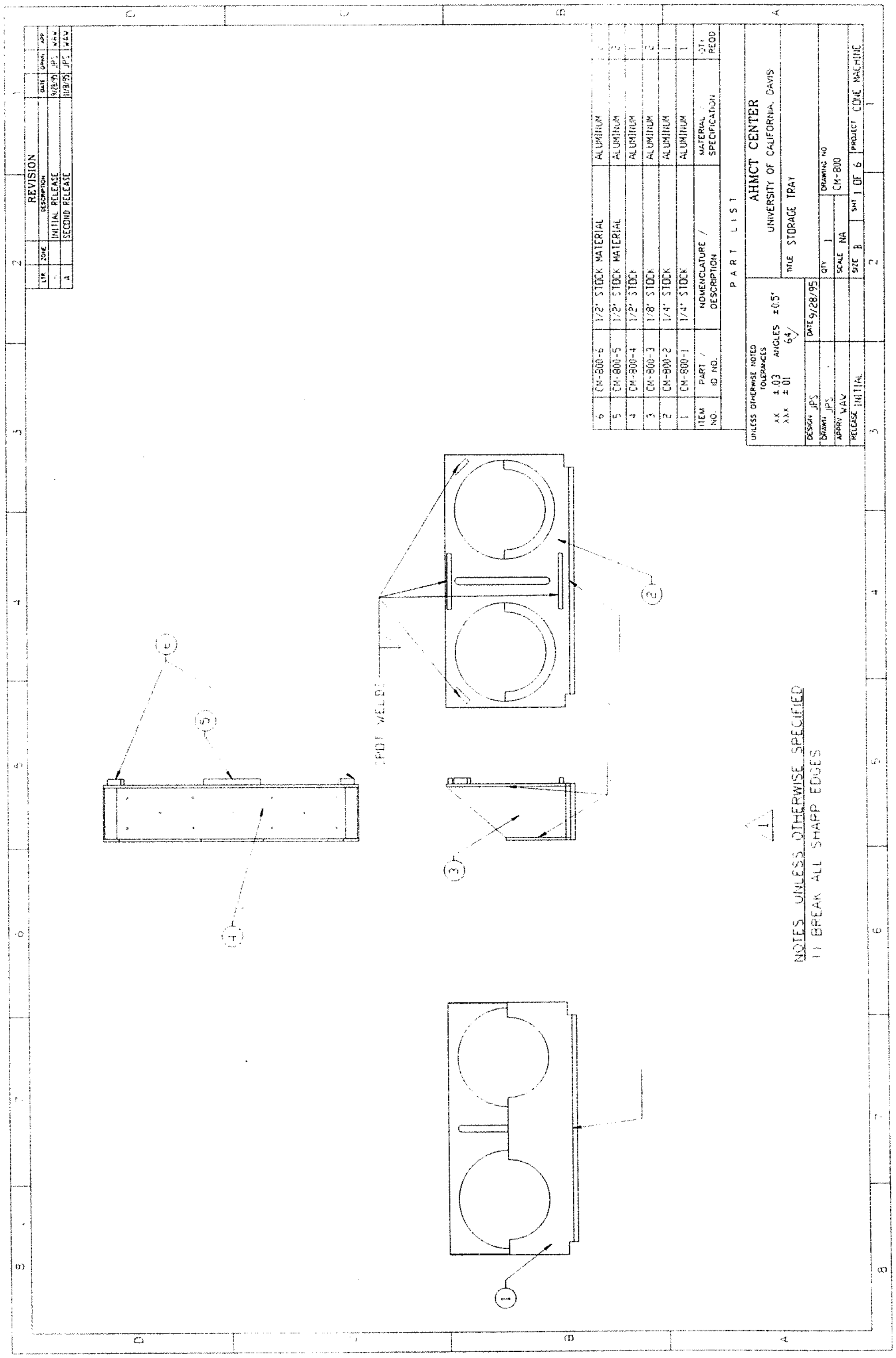
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS

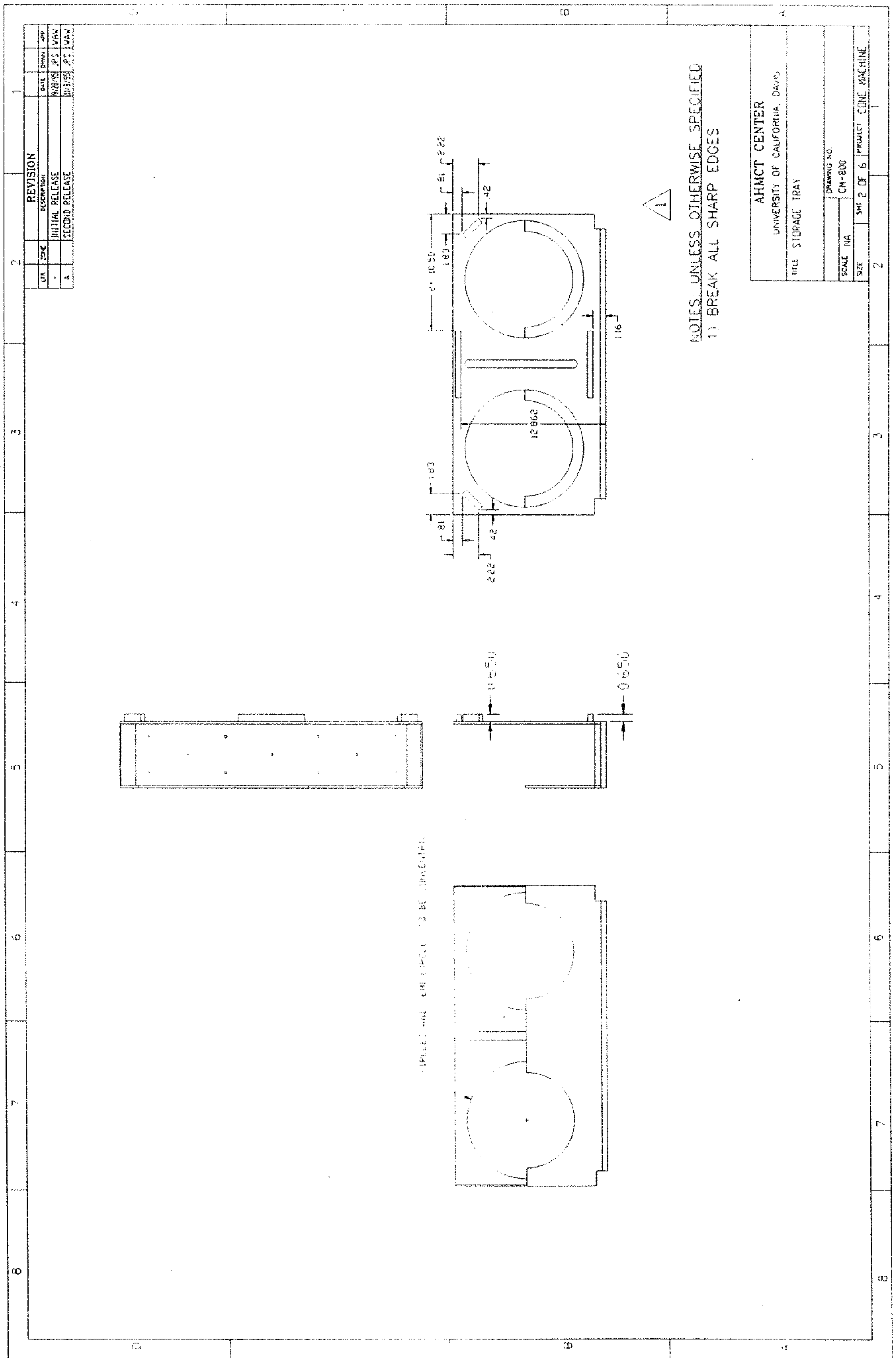
TITLE DOOR

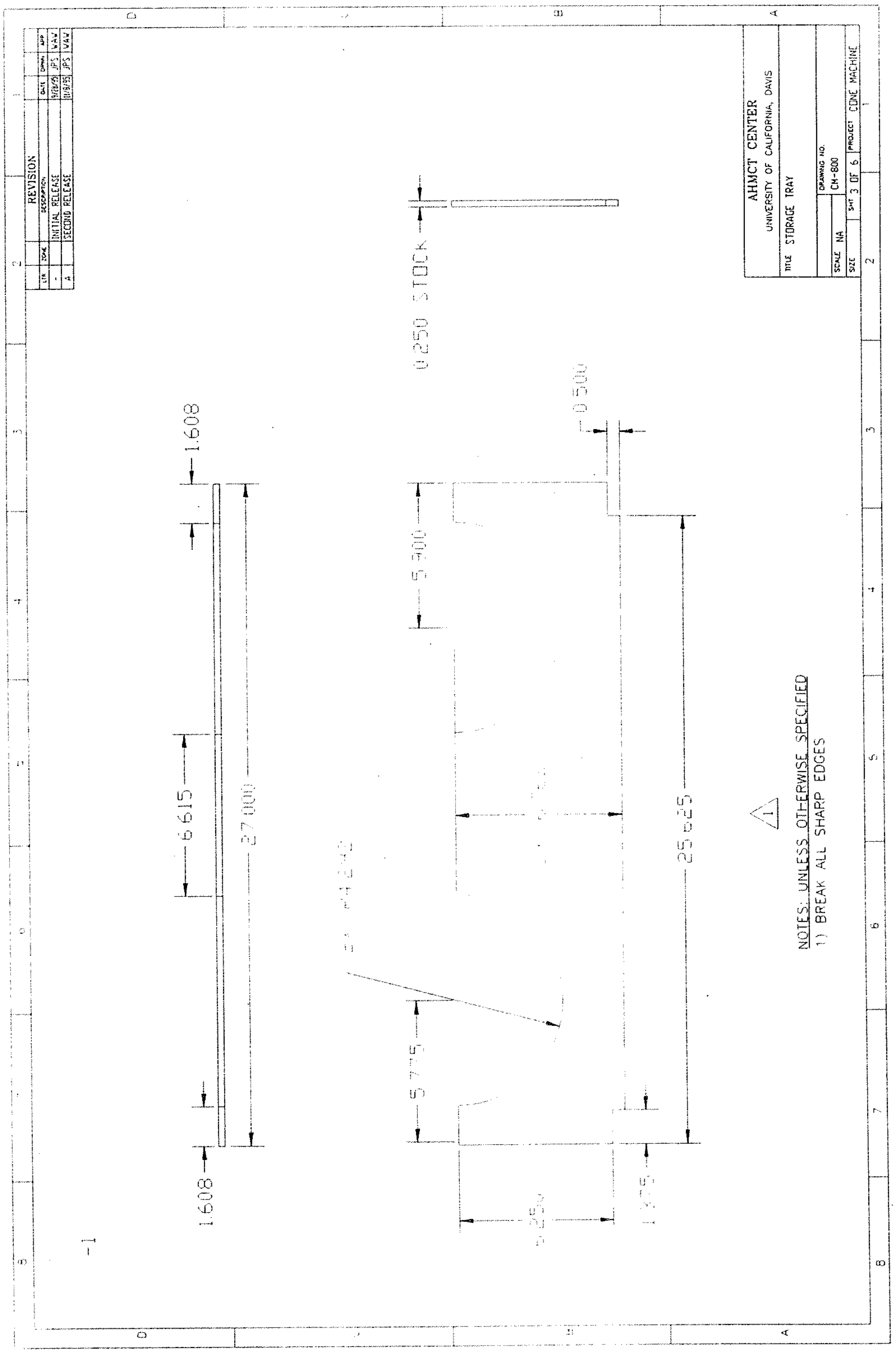
DESIGN JPS DATE 6/26/95
DRAWN JPS
APPRV JPS
RELEASE INITIAL

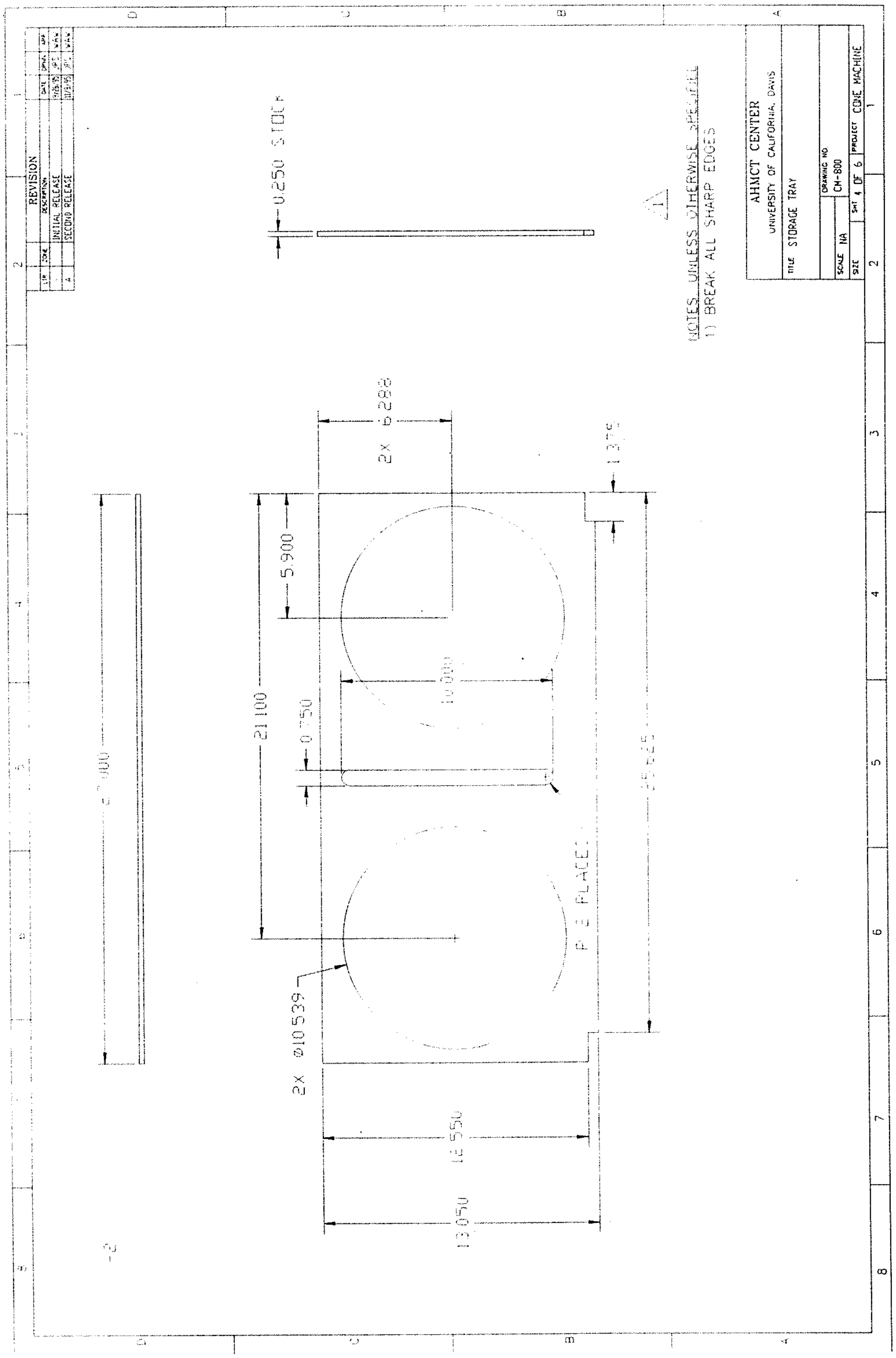
QTY 2
SCALE NA
DRAWING NO. 405
SIZE NA SHT 1 OF 1 PROJECT CONE MACHINE

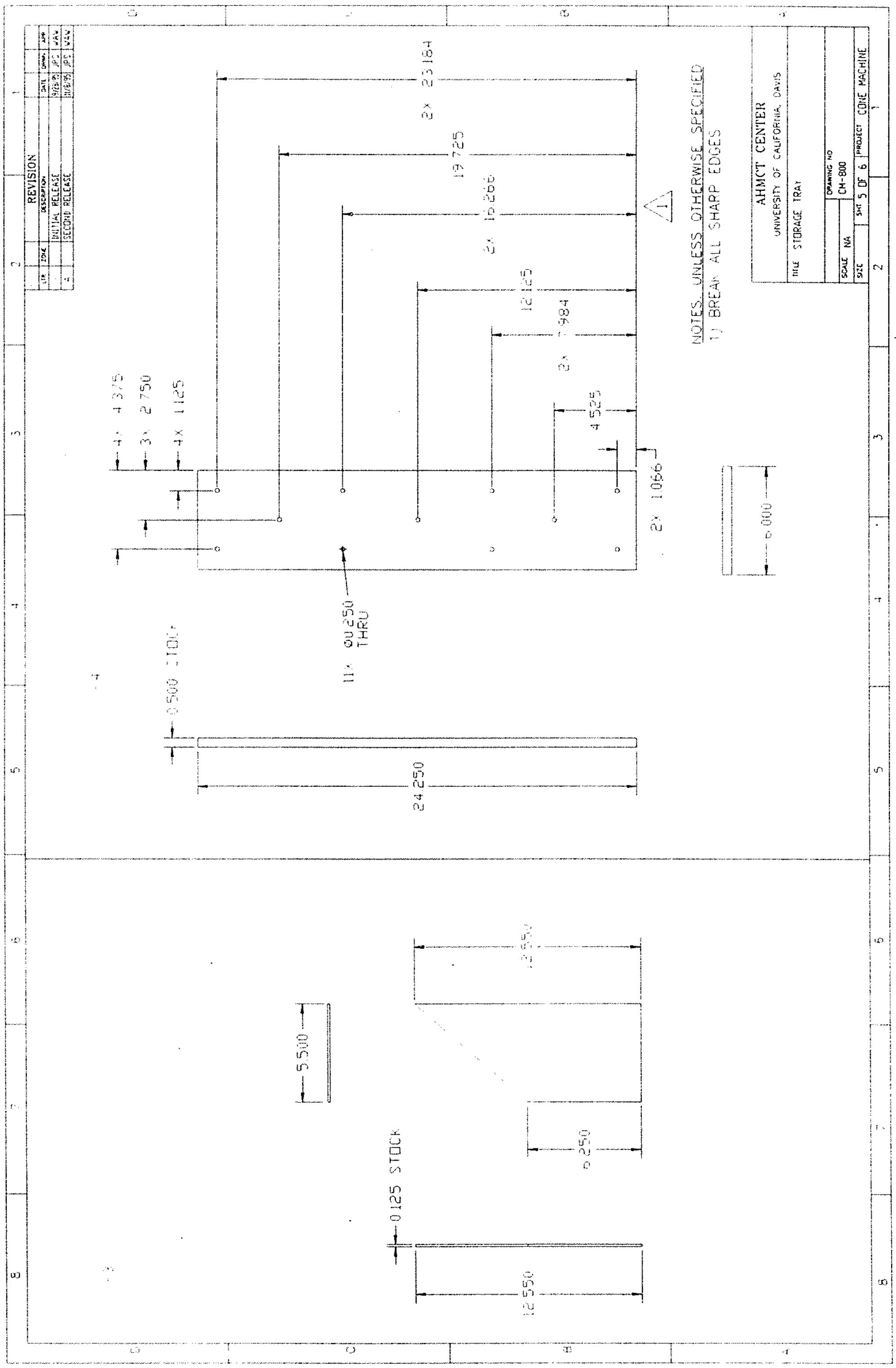

REVISION
INITIAL RELEASE
SECOND RELEASE
10-32 UNF-2B
NOTES UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
THREADED SECTION
SHAFT
NOMENCLATURE / DESCRIPTION
MATERIAL / SPECIFICATION
PART LIST
AHMCT CENTER
UNIVERSITY OF CALIFORNIA DAVIS
DOOR SHAFT
CM-406-2
CM-406-1
CM-406
6/26/95
Ø0.190
Ø0.200 THRU
0.125
0.095

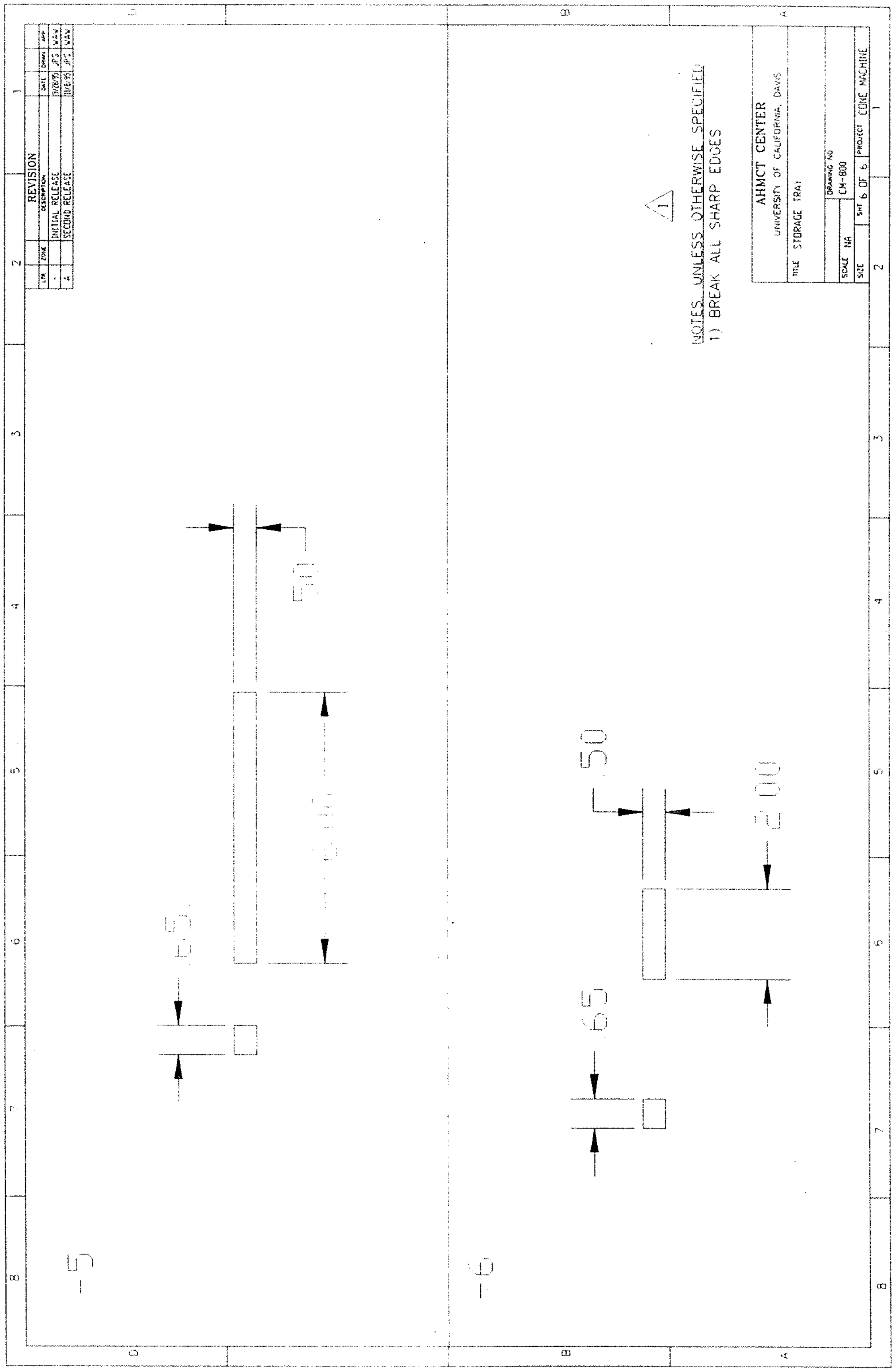

REVISION
LTR ZONE DESCRIPTION DATE DRWN APP
- INITIAL RELEASE 9/28/95 JPS WAV
A SECOND RELEASE 11/8/95 JPS WAV
6 CM-800-6 1/2" STOCK MATERIAL ALUMINUM
5 CM-800-5 1/2" STOCK MATERIAL ALUMINUM
4 CM-800-4 1/2" STOCK ALUMINUM
3 CM-800-3 1/8" STOCK ALUMINUM
2 CM-800-2 1/4" STOCK ALUMINUM
1 CM-800-1 1/4" STOCK ALUMINUM
ITEM NO. PART / ID NO. NOMENCLATURE / DESCRIPTION MATERIAL SPECIFICATION QTY REQD
PART LIST
UNLESS OTHERWISE NOTED TOLERANCES
.XX ±.03 ANGLES ±0.5°
.XXX ±.01
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
TITLE STORAGE TRAY
DESIGN JPS DATE 9/28/95
DRAWN JPS
APPRV WAV
RELEASE INITIAL
QTY 1
SCALE NA
SIZE B
SHT 1 OF 6
DRAWING NO CM-800
PROJECT CONE MACHINE
SPOT WELD
NOTES UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES

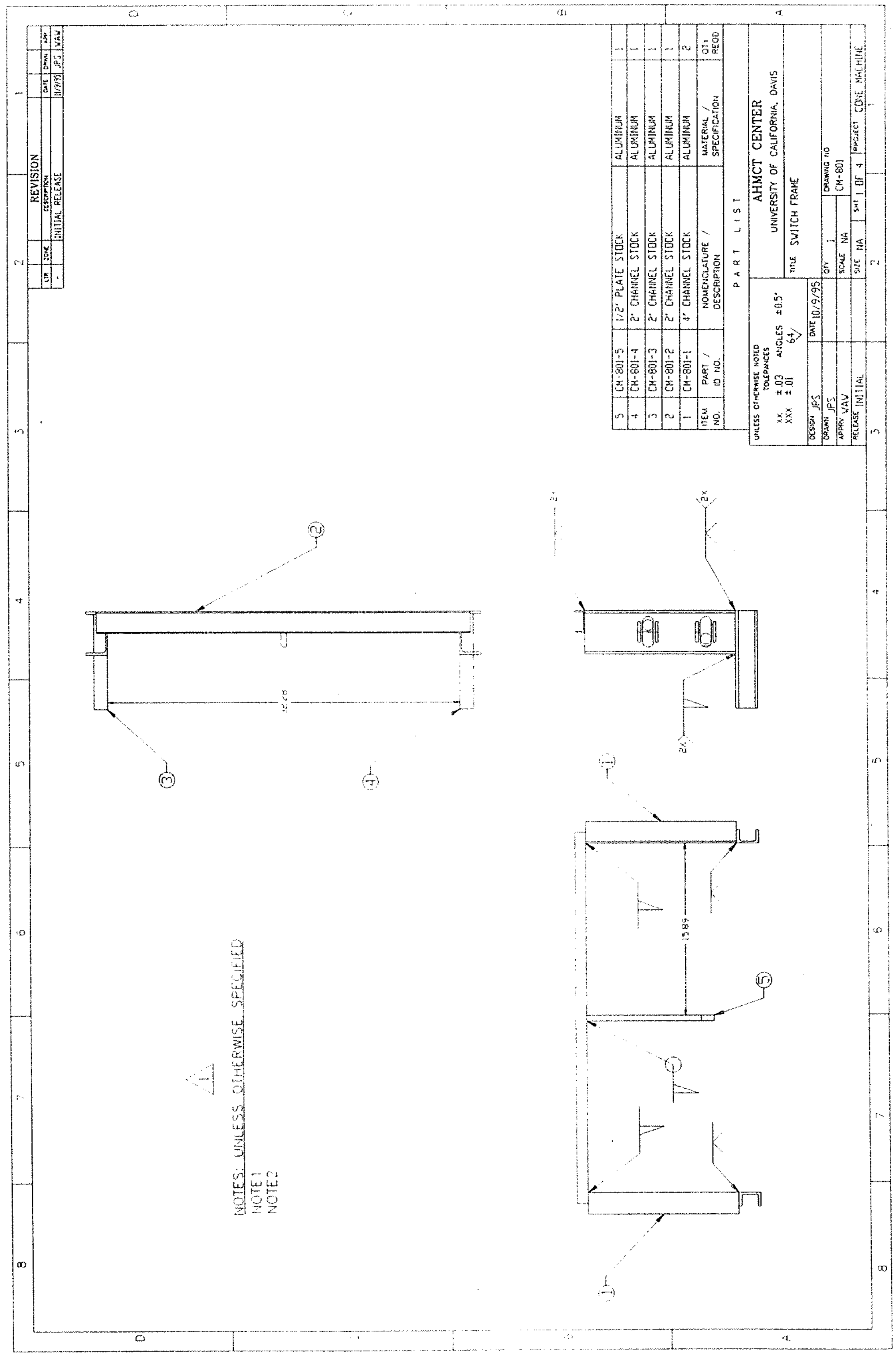

REVISION
INITIAL RELEASE
SECOND RELEASE
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
STORAGE TRAY
CM-800
SCALE NA
SHT 2 OF 6
PROJECT CONE MACHINE
12.862

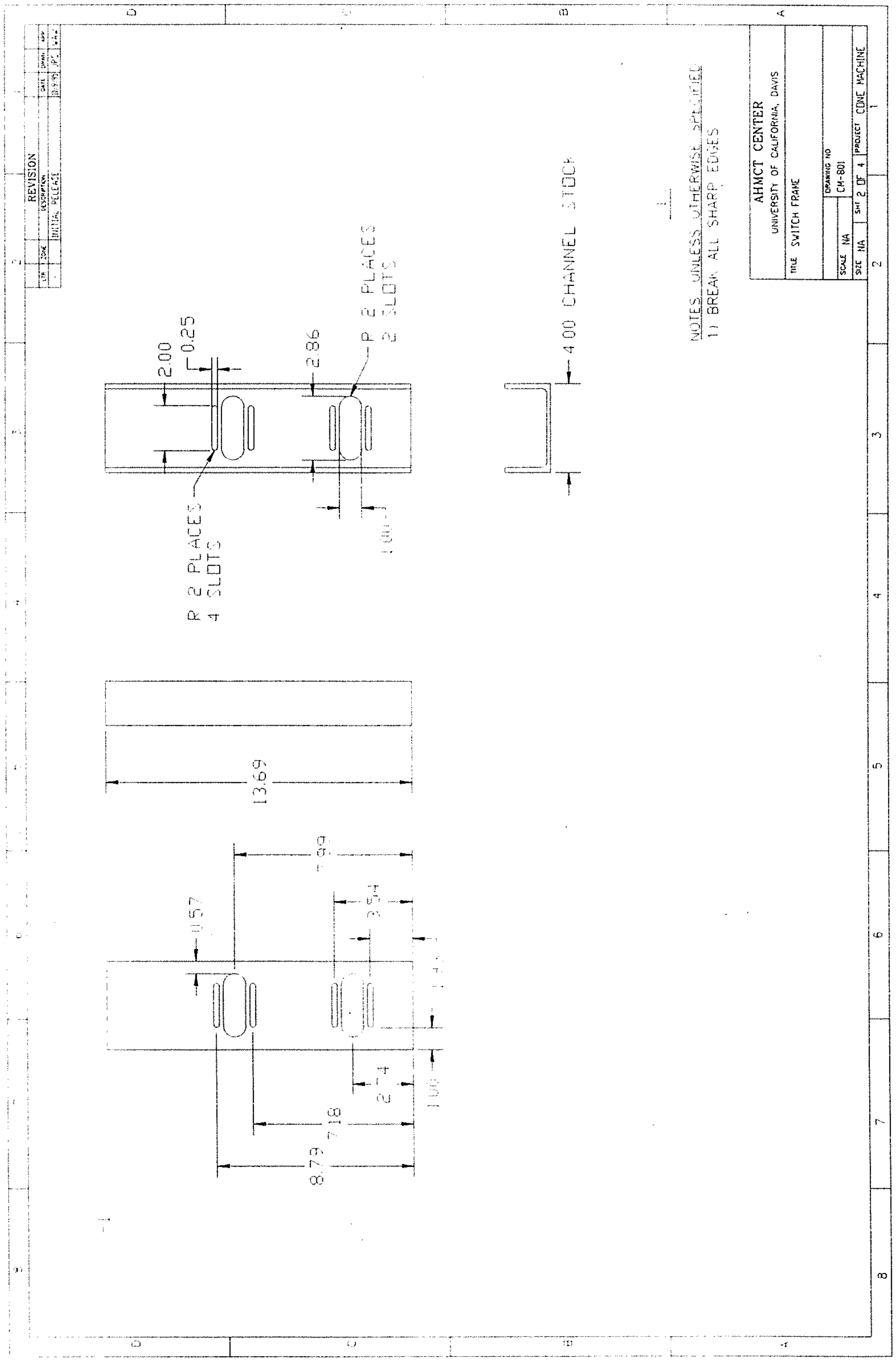

REVISION
INITIAL RELEASE
SECOND RELEASE
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
STORAGE TRAY
CM-800
3 OF 6
CONE MACHINE
NA
0.250 STOCK
0.500
1.608
6.615
27.000
5.900
25.625
5.775
1.608
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHAPP EDGES

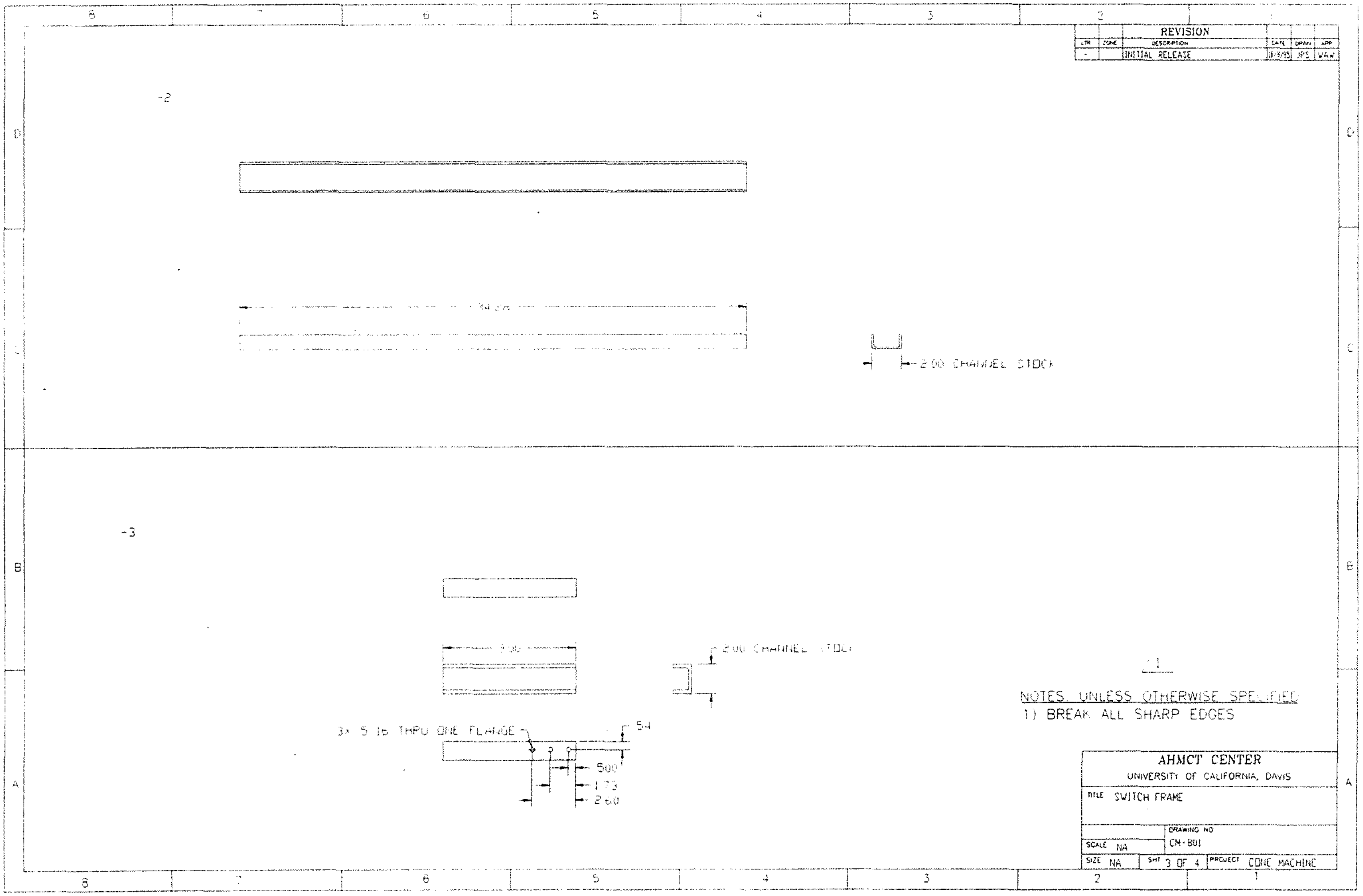

REVISION
INITIAL RELEASE
SECOND RELEASE
0.250 STOCK
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
STORAGE TRAY
CM-800
SCALE NA
SHT 4 OF 6
CORE MACHINE
2x 6.288
5.900
21.100
0.750
2x Ø10.539
12.550
13.050

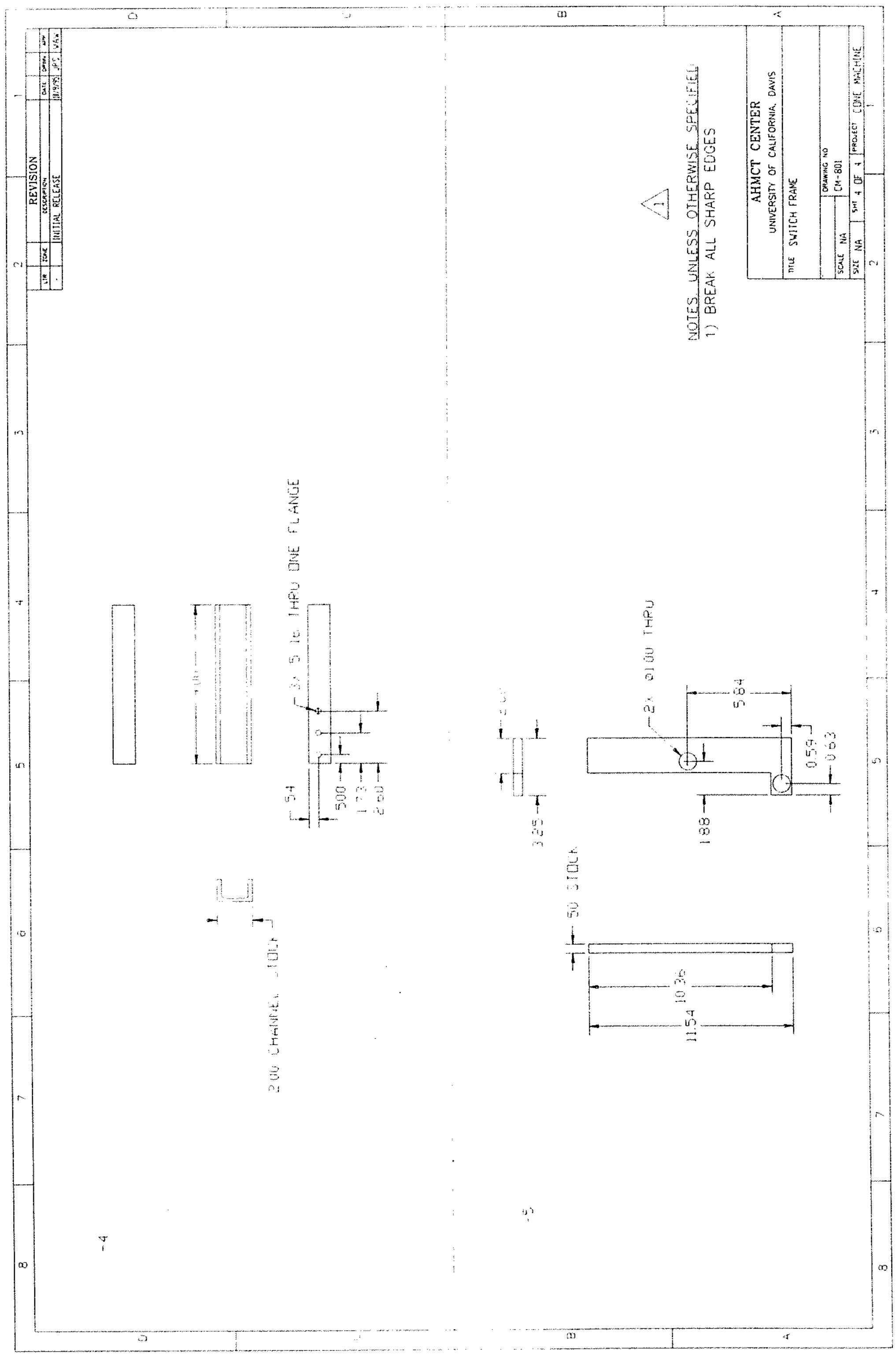

REVISION
INITIAL RELEASE
SECOND RELEASE
2X 23.184
19.725
2X 16.266
12.125
2X 7.984
4.525
2X 1.066
4X 4.375
3X 2.750
4X 1.125
11X Ø0.250 THRU
6.000
0.500 THICK
24.250
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
STORAGE TRAY
CM-800
SCALE NA
SHT 5 OF 6
CORE MACHINE
5.500
6.250
0.125 STOCK
12.550


REVISION
INITIAL RELEASE
SECOND RELEASE
NOTES UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
TITLE STORAGE TRAY
DRAWING NO CM-800
SCALE NA
SHT 6 OF 6
PROJECT CONE MACHINE
.50
2.00
.65
-5
-6


REVISION
LTR ZONE DESCRIPTION DATE DRWN APVD
- INITIAL RELEASE 10/9/95 JPS VAV
5 CM-801-5 1/2" PLATE STOCK ALUMINUM 1
4 CM-801-4 2" CHANNEL STOCK ALUMINUM 1
3 CM-801-3 2" CHANNEL STOCK ALUMINUM 1
2 CM-801-2 2" CHANNEL STOCK ALUMINUM 1
1 CM-801-1 4" CHANNEL STOCK ALUMINUM 2
ITEM NO. PART / ID NO. NOMENCLATURE / DESCRIPTION MATERIAL / SPECIFICATION QTY REQD
PART LIST
UNLESS OTHERWISE NOTED TOLERANCES .XX ±.03 .XXX ±.01 ANGLES ±0.5°
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
TITLE SWITCH FRAME
DESIGN JPS DATE 10/9/95
DRAWN JPS
APPRV VAV
RELEASE INITIAL
QTY 1 DRAWING NO CM-801
SCALE NA
SIZE NA SHT 1 OF 4 PROJECT CONE MACHINE
15.89
NOTES: UNLESS OTHERWISE SPECIFIED
NOTE1
NOTE2


REVISION
INITIAL RELEASE
2.00
0.25
2.86
R 2 PLACES
4 SLOTS
R 2 PLACES
2 SLOTS
4.00 CHANNEL STOCK
NOTES UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
13.69
7.99
3.54
0.57
2.74
7.18
8.79
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
TITLE SWITCH FRAME
DRAWING NO
CM-801
SCALE NA
SIZE NA
SHT 2 OF 4
PROJECT CONE MACHINE


REVISION
INITIAL RELEASE
-2
-3
NOTES. UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
TITLE SWITCH FRAME
DRAWING NO
CM-801
SCALE NA
SIZE NA
SHT 3 OF 4
PROJECT CONE MACHINE



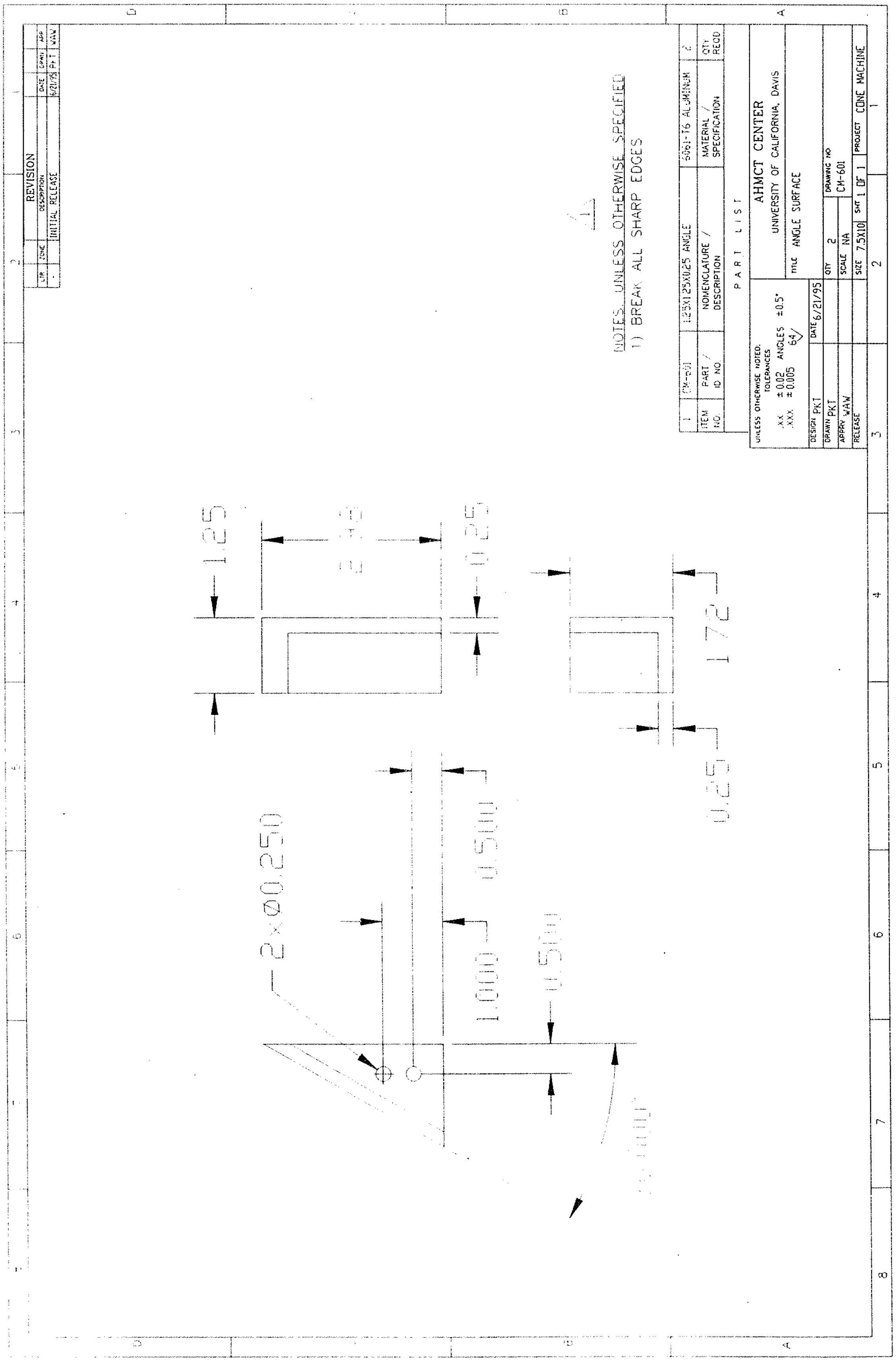
REVISION
INITIAL RELEASE
NOTES UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
TITLE SWITCH FRAME
CM-801
SCALE NA
SIZE NA
SHT 4 OF 4
PROJECT CONE MACHINE

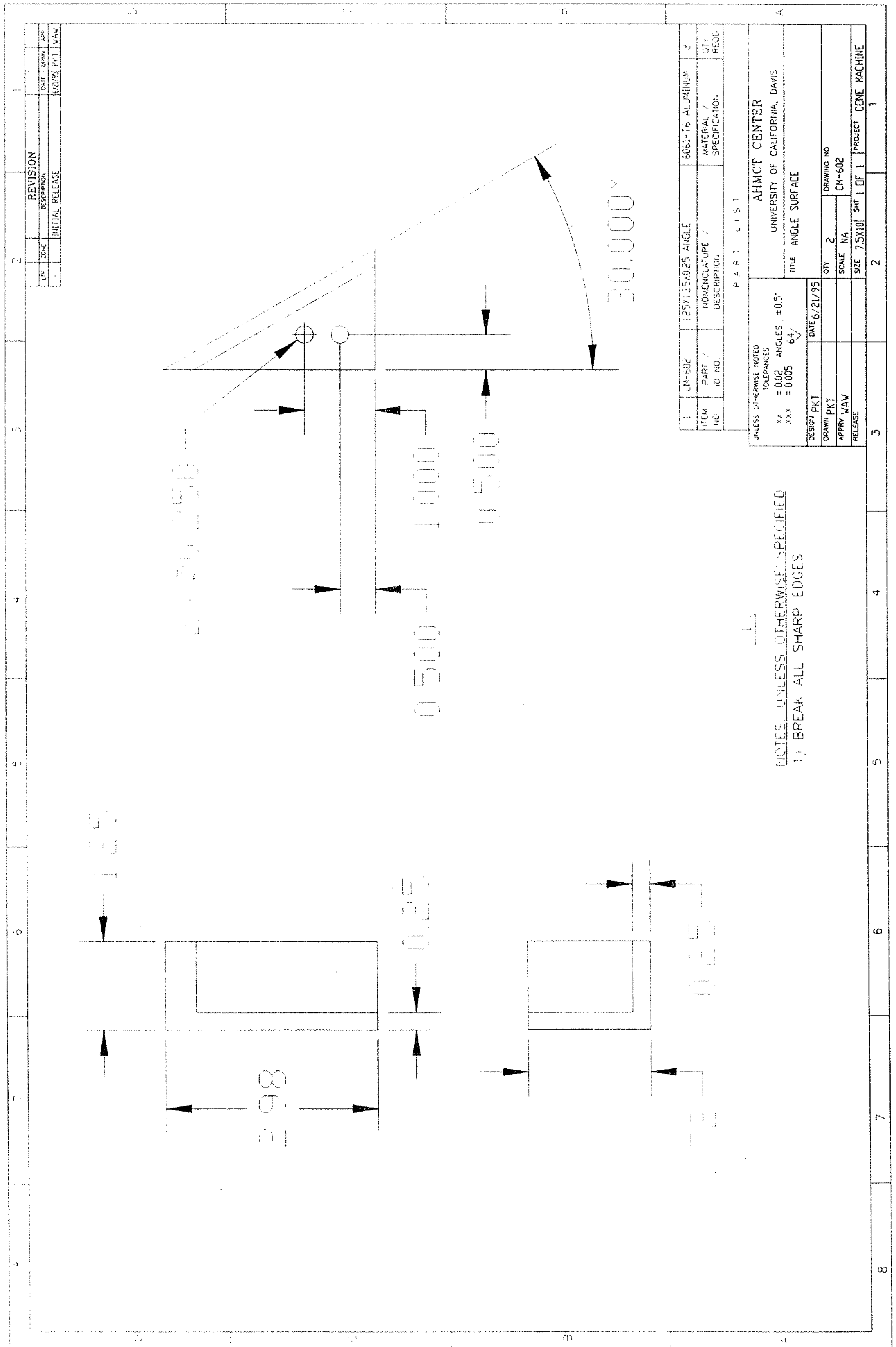
APPENDIX C

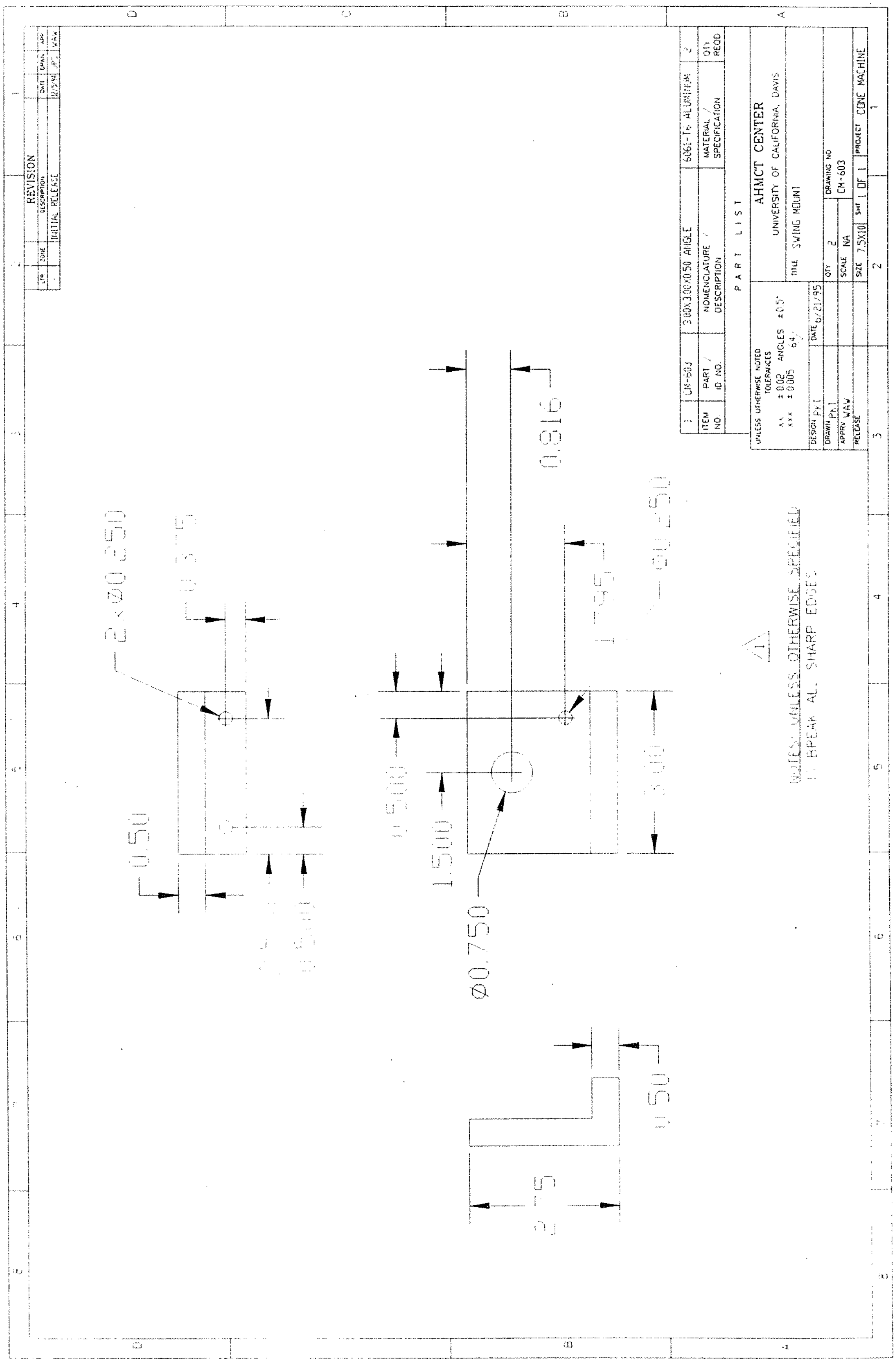
DETAILED DRAWINGS FOR STOWAGE SYSTEM

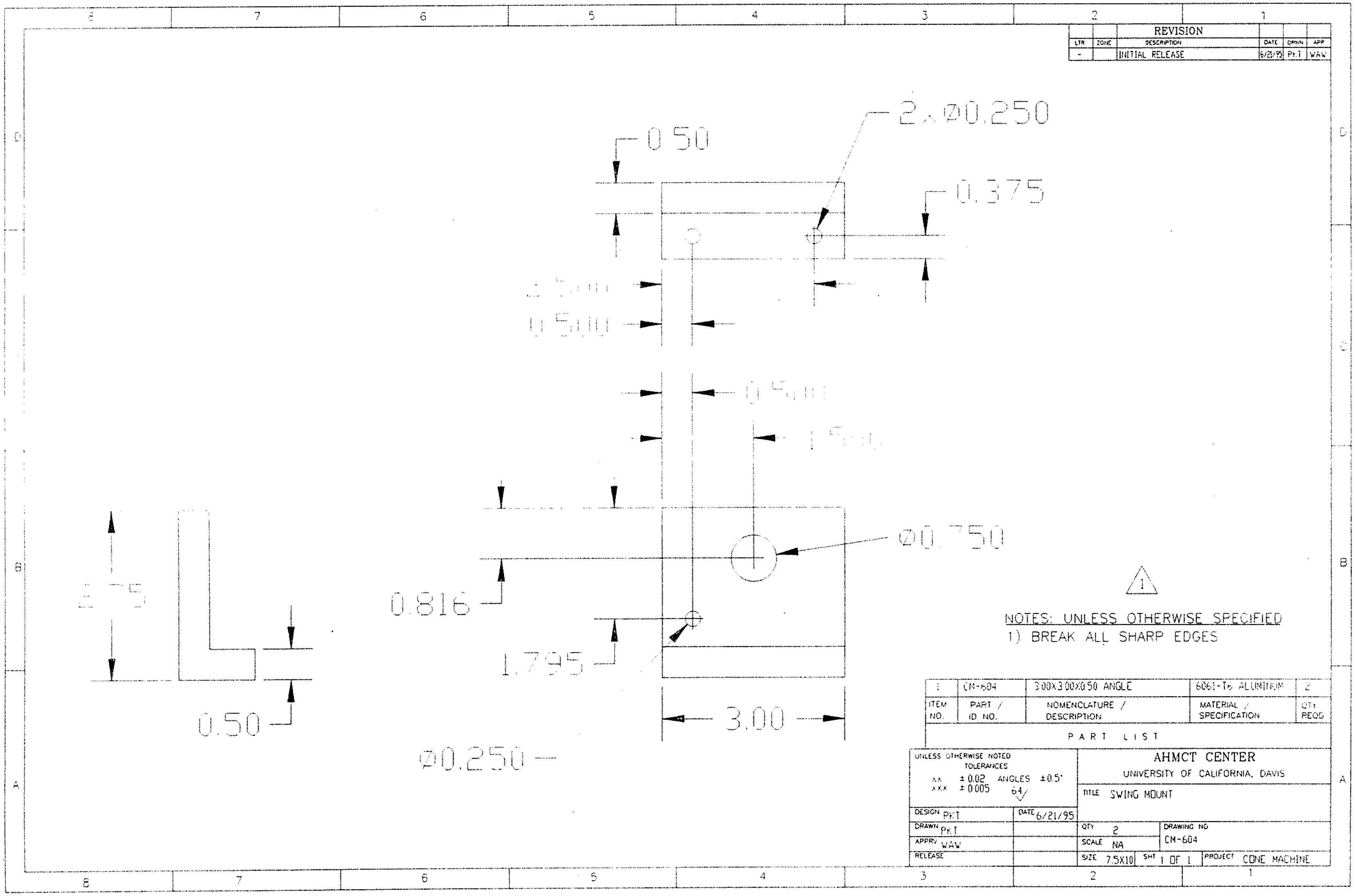
STOWAGE SYSTEM DRAWING LIST

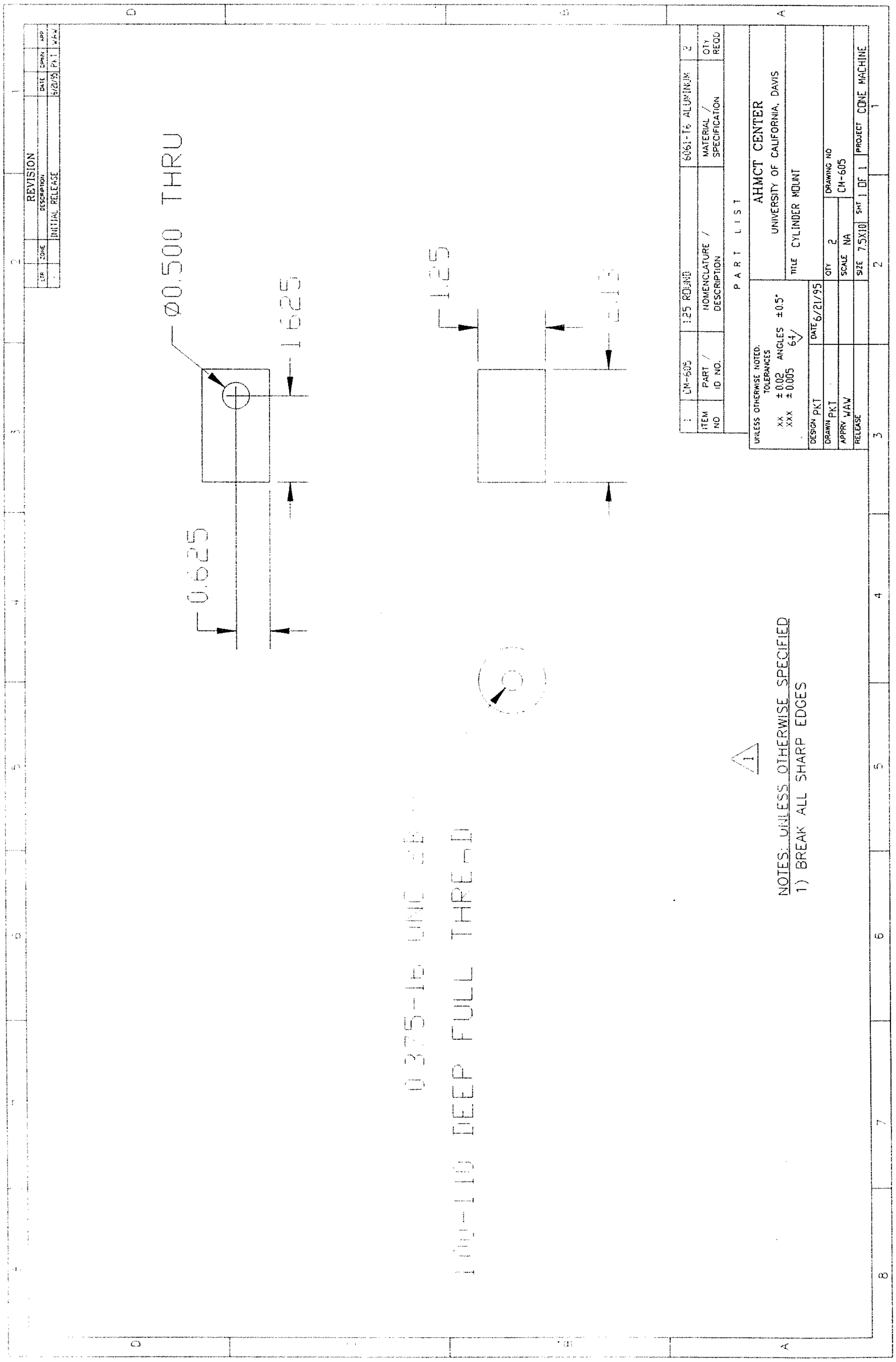
DWG NO.	DESCRIPTION
CM-601	ANGLE SURFACE
CM-602	ANGLE SURFACE
CM-603	SWING MOUNT
CM-604	SWING MOUNT
CM-605	CYLINDER MOUNT
CM-606	CYLINDER MOUNT
CM-607	MOUNT SHAFT
CM-608	BELT MOUNT
CM-609	SWING STOP
CM-610	GRIP SPACER
CM-611	MOUNT BRACKET
CM-612	SLEEVE WELDMENT
CM-613	SLEEVE PLATE
CM-614	PULL ROD WELDMENT
CM-615	PULL ROD WELDMENT
CM-616	RAIL SPACER
CM-617	TOP ANGLE RAMP
CM-618	BOTTOM ANGLE RAMP
CM-619	SLIDER PLATE
CM-620	OUTER ROLLER RAIL
CM-621	INNER ROLLER RAIL
CM-622	GRIPPER ARM WELDMENT
CM-624	BLOCK PLATE
CM-625	FRAME PLATE
CM-626	SWING PLATE
CM-627	BLOCK WELDMENT
CM-628	SPRING PLUNGER
CM-629	SPRING PLATE
CM-630	SPRING BLOCK

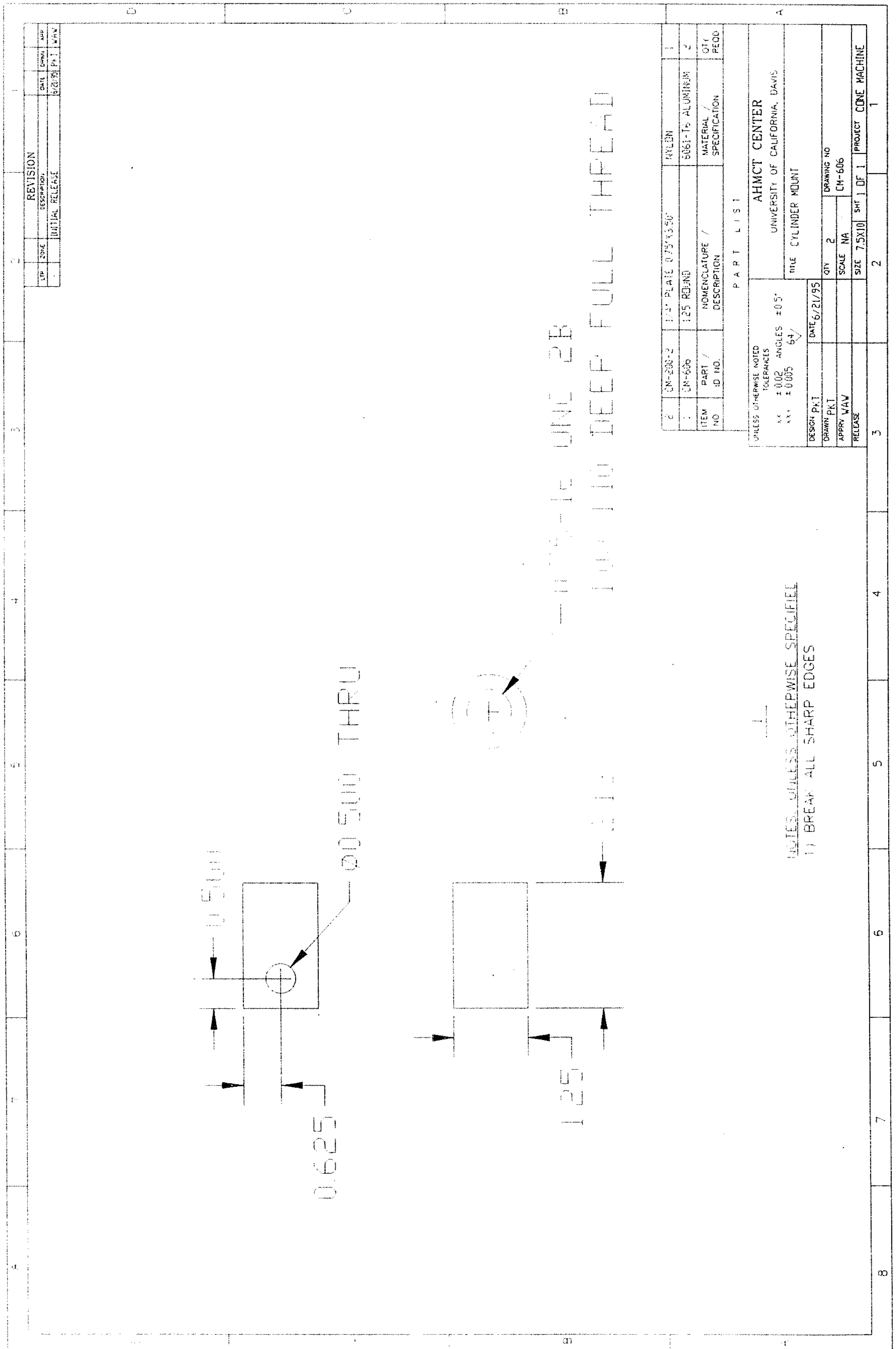

REVISION
LTR ZONE DESCRIPTION DATE DRWN APP
- INITIAL RELEASE 6/21/95 PKT WAW
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
1 CM-601 1.25X1.25X0.25 ANGLE 6061-T6 ALUMINUM 2
ITEM NO. PART / ID NO NOMENCLATURE / DESCRIPTION MATERIAL / SPECIFICATION QTY REQD
PART LIST
UNLESS OTHERWISE NOTED. TOLERANCES .XX ±0.02 .XXX ±0.005 ANGLES ±0.5°
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
TITLE ANGLE SURFACE
DESIGN PKT
DRAWN PKT
APPRV WAW
RELEASE
DATE 6/21/95
QTY 2
SCALE NA
SIZE 7.5X10
DRAWING NO CM-601
SHT 1 OF 1
PROJECT CONE MACHINE
1.25
0.25
1.72
0.25
2×Ø0.250
0.500
1.000
0.500

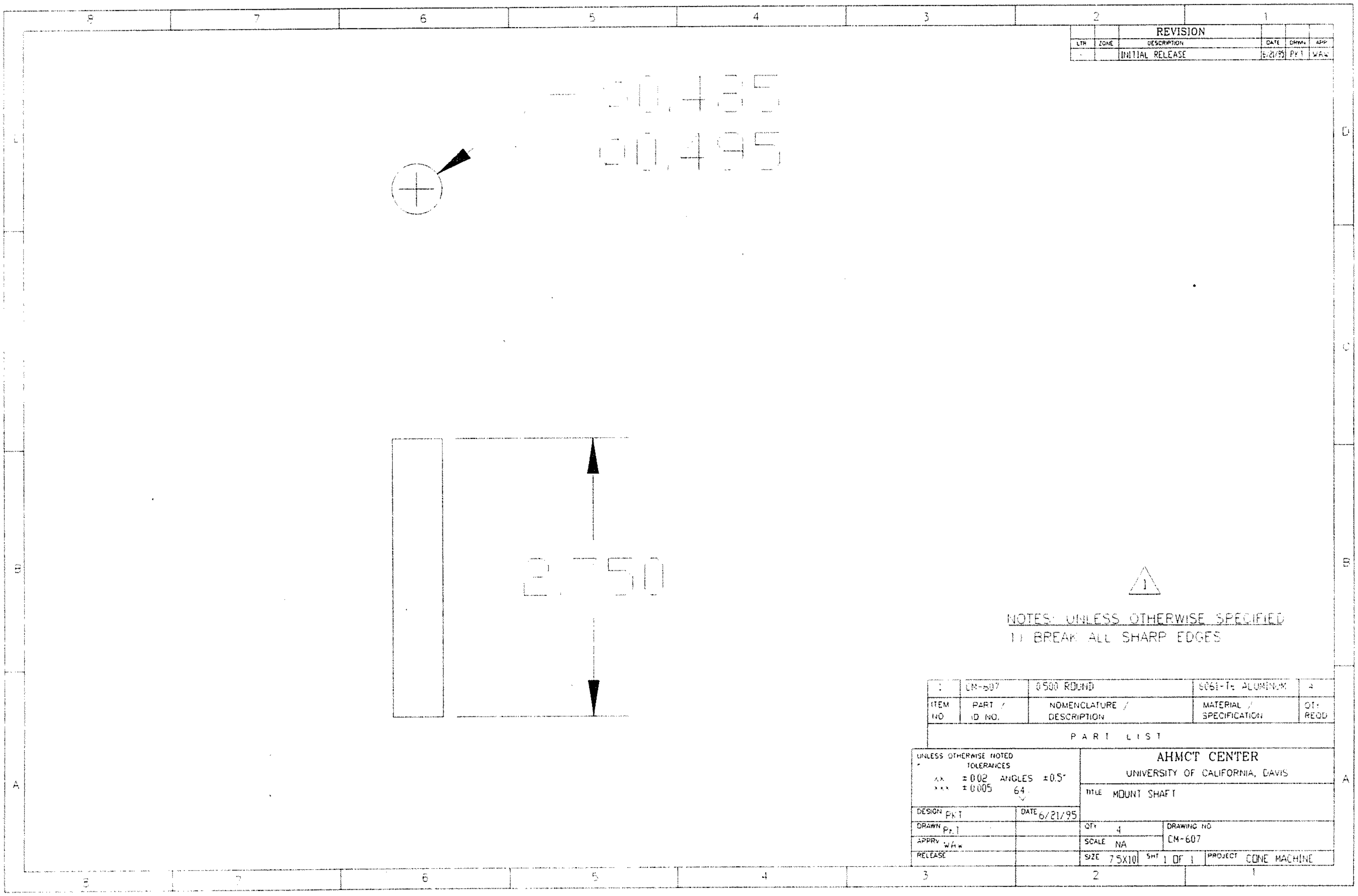

REVISION
INITIAL RELEASE
30.000°
0.500
1.000
0.500
2.98
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
6061-T6 ALUMINUM
MATERIAL / SPECIFICATION
NOMENCLATURE / DESCRIPTION
PART / ID NO
PARTS LIST
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
ANGLE SURFACE
CM-602
PROJECT CONE MACHINE
DESIGN PKT
DRAWN PKT
APPRV WAV
DATE 6/21/95
QTY 2
SCALE NA
SIZE 7.5X10
SHT 1 OF 1

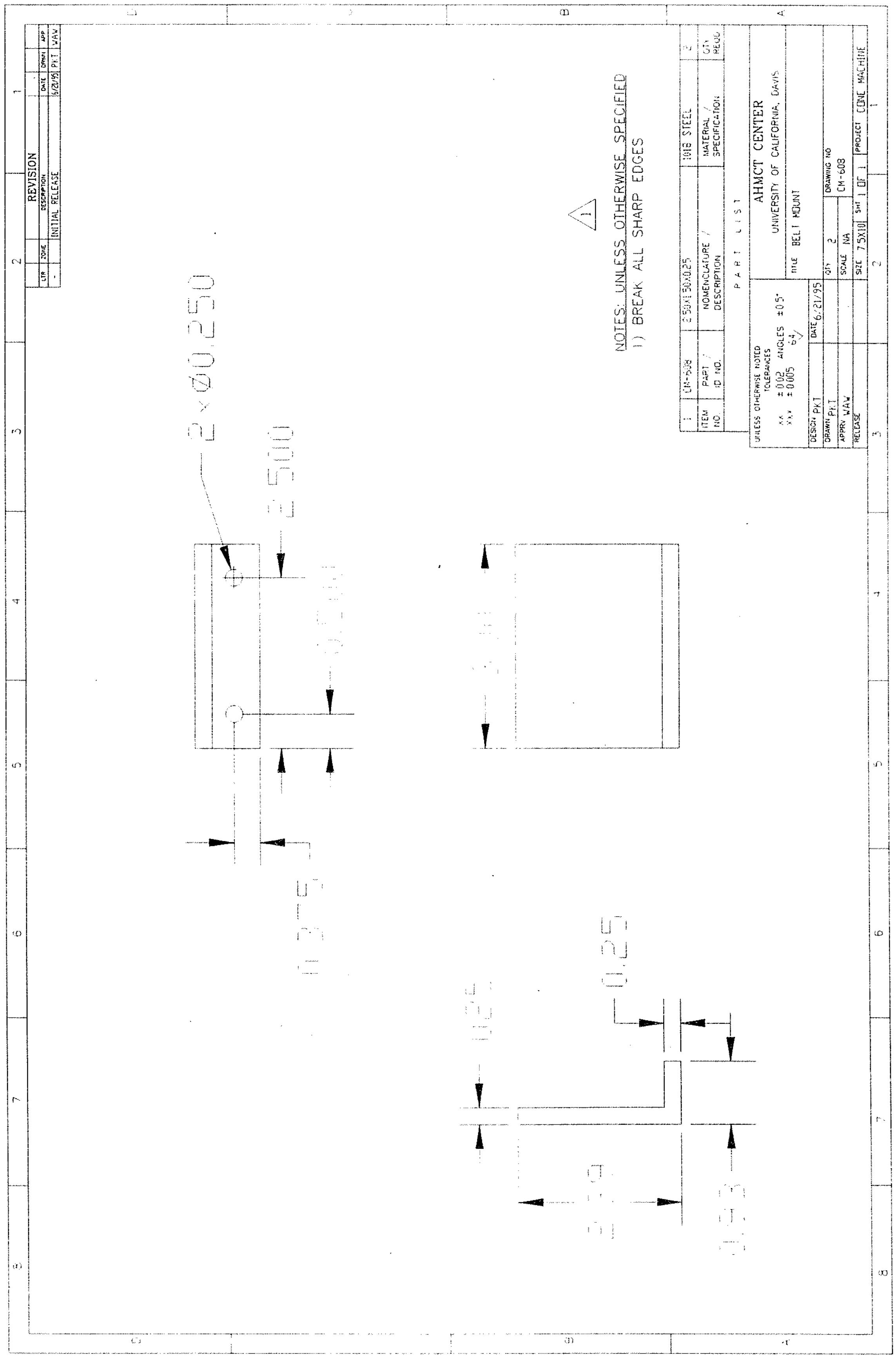

REVISION
INITIAL RELEASE
CM-603
3.00X3.00X0.50 ANGLE
6061-T6 ALUMINUM
ITEM NO
PART / ID NO.
NOMENCLATURE / DESCRIPTION
MATERIAL / SPECIFICATION
QTY REQD
PART LIST
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
TITLE SWING MOUNT
DRAWING NO CM-603
SCALE NA
SIZE 7.5X10
SHT 1 OF 1
PROJECT CONE MACHINE
UNLESS OTHERWISE NOTED TOLERANCES
DESIGN PKT
DRAWN PKT
APPRV WAW
RELEASE
0.816
2XØ0.250
Ø0.750
1.500
3.00
0.50
NOTES: UNLESS OTHERWISE SPECIFIED
1. BREAK ALL SHARP EDGES

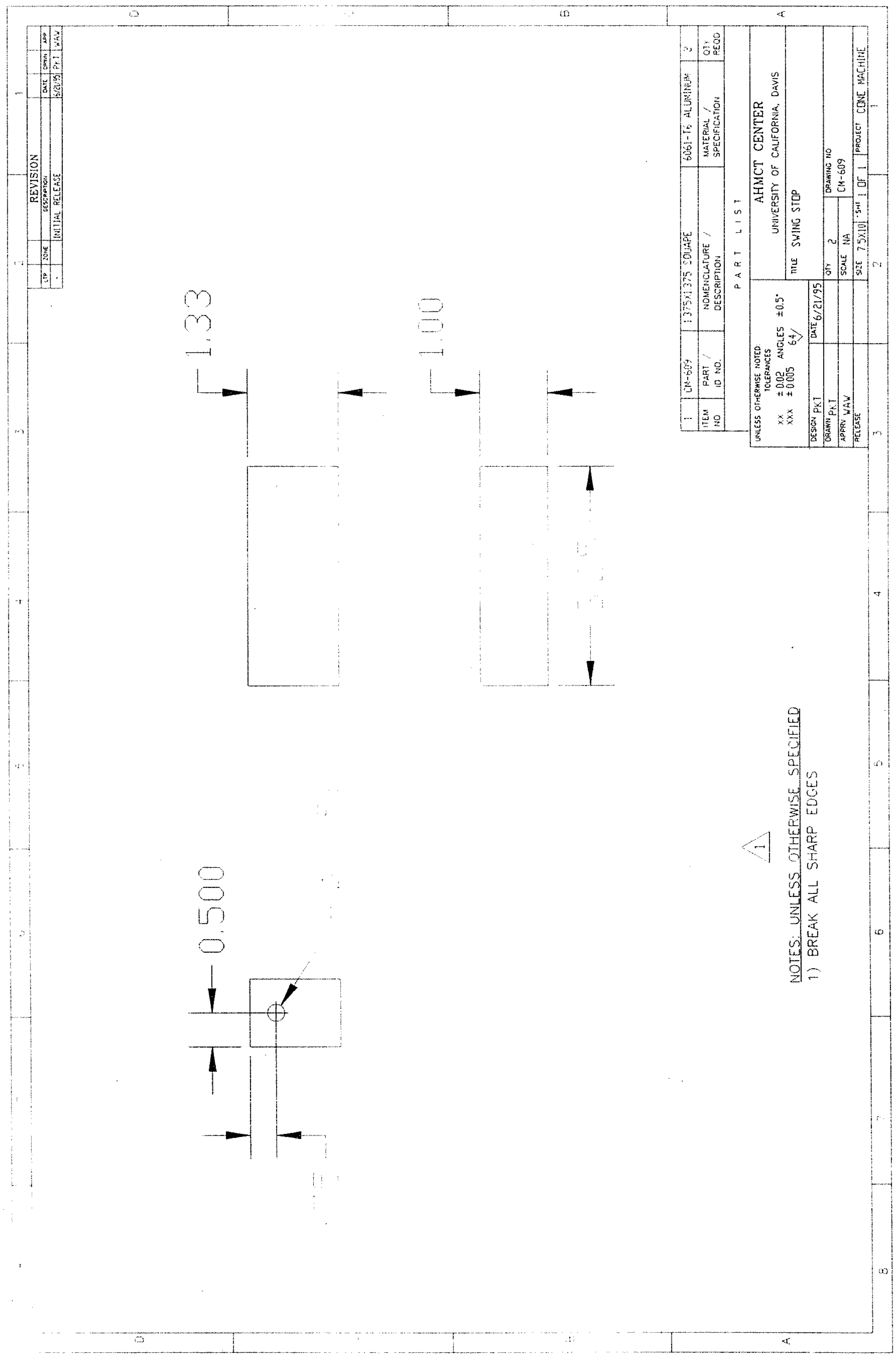

REVISION
LTR ZONE DESCRIPTION DATE DRWN APP
- INITIAL RELEASE 6/21/95 PKT WAW
2X Ø0.250
0.50
0.375
0.500
Ø0.750
0.816
1.795
3.00
Ø0.250
0.50
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
1 CM-604 3.00X3.00X0.50 ANGLE 6061-T6 ALUMINUM 2
ITEM NO. PART / ID NO. NOMENCLATURE / DESCRIPTION MATERIAL / SPECIFICATION QTY REQD
PART LIST
UNLESS OTHERWISE NOTED TOLERANCES
.XX ± 0.02 ANGLES ± 0.5°
.XXX ± 0.005
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
TITLE SWING MOUNT
DESIGN PKT DATE 6/21/95
DRAWN PKT
APPRV WAW
RELEASE
QTY 2
SCALE NA
DRAWING NO CM-604
SIZE 7.5X10 SHT 1 OF 1 PROJECT CONE MACHINE

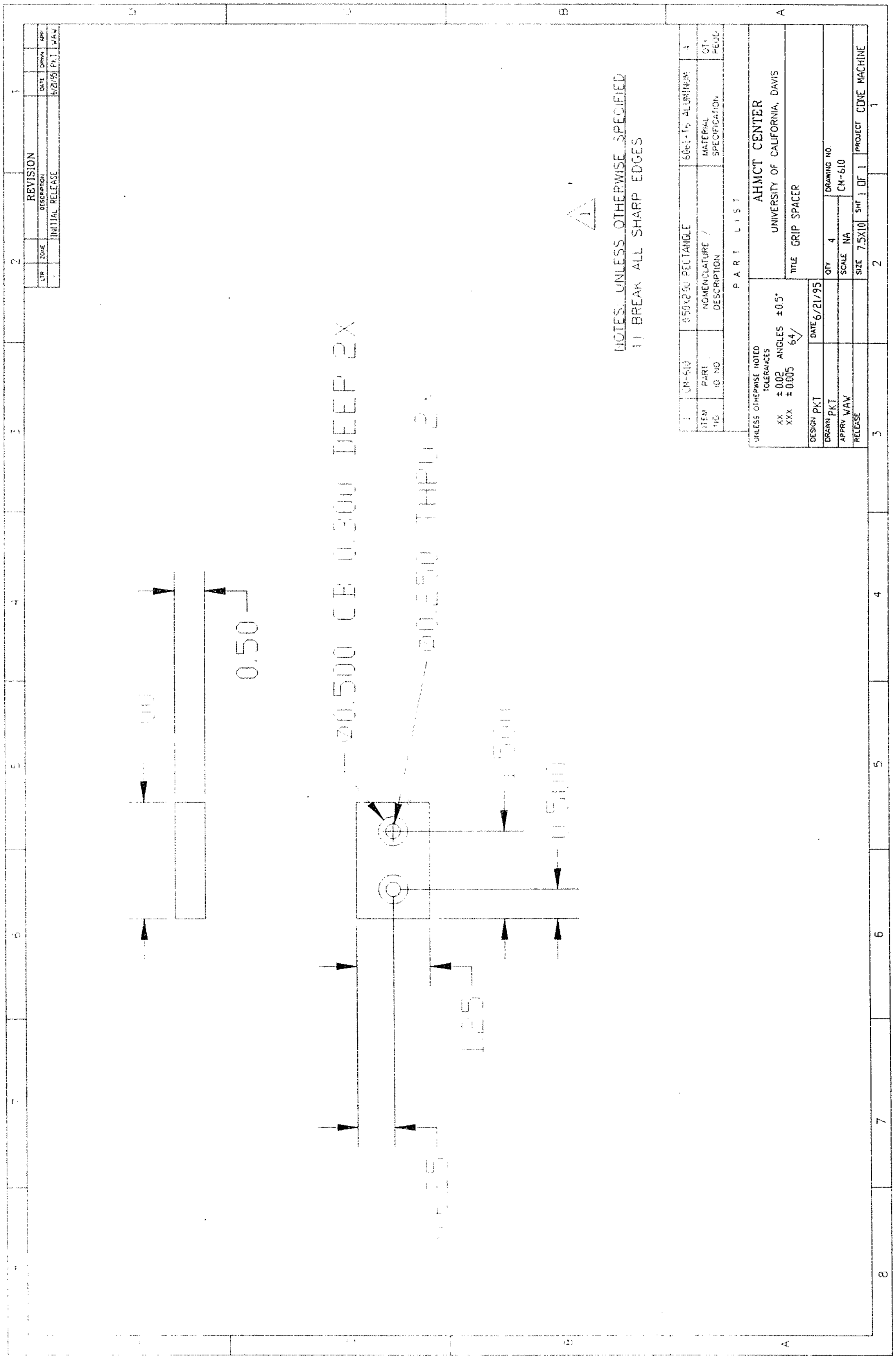

REVISION
LTR ZONE DESCRIPTION DATE DRWN APP
- INITIAL RELEASE 6/21/95 PKT WAW
Ø0.500 THRU
1.625
0.625
1.25
0.375-16 UNC 2B
DEEP FULL THRE_D
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
1 CM-605 1.25 ROUND 6061-T6 ALUMINUM 2
ITEM NO PART / ID NO. NOMENCLATURE / DESCRIPTION MATERIAL / SPECIFICATION QTY REQD
PART LIST
UNLESS OTHERWISE NOTED. TOLERANCES
XX ±0.02 XXX ±0.005 ANGLES ±0.5°
DESIGN PKT DATE 6/21/95
DRAWN PKT
APPRV WAW
RELEASE
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
TITLE CYLINDER MOUNT
QTY 2
SCALE NA
SIZE 7.5X10 SHT 1 OF 1
DRAWING NO CM-605
PROJECT CONE MACHINE

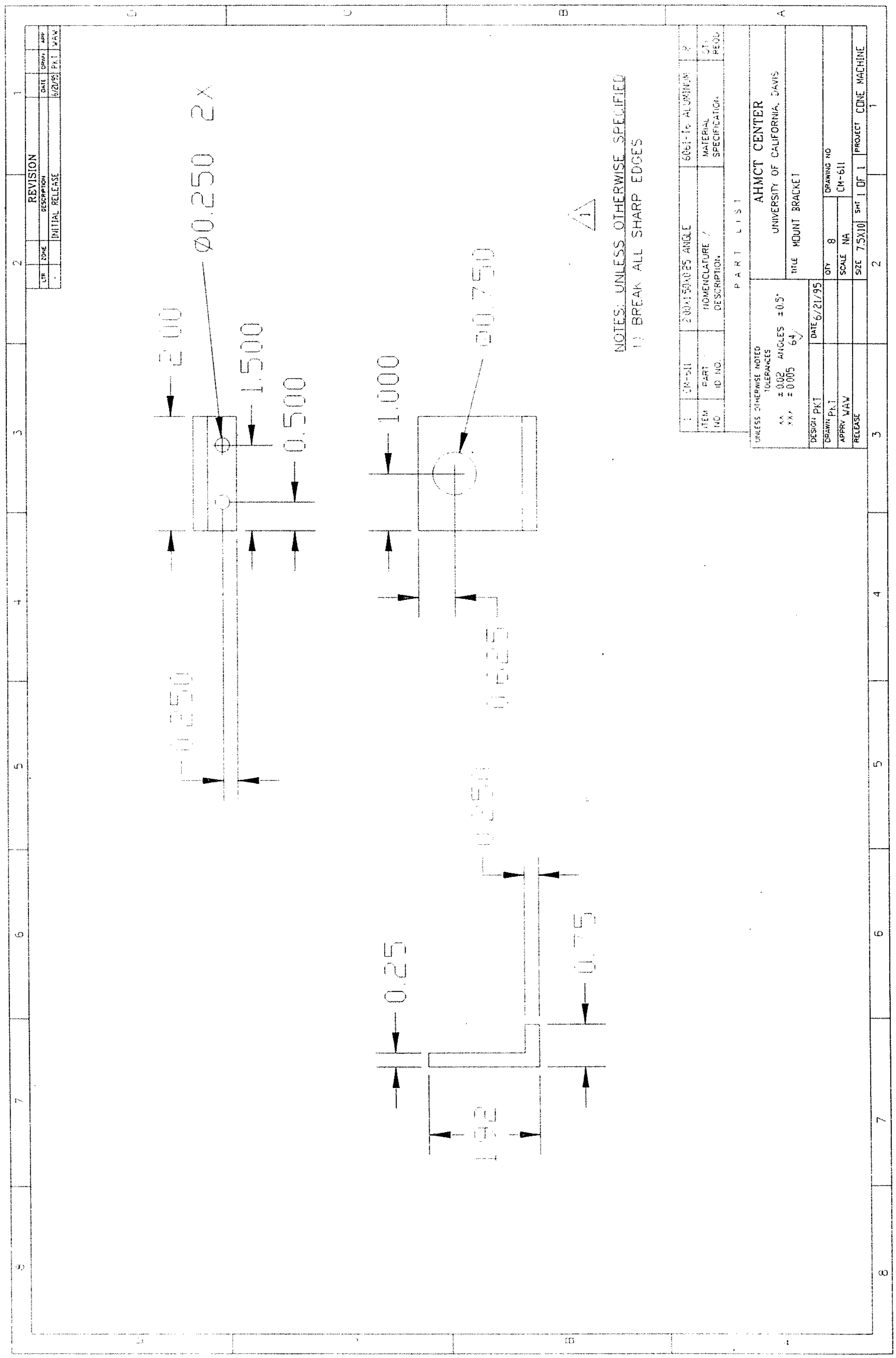

REVISION
LTR ZONE DESCRIPTION DATE CHK'D APP
INITIAL RELEASE 6/20/95 PKT WAW
0.500
Ø0.500 THRU
0.625
1.25
1/2-13 UNC 2B
1.00 DEEP FULL THREAD
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
1 | CM-606 | 1.25 ROUND | 6061-T6 ALUMINUM | 2
ITEM NO | PART / ID NO. | NOMENCLATURE / DESCRIPTION | MATERIAL / SPECIFICATION | QTY REQD
PART LIST
UNLESS OTHERWISE NOTED TOLERANCES
.XX ±0.02 ANGLES ±0.5°
.XXX ±0.005
DESIGN PKT DATE 6/21/95
DRAWN PKT
APPRV WAW
RELEASE
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
TITLE CYLINDER MOUNT
QTY 2
SCALE NA
DRAWING NO CM-606
SIZE 7.5X10 SHT 1 OF 1
PROJECT CONE MACHINE

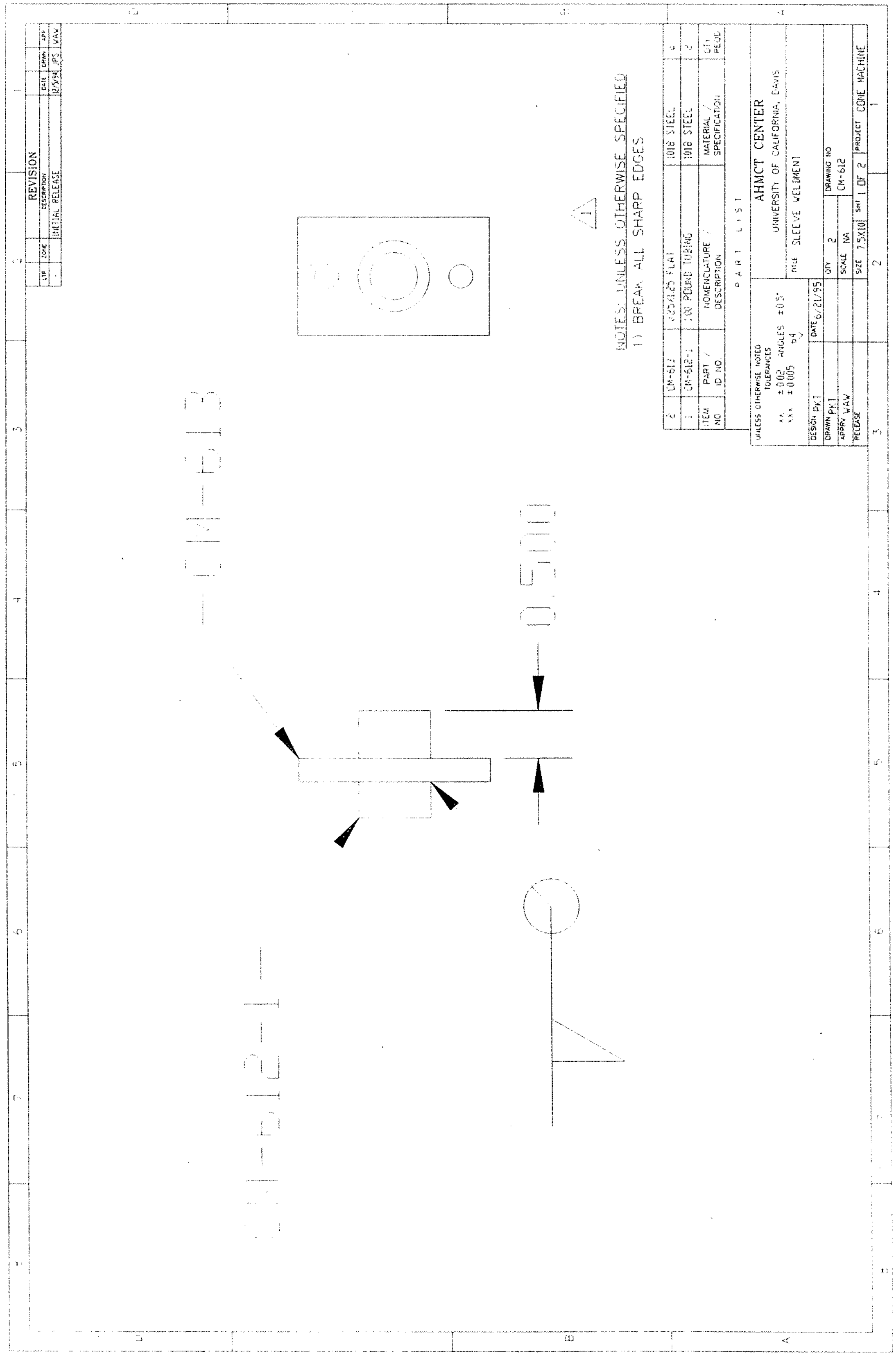

REVISION
LTR ZONE DESCRIPTION DATE DRWN APP
INITIAL RELEASE 6/21/95 PKT WAW
Ø0.485
Ø0.495
2.750
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
1 CM-607 0.500 ROUND 6061-T6 ALUMINUM 4
ITEM NO PART / ID NO. NOMENCLATURE / DESCRIPTION MATERIAL / SPECIFICATION QTY REQD
PART LIST
UNLESS OTHERWISE NOTED TOLERANCES
.XX ±0.02 ANGLES ±0.5°
.XXX ±0.005 64
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
TITLE MOUNT SHAFT
DESIGN PKT DATE 6/21/95
DRAWN PKT
APPRV WAW
RELEASE
QTY 4
SCALE NA
DRAWING NO CM-607
SIZE 7.5X10 SHT 1 OF 1 PROJECT CONE MACHINE


REVISION
INITIAL RELEASE
6/21/95
2×Ø0.250
2.500
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
1018 STEEL
PART LIST
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
BELT MOUNT
CM-608
CONE MACHINE

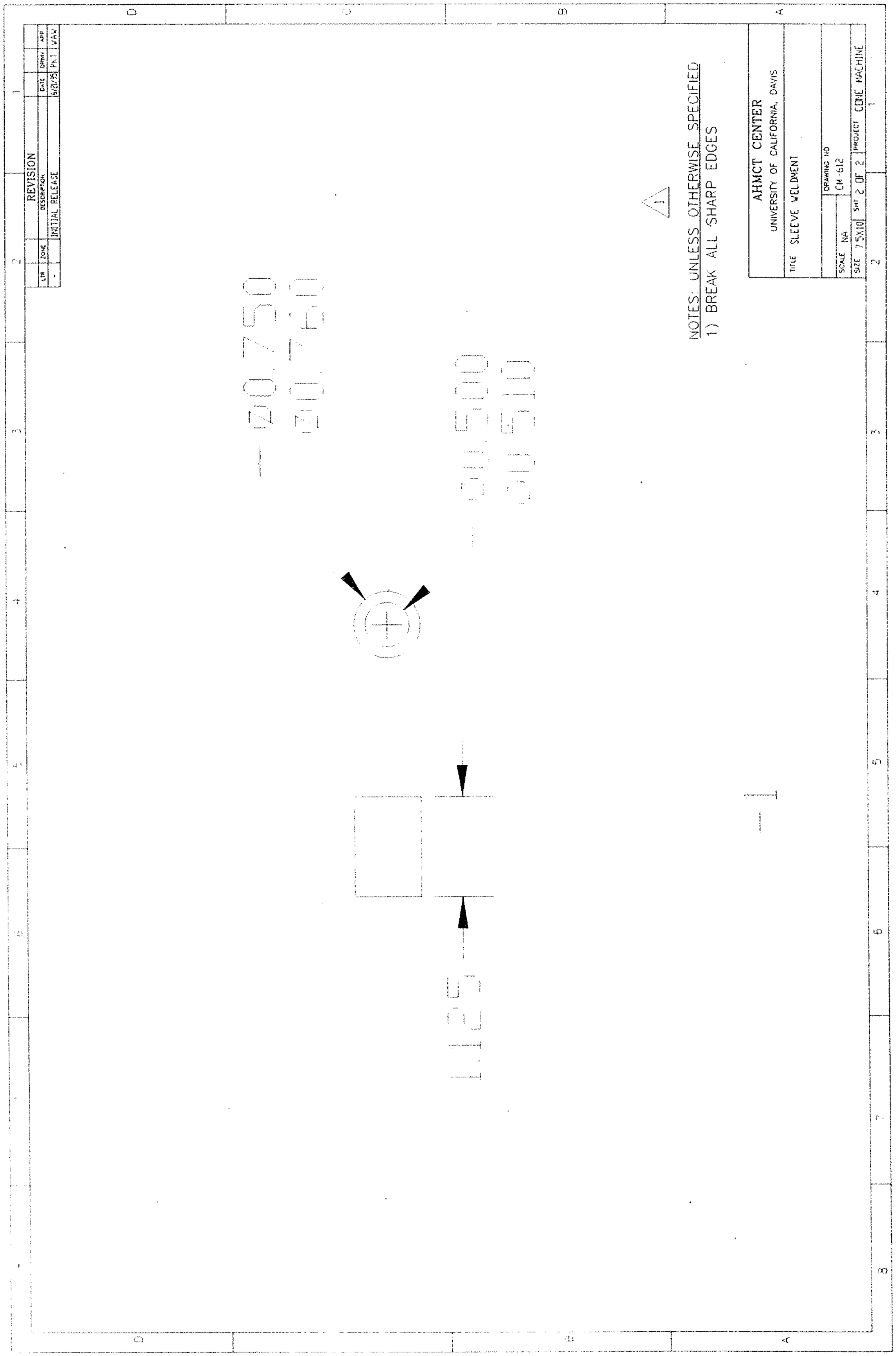

REVISION
LTR | ZONE | DESCRIPTION | DATE | DRWN | APP
- | | INITIAL RELEASE | 6/21/95 | PKT | WAW
1.33
1.00
0.500
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
1
1 | CM-609 | .375X1.375 SQUARE | 6061-T6 ALUMINUM | 2
ITEM NO | PART / ID NO. | NOMENCLATURE / DESCRIPTION | MATERIAL / SPECIFICATION | QTY REQD
PART LIST
UNLESS OTHERWISE NOTED TOLERANCES
XX ±0.02 ANGLES ±0.5°
XXX ±0.005
64
DESIGN PKT
DRAWN PKT
APPRV WAW
RELEASE
DATE 6/21/95
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
TITLE SWING STOP
QTY 2
SCALE NA
DRAWING NO CM-609
SIZE 7.5X10
SHT 1 OF 1
PROJECT CONE MACHINE

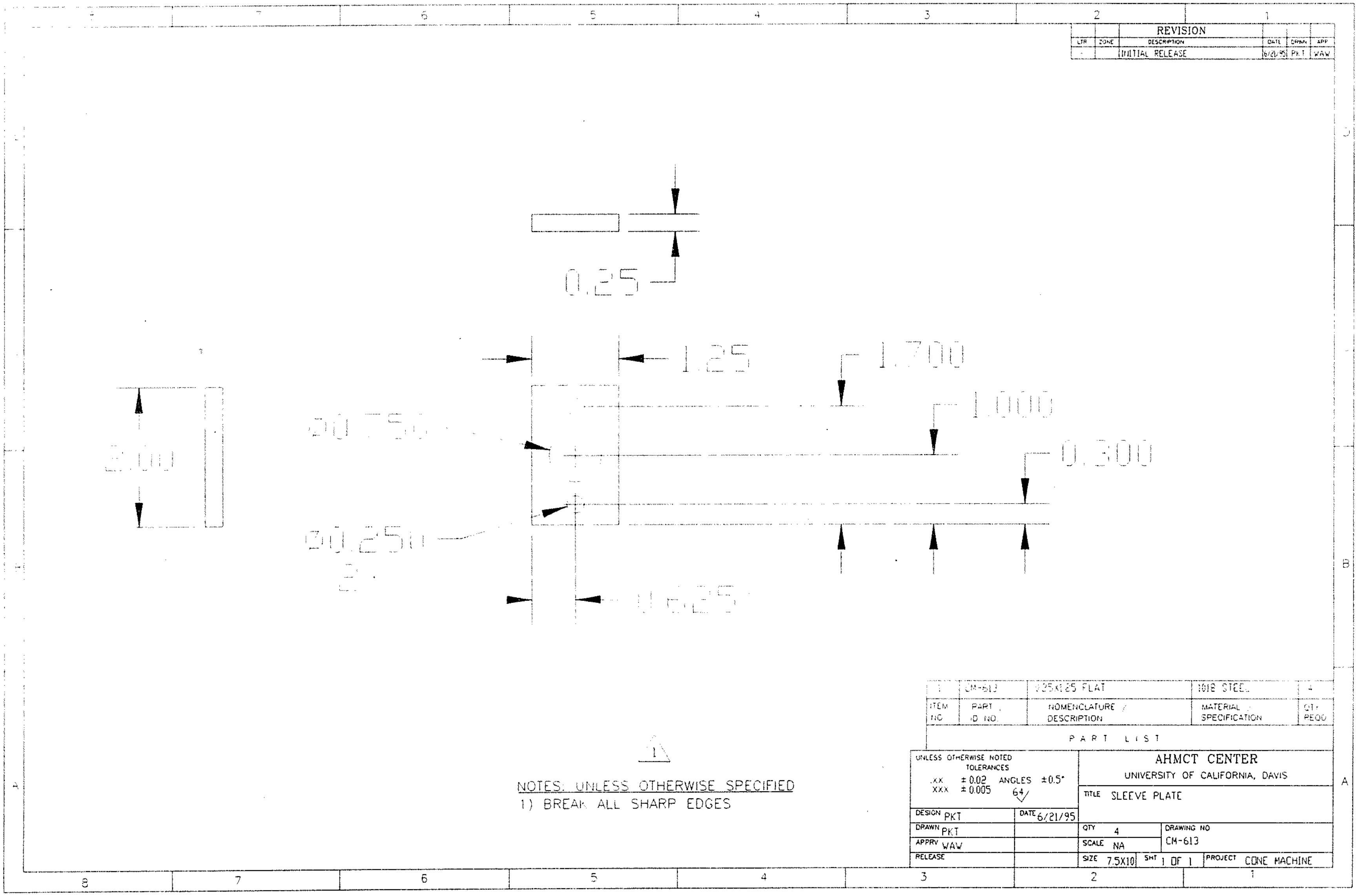

REVISION
LTR
ZONE
DESCRIPTION
DATE
DRAWN
APP
INITIAL RELEASE
6/21/95
PKT
VAW
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
0.50
ITEM NO
PART ID NO
NOMENCLATURE / DESCRIPTION
MATERIAL SPECIFICATION
QTY REQD
PART LIST
UNLESS OTHERWISE NOTED TOLERANCES
XX ± 0.02
XXX ± 0.005
ANGLES ±0.5°
DESIGN PKT
DRAWN PKT
APPRV VAW
RELEASE
DATE 6/21/95
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
TITLE GRIP SPACER
QTY 4
SCALE NA
DRAWING NO CM-610
SIZE 7.5X10
SHT 1 OF 1
PROJECT CONE MACHINE

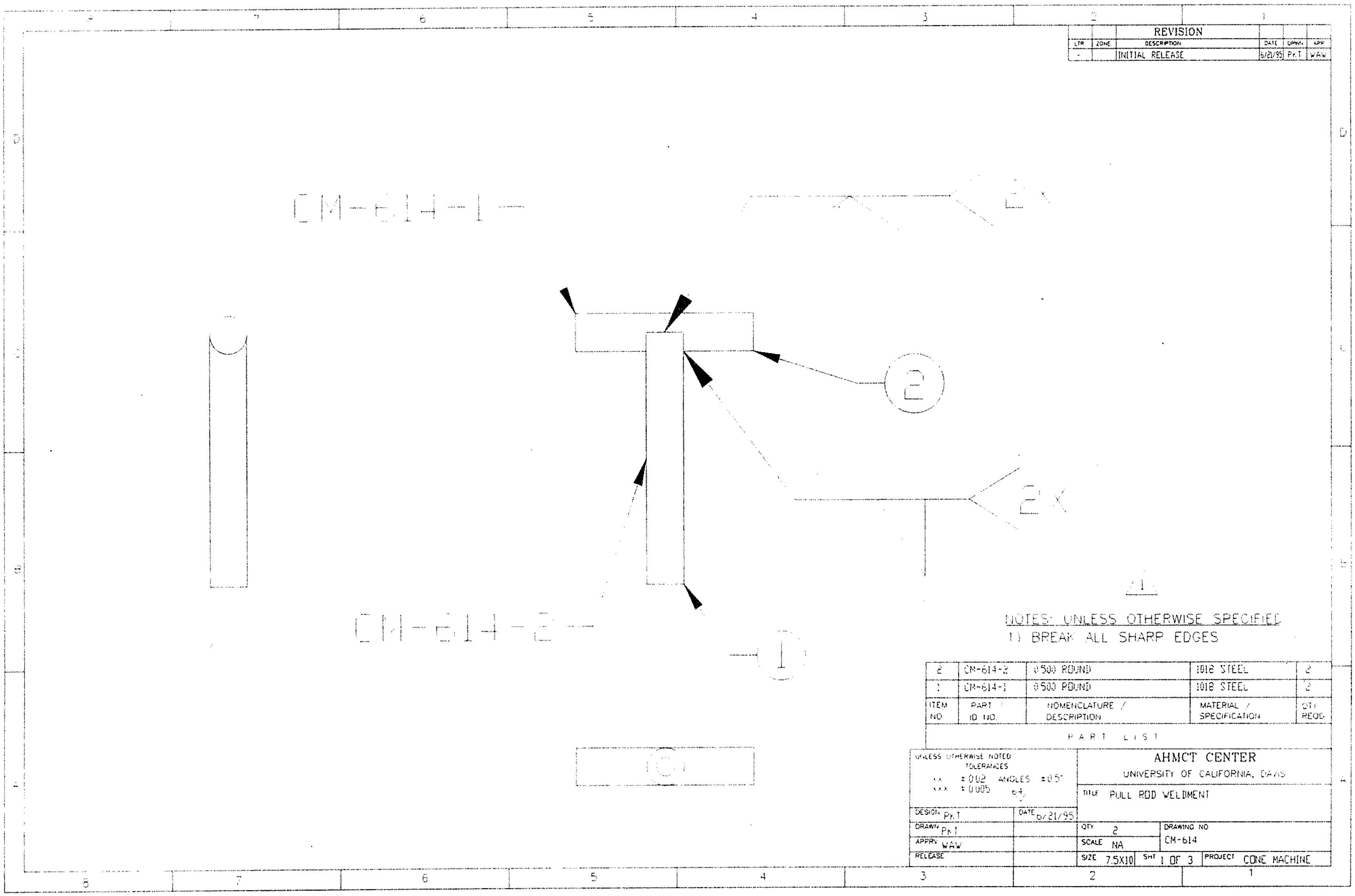

REVISION
INITIAL RELEASE
6/21/95
PKT
WAW
Ø0.250 2X
2.00
1.500
0.500
1.000
Ø0.750
0.250
0.625
0.25
0.75
1.92
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
2.00x1.50x0.25 ANGLE
6061-T6 ALUMINUM
PART LIST
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
MOUNT BRACKET
CM-611
8
NA
7.5X10
1 OF 1
CONE MACHINE
6/21/95

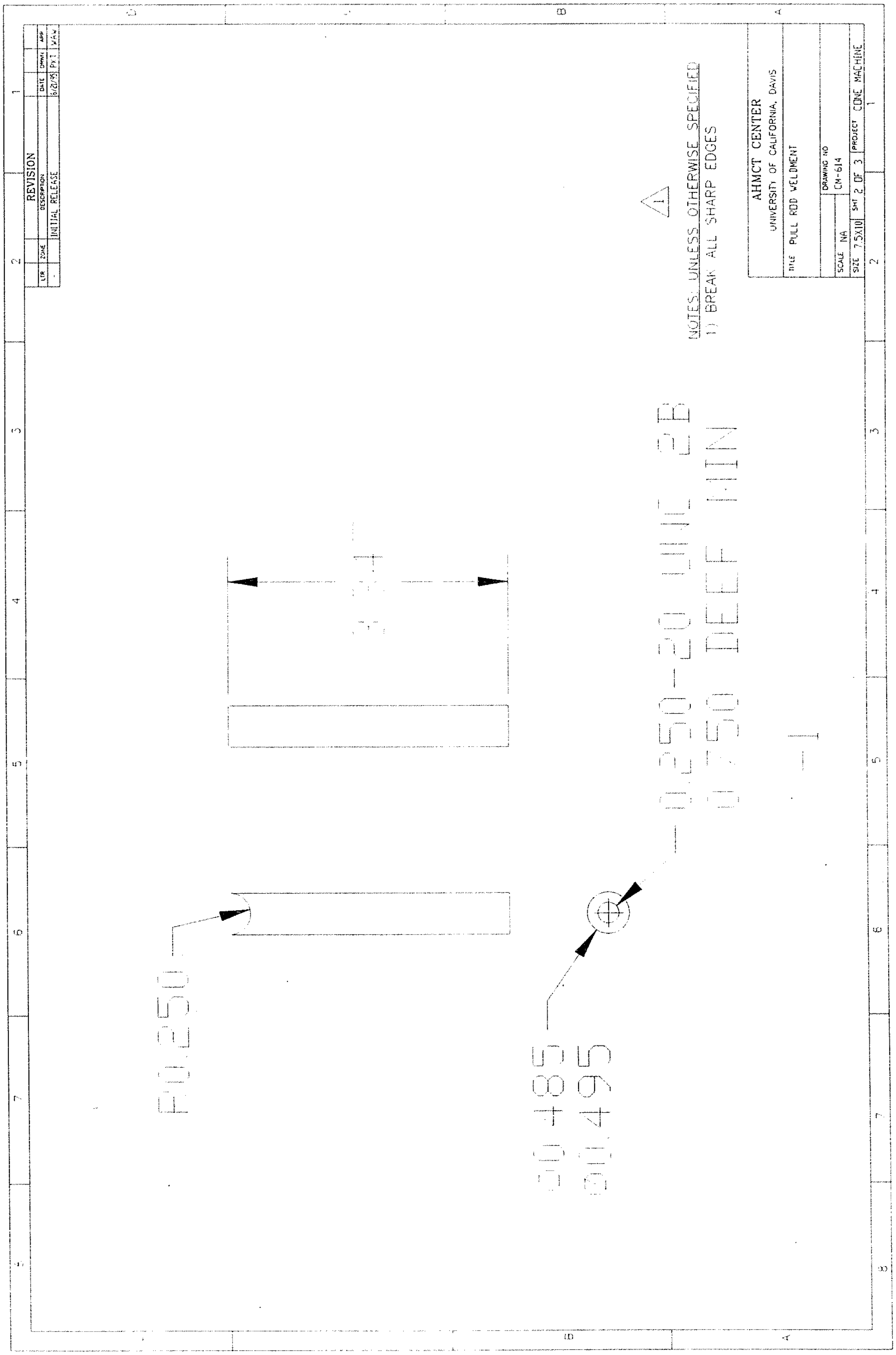


REVISION
LTR | ZONE | DESCRIPTION | DATE | DRWN | APP
- | | INITIAL RELEASE | 12/5/94 | JPS | WAW
CM-613
CM-612-1
0.500
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
2 | CM-613 | .25X1.25 FLAT | 1018 STEEL | 2
1 | CM-612-1 | 1.00 ROUND TUBING | 1018 STEEL | 2
ITEM NO | PART / ID NO. | NOMENCLATURE / DESCRIPTION | MATERIAL / SPECIFICATION | QTY REQD
PART LIST
UNLESS OTHERWISE NOTED TOLERANCES
.XX ±.002 ANGLES ±0.5°
.XXX ±.0005
64
DESIGN PKT
DATE 6/21/95
DRAWN PKT
APPRV WAW
RELEASE
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
TITLE SLEEVE WELDMENT
QTY 2
SCALE NA
DRAWING NO CM-612
SIZE 7.5X10
SHT 1 OF 2
PROJECT CONE MACHINE

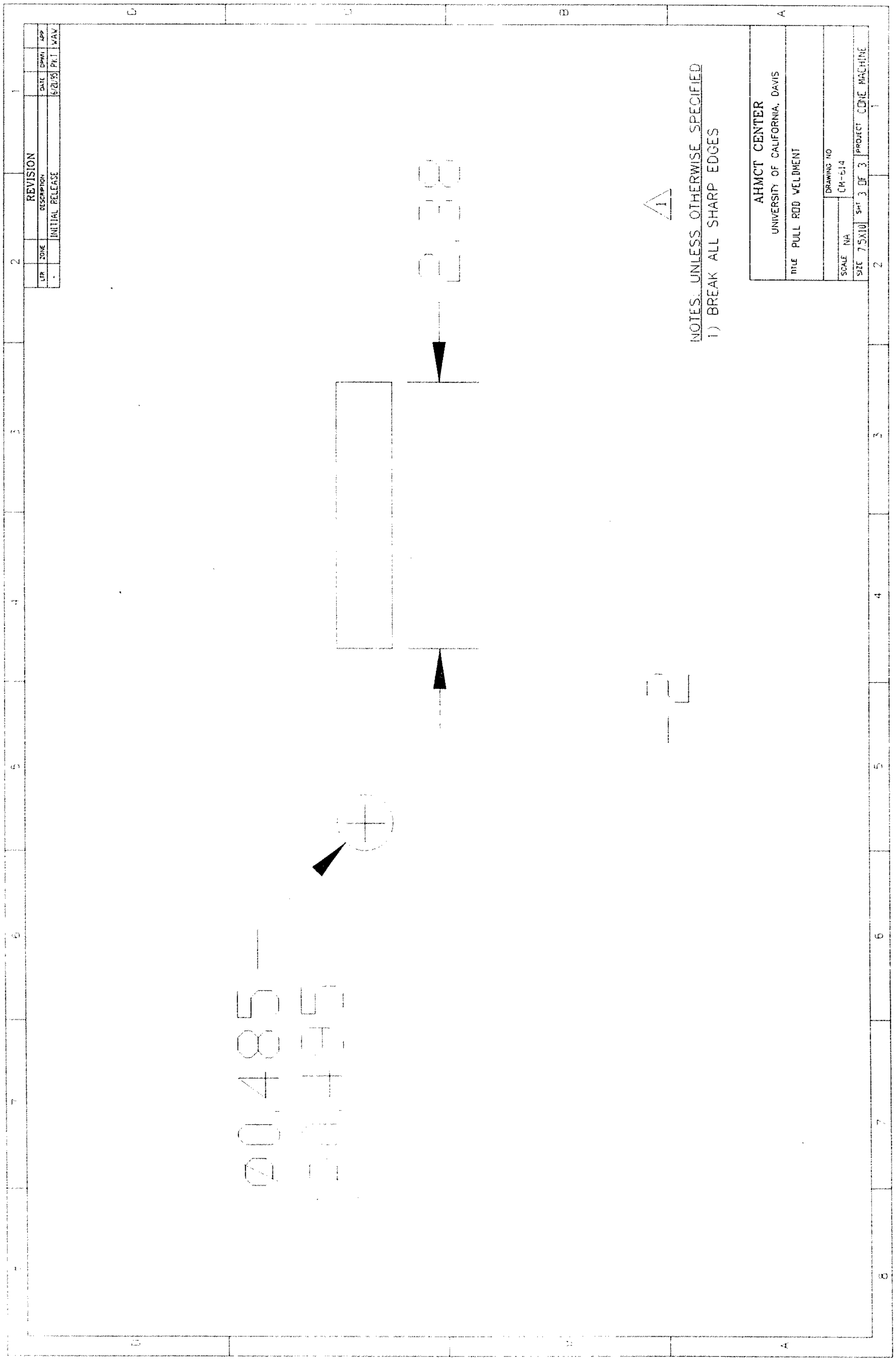

REVISION
LTR
ZONE
DESCRIPTION
DATE
DRWN
APP
-
INITIAL RELEASE
6/21/95
PKT
WAW
Ø0.750
Ø0.760
Ø0.500
Ø0.510
1.125
1
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
TITLE SLEEVE WELDMENT
DRAWING NO
CM-612
SCALE NA
SIZE 7.5X10
SHT 2 OF 2
PROJECT CONE MACHINE


REVISION
LTR
ZONE
DESCRIPTION
DATE
DRWN
APP
INITIAL RELEASE
PKT
WAW
0.25
1.25
1.700
1.000
0.300
2.00
0.625
2X
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
1
CM-613
.25X1.25 FLAT
1018 STEEL
4
ITEM NO
PART / ID NO
NOMENCLATURE / DESCRIPTION
MATERIAL / SPECIFICATION
QTY REQD
PART LIST
UNLESS OTHERWISE NOTED TOLERANCES
.XX ± 0.02 ANGLES ± 0.5°
.XXX ± 0.005
64
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
TITLE SLEEVE PLATE
DESIGN PKT
DATE 6/21/95
DRAWN PKT
APPRV WAW
RELEASE
QTY 4
DRAWING NO CM-613
SCALE NA
SIZE 7.5X10
SHT 1 OF 1
PROJECT CONE MACHINE

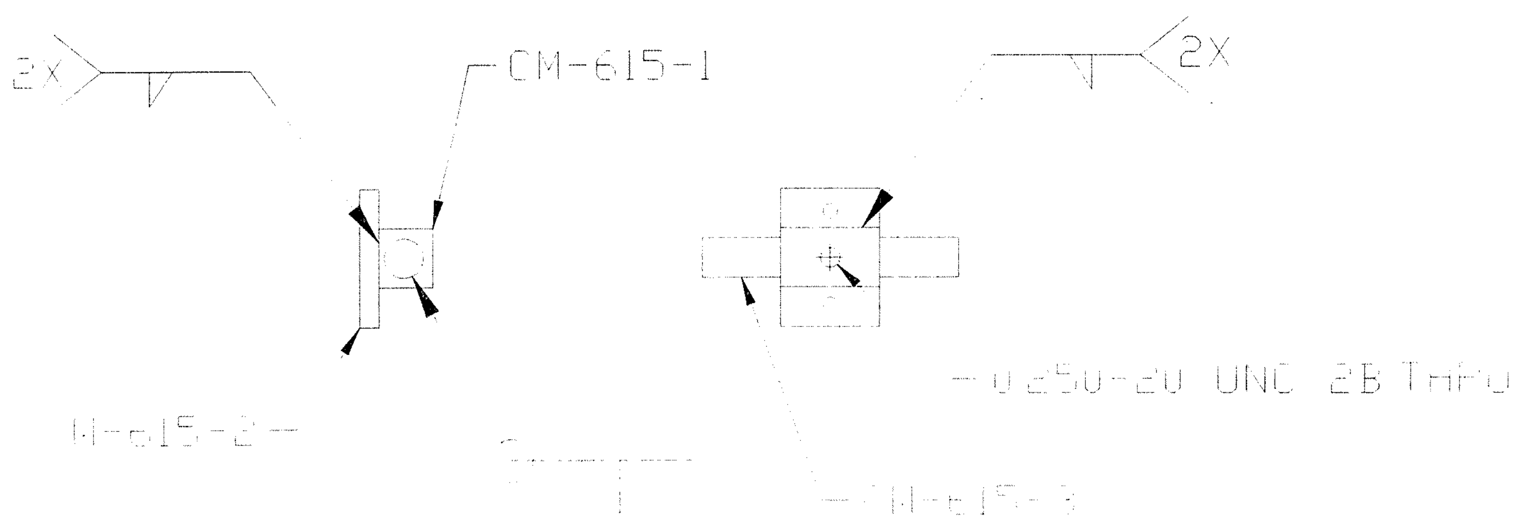

REVISION
LTR ZONE DESCRIPTION DATE APPR
- INITIAL RELEASE 6/21/95 P.K.T WAW
CM-614-1
CM-614-2
2X
2X
2
1
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
2 CM-614-2 Ø.500 ROUND 1018 STEEL 2
1 CM-614-1 Ø.500 ROUND 1018 STEEL 2
ITEM NO PART ID NO. NOMENCLATURE / DESCRIPTION MATERIAL / SPECIFICATION QTY REQD
PART LIST
UNLESS OTHERWISE NOTED TOLERANCES
.XX ±.002 ANGLES ±0.5°
.XXX ±0.005
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
TITLE PULL ROD WELDMENT
DESIGN P.K.T DATE 6/21/95
DRAWN P.K.T
APPRV WAW
RELEASE
QTY 2
SCALE NA
DRAWING NO CM-614
SIZE 7.5X10 SHT 1 OF 3 PROJECT CONE MACHINE



REVISION
LTR
ZONE
DESCRIPTION
DATE
DRWN
APP
-
INITIAL RELEASE
6/21/95
PKT
WAW
R0.250
Ø0.485
Ø0.495
0.250-20 UNC 2B
0.750 DEEP MIN
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
TITLE PULL ROD WELDMENT
DRAWING NO
CM-614
SCALE NA
SIZE 7.5X10
SHT 2 OF 3
PROJECT CONE MACHINE


REVISION
LTR ZONE DESCRIPTION DATE DRWN APP
- INITIAL RELEASE 6/21/95 PKT WAW
Ø0.485
2.38
-2
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
TITLE PULL ROD WELDMENT
DRAWING NO CM-614
SCALE NA
SIZE 7.5X10 SHT 3 OF 3 PROJECT CONE MACHINE

LTR	ZONE	REVISION DESCRIPTION	DATE	DRWN	APP
		INITIAL RELEASE	6/21/95	PKT	WAW



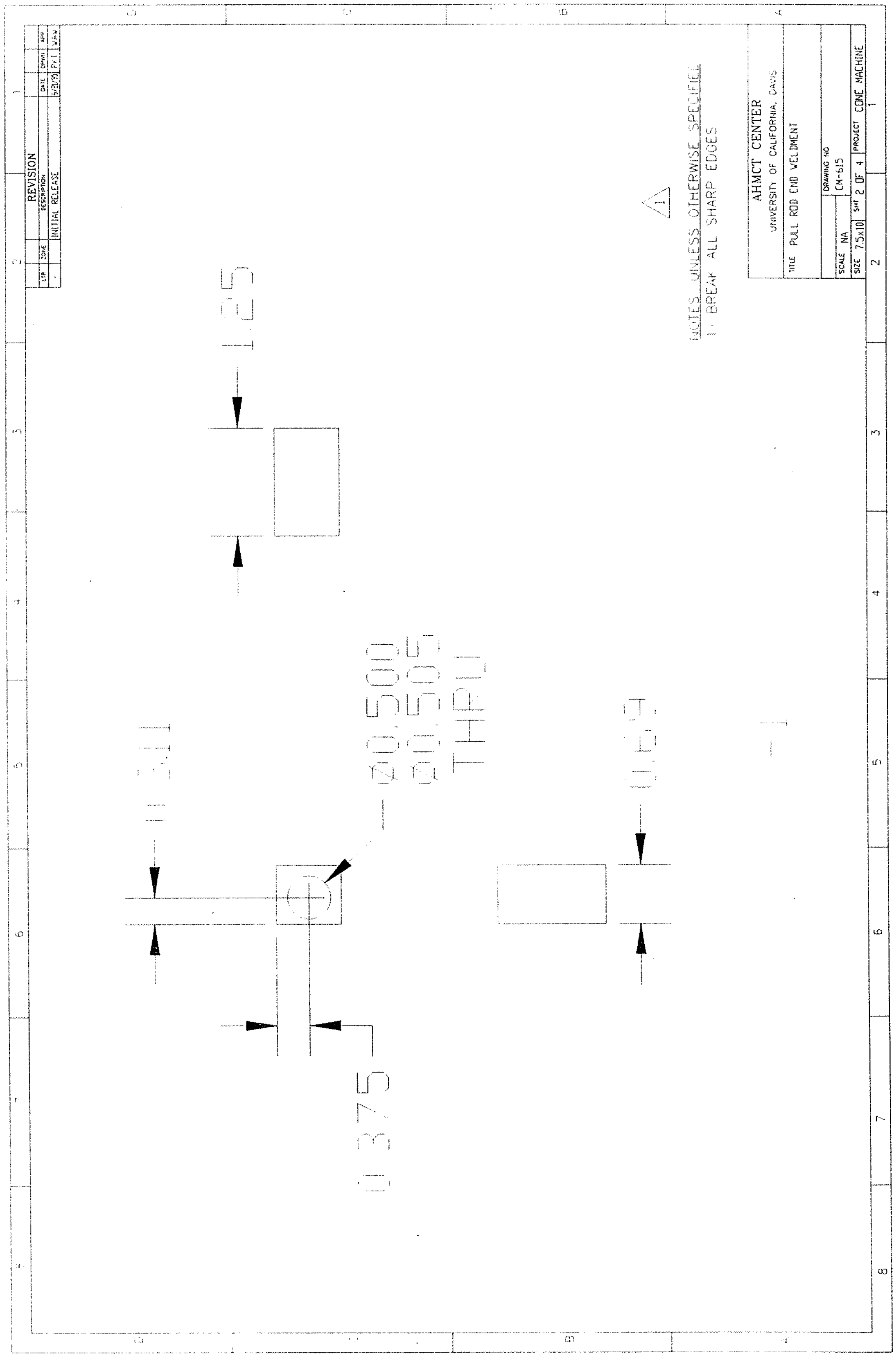
△1

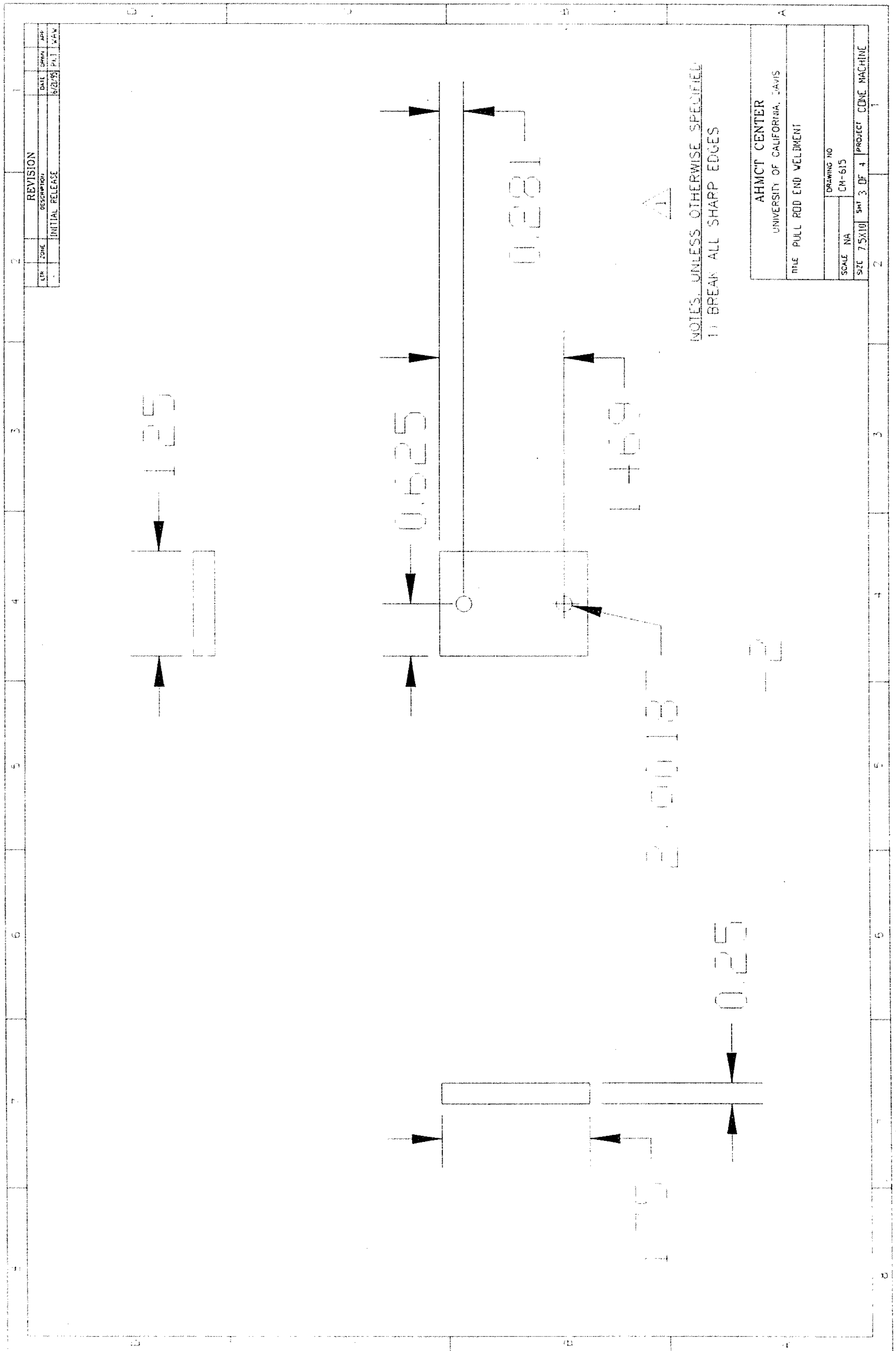
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES

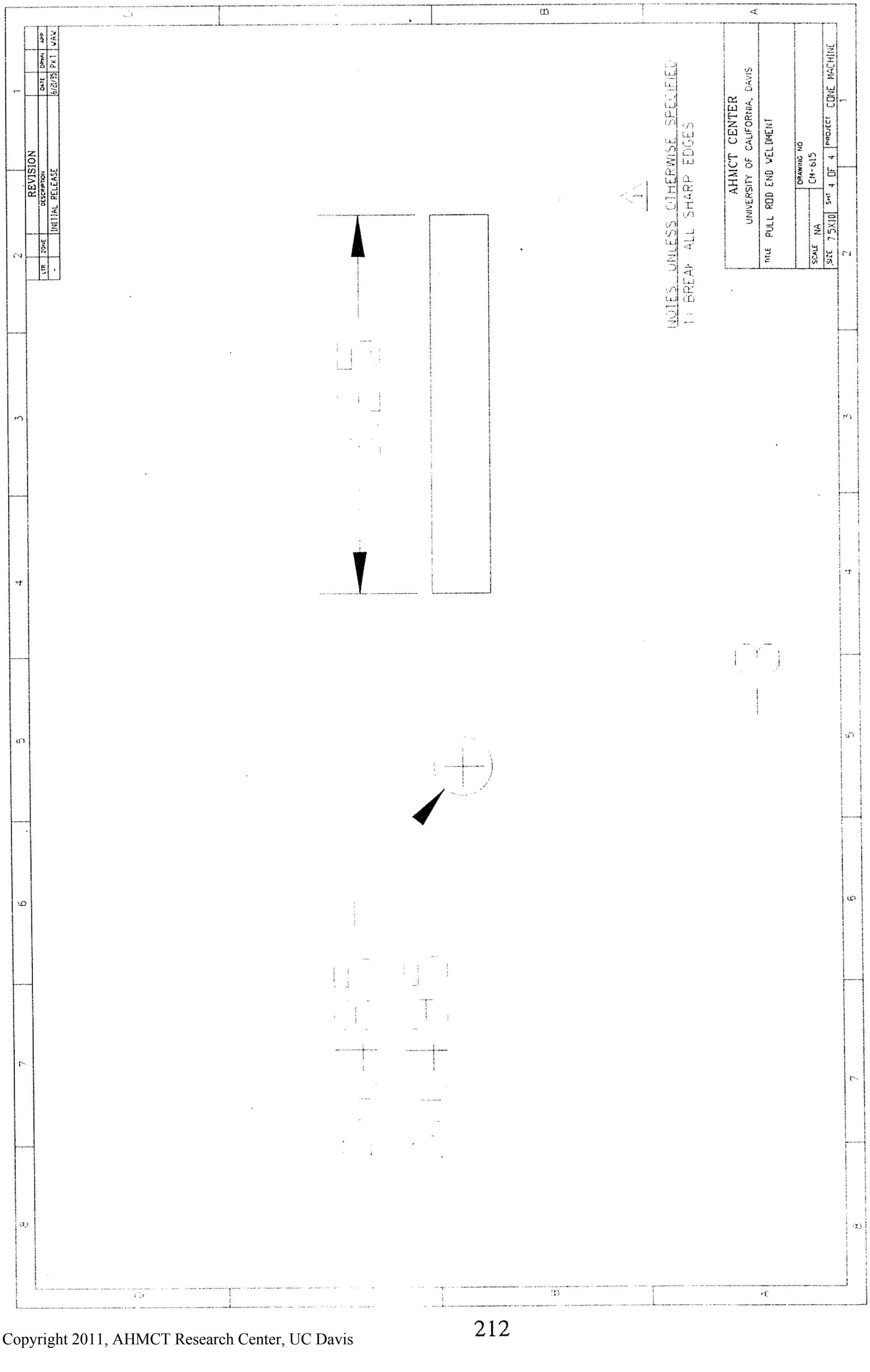
ITEM NO	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
3	CM-615-3	.125x.625 FLAT	1018 STEEL	2
2	CM-615-2	.125x0.25 FLAT	1018 STEEL	[illegible]
1	CM-615-1	0.75x0.75 SQUARE	1018 STEEL	2

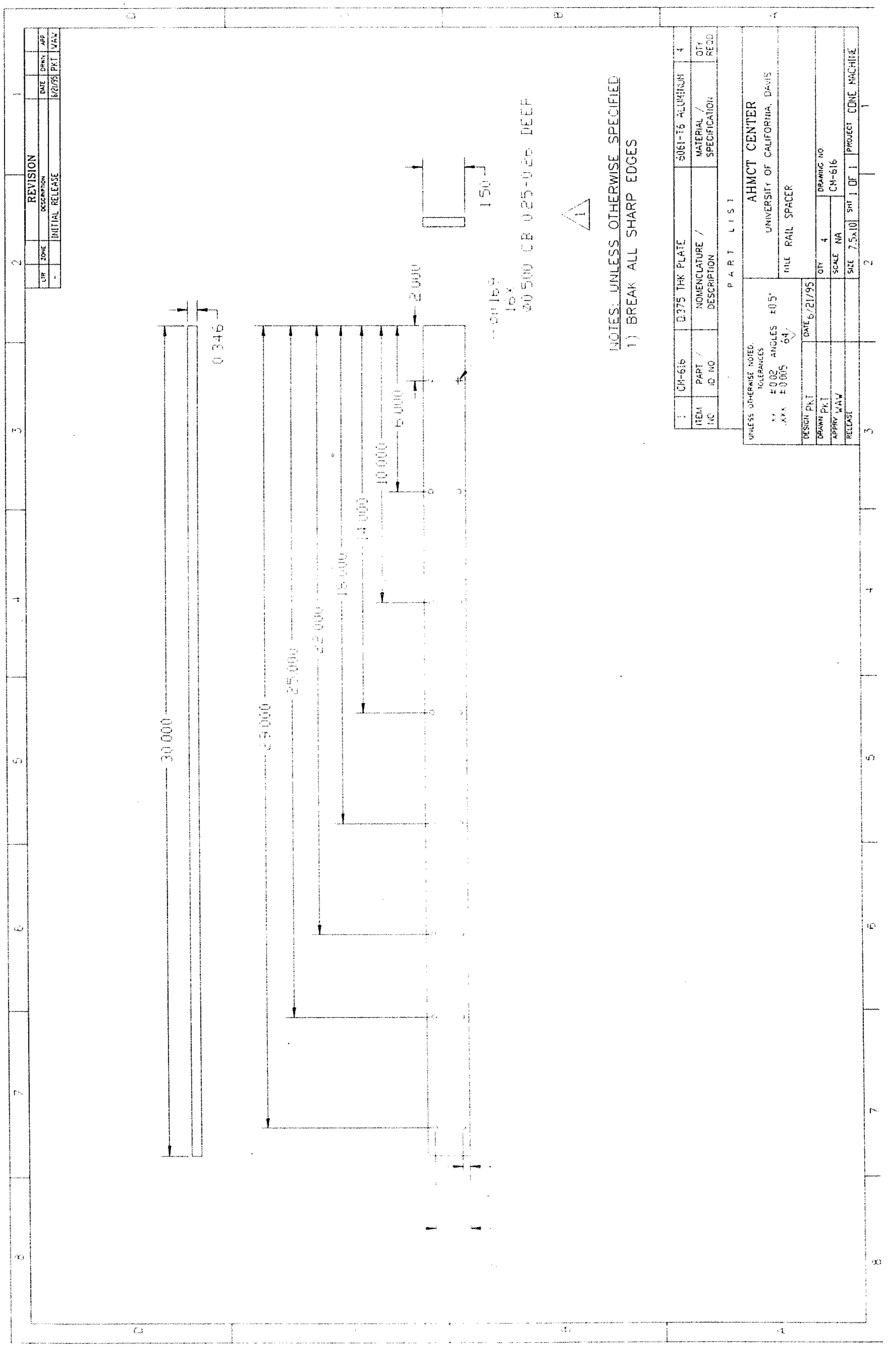
PART LIST

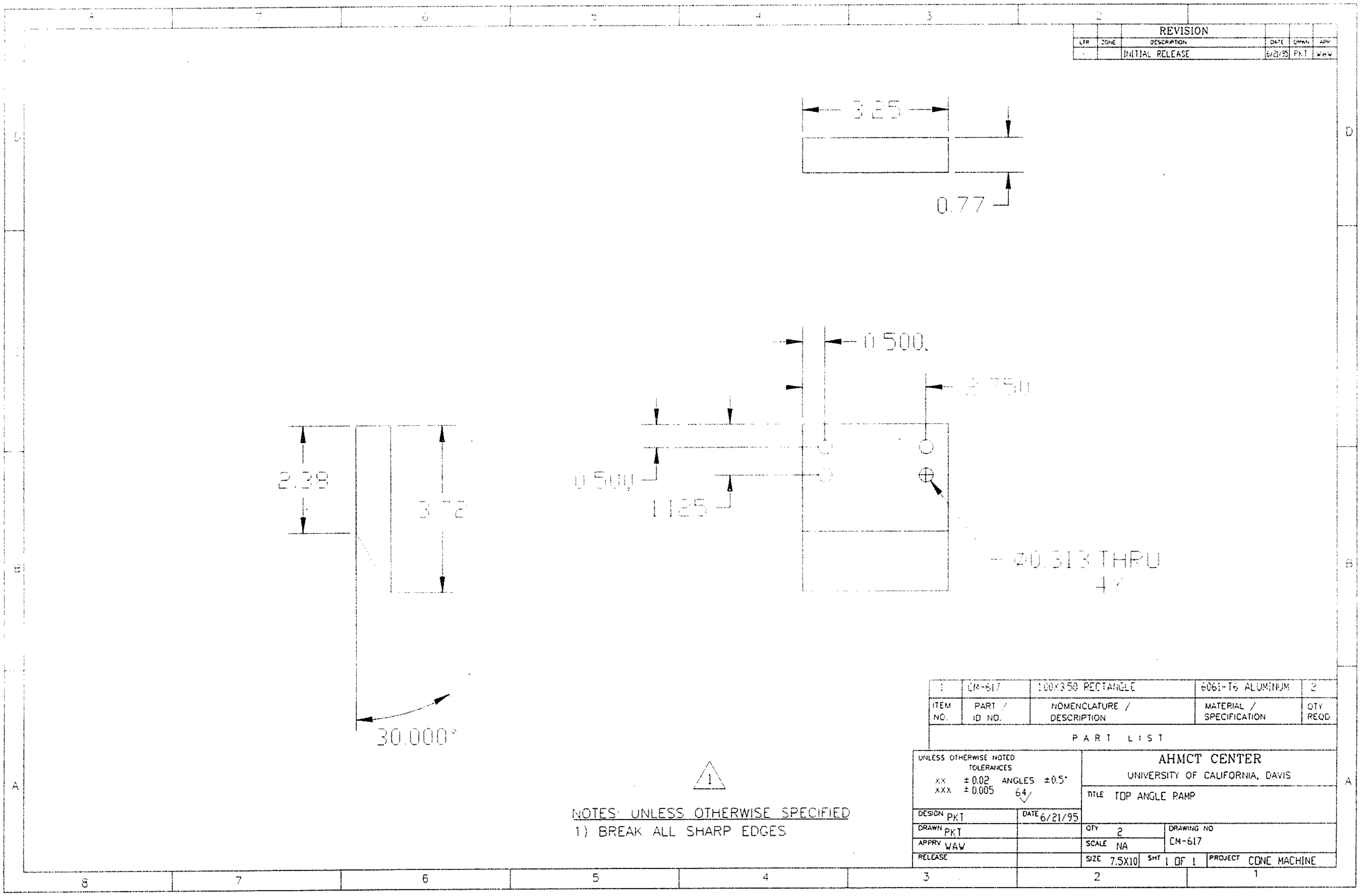
UNLESS OTHERWISE NOTED TOLERANCES: XX ± 0.02, XXX ± 0.005, ANGLES ±0.5°, 64	AHMCT CENTER, UNIVERSITY OF CALIFORNIA, DAVIS
DESIGN PKT, DATE 6/21/95	TITLE PULL ROD END ASSEMBLY
DRAWN PKT	QTY 2; DRAWING NO CM-615
APPRV WAW	SCALE NA
RELEASE	SIZE 7.5X10; SHT 1 OF 4; PROJECT CONE MACHINE

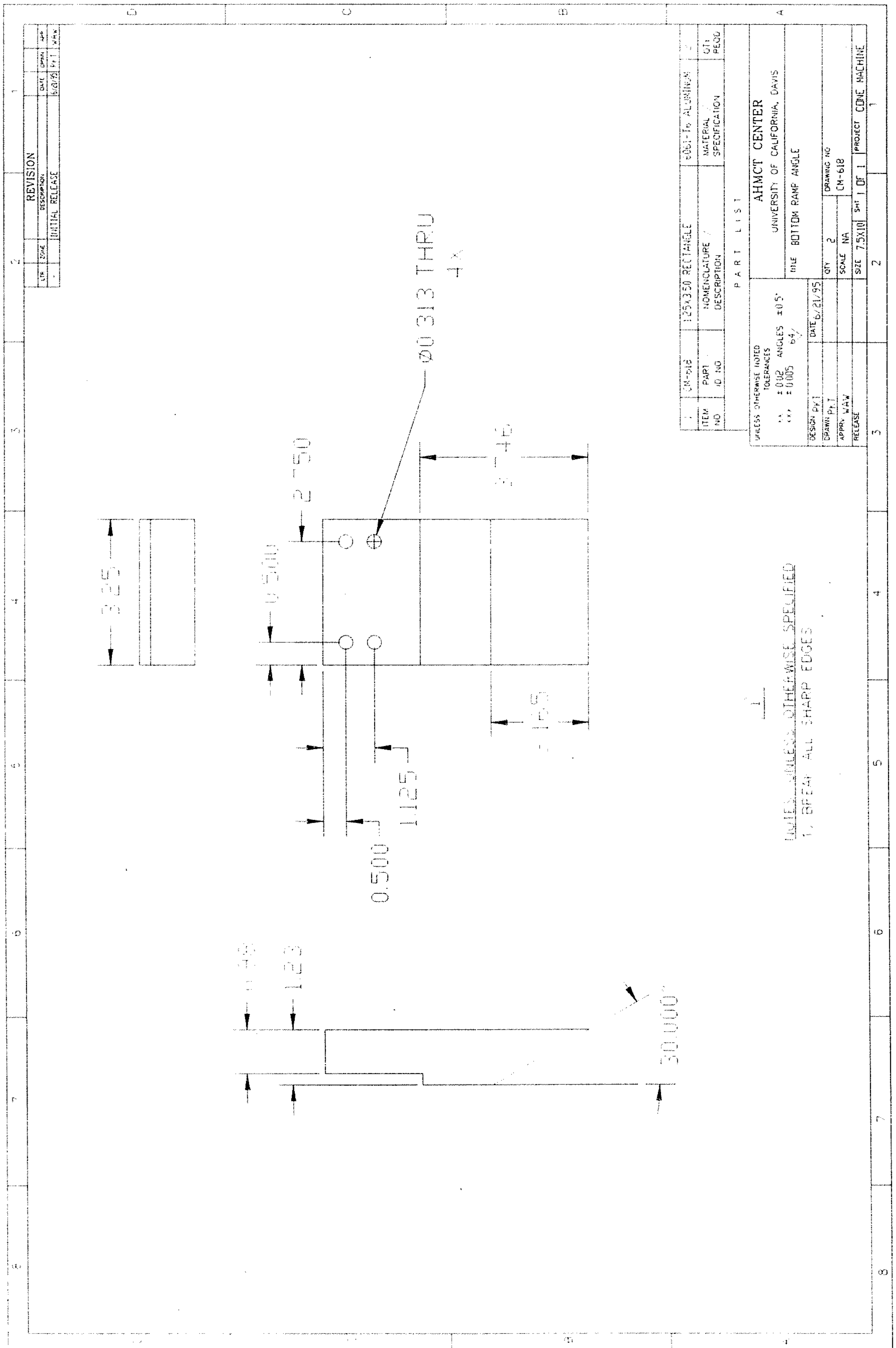

REVISION
INITIAL RELEASE
5/21/95
NOTES UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
1.25
Ø0.500
Ø0.505
THRU
0.375
0.63
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
TITLE PULL ROD END WELDMENT
DRAWING NO CM-615
SCALE NA
SIZE 7.5x10 SHT 2 OF 4 PROJECT CONE MACHINE

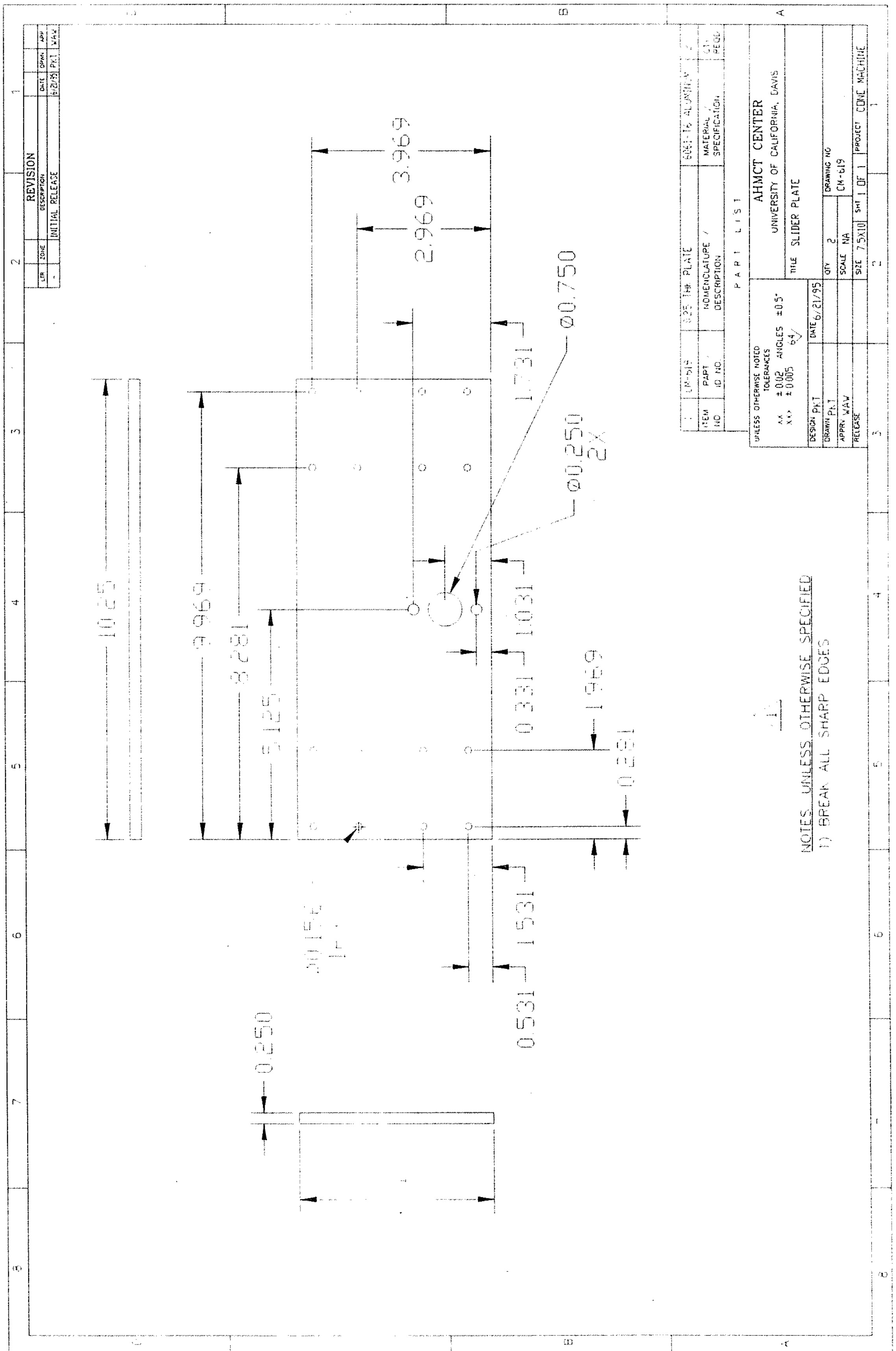

REVISION
LTR
ZONE
DESCRIPTION
DATE
DRWN
APP
INITIAL RELEASE
6/21/95
PLT
WAW
0.281
0.625
1.25
1.469
2.0018
0.25
1.75
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
TITLE PULL ROD END WELDMENT
DRAWING NO
CM-615
SCALE NA
SIZE 7.5X10
SHT 3 OF 4
PROJECT CONE MACHINE

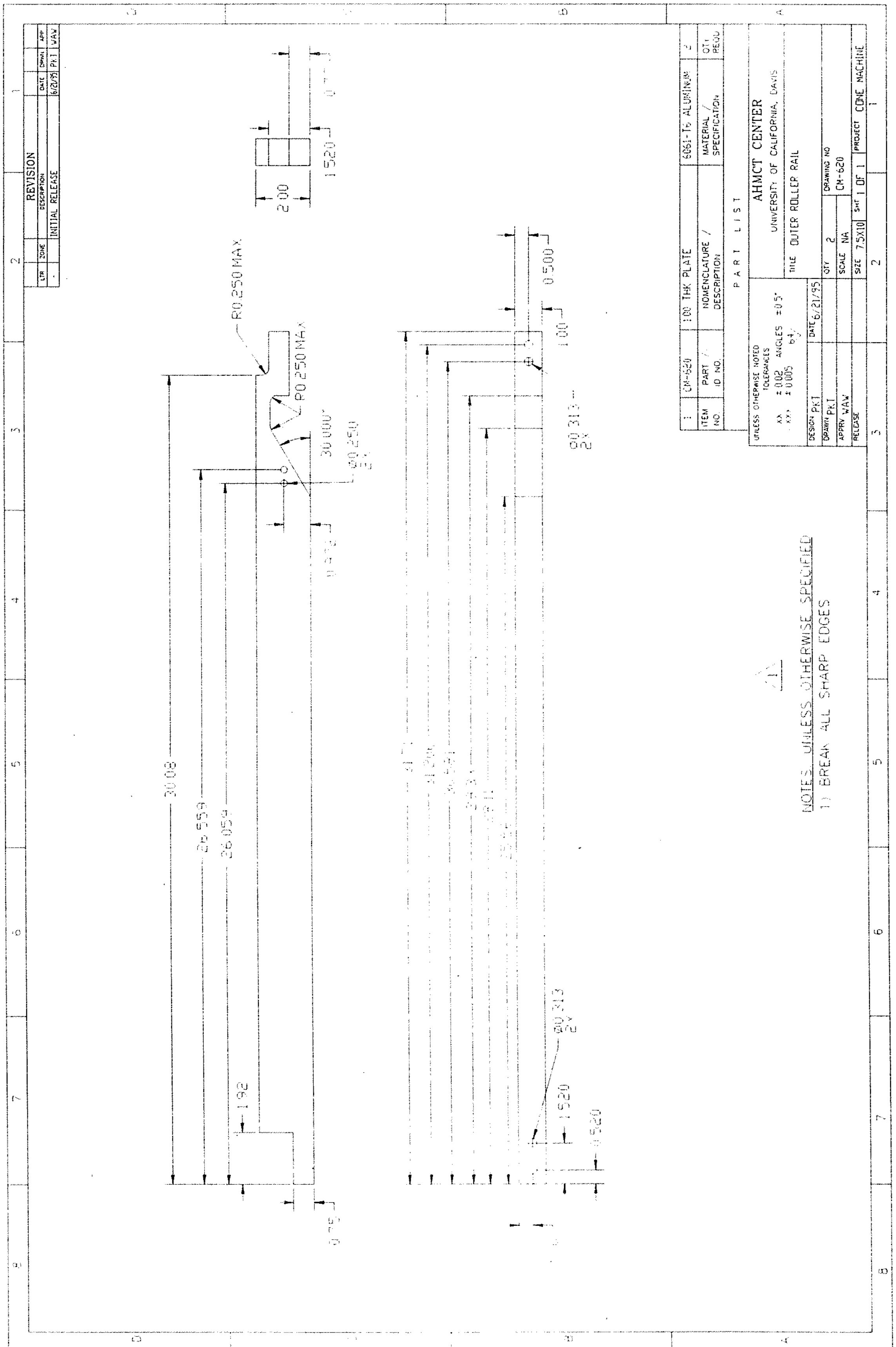

REVISION
LTR
ZONE
DESCRIPTION
DATE
DRWN
APP
-
INITIAL RELEASE
6/21/95
PKT
WAW
NOTES UNLESS OTHERWISE SPECIFIED
1. BREAK ALL SHARP EDGES
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
TITLE
PULL ROD END WELDMENT
DRAWING NO
CM-615
SCALE
NA
SIZE
7.5X10
SHT
4 OF 4
PROJECT
CONE MACHINE

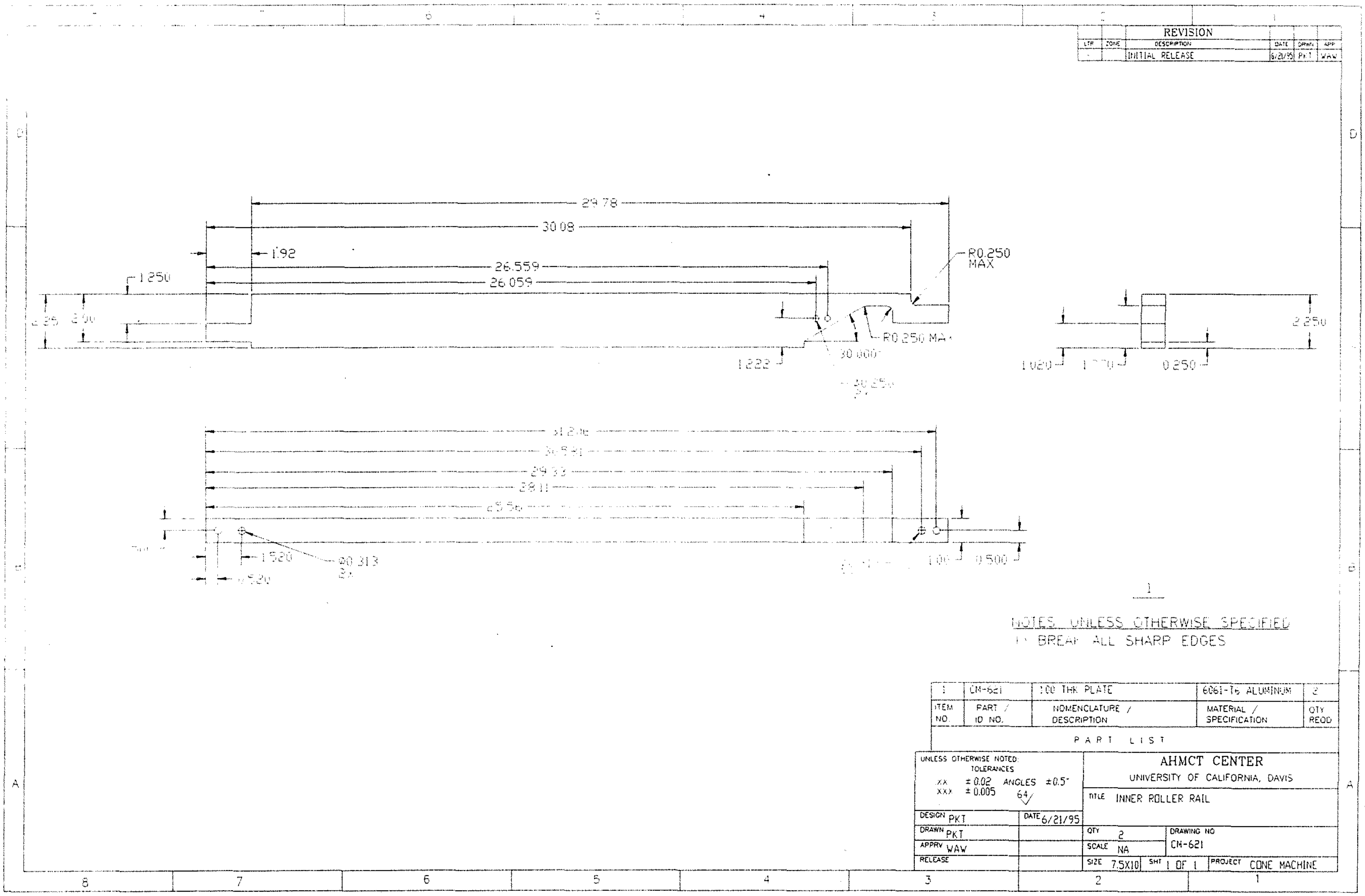

REVISION
INITIAL RELEASE
6/21/95
PKT
WAW
30.000
29.000
25.000
22.000
18.000
14.000
10.000
6.000
2.000
0.346
.150
Ø0.500 CB 0.25-0.26 DEEP
16X
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
CM-616
0.375 THK PLATE
6061-T6 ALUMINUM
4
ITEM NO
PART / ID NO
NOMENCLATURE / DESCRIPTION
MATERIAL / SPECIFICATION
QTY REQD
PARTS LIST
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
TITLE RAIL SPACER
UNLESS OTHERWISE NOTED, TOLERANCES
.XX ±0.02
.XXX ±0.005
ANGLES ±0.5°
DESIGN PKT
DRAWN PKT
APPRV WAW
RELEASE
DATE 6/21/95
QTY 4
SCALE NA
SIZE 7.5x10
SHT 1 OF 1
DRAWING NO CM-616
PROJECT CONE MACHINE

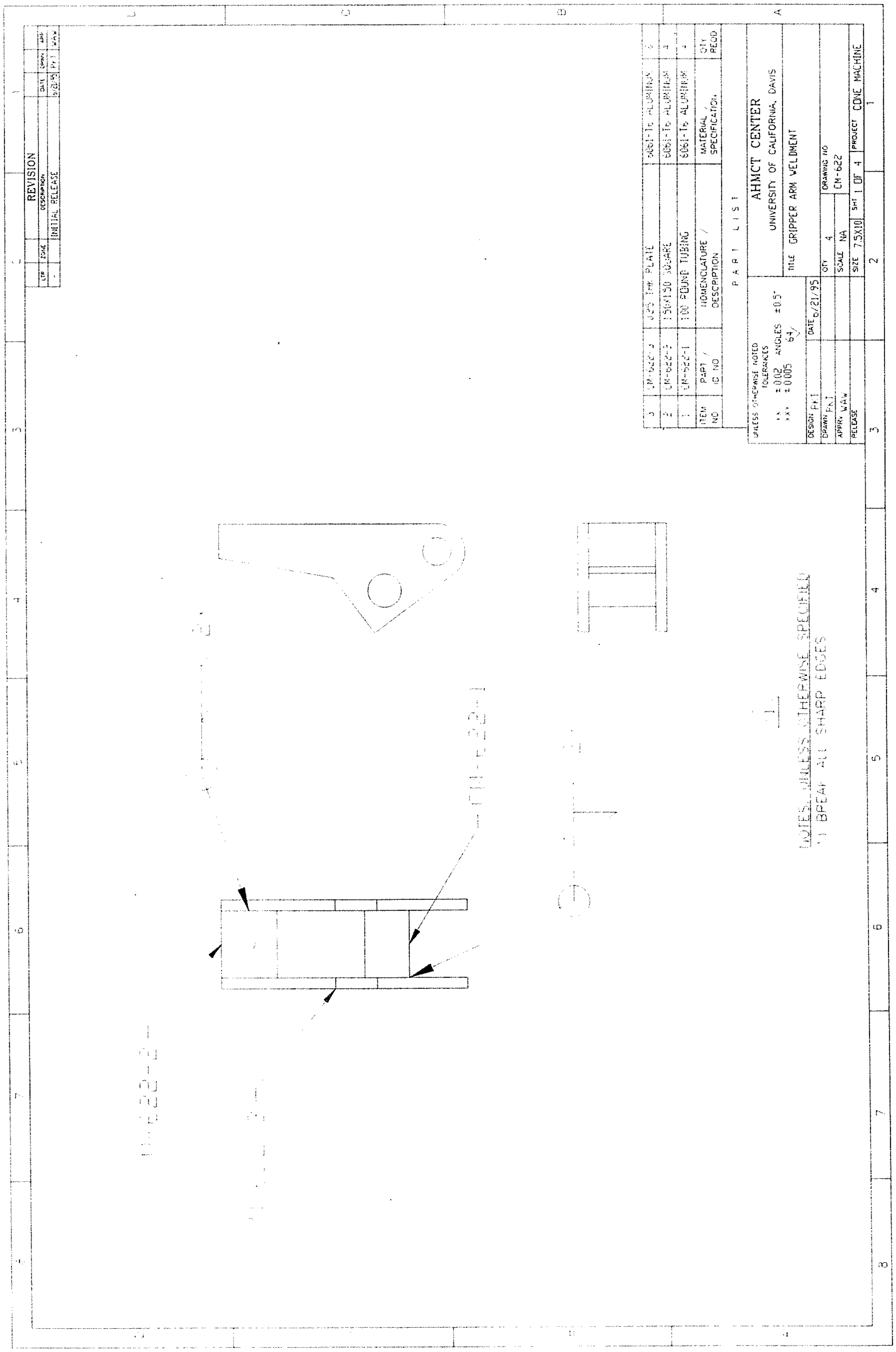

REVISION
LTR ZONE DESCRIPTION DATE DRWN APP
INITIAL RELEASE 6/21/95 PKT WAW
3.25
0.77
0.500
0.750
0.500
1.125
2.38
3.72
Ø0.313 THRU
4X
30.000°
1
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
1 CM-617 100X350 RECTANGLE 6061-T6 ALUMINUM 2
ITEM NO. PART / ID NO. NOMENCLATURE / DESCRIPTION MATERIAL / SPECIFICATION QTY REQD
PART LIST
UNLESS OTHERWISE NOTED TOLERANCES
XX ± 0.02 ANGLES ±0.5°
XXX ± 0.005 64
DESIGN PKT DATE 6/21/95
DRAWN PKT
APPRV WAW
RELEASE
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
TITLE TOP ANGLE RAMP
QTY 2
DRAWING NO CM-617
SCALE NA
SIZE 7.5X10 SHT 1 OF 1 PROJECT CONE MACHINE

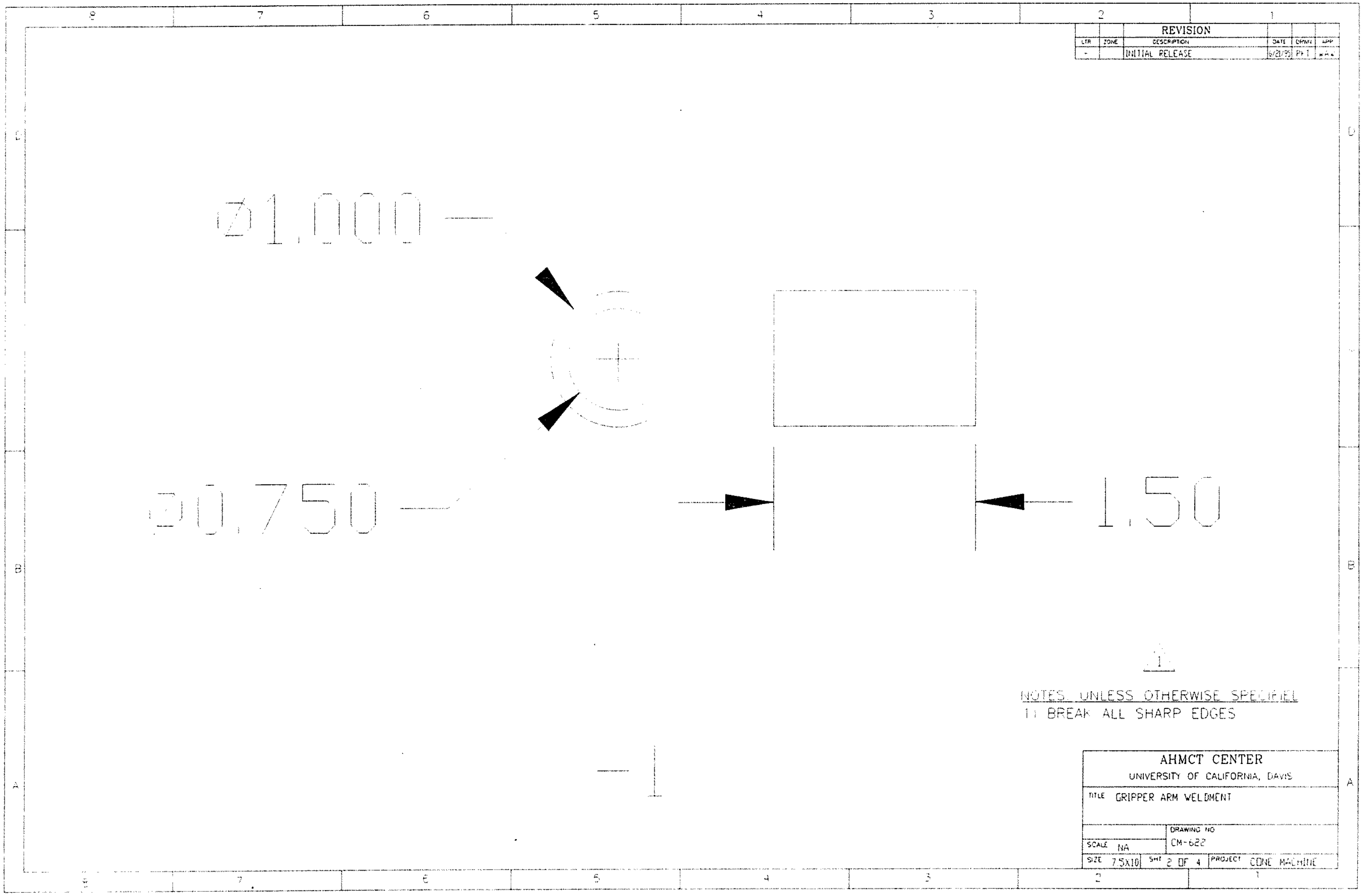

REVISION
INITIAL RELEASE
6/21/95
Ø0.313 THRU
4X
3.25
0.500
1.125
30.000°
PART LIST
125X350 RECTANGLE
NOMENCLATURE / DESCRIPTION
MATERIAL SPECIFICATION
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
BOTTOM RAMP ANGLE
CM-618
CONE MACHINE
1. BREAK ALL SHARP EDGES

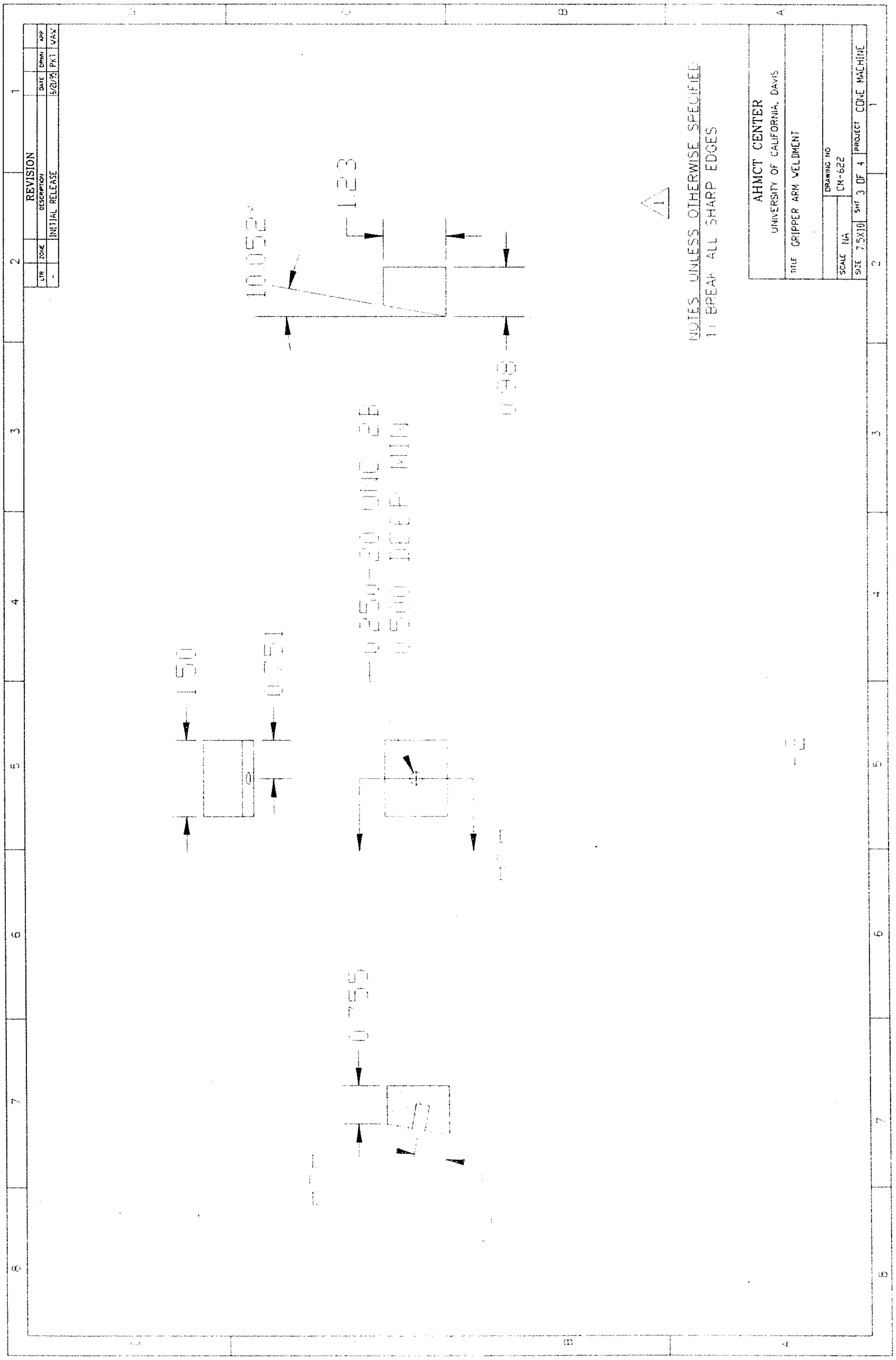

REVISION
LTR ZONE DESCRIPTION DATE DRWN APP
- INITIAL RELEASE 6/21/95 PKT WAW
3.969
2.969
Ø0.750
1.731
Ø0.250
2X
10.25
9.969
8.281
5.125
1.031
0.331
1.969
0.281
1.531
0.531
0.250
NOTES UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
1 CM-619 .625 THK PLATE 6061-T6 ALUMINUM
ITEM NO PART ID NO NOMENCLATURE / DESCRIPTION MATERIAL / SPECIFICATION
PART LIST
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
TITLE SLIDER PLATE
QTY 2
SCALE NA
SIZE 7.5X10 SHT 1 OF 1
DRAWING NO CM-619
PROJECT CONE MACHINE
UNLESS OTHERWISE NOTED TOLERANCES
ANGLES ±0.5°
DESIGN PKT
DRAWN PKT
APPR WAW
RELEASE
DATE 6/21/95


REVISION
LTR
ZONE
DESCRIPTION
DATE
DRAWN
APP
INITIAL RELEASE
6/21/95
PKT
VAW
R0.250 MAX
R0.250 MAX
30.000°
30.08
26.559
26.059
1.92
2.00
1.520
.100
1.520
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
1
CM-620
.100 THK PLATE
6061-T6 ALUMINUM
2
ITEM NO
PART / ID NO
NOMENCLATURE / DESCRIPTION
MATERIAL / SPECIFICATION
QTY REQD
PART LIST
UNLESS OTHERWISE NOTED TOLERANCES
ANGLES ±0.5°
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
TITLE OUTER ROLLER RAIL
DESIGN PKT
DRAWN PKT
APPRV VAW
RELEASE
DATE 6/21/95
QTY 2
SCALE NA
SIZE 7.5X10
DRAWING NO CM-620
SHT 1 OF 1
PROJECT CONE MACHINE

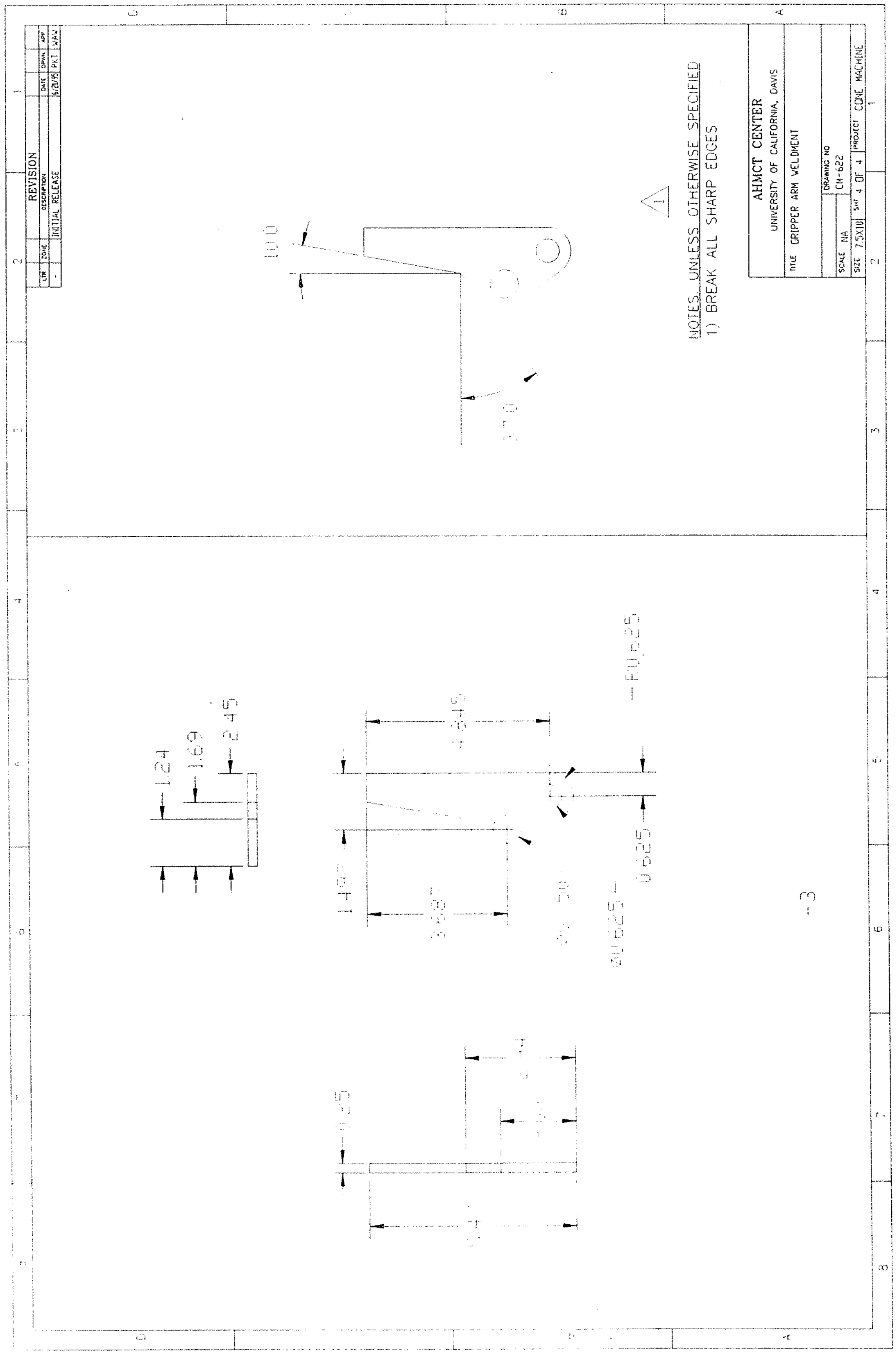

REVISION
INITIAL RELEASE 6/21/95 PKT WAW
29.78
30.08
1.92
26.559
26.059
1.250
R0.250 MAX
2.250
1.222
1.020
0.250
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
1 CM-621 1.00 THK PLATE 6061-T6 ALUMINUM 2
ITEM NO. PART / ID NO. NOMENCLATURE / DESCRIPTION MATERIAL / SPECIFICATION QTY REQD
PART LIST
UNLESS OTHERWISE NOTED TOLERANCES
.XX ± 0.02 ANGLES ± 0.5°
.XXX ± 0.005
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
TITLE INNER ROLLER RAIL
DESIGN PKT DATE 6/21/95
DRAWN PKT
APPRV WAW
RELEASE
QTY 2
DRAWING NO CM-621
SCALE NA
SIZE 7.5X10 SHT 1 OF 1 PROJECT CONE MACHINE

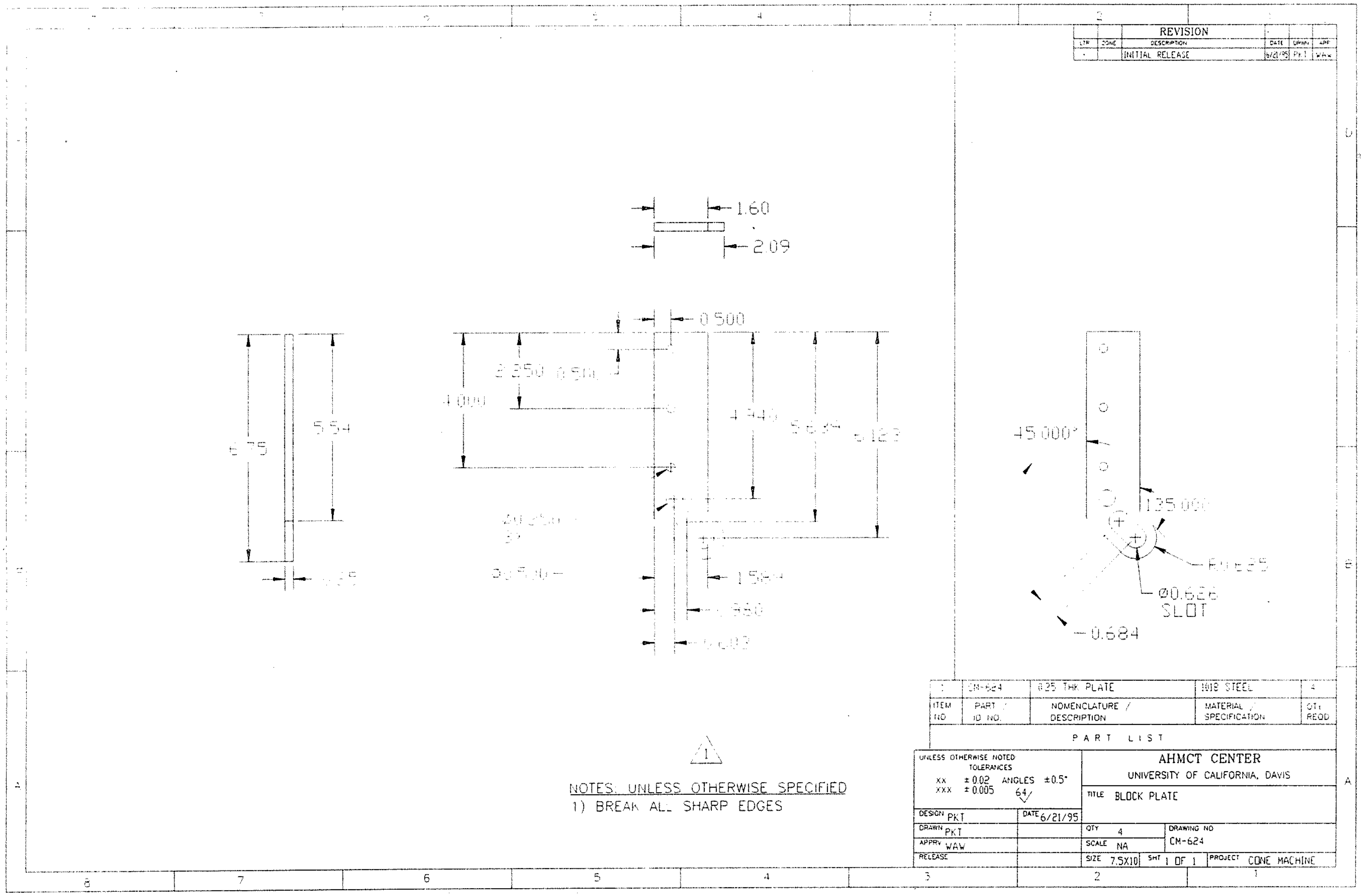

REVISION
INITIAL RELEASE
PART LIST
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
GRIPPER ARM WELDMENT
CM-622
SCALE NA
SIZE 7.5X10
SHT 1 OF 4
PROJECT CONE MACHINE
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES

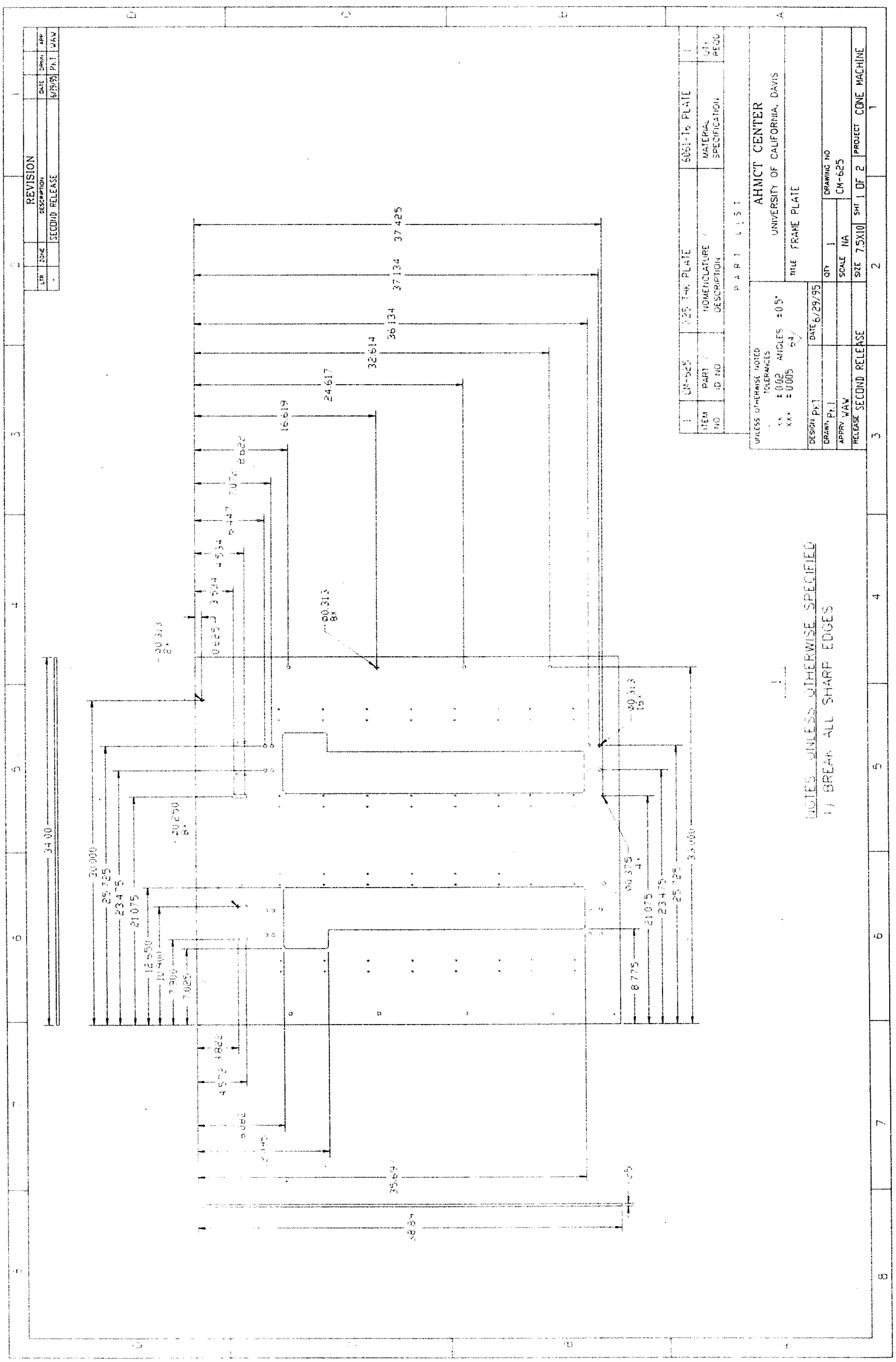

REVISION
LTR ZONE DESCRIPTION DATE DRWN APP
INITIAL RELEASE
Ø1.000
Ø0.750
1.50
NOTES UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
TITLE GRIPPER ARM WELDMENT
DRAWING NO CM-622
SCALE NA
SIZE 7.5X10 SHT 2 OF 4 PROJECT CONE MACHINE

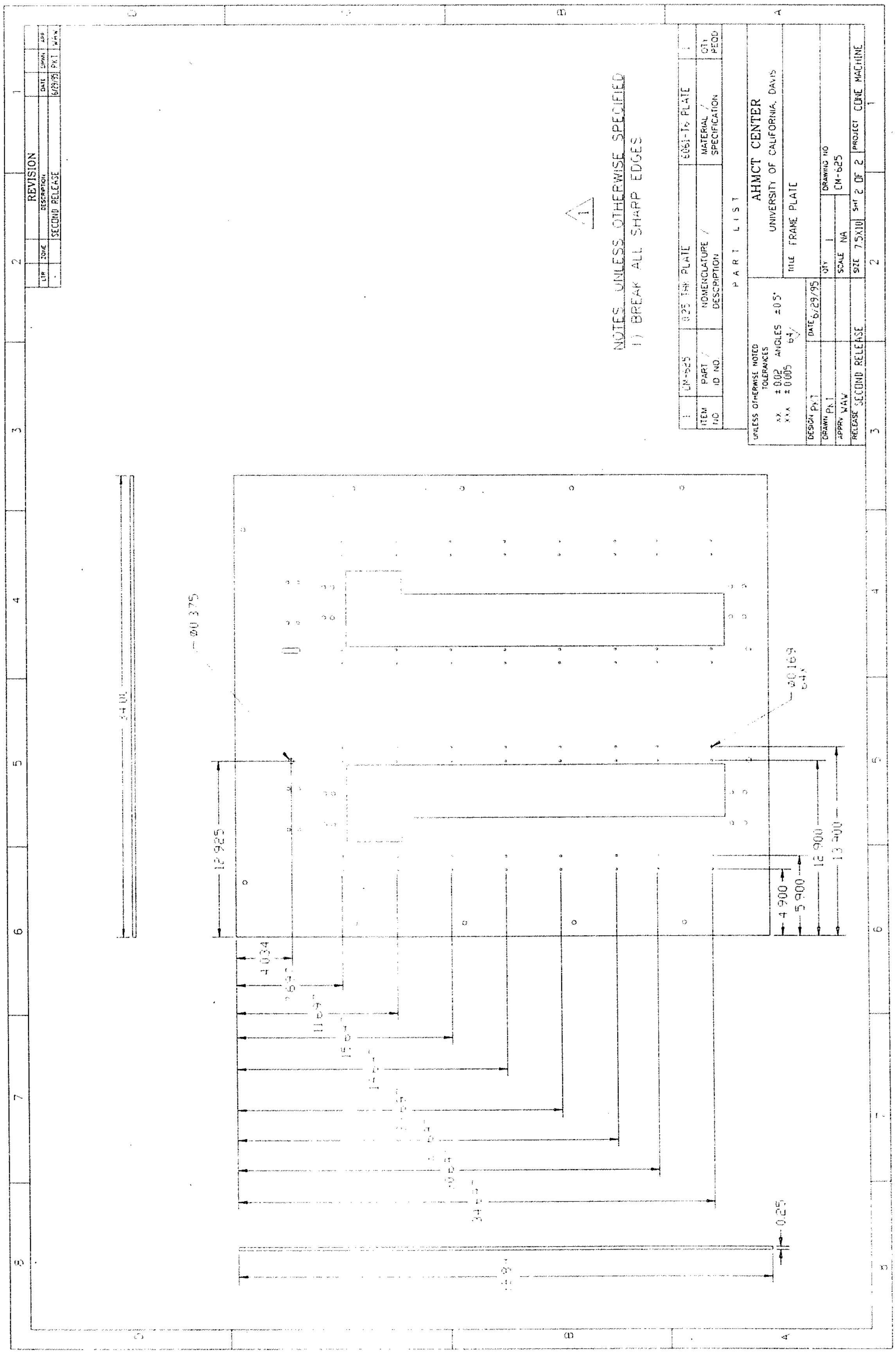


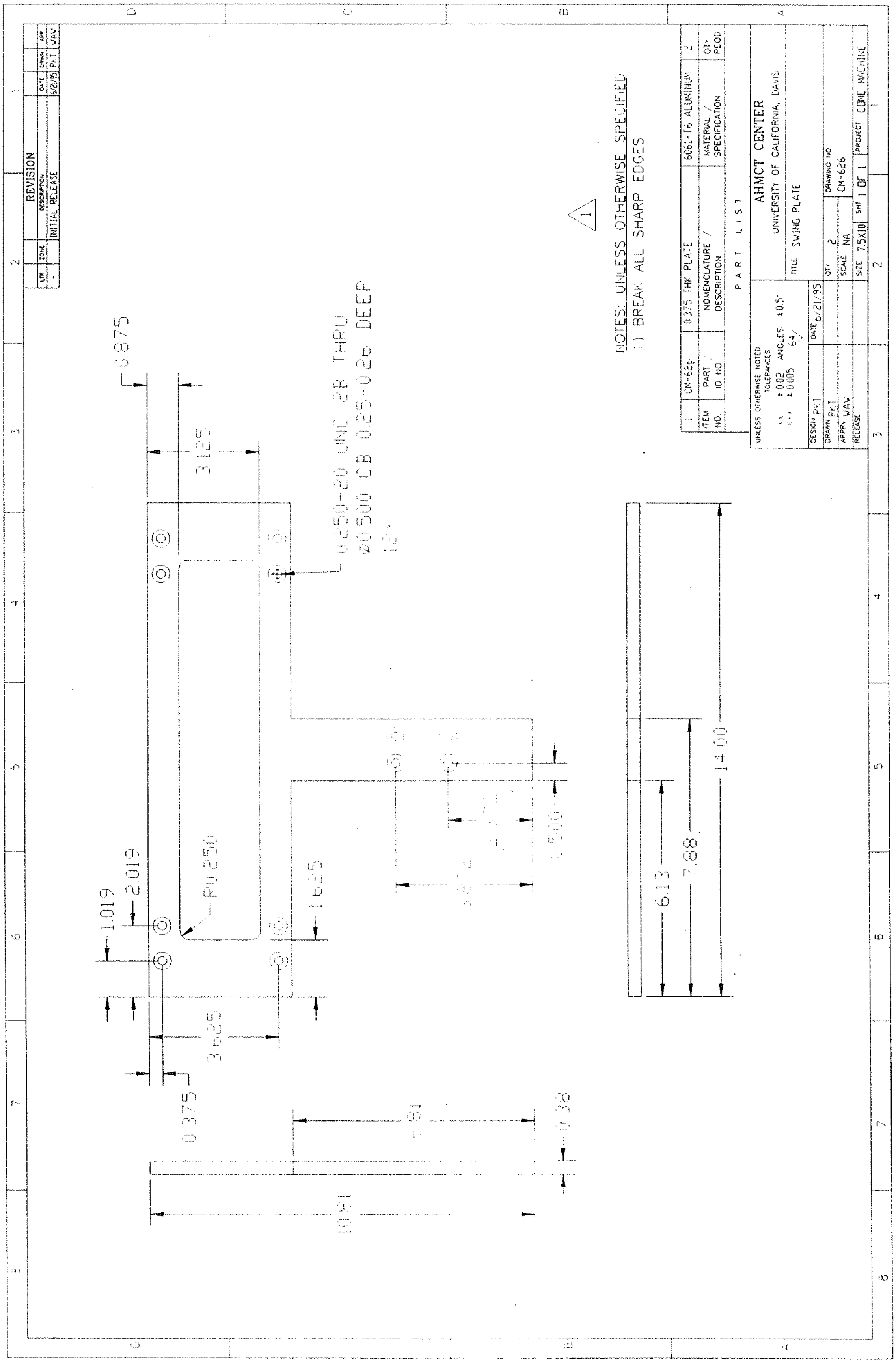
REVISION
LTR ZONE DESCRIPTION DATE DRWN APP
- INITIAL RELEASE 6/21/95 PK1 VAV
10.052°
1.23
1.98
0.250-20 UNC 2B
0.500 DEEP MIN
1.50
0.751
0.755
NOTES UNLESS OTHERWISE SPECIFIED
1. BREAK ALL SHARP EDGES
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
TITLE GRIPPER ARM WELDMENT
DRAWING NO CM-622
SCALE NA
SIZE 7.5X10 SHT 3 OF 4 PROJECT CONE MACHINE


REVISION
LTR ZONE DESCRIPTION DATE DRWN APP
- INITIAL RELEASE 6/21/95 PKT WAW
NOTES UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
TITLE GRIPPER ARM WELDMENT
DRAWING NO CM-622
SCALE NA
SIZE 7.5X10 SHT 4 OF 4 PROJECT CONE MACHINE
1.24
1.69
2.45
4.845
R0.625
0.625
1.487
3.687
-3


REVISION
INITIAL RELEASE
1.60
2.09
0.500
4.000
5.54
6.75
45.000°
135.000
R0.625
Ø0.626
SLOT
0.684
1.584
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
CM-624
0.25 THK PLATE
1018 STEEL
ITEM NO
PART / ID NO.
NOMENCLATURE / DESCRIPTION
MATERIAL / SPECIFICATION
QTY REQD
PART LIST
UNLESS OTHERWISE NOTED TOLERANCES
XX ± 0.02 ANGLES ± 0.5°
XXX ± 0.005
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
TITLE BLOCK PLATE
DESIGN PKT
DATE 6/21/95
DRAWN PKT
APPRV WAW
RELEASE
QTY 4
DRAWING NO CM-624
SCALE NA
SIZE 7.5X10
SHT 1 OF 1
PROJECT CONE MACHINE

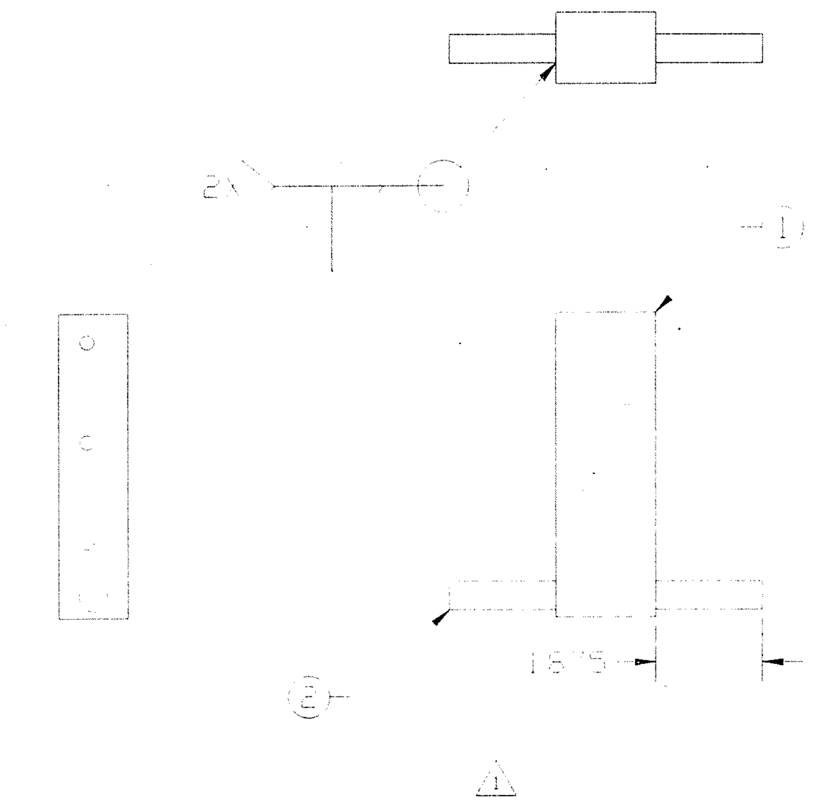

REVISION
SECOND RELEASE
6061-T6 PLATE
MATERIAL SPECIFICATION
NOMENCLATURE / DESCRIPTION
PART / ID NO
CM-625
PARTS LIST
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
TITLE FRAME PLATE
DRAWING NO CM-625
SCALE NA
SIZE 7.5X10
SHT 1 OF 2
PROJECT CONE MACHINE
RELEASE SECOND RELEASE
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES


REVISION
SECOND RELEASE
NOTES UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
PART LIST
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
FRAME PLATE
CM-625
CONE MACHINE



REVISION
INITIAL RELEASE
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
SWING PLATE
CM-626
6061-T6 ALUMINUM
0.375 THK PLATE
PART LIST
CONE MACHINE
14.00
7.88
6.13
3.125
0.875
1.019
2.019
1.625
3.625
0.375

REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
-		INITIAL RELEASE	6/21/95	PKT	WAW



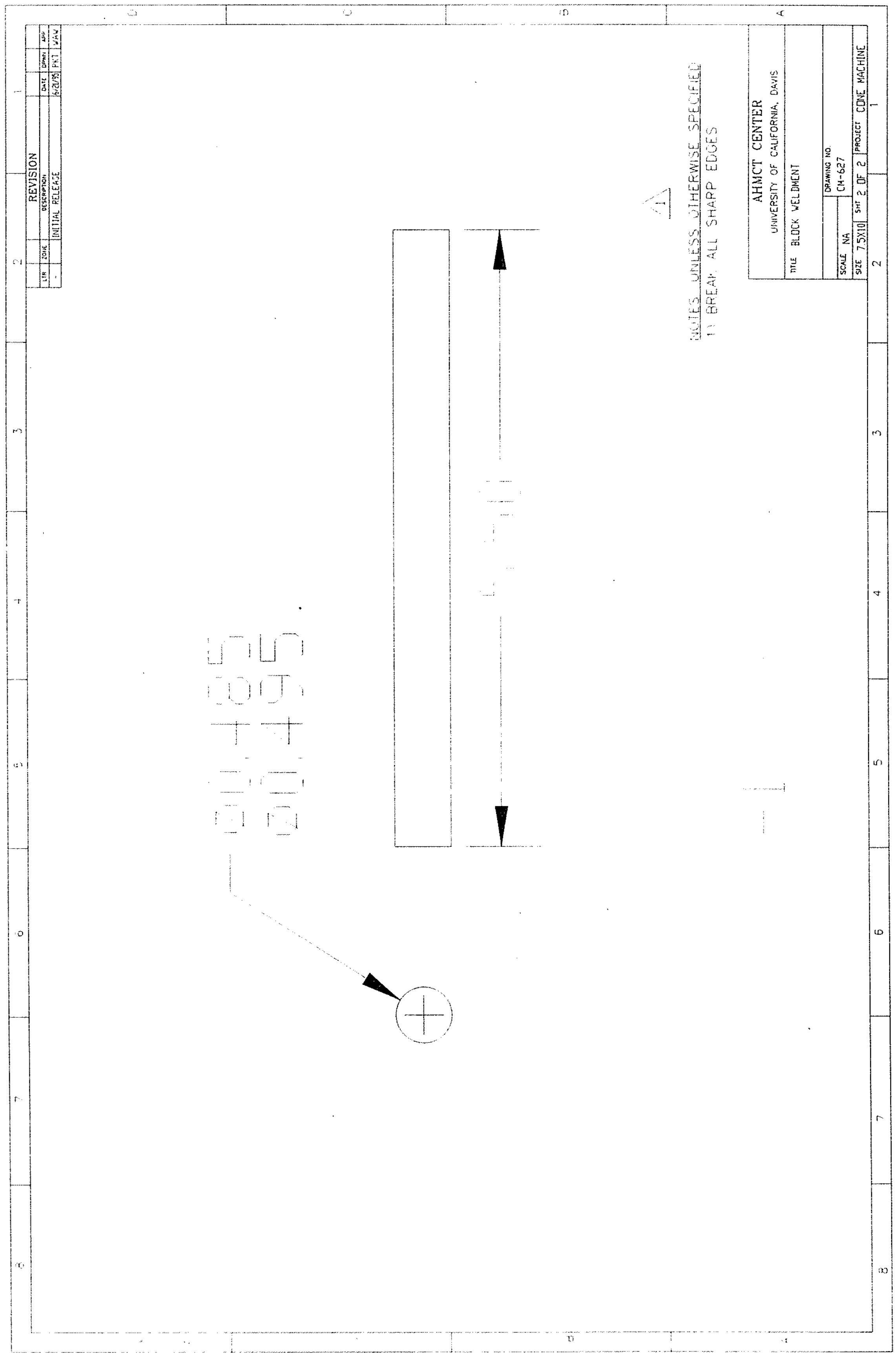
NOTES: UNLESS OTHERWISE SPECIFIED

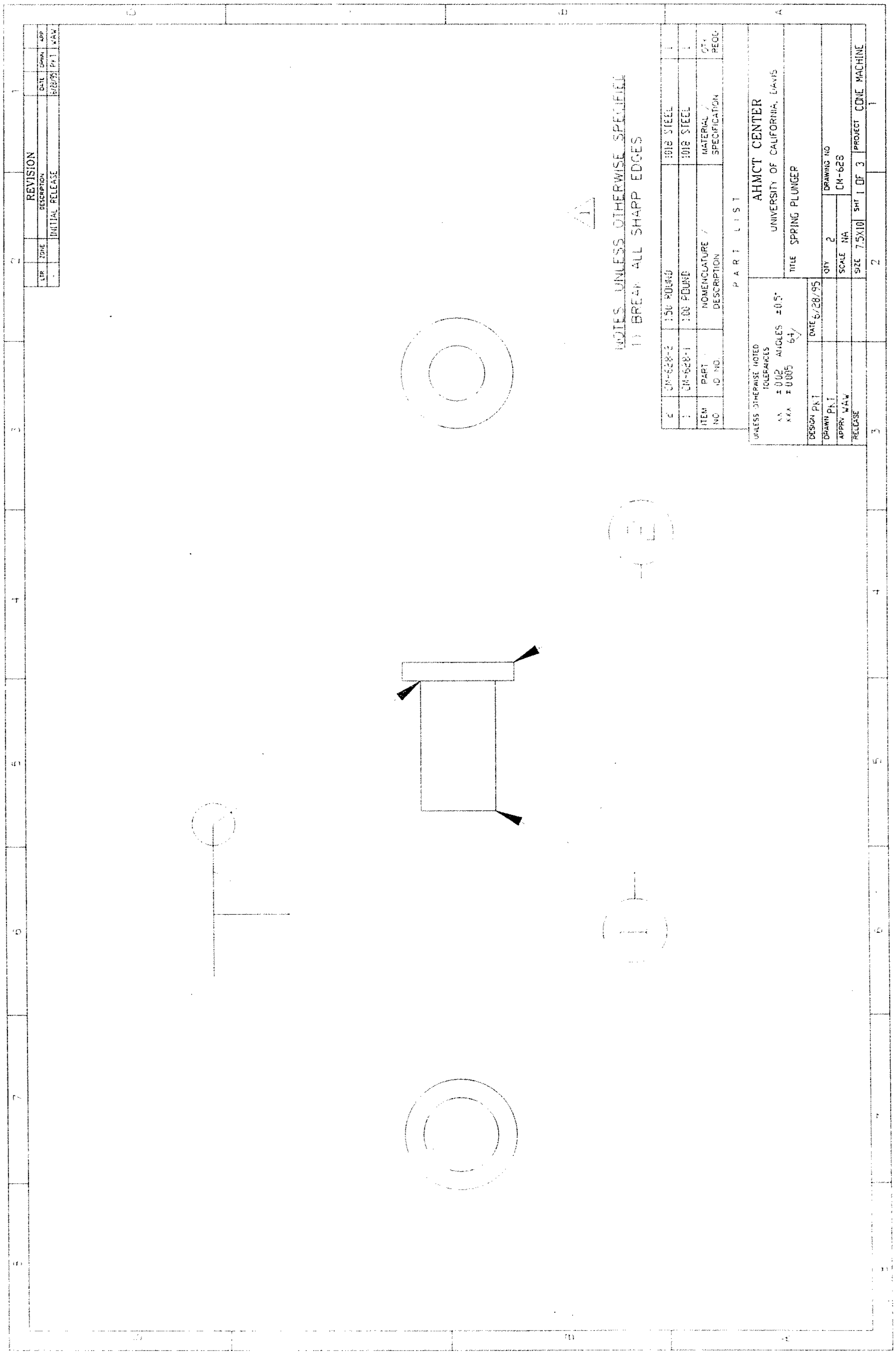
1) BREAK ALL SHARP EDGES

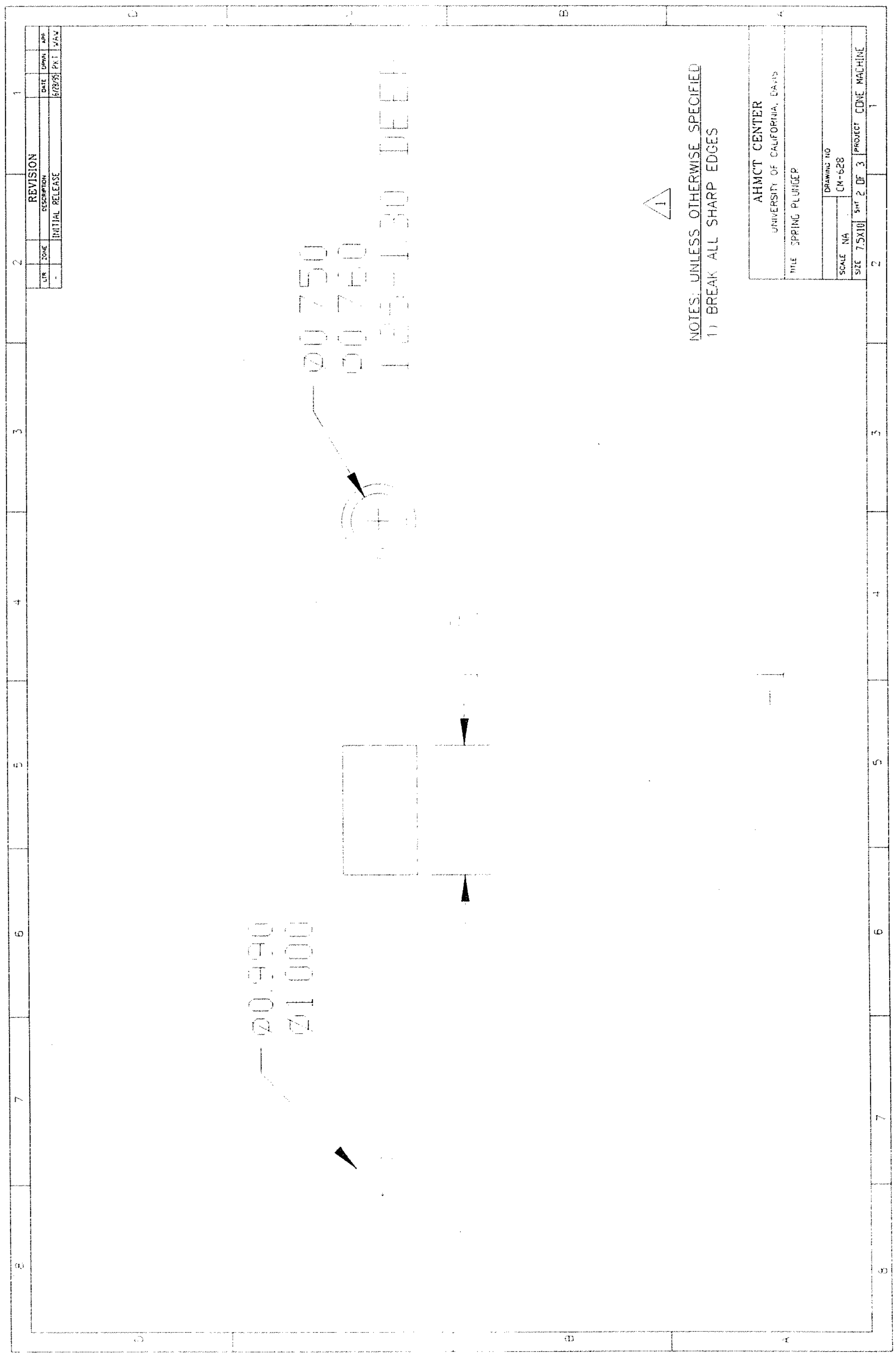
ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
2	CM-627-1	Ø.500 ROUND	6061-T6 ALUMINUM	2
1	CM-623	1.75X1.75 SQUARE	6061-T6 ALUMINUM	2

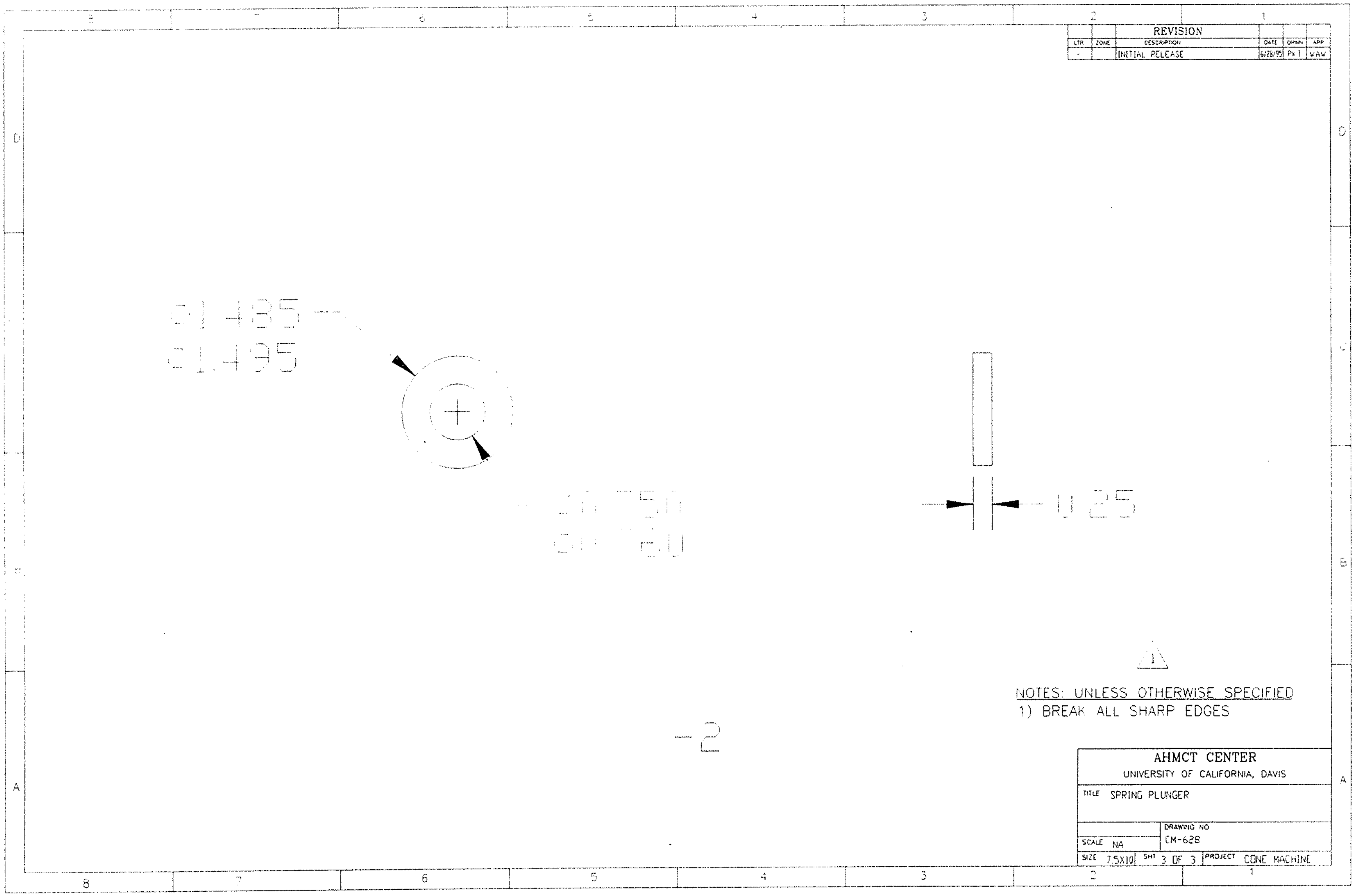
PART LIST

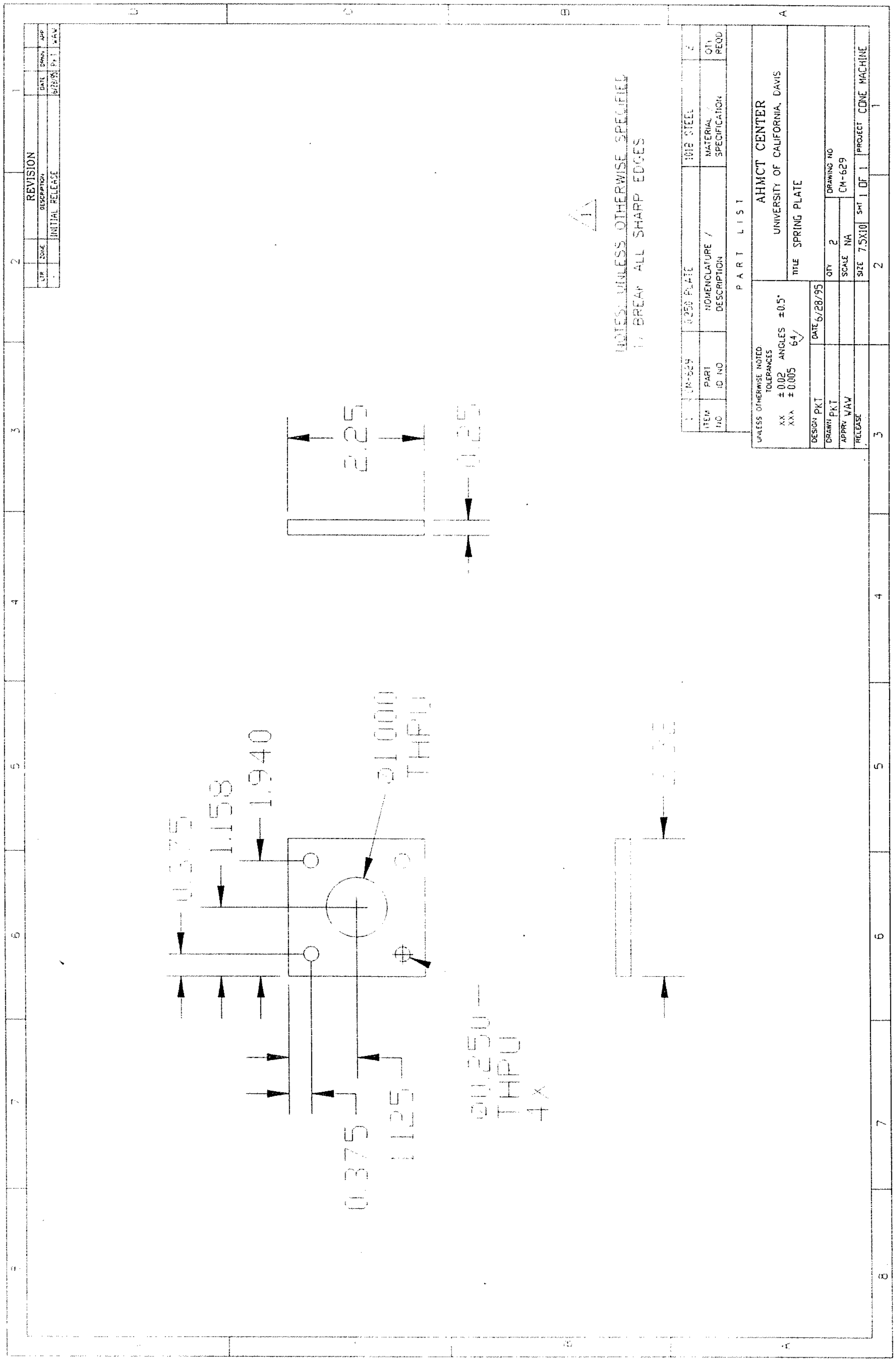
UNLESS OTHERWISE NOTED TOLERANCES XX ±0.02 ANGLES ±0.5° XXX ±0.005 64√		AHMCT CENTER UNIVERSITY OF CALIFORNIA, DAVIS	
		TITLE BLOCK WELDMENT	
DESIGN PKT	DATE 6/21/95		
DRAWN PKT		QTY 2	DRAWING NO CM-627
APPRV WAW		SCALE NA	
RELEASE		SIZE 7.5X10 SHT 1 OF 2	PROJECT CONE MACHINE

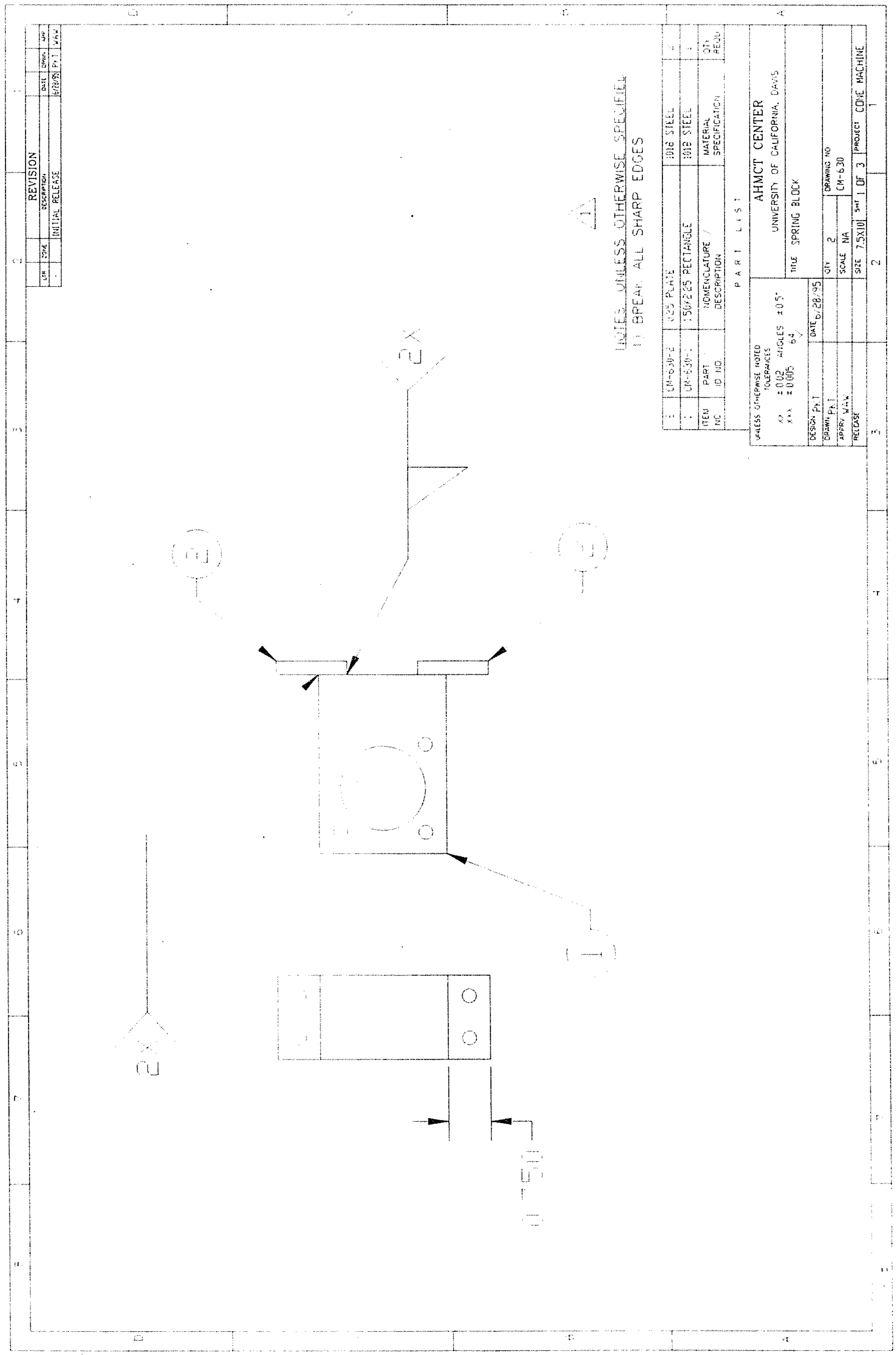

REVISION
LTR ZONE DESCRIPTION DATE DRWN APP
- INITIAL RELEASE 6/21/95 PKT WAW
NOTES UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
TITLE BLOCK WELDMENT
DRAWING NO. CM-627
SCALE NA
SIZE 7.5X10 SHT 2 OF 2 PROJECT CONE MACHINE


REVISION
LTR
ZONE
DESCRIPTION
DATE
DRAWN
APP
INITIAL RELEASE
PKT
WAW
NOTES UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
2
CM-628-2
1.50 ROUND
1018 STEEL
1
1
CM-628-1
1.00 ROUND
1018 STEEL
1
ITEM NO
PART ID NO.
NOMENCLATURE / DESCRIPTION
MATERIAL / SPECIFICATION
QTY REQD
PART LIST
UNLESS OTHERWISE NOTED TOLERANCES
±.002
±.0005
ANGLES ±0.5°
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
TITLE SPRING PLUNGER
DESIGN PKT
DRAWN PKT
APPRV WAW
RELEASE
DATE 6/28/95
QTY 2
SCALE NA
SIZE 7.5X10
SHT 1 OF 3
DRAWING NO CM-628
PROJECT CONE MACHINE

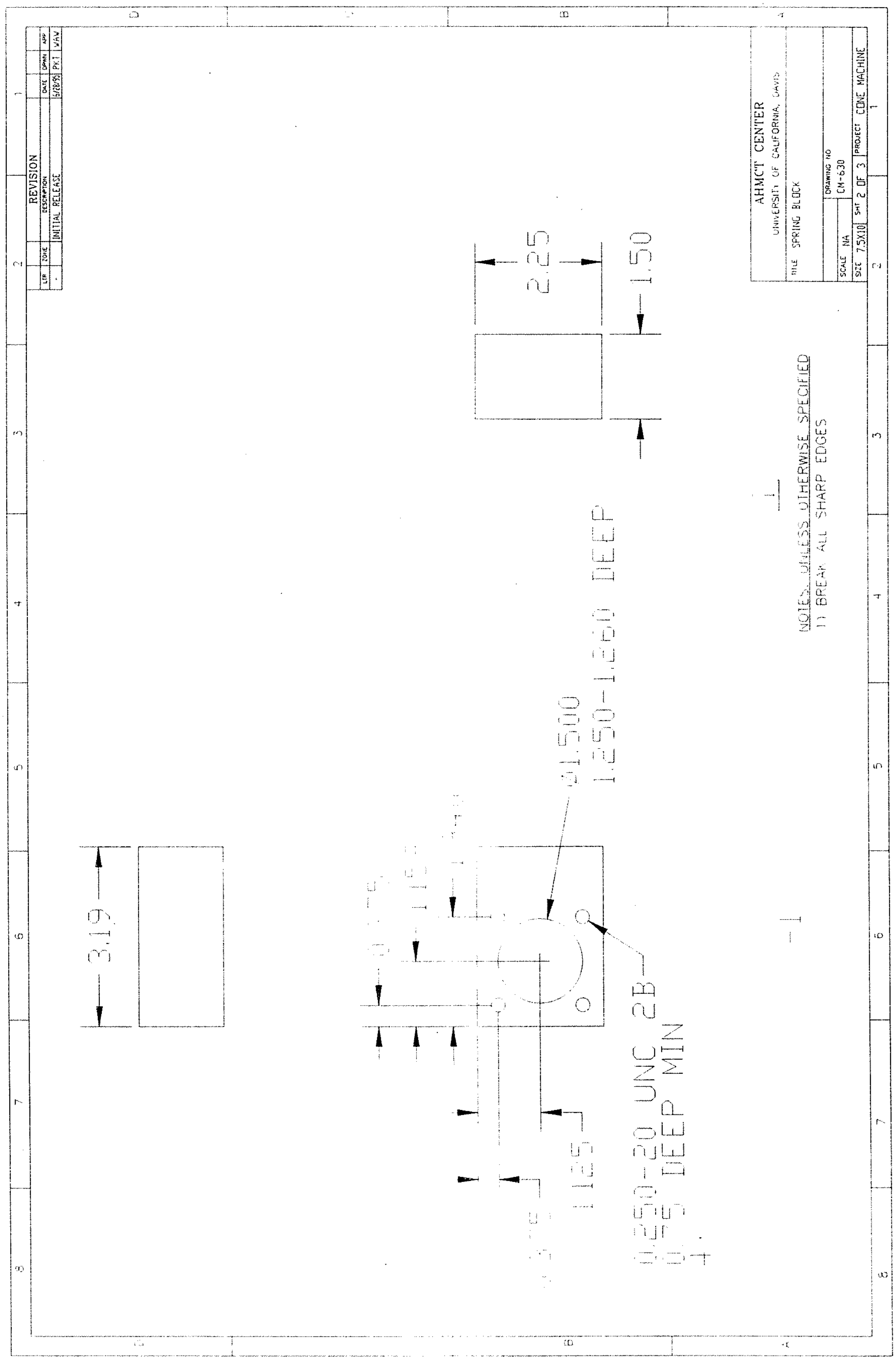

REVISION
LTR
ZONE
DESCRIPTION
DATE
DRWN
APR
-
INITIAL RELEASE
6/28/95
PKT
WAW
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
TITLE
DRAWING NO
CM-628
SCALE NA
SIZE 7.5X10
SHT 2 OF 3
PROJECT CONE MACHINE

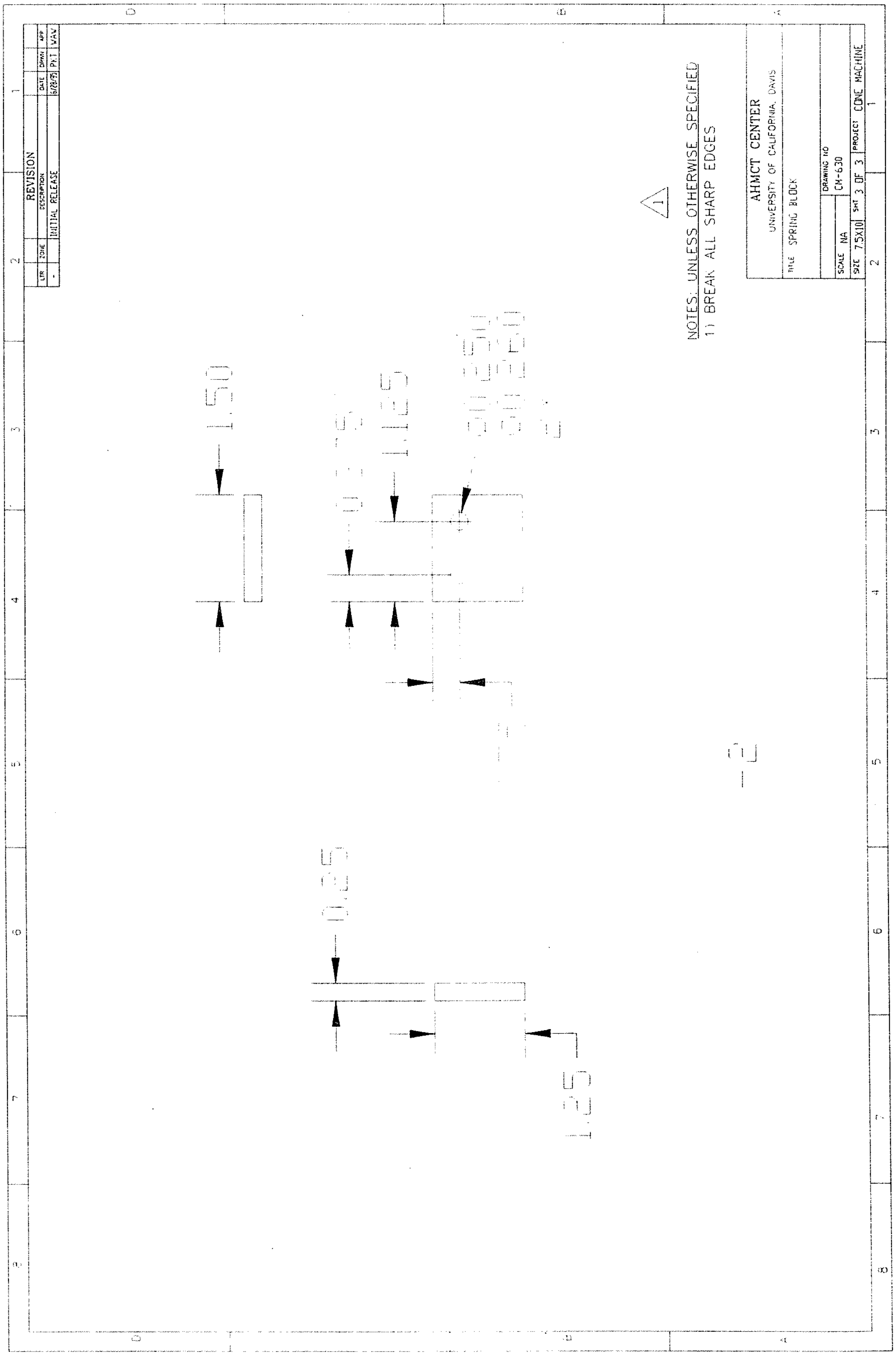

REVISION
LTR ZONE DESCRIPTION DATE DRWN APP
- INITIAL RELEASE 6/28/95 PY T WAW
1.485
1.495
0.25
-2
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
TITLE SPRING PLUNGER
DRAWING NO CM-628
SCALE NA
SIZE 7.5X10 SHT 3 OF 3 PROJECT CONE MACHINE


REVISION
INITIAL RELEASE
NOTES: UNLESS OTHERWISE SPECIFIED
1. BREAK ALL SHARP EDGES
2.25
0.25
1.940
1.158
0.375
Ø1.000 THRU
Ø0.250 THRU 4X
0.375
1.125
1018 STEEL
0.250 PLATE
PART LIST
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
SPRING PLATE
CM-629
CONE MACHINE
DESIGN PKT
DRAWN PKT
APPRV WAW
DATE 6/28/95
SCALE NA
SIZE 7.5X10
SHT 1 OF 1



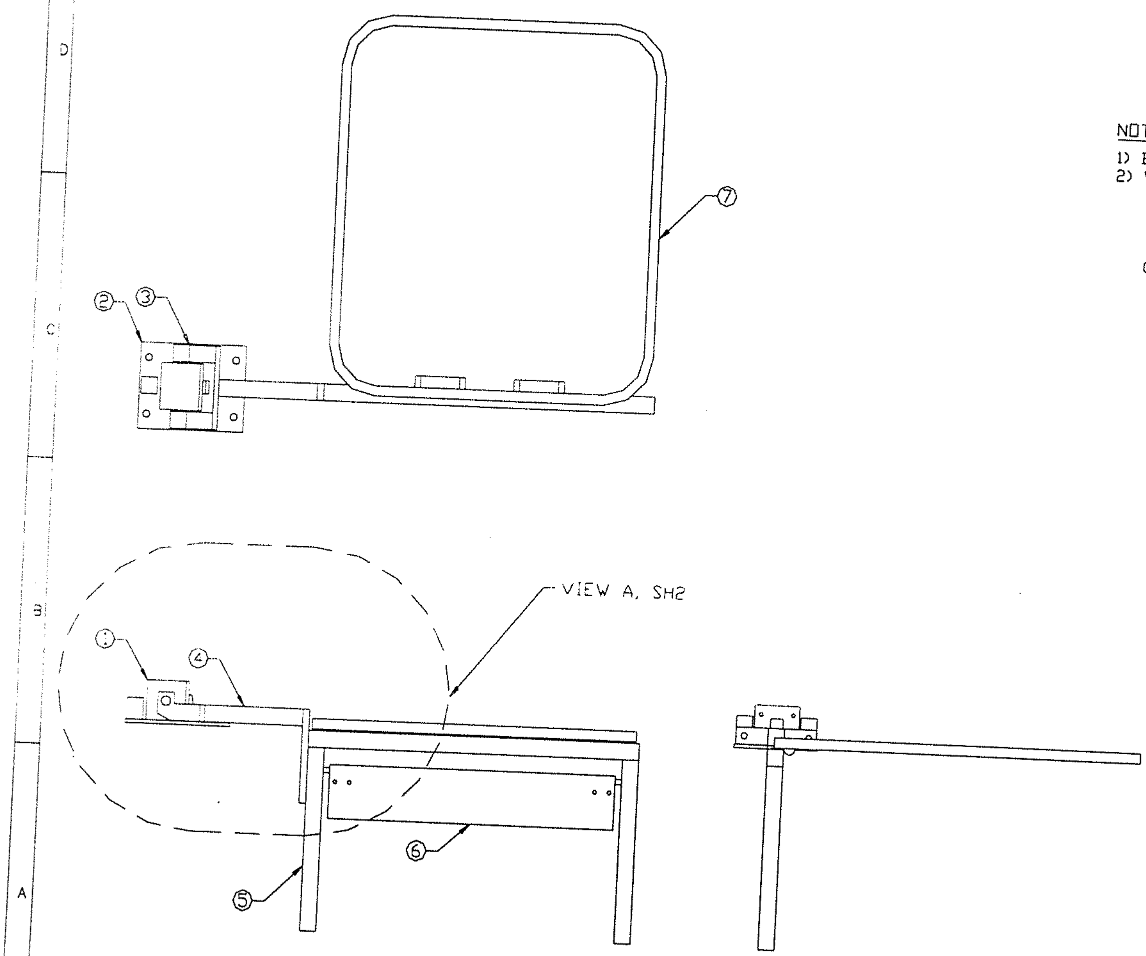
REVISION
LTR
ZONE
DESCRIPTION
DATE
DRWN
APP
INITIAL RELEASE
6/28/95
PKT
WAW
NOTES UNLESS OTHERWISE SPECIFIED
BREAK ALL SHARP EDGES
1018 STEEL
1018 STEEL
MATERIAL SPECIFICATION
150X2.25 RECTANGLE
NOMENCLATURE / DESCRIPTION
PART ID NO.
ITEM NO
QTY REQD
P A R T L I S T
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
TITLE SPRING BLOCK
UNLESS OTHERWISE NOTED TOLERANCES
±.002
±.0005
ANGLES ±0.5°
64
DESIGN PKT
DATE 6/28/95
DRAWN PKT
APPRV WAW
RELEASE
QTY 2
SCALE NA
DRAWING NO CM-630
SIZE 7.5X10
SHT 1 OF 3
PROJECT CONE MACHINE
2X
2X


REVISION
LTR
ZONE
DESCRIPTION
DATE
DRWN
APP
INITIAL RELEASE
5/28/95
PKT
WAV
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
TITLE SPRING BLOCK
DRAWING NO
CM-630
SCALE NA
SIZE 7.5X10
SHT 2 OF 3
PROJECT CONE MACHINE
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
2.25
1.50
3.19
Ø1.500
1.250-1.260 DEEP
0.250-20 UNC 2B
0.75 DEEP MIN
1.125


REVISION
LTR ZONE DESCRIPTION DATE DRWN APP
- INITIAL RELEASE 5/28/95 PKT VAV
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
TITLE SPRING BLOCK
DRAWING NO CM-630
SCALE NA
SIZE 7.5X10 SHT 3 OF 3
PROJECT CONE MACHINE
1.50
1.125
0.25
1.25

APPENDIX D
DETAILED DRAWINGS OF PRIMARY FUNNEL AND GATES

LIST OF DRAWINGS



REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
-		INITIAL RELEASE	11/4/95	SFC	WAV

NOTES: UNLESS OTHERWISE SPECIFIED

1) BREAK ALL SHARP EDGES
2) WELDS SHALL BE AS FOLLOWS
   A. V-GROOVE WELDS SHALL BE 1/4 IN SIZE WITH 60-90 DEG. GROOVE ANGLE GRIND FLUSH
   B. BEVEL GROOVE WELDS SHALL BE 3/16 IN SIZE WITH 45 GROOVE ANGLE
   C. ALL FILLET WELDS SHALL BE 1/4 IN SIZE

ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
8	CM-707	LINK C		1
7	CM-706	TIPPING BAR		1
6	CM-705	GATE		1
5	CM-704	FUNNEL		1
4	CM-703	LINK B		1
3	CM-702	LINK A		1
2	CM-701	BASE PLATE		2
1		REUTER-SOLLEM: ROT. ACTUATOR	NO. 25F-15-1V-0003	1

PART LIST

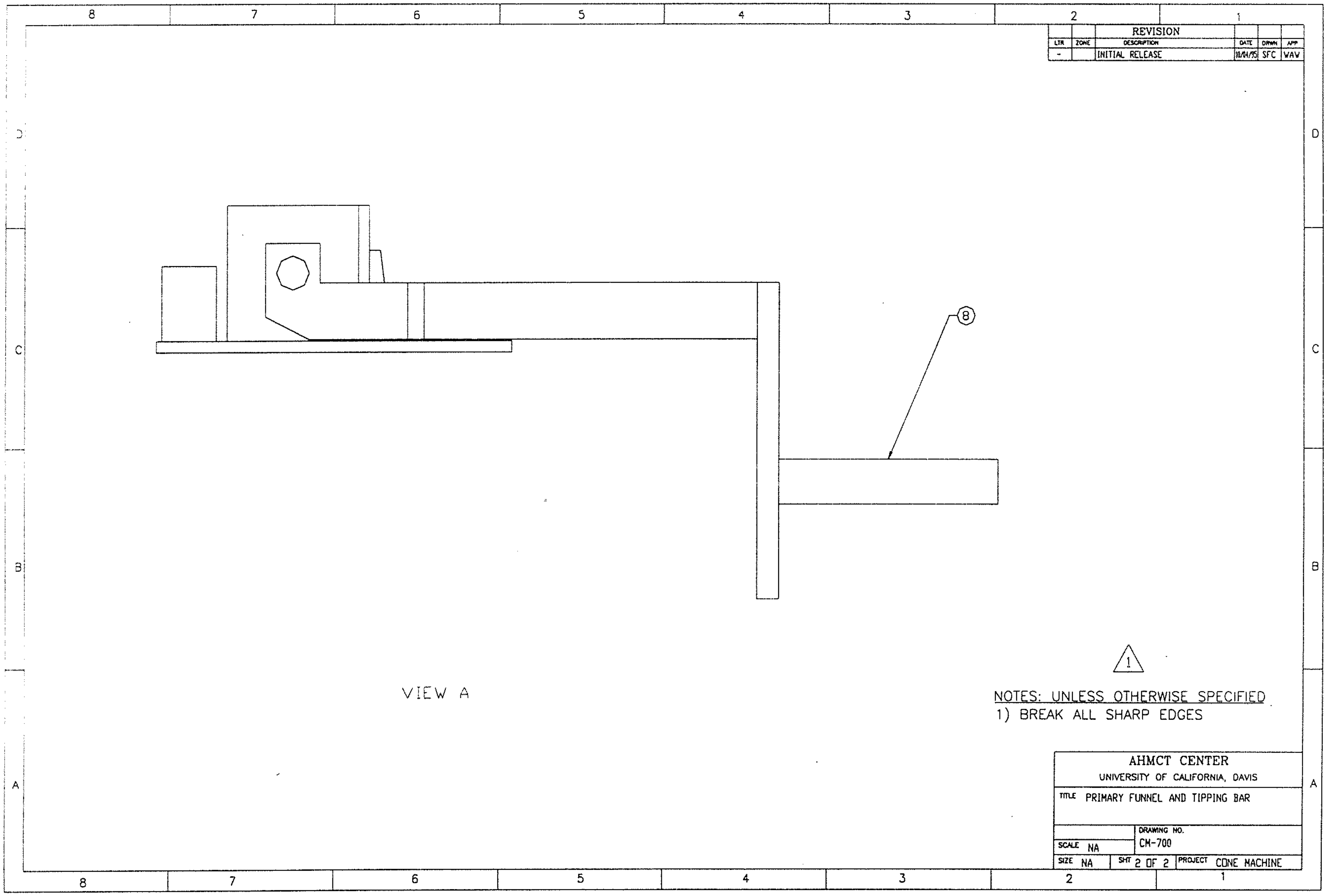
UNLESS OTHERWISE NOTED: TOLERANCES
.XX ±.02 ANGLES ±0.5°
.XXX ±.005
64

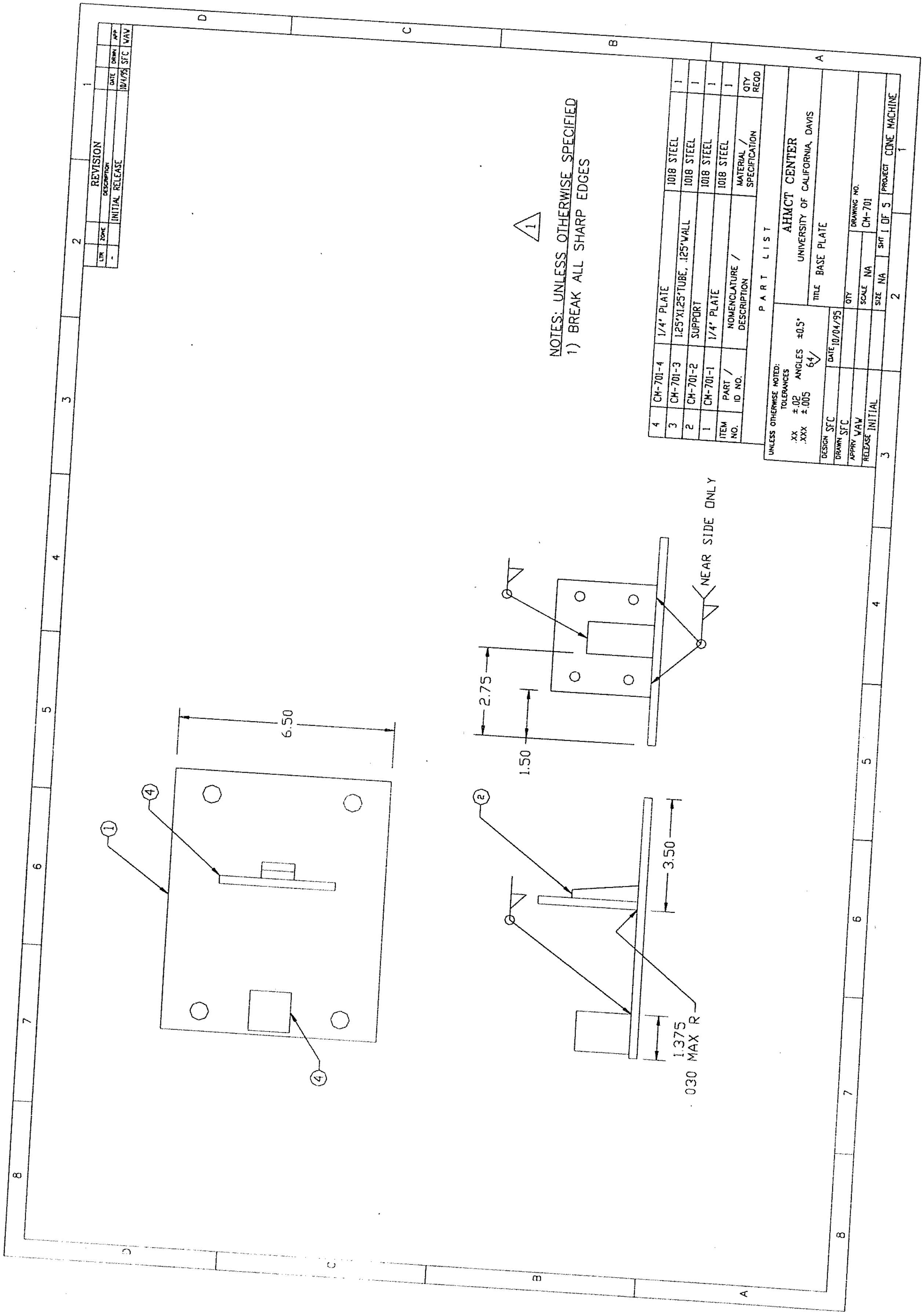
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS

TITLE PRIMARY FUNNEL AND TIPPING BAR

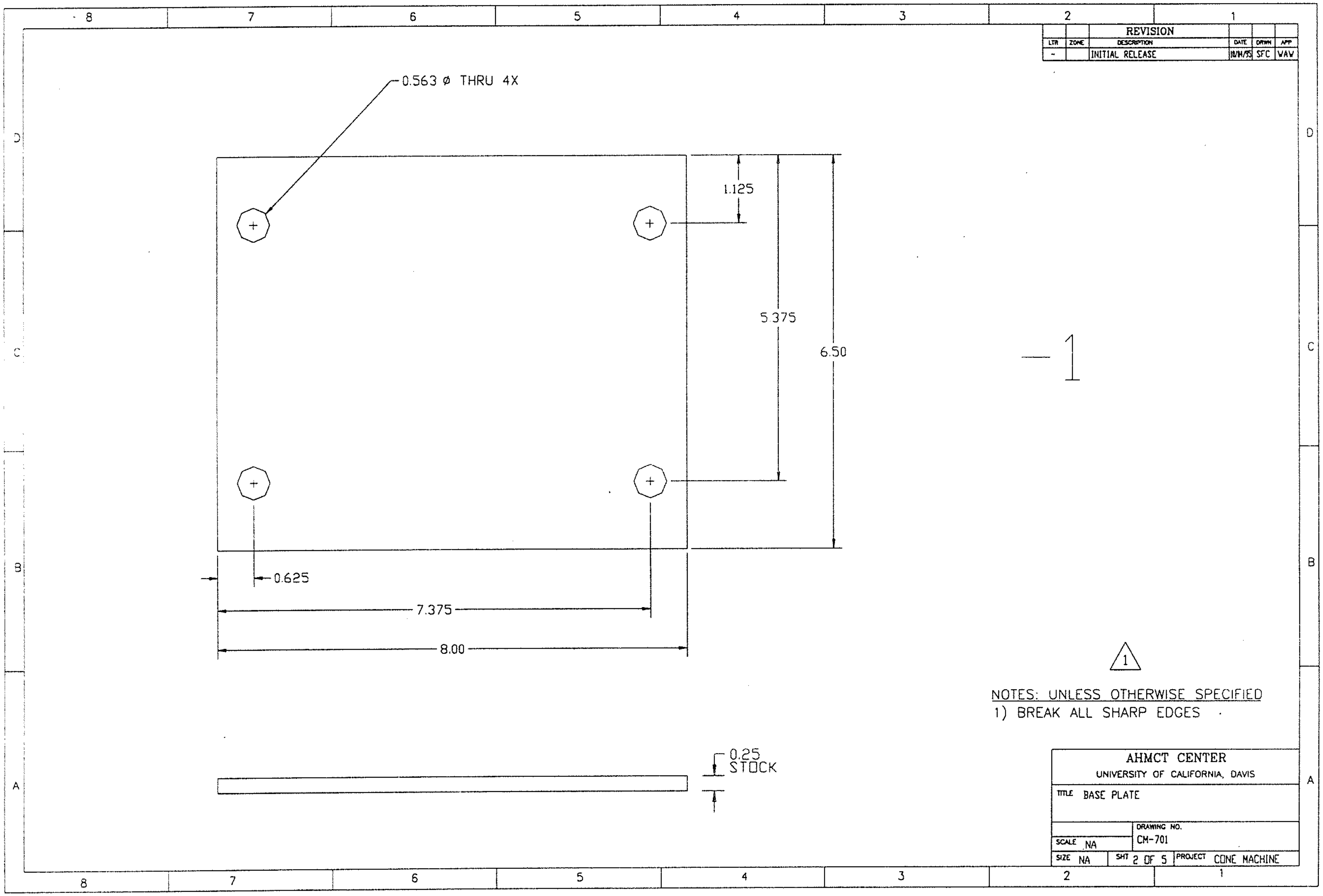
DESIGN SFC DATE 10/04/95
DRAWN SFC
APPRV WAV
RELEASE INITIAL

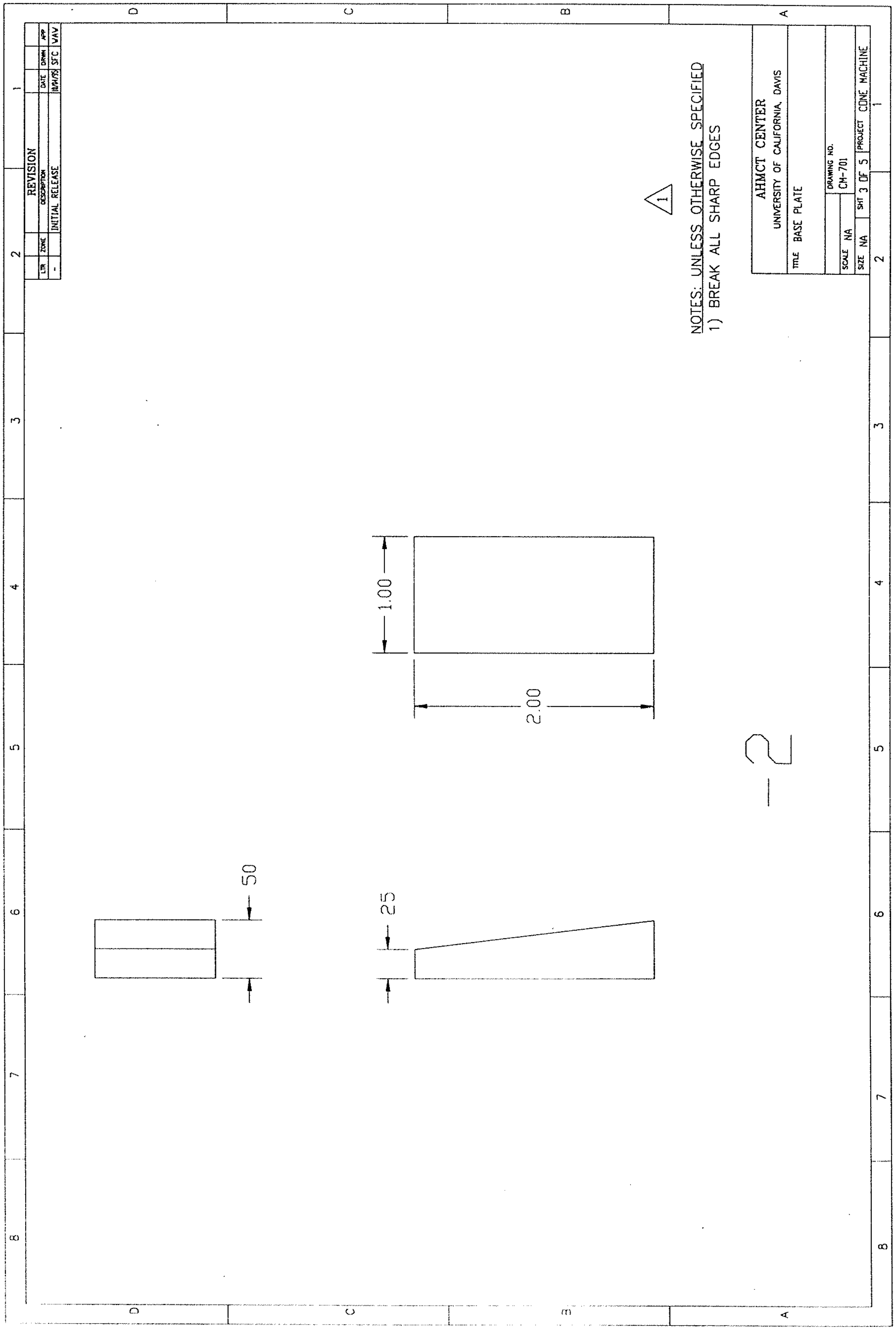
QTY 1
SCALE NA
SIZE NA SHT 1 OF 2
DRAWING NO. CM-700
PROJECT CONE MACHINE

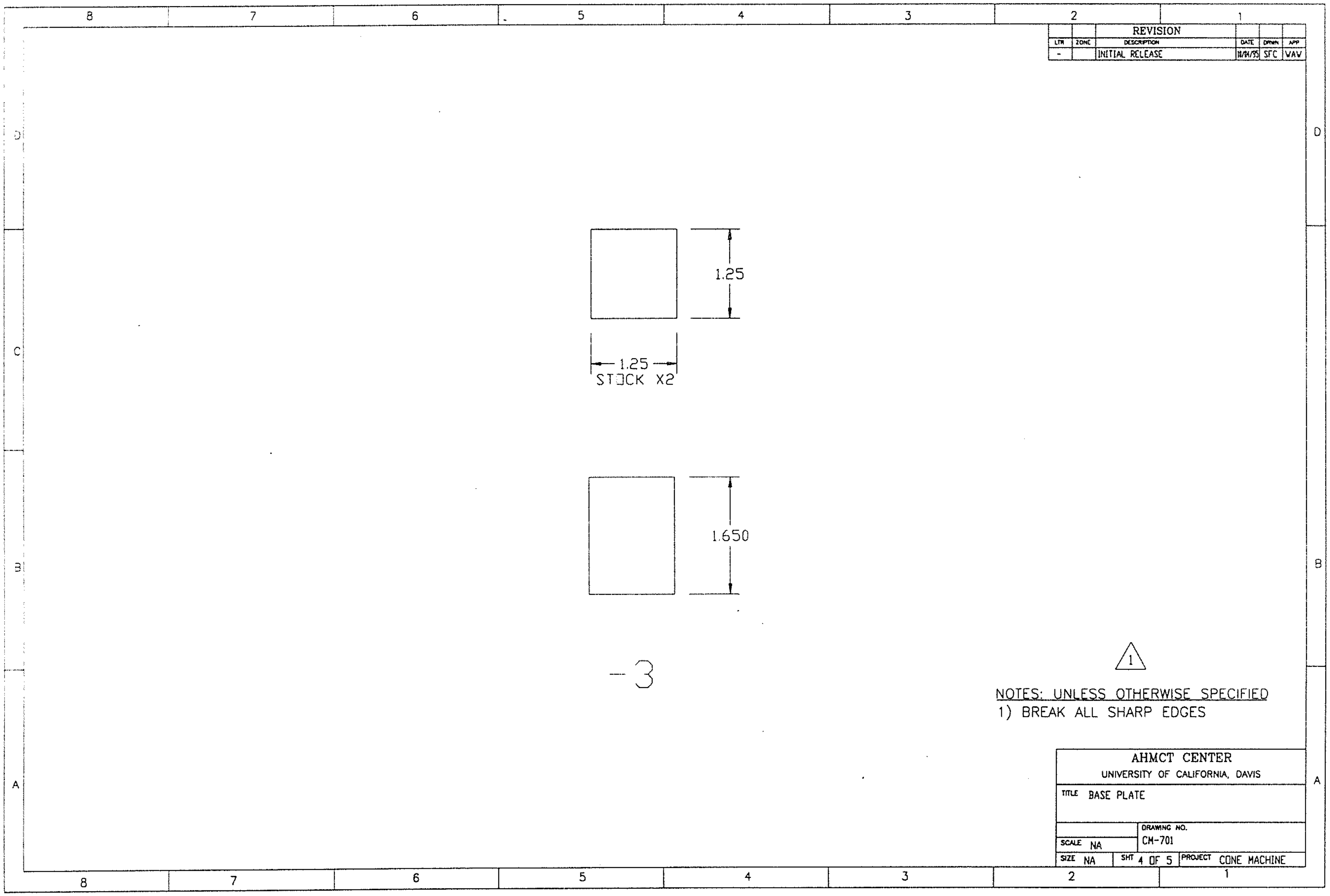

REVISION
LTR ZONE DESCRIPTION DATE DRWN APP
- INITIAL RELEASE SFC WAV
8
VIEW A
1
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
TITLE PRIMARY FUNNEL AND TIPPING BAR
DRAWING NO. CM-700
SCALE NA
SIZE NA
SHT 2 OF 2
PROJECT CONE MACHINE

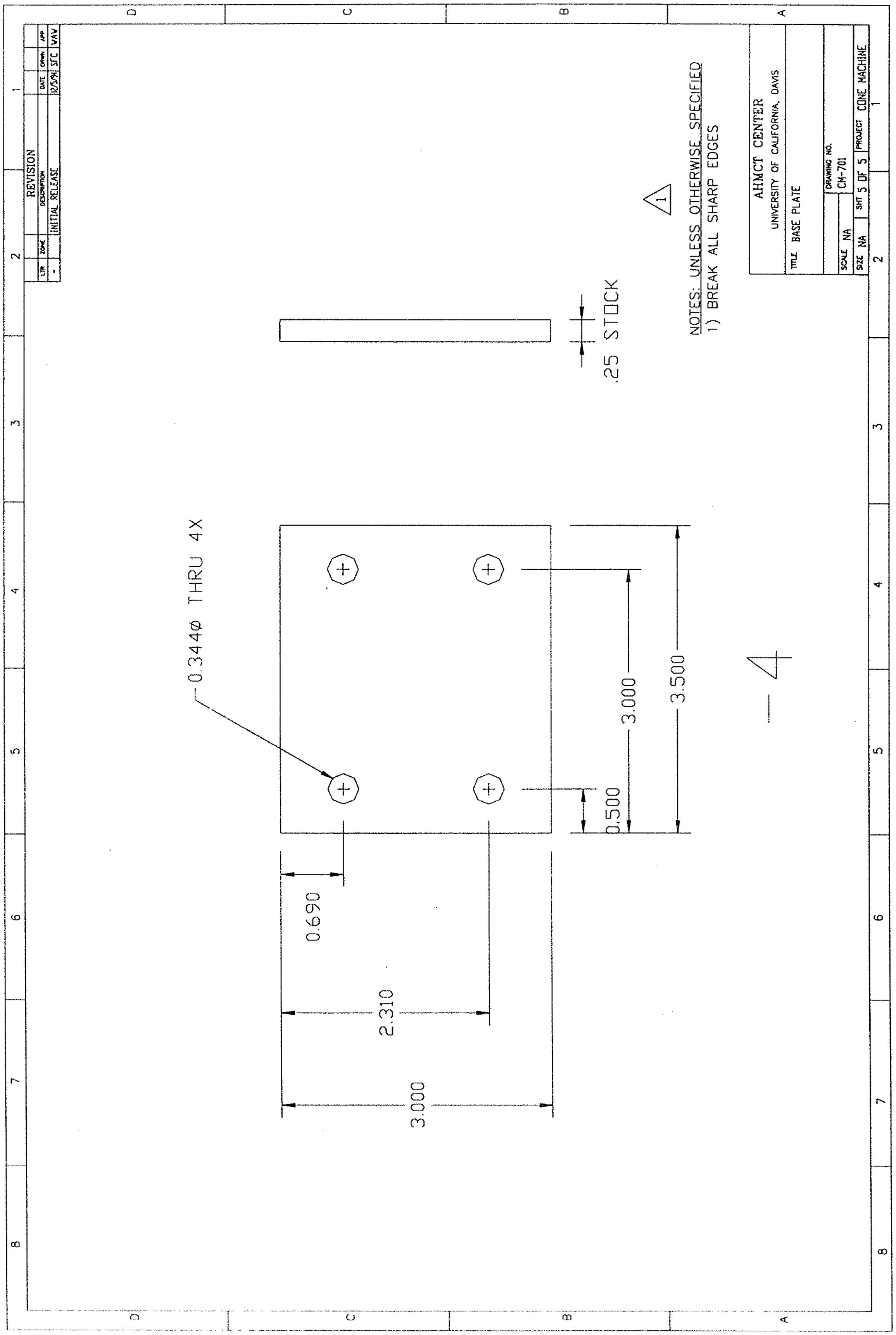


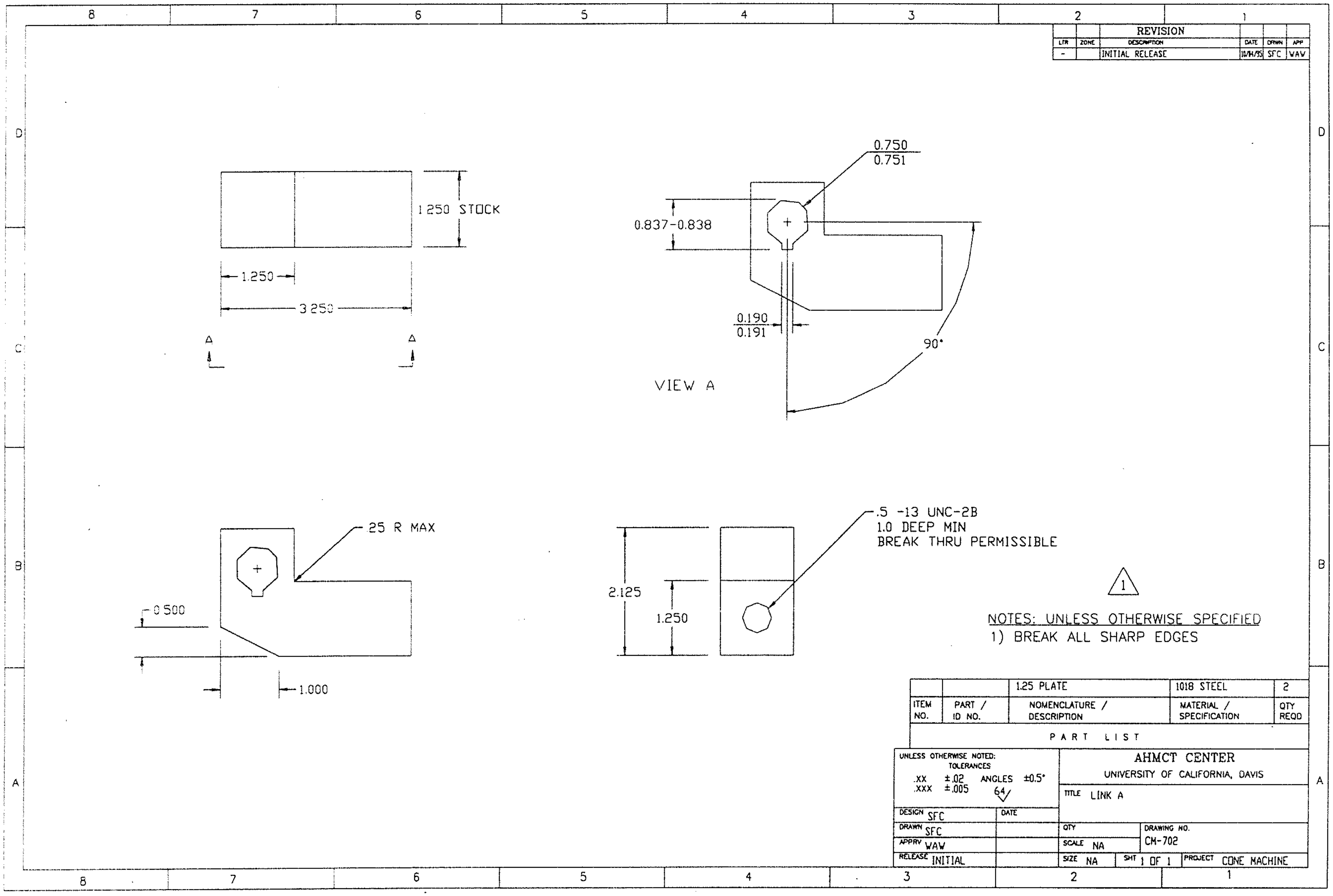
REVISION
LTR ZONE DESCRIPTION DATE DRAWN APP
- INITIAL RELEASE 10/4/95 SFC VAV
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
4 CM-701-4 1/4" PLATE 1018 STEEL 1
3 CM-701-3 1.25"X1.25"TUBE, .125"WALL 1018 STEEL 1
2 CM-701-2 SUPPORT 1018 STEEL 1
1 CM-701-1 1/4" PLATE 1018 STEEL 1
ITEM NO. PART / ID NO. NOMENCLATURE / DESCRIPTION MATERIAL / SPECIFICATION QTY REQD
PART LIST
UNLESS OTHERWISE NOTED: TOLERANCES
.XX ±.02 ANGLES ±0.5°
.XXX ±.005
DESIGN SFC DATE 10/04/95
DRAWN SFC
APPRV VAV
RELEASE INITIAL
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
TITLE BASE PLATE
QTY
SCALE NA
SIZE NA
DRAWING NO. CM-701
SHT 1 OF 5
PROJECT CONE MACHINE
6.50
2.75
1.50
3.50
1.375
.030 MAX R
NEAR SIDE ONLY

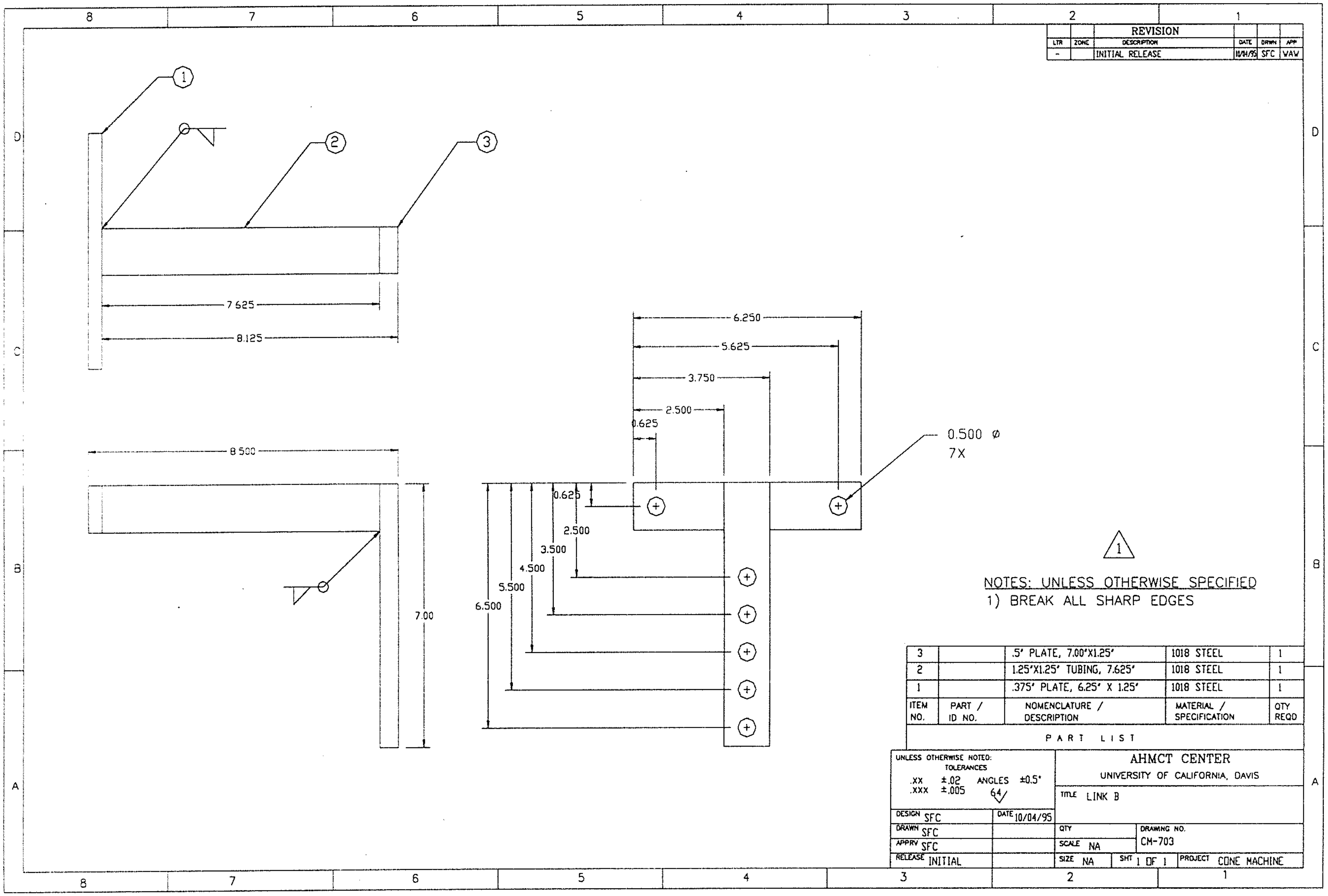

REVISION
LTR | ZONE | DESCRIPTION | DATE | DRWN | APP
- | | INITIAL RELEASE | 10/14/95 | SFC | WAV
0.563 ø THRU 4X
1.125
5.375
6.50
0.625
7.375
8.00
1
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
0.25 STOCK
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
TITLE BASE PLATE
DRAWING NO. CM-701
SCALE NA
SIZE NA
SHT 2 OF 5
PROJECT CONE MACHINE


REVISION
LTR
ZONE
DESCRIPTION
DATE
DRWN
APP
-
INITIAL RELEASE
SFC
VAV
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
TITLE BASE PLATE
DRAWING NO.
CM-701
SCALE NA
SIZE NA
SHT 3 OF 5
PROJECT CONE MACHINE
1.00
2.00
.50
.25
-2


REVISION
LTR | ZONE | DESCRIPTION | DATE | DRWN | APP
- | | INITIAL RELEASE | 11/14/95 | SFC | VAV
1.25
1.25
STOCK X2
1.650
-3
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
TITLE BASE PLATE
DRAWING NO. CM-701
SCALE NA
SIZE NA
SHT 4 OF 5
PROJECT CONE MACHINE

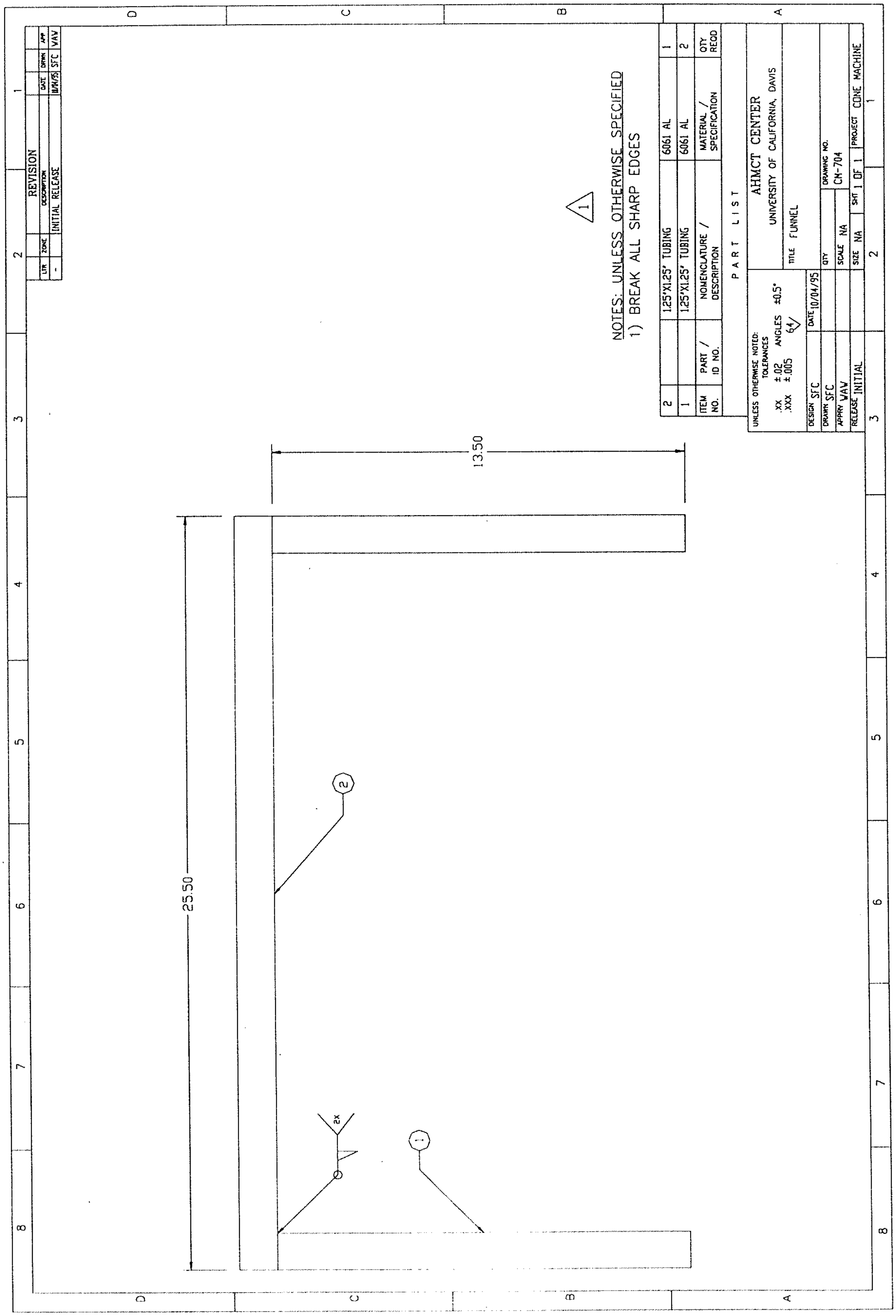

REVISION
LTR ZONE DESCRIPTION DATE DRWN APP
- INITIAL RELEASE 12/5/94 SFC VAV
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
.25 STOCK
0.344Ø THRU 4X
3.000
3.500
0.500
0.690
2.310
3.000
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
TITLE BASE PLATE
DRAWING NO. CM-701
SCALE NA
SIZE NA SHT 5 OF 5 PROJECT CONE MACHINE

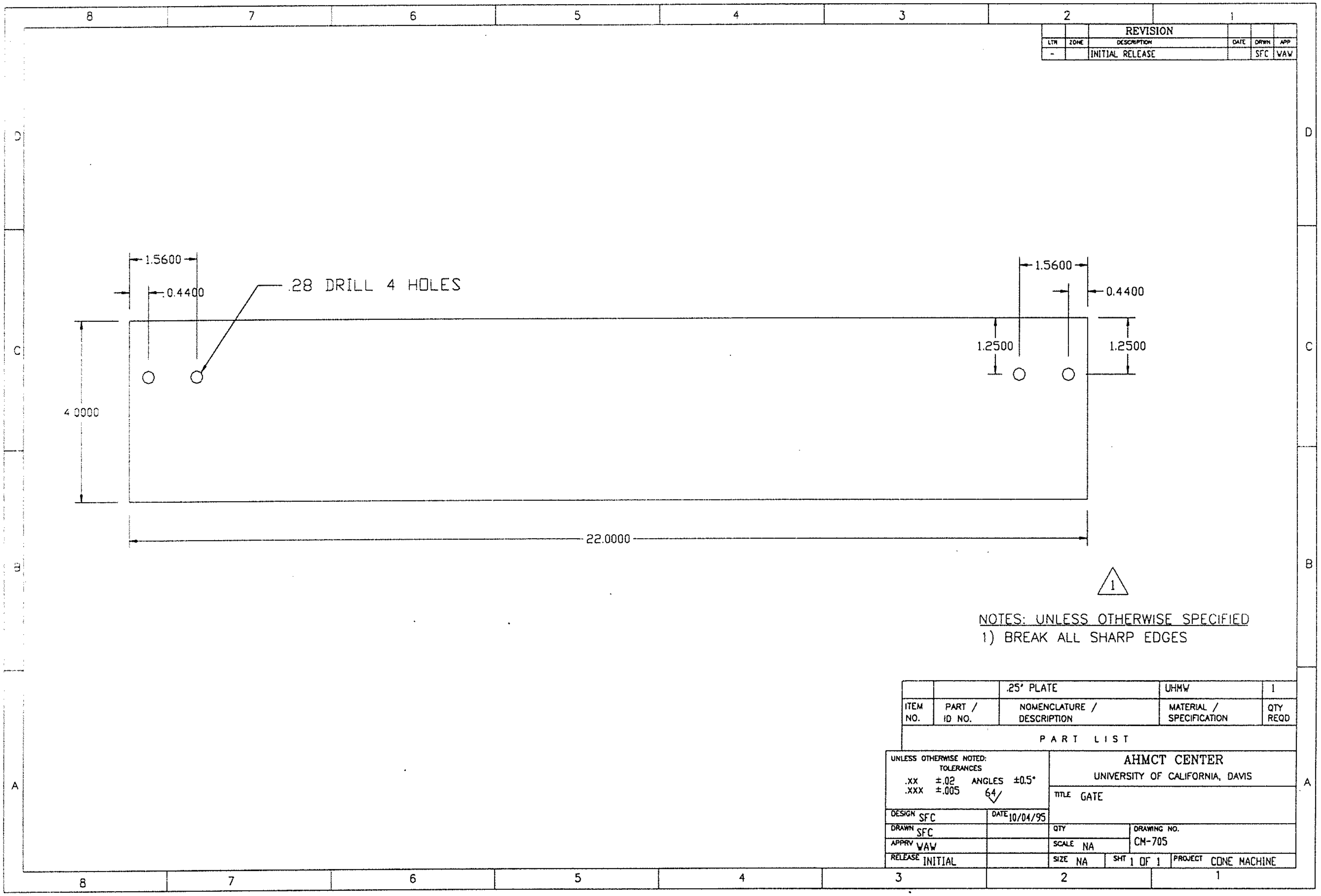

REVISION
LTR ZONE DESCRIPTION DATE DRWN APP
- INITIAL RELEASE 10/H/95 SFC WAV
1.250 STOCK
1.250
3.250
A
A
0.750
0.751
0.837-0.838
0.190
0.191
90°
VIEW A
25 R MAX
0.500
1.000
.5 -13 UNC-2B
1.0 DEEP MIN
BREAK THRU PERMISSIBLE
2.125
1.250
1
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
1.25 PLATE 1018 STEEL 2
ITEM NO. PART / ID NO. NOMENCLATURE / DESCRIPTION MATERIAL / SPECIFICATION QTY REQD
PART LIST
UNLESS OTHERWISE NOTED: TOLERANCES
.XX ±.02 ANGLES ±0.5°
.XXX ±.005
64
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
TITLE LINK A
DESIGN SFC
DATE
DRAWN SFC
APPRV WAW
RELEASE INITIAL
QTY
DRAWING NO. CM-702
SCALE NA
SIZE NA
SHT 1 OF 1
PROJECT CONE MACHINE



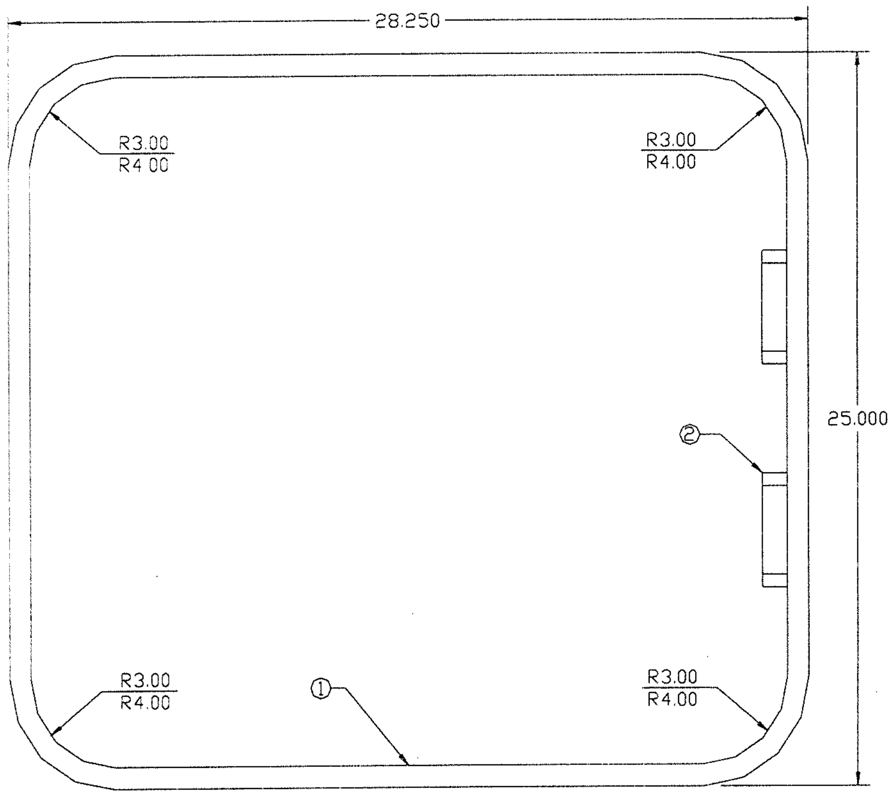
PART LIST

ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
3		.5' PLATE, 7.00'X1.25'	1018 STEEL	1
2		1.25'X1.25' TUBING, 7.625'	1018 STEEL	1
1		.375' PLATE, 6.25' X 1.25'	1018 STEEL	1


REVISION
LTR ZONE DESCRIPTION DATE DRWN APP
- INITIAL RELEASE 11/14/95 SFC VAV
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
1
13.50
25.50
2
1
2X
2 | 1.25"X1.25" TUBING | 6061 AL | 1
1 | 1.25"X1.25" TUBING | 6061 AL | 2
ITEM NO. | PART / ID NO. | NOMENCLATURE / DESCRIPTION | MATERIAL / SPECIFICATION | QTY REQD
PART LIST
UNLESS OTHERWISE NOTED: TOLERANCES
.XX ±.02 .XXX ±.005 ANGLES ±0.5°
64
DESIGN SFC
DRAWN SFC
APPRV VAV
RELEASE INITIAL
DATE 10/04/95
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
TITLE FUNNEL
QTY
SCALE NA
SIZE NA
SHT 1 OF 1
DRAWING NO. CM-704
PROJECT CONE MACHINE


REVISION
LTR ZONE DESCRIPTION DATE DRWN APP
- INITIAL RELEASE SFC VAW
1.5600
0.4400
.28 DRILL 4 HOLES
1.5600
0.4400
1.2500
1.2500
4.0000
22.0000
1
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
.25" PLATE
UHMW
1
ITEM NO.
PART / ID NO.
NOMENCLATURE / DESCRIPTION
MATERIAL / SPECIFICATION
QTY REQD
PART LIST
UNLESS OTHERWISE NOTED: TOLERANCES
.XX ±.02 ANGLES ±0.5°
.XXX ±.005
64
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
TITLE GATE
DESIGN SFC
DATE 10/04/95
DRAWN SFC
APPRV VAW
RELEASE INITIAL
QTY
SCALE NA
DRAWING NO. CM-705
SIZE NA
SHT 1 OF 1
PROJECT CONE MACHINE

REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
-		INITIAL RELEASE	10/14/95	JPS	VAV

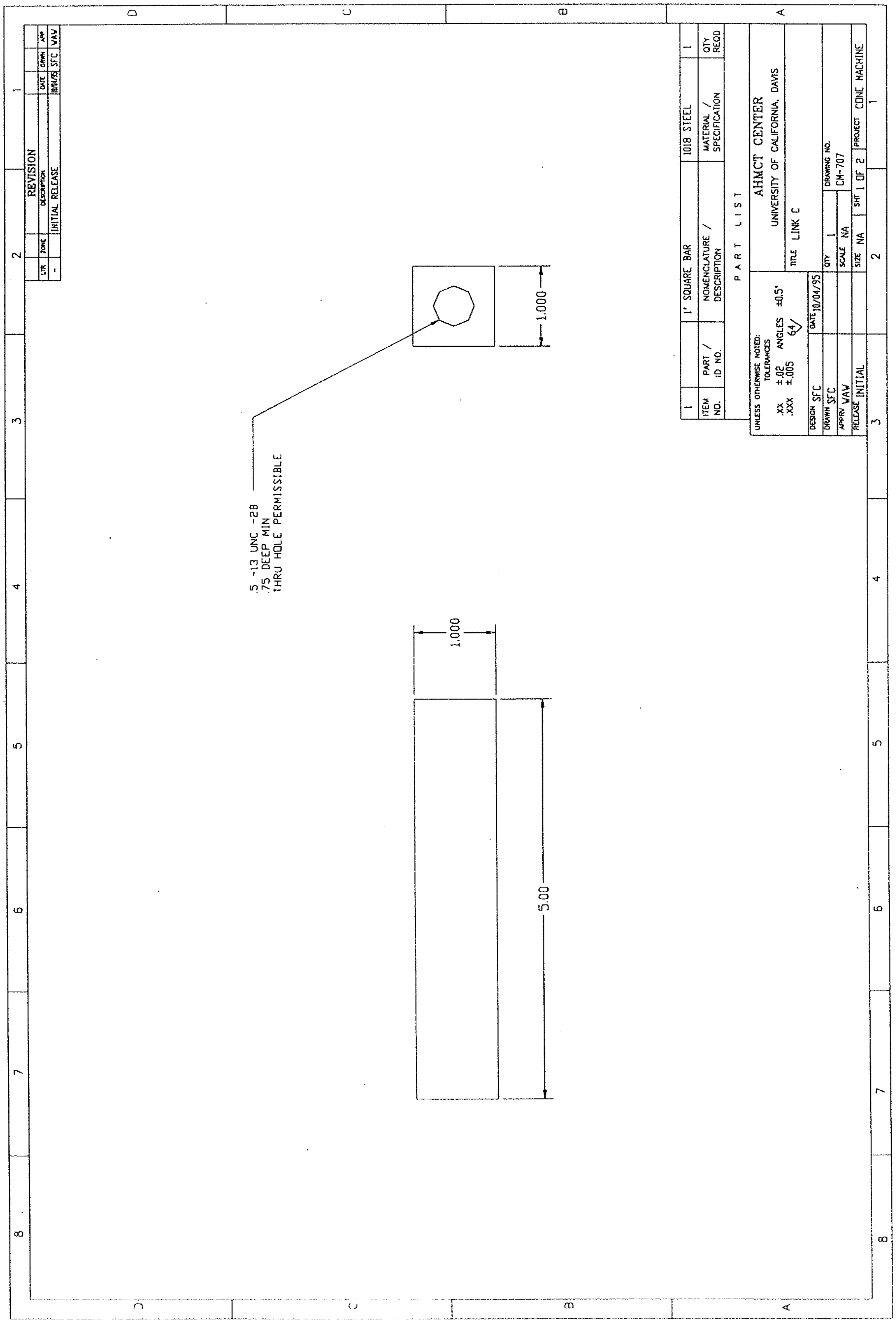


NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES

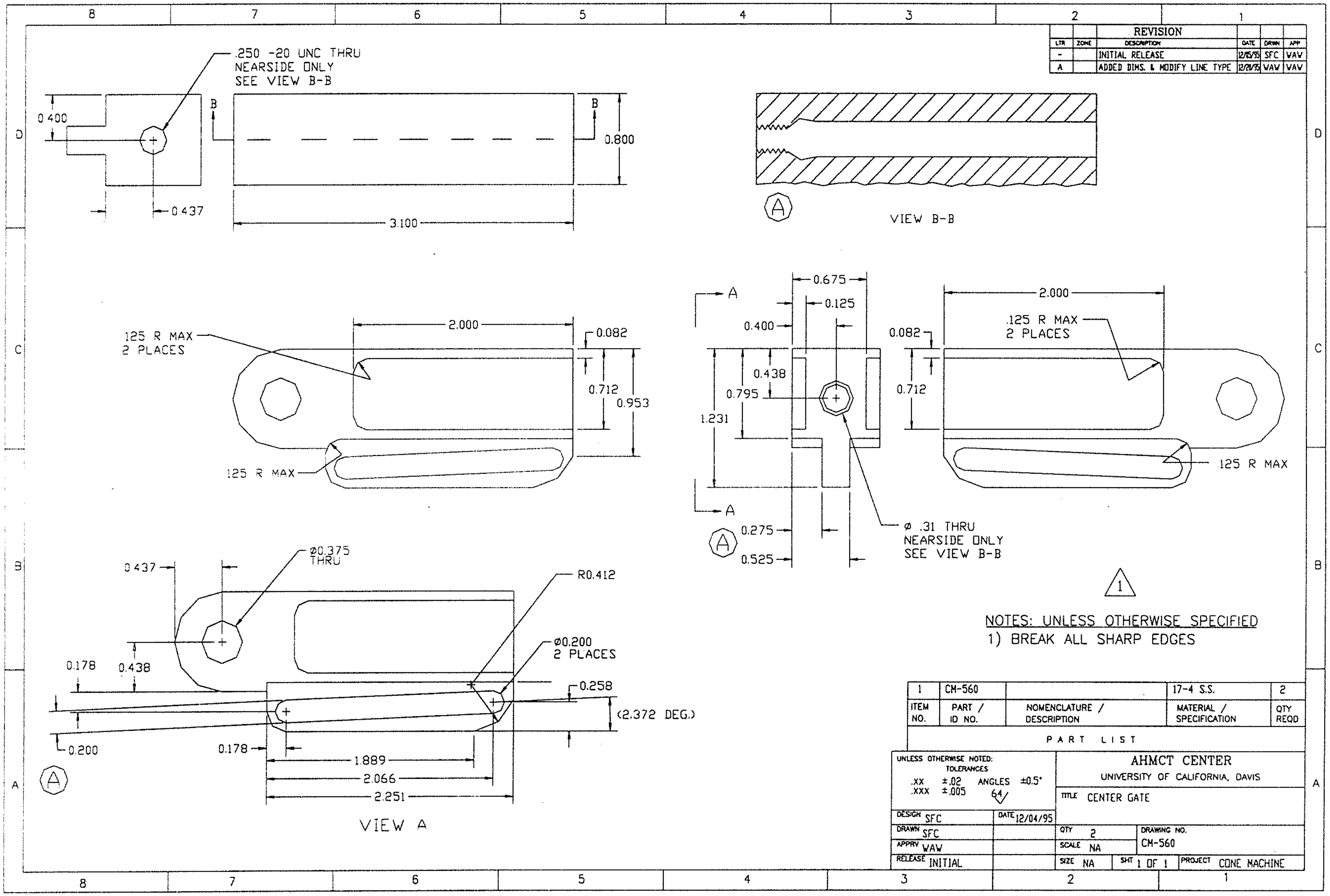
ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
2		SPRING HING BY McMASTER CARR	STEEL	2
1		3/4" TUBING	6063 AL	1

PART LIST

UNLESS OTHERWISE NOTED: TOLERANCES .XX ±.02 .XXX ±.005 ANGLES ±0.5° 64	AHMCT CENTER UNIVERSITY OF CALIFORNIA, DAVIS
DESIGN SFC DATE 10/04/95	TITLE TIPPING BAR
DRAWN SFC	QTY 1 DRAWING NO. CM-706
APPRV WAW	SCALE NA
RELEASE INITIAL	SIZE NA SHT 1 OF 1 PROJECT CONE MACHINE



REVISION
LTR ZONE DESCRIPTION DATE DRWN APP
- INITIAL RELEASE 10/04/95 SFC VAV
1.000
.5 -13 UNC -2B
.75 DEEP MIN
THRU HOLE PERMISSIBLE
1.000
5.00
1 1" SQUARE BAR 1018 STEEL 1
ITEM NO. PART / ID NO. NOMENCLATURE / DESCRIPTION MATERIAL / SPECIFICATION QTY REQD
PART LIST
UNLESS OTHERWISE NOTED: TOLERANCES
.XX ±.02 ANGLES ±0.5°
.XXX ±.005
64
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
TITLE LINK C
DESIGN SFC DATE 10/04/95
DRAWN SFC
APPRV VAV
RELEASE INITIAL
QTY 1
SCALE NA
SIZE NA
SHT 1 OF 2
DRAWING NO. CM-707
PROJECT CONE MACHINE



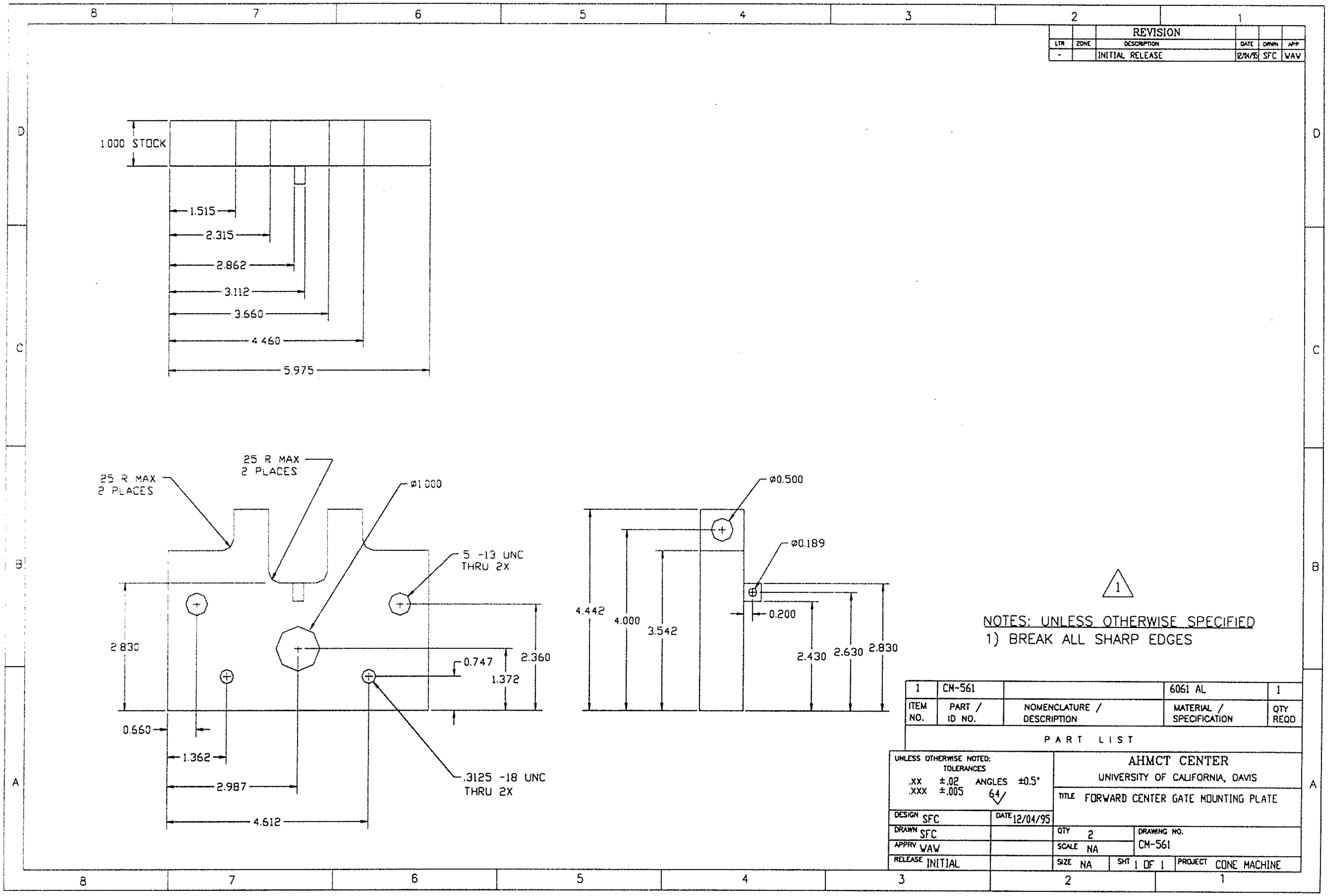
REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
-		INITIAL RELEASE	12/15/95	SFC	VAV
A		ADDED DIMS. & MODIFY LINE TYPE	12/28/95	VAV	VAV

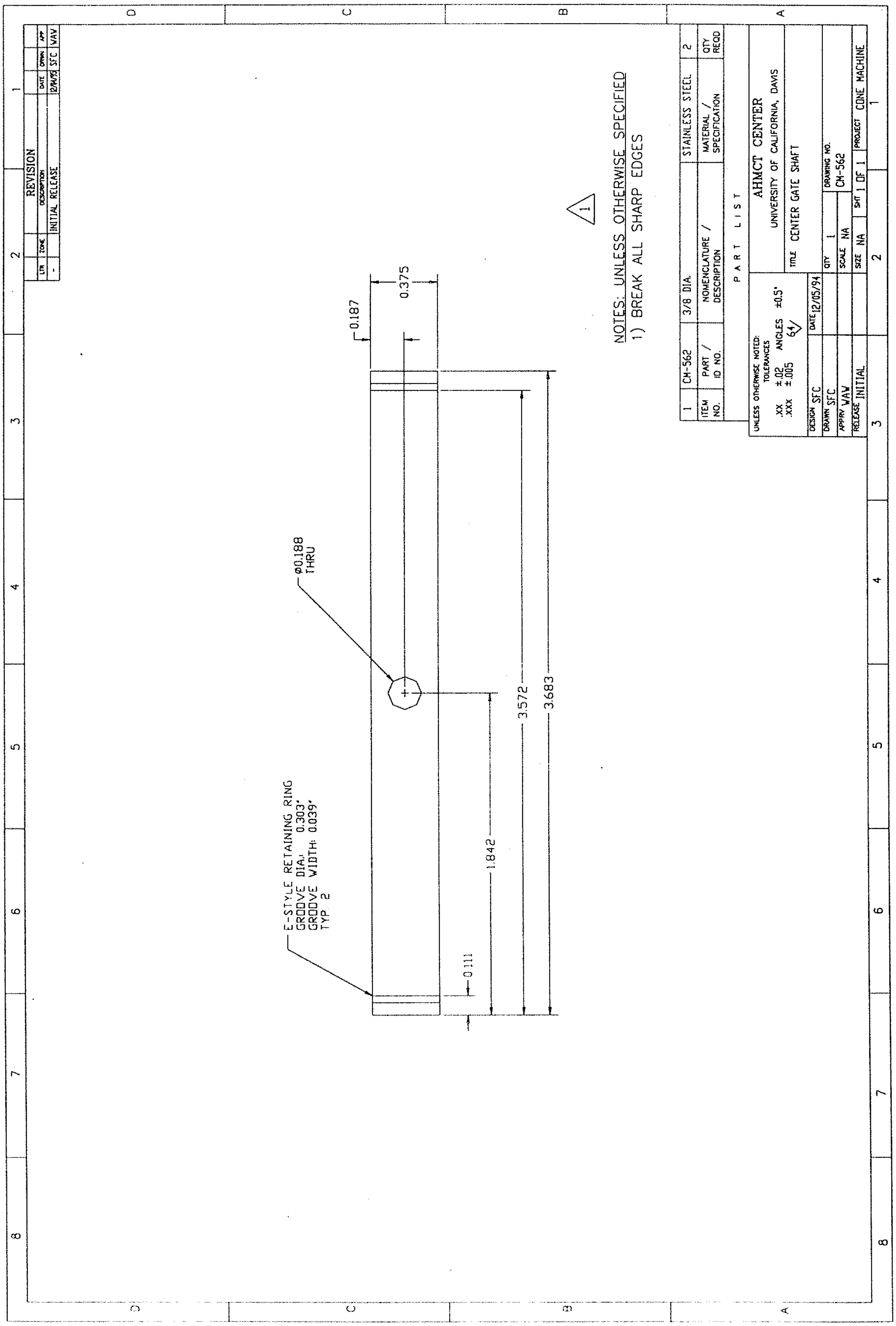
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES

ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
1	CM-560		17-4 S.S.	2

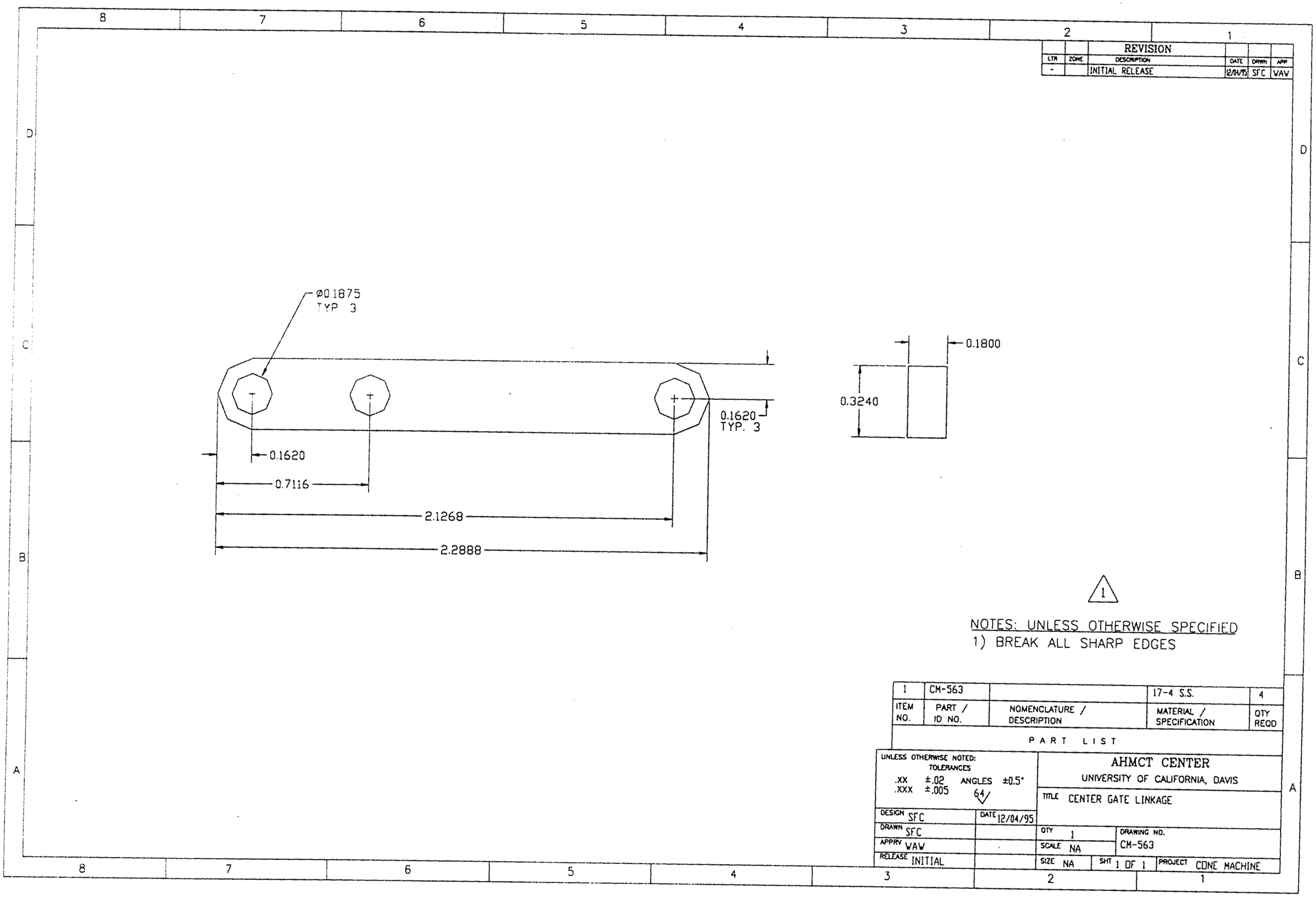
PART LIST

UNLESS OTHERWISE NOTED: TOLERANCES .XX ±.02 .XXX ±.005 ANGLES ±0.5° 64	AHMCT CENTER UNIVERSITY OF CALIFORNIA, DAVIS
	TITLE CENTER GATE
DESIGN SFC / DATE 12/04/95	
DRAWN SFC	QTY 2 / DRAWING NO. CM-560
APPRV VAW	SCALE NA
RELEASE INITIAL	SIZE NA / SHT 1 OF 1 / PROJECT CONE MACHINE

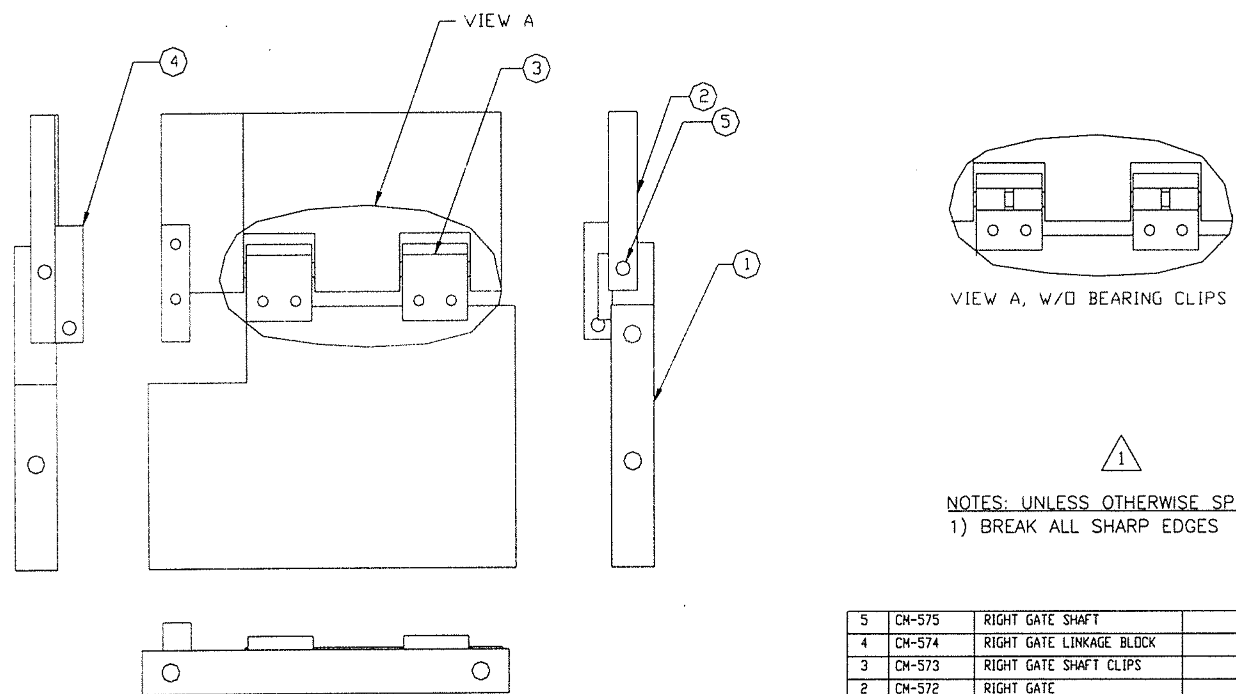

REVISION
LTR ZONE DESCRIPTION DATE DRWN APP
- INITIAL RELEASE 12/04/95 SFC WAV
1.000 STOCK
1.515
2.315
2.862
3.112
3.660
4.460
5.975
.25 R MAX 2 PLACES
.25 R MAX 2 PLACES
⌀1.000
.5 -13 UNC THRU 2X
2.830
0.747
1.372
2.360
0.660
1.362
2.987
4.612
.3125 -18 UNC THRU 2X
⌀0.500
⌀0.189
4.442
4.000
3.542
0.200
2.430
2.630
2.830
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
1 CM-561 6061 AL 1
ITEM NO. PART / ID NO. NOMENCLATURE / DESCRIPTION MATERIAL / SPECIFICATION QTY REQD
PART LIST
UNLESS OTHERWISE NOTED: TOLERANCES .XX ±.02 .XXX ±.005 ANGLES ±0.5°
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
TITLE FORWARD CENTER GATE MOUNTING PLATE
DESIGN SFC DATE 12/04/95
DRAWN SFC
APPRV WAV
RELEASE INITIAL
QTY 2
SCALE NA
DRAWING NO. CM-561
SIZE NA SHT 1 OF 1 PROJECT CONE MACHINE



REVISION
LTR ZONE DESCRIPTION DATE DRWN APP
- - INITIAL RELEASE 12/14/94 SFC WAV
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
1
0.375
0.187
ø0.188 THRU
3.572
3.683
1.842
0.111
E-STYLE RETAINING RING
GROOVE DIA.: 0.303"
GROOVE WIDTH: 0.039"
TYP 2
1 CM-562 3/8 DIA. STAINLESS STEEL 2
ITEM NO. PART / ID NO. NOMENCLATURE / DESCRIPTION MATERIAL / SPECIFICATION QTY REQD
PART LIST
UNLESS OTHERWISE NOTED: TOLERANCES
.XX ±.02 ANGLES ±0.5°
.XXX ±.005
64
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
DESIGN SFC DATE 12/05/94
DRAWN SFC
APPRV WAV
RELEASE INITIAL
TITLE CENTER GATE SHAFT
QTY 1
SCALE NA
SIZE NA
SHT 1 OF 1
DRAWING NO. CM-562
PROJECT CONE MACHINE



REVISION
LTR ZONE DESCRIPTION DATE DRWN APP
- INITIAL RELEASE 12/04/95 SFC WAV
Ø0.1875 TYP 3
0.1800
0.3240
0.1620 TYP. 3
0.1620
0.7116
2.1268
2.2888
1
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
1 CM-563 17-4 S.S. 4
ITEM NO. PART / ID NO. NOMENCLATURE / DESCRIPTION MATERIAL / SPECIFICATION QTY REQD
PART LIST
UNLESS OTHERWISE NOTED: TOLERANCES
.XX ±.02 ANGLES ±0.5°
.XXX ±.005
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
TITLE CENTER GATE LINKAGE
DESIGN SFC DATE 12/04/95
DRAWN SFC
APPRV WAV
RELEASE INITIAL
QTY 1 DRAWING NO. CM-563
SCALE NA
SIZE NA SHT 1 OF 1 PROJECT CONE MACHINE



REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
-		INITIAL RELEASE	06/11/96	SFC	WAV

NOTES: UNLESS OTHERWISE SPECIFIED

1) BREAK ALL SHARP EDGES

ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
5	CM-575	RIGHT GATE SHAFT		1
4	CM-574	RIGHT GATE LINKAGE BLOCK		1
3	CM-573	RIGHT GATE SHAFT CLIPS		2
2	CM-572	RIGHT GATE		1
1	CM-571	RIGHT BASE PLATE		1

PART LIST

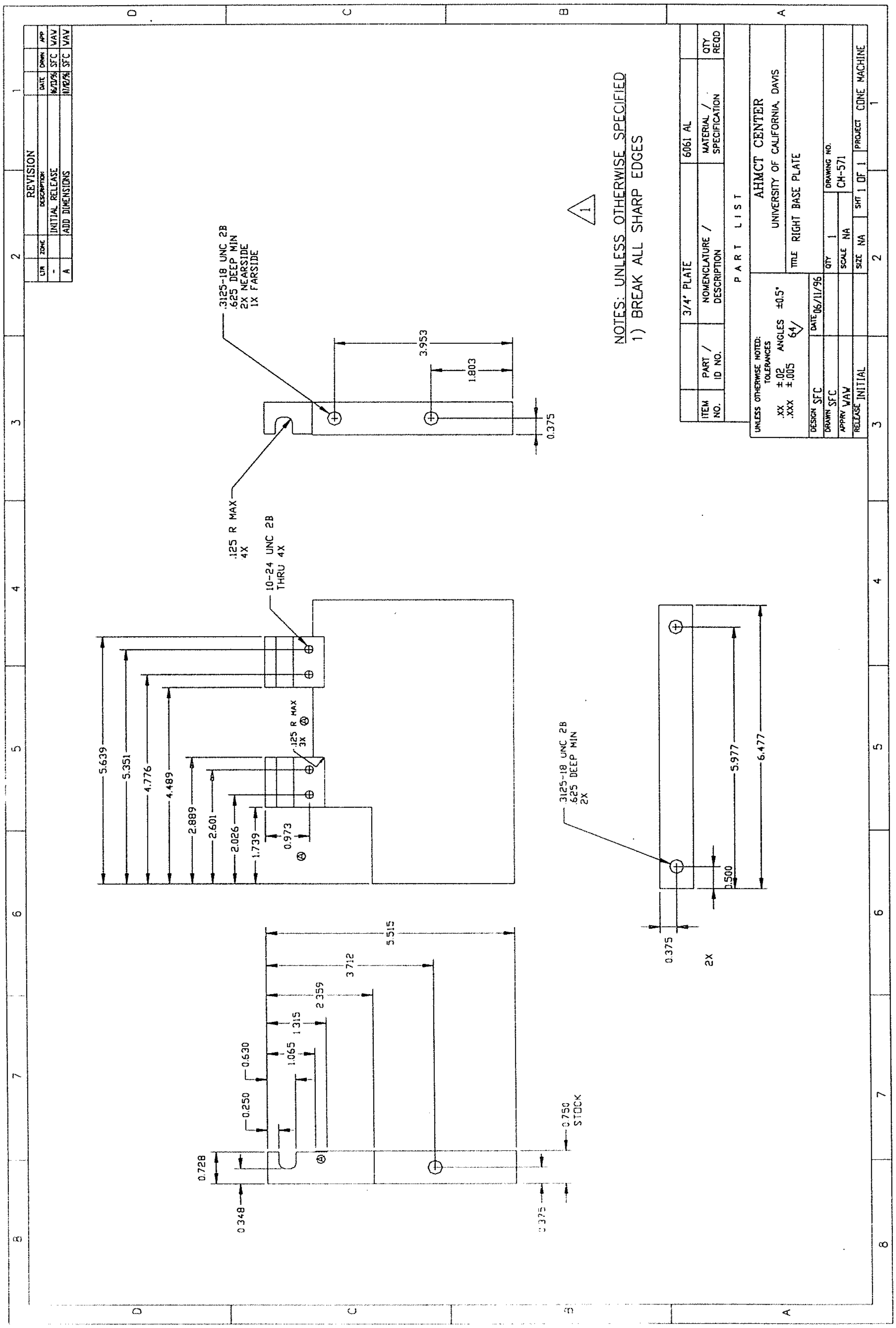
UNLESS OTHERWISE NOTED: TOLERANCES
.XX ±.005 ANGLES ±0.5°
.XXX ±.02 64√

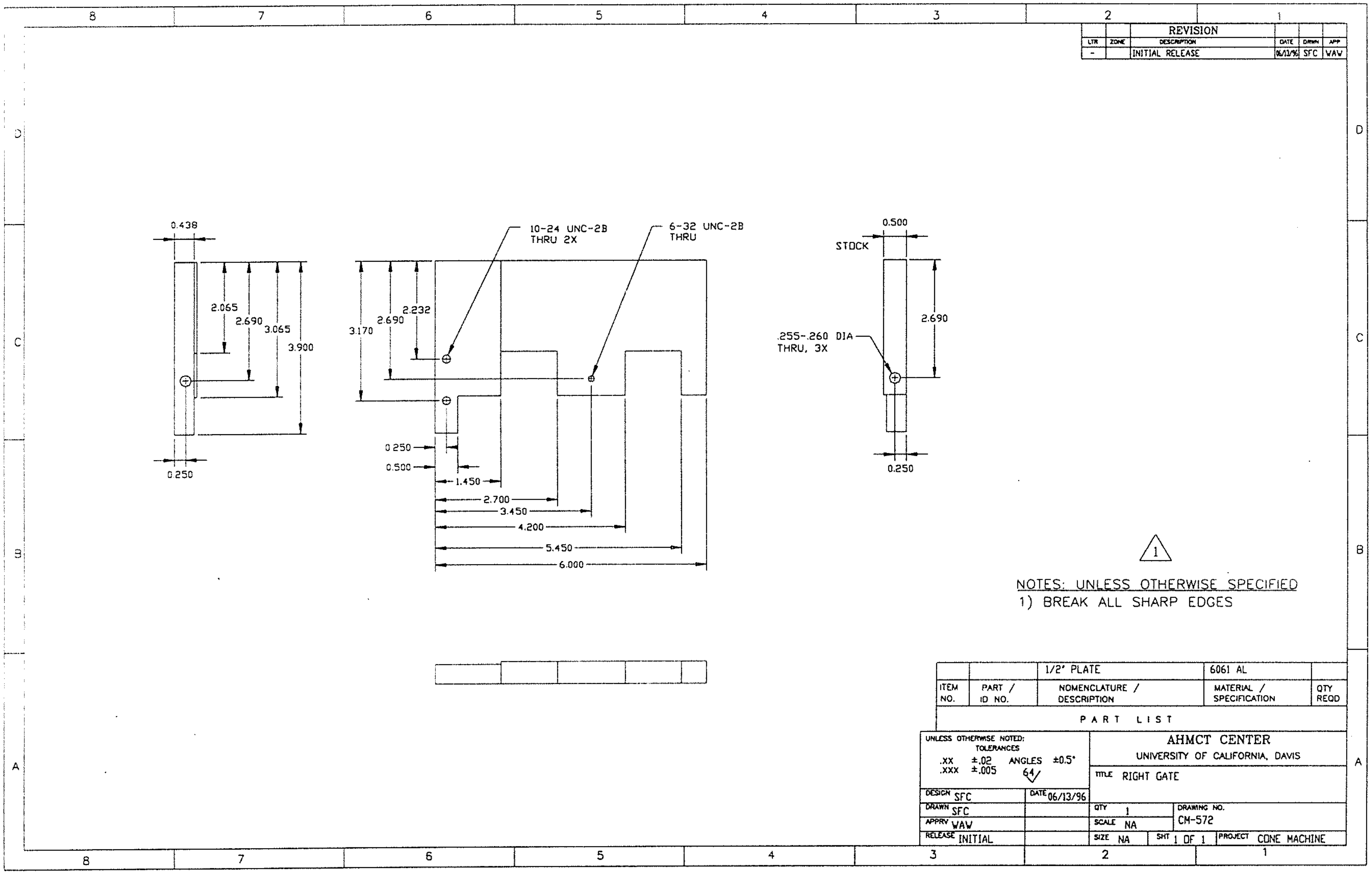
DESIGN SFC DATE 06/11/96
DRAWN SFC
APPRV WAV
RELEASE INITIAL

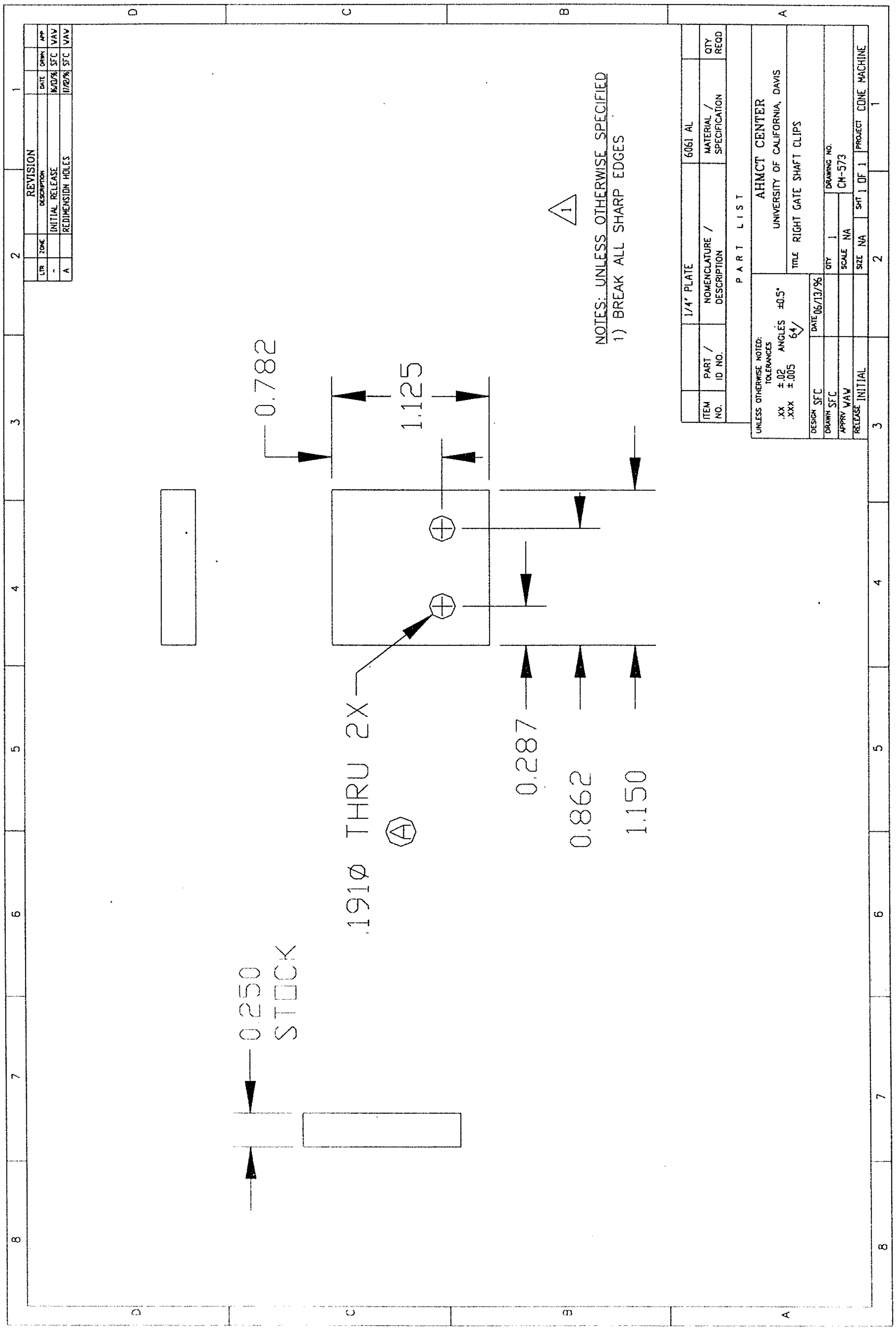
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS

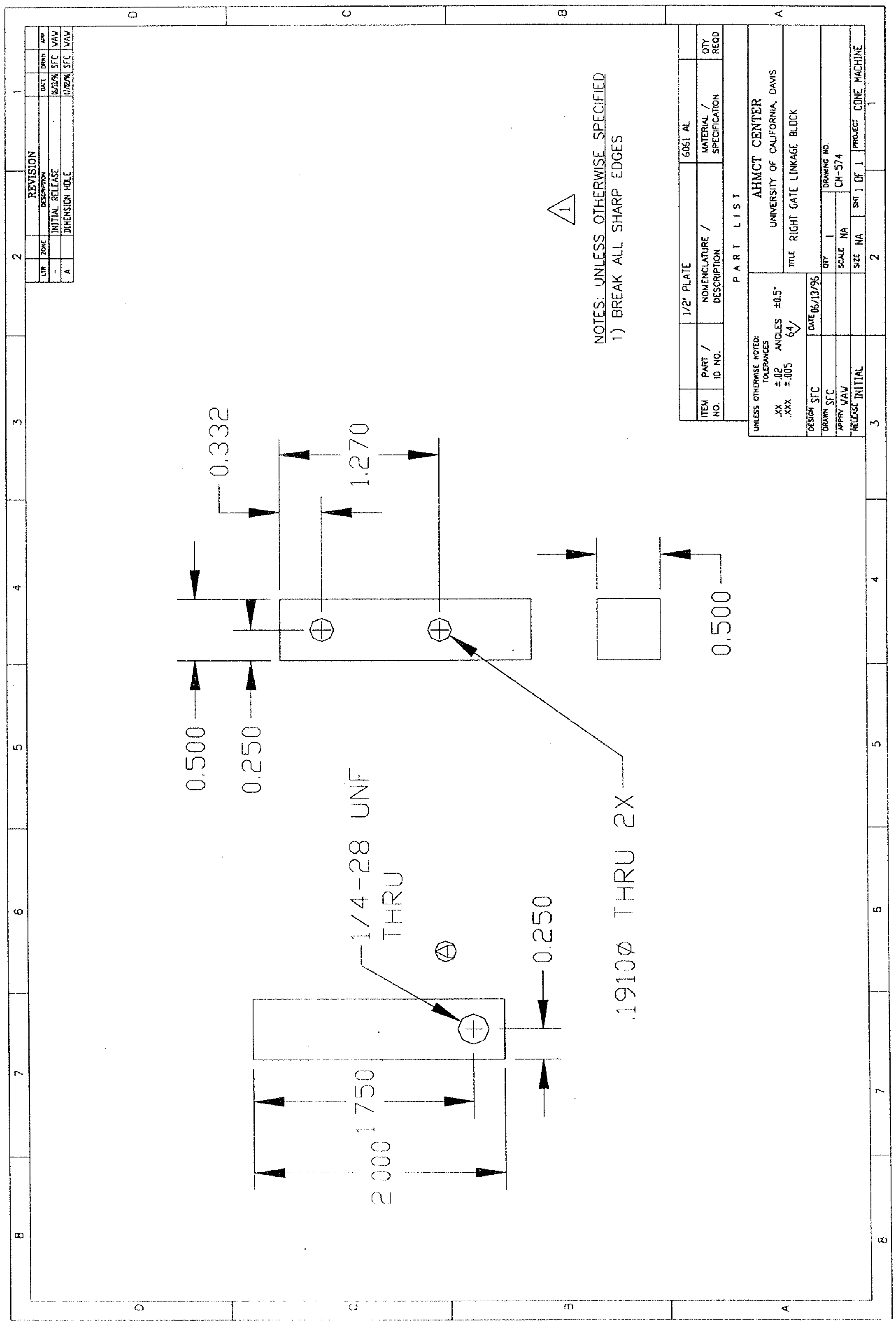
TITLE RIGHT GATE ASSEMBLY

QTY 1 DRAWING NO. CM-570
SCALE NA
SIZE NA SHT 1 OF 1 PROJECT CONE MACHINE

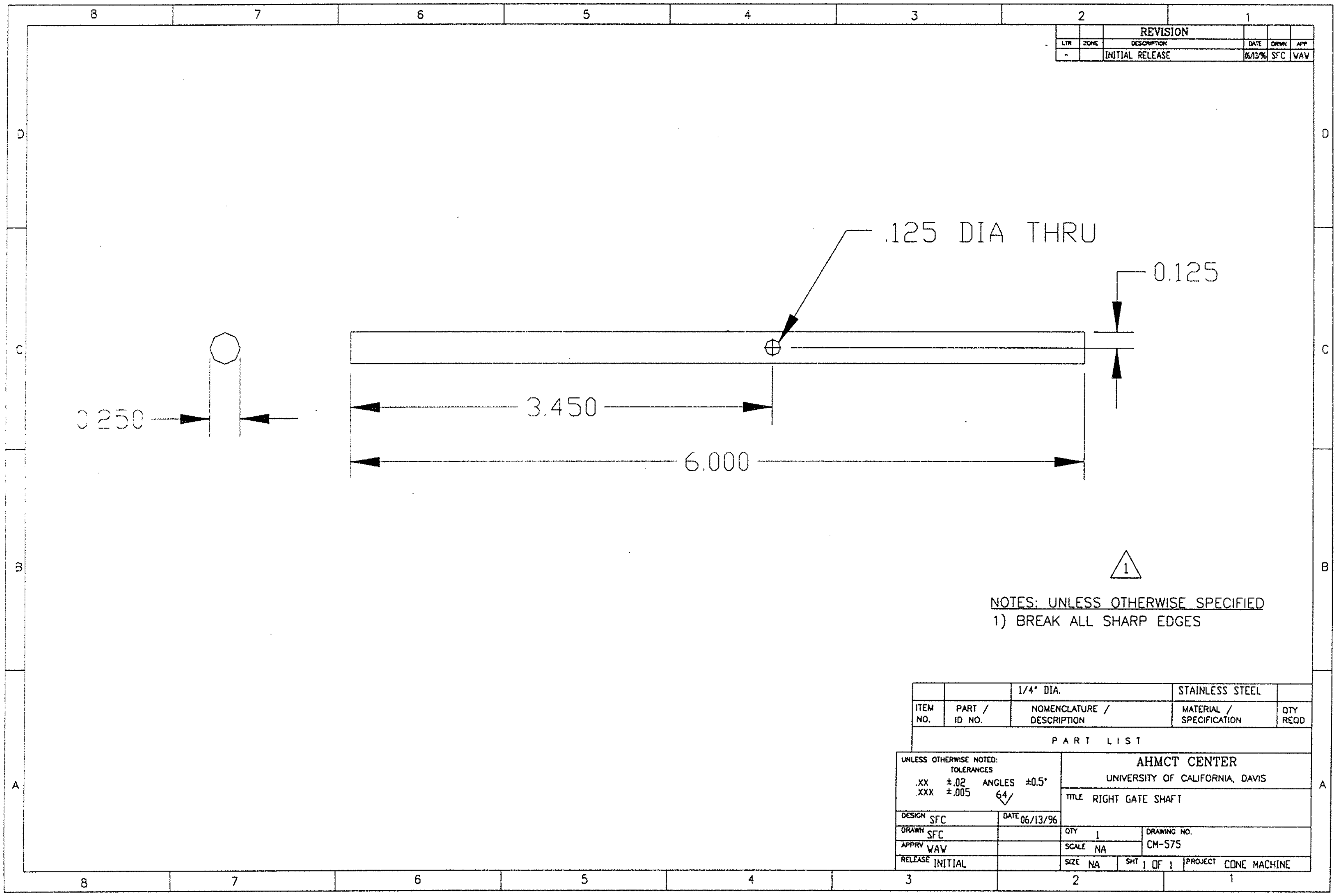

REVISION
INITIAL RELEASE
ADD DIMENSIONS
.3125-18 UNC 2B
.625 DEEP MIN
2X NEARSIDE
1X FARSIDE
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
.125 R MAX
4X
10-24 UNC 2B
THRU 4X
.3125-18 UNC 2B
.625 DEEP MIN
2X
0.750
STOCK
3/4" PLATE
6061 AL
PART LIST
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
RIGHT BASE PLATE
CM-571
CONE MACHINE

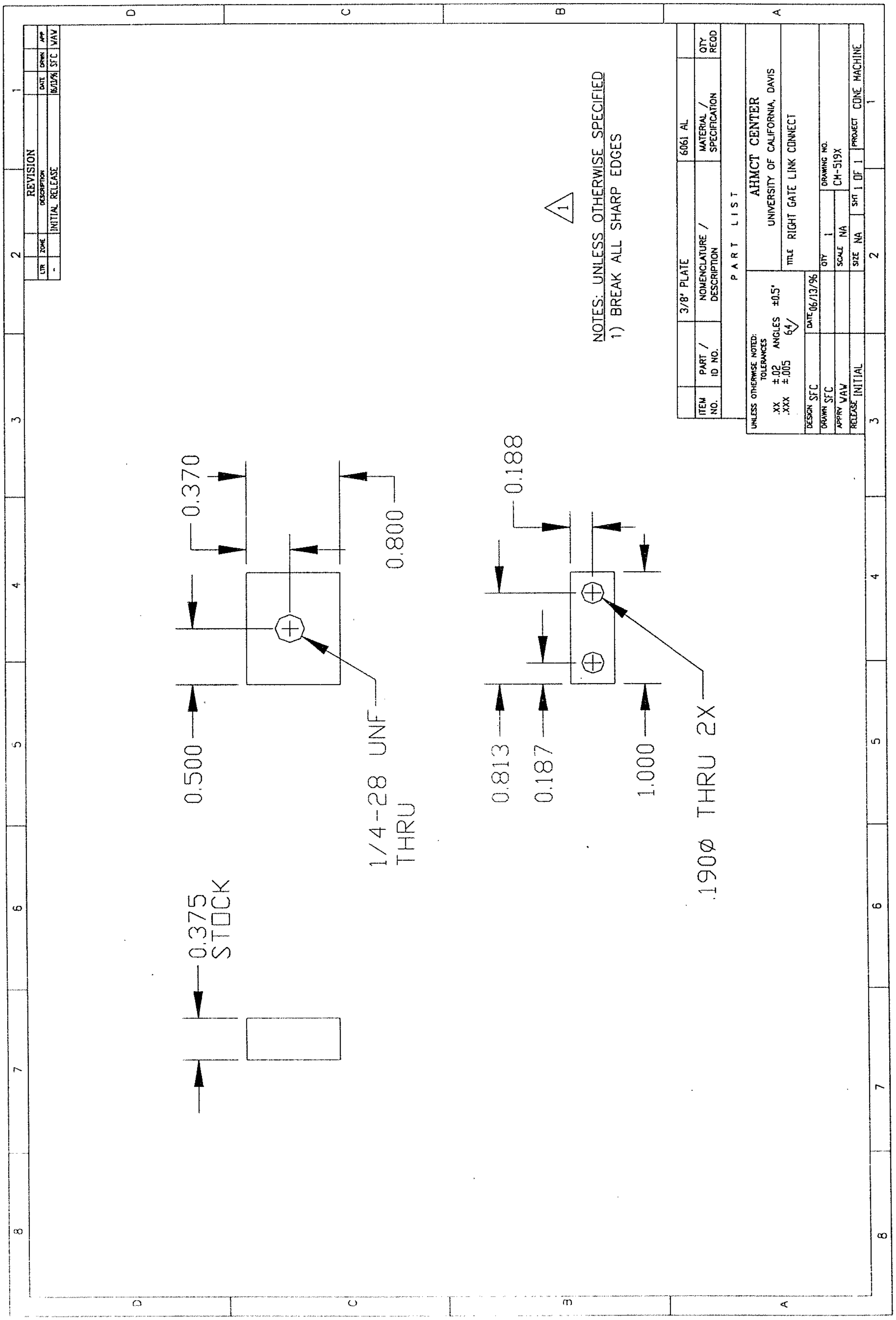

REVISION
LTR ZONE DESCRIPTION DATE DRAWN APP
- INITIAL RELEASE 06/13/96 SFC WAV
0.438
2.065
2.690
3.065
3.900
0.250
10-24 UNC-2B THRU 2X
6-32 UNC-2B THRU
3.170
2.690
2.232
0.250
0.500
1.450
2.700
3.450
4.200
5.450
6.000
0.500
STOCK
2.690
.255-.260 DIA THRU, 3X
0.250
1
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
1/2" PLATE
6061 AL
ITEM NO.
PART / ID NO.
NOMENCLATURE / DESCRIPTION
MATERIAL / SPECIFICATION
QTY REQD
PART LIST
UNLESS OTHERWISE NOTED: TOLERANCES
.XX ±.02 ANGLES ±0.5°
.XXX ±.005 64
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
TITLE RIGHT GATE
DESIGN SFC
DATE 06/13/96
DRAWN SFC
APPRV WAV
RELEASE INITIAL
QTY 1
SCALE NA
SIZE NA
SHT 1 OF 1
DRAWING NO. CM-572
PROJECT CONE MACHINE


REVISION
LTR ZONE DESCRIPTION DATE DRWN APP
- INITIAL RELEASE 6/13/96 SFC VAV
A REDIMENSION HOLES 11/20/96 SFC VAV
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
0.782
1.125
.191Ø THRU 2X
A
0.287
0.862
1.150
0.250
STOCK
1/4" PLATE
6061 AL
ITEM NO.
PART / ID NO.
NOMENCLATURE / DESCRIPTION
MATERIAL / SPECIFICATION
QTY REQD
PART LIST
UNLESS OTHERWISE NOTED: TOLERANCES
.XX ±.02
.XXX ±.005
ANGLES ±0.5°
64
DESIGN SFC
DRAWN SFC
APPRV VAV
RELEASE INITIAL
DATE 06/13/96
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
TITLE RIGHT GATE SHAFT CLIPS
QTY 1
SCALE NA
SIZE NA
DRAWING NO. CM-573
SHT 1 OF 1
PROJECT CONE MACHINE



REVISION
LTR ZONE DESCRIPTION DATE DRAWN APP
- INITIAL RELEASE 06/13/96 SFC VAV
A DIMENSION HOLE 10/02/96 SFC VAV
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
0.332
1.270
0.500
0.250
0.500
.1910Ø THRU 2X
1/4-28 UNF THRU
A
0.250
1.750
2.000
ITEM NO. PART / ID NO. 1/2" PLATE NOMENCLATURE / DESCRIPTION 6061 AL MATERIAL / SPECIFICATION QTY REQD
PART LIST
UNLESS OTHERWISE NOTED: TOLERANCES .XX ±.02 .XXX ±.005 ANGLES ±0.5°
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
TITLE RIGHT GATE LINKAGE BLOCK
DESIGN SFC DATE 06/13/96
DRAWN SFC
APPRV VAV
RELEASE INITIAL
QTY 1
SCALE NA
SIZE NA
DRAWING NO. CM-574
SHT 1 OF 1
PROJECT CONE MACHINE


REVISION
LTR
ZONE
DESCRIPTION
DATE
DRWN
APP
-
INITIAL RELEASE
6/13/96
SFC
VAV
.125 DIA THRU
0.125
0.250
3.450
6.000
1
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
1/4" DIA.
STAINLESS STEEL
ITEM NO.
PART / ID NO.
NOMENCLATURE / DESCRIPTION
MATERIAL / SPECIFICATION
QTY REQD
PART LIST
UNLESS OTHERWISE NOTED: TOLERANCES
.XX ±.02 ANGLES ±0.5°
.XXX ±.005
64
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
TITLE RIGHT GATE SHAFT
DESIGN SFC
DATE 06/13/96
DRAWN SFC
APPRV VAV
RELEASE INITIAL
QTY 1
DRAWING NO. CM-575
SCALE NA
SIZE NA
SHT 1 OF 1
PROJECT CONE MACHINE


REVISION
LTR ZONE DESCRIPTION DATE DRWN APP
- INITIAL RELEASE 06/13/96 SFC VAV
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
1
0.370
0.800
0.500
1/4-28 UNF THRU
0.188
0.813
0.187
1.000
.190Ø THRU 2X
0.375 STOCK
3/8" PLATE
6061 AL
ITEM NO.
PART / ID NO.
NOMENCLATURE / DESCRIPTION
MATERIAL / SPECIFICATION
QTY REQD
PART LIST
UNLESS OTHERWISE NOTED: TOLERANCES
.XX ±.02 ANGLES ±0.5°
.XXX ±.005
64
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
TITLE RIGHT GATE LINK CONNECT
DESIGN SFC
DATE 06/13/96
DRAWN SFC
APPRV VAV
RELEASE INITIAL
QTY 1
SCALE NA
SIZE NA
DRAWING NO. CM-519X
SHT 1 OF 1
PROJECT CONE MACHINE

APPENDIX E
CONTROL SYSTEM CODE

```
/*****************************************************************/
/*****                                                     *****/
/*****           MASTER PROGRAM   Ver1.5dn                 *****/
/*****                                                     *****/
/*****            CONE MACHINE                             *****/
/*****                                                     *****/
/*****  This program is designed to operate on a Little Giant *****/
/*****  Z-World Controller called the Master, which is used as *****/
/*****  a user interface.  It also communicates via RS 485   *****/
/*****  communications with a second controller, called the Slave. *****/
/*****                                                     *****/
/*****                                                     *****/
/*****                                                     *****/
/*****                  9/16/96                            *****/
/*****                                                     *****/
/*****************************************************************/

#define KEYPAD_SIZE 40
#define LK_LINES 4
#define LK_COLS 40

/*******************************************************************/

void setup();

int menua();
int menub();
int menultest();
int menumtest();

/*****************************************************************/

main()
{
  char OutString[15];
  char InString[15];
  int readme,index,i,eCode,exit,out;
  int abtkey,inputa,inputb,inputc,inputmt,inputlt,dist,check;
  int lk_init_keypad();
  int lk_kxget();

  outport(PIOCA,0xff);
  outport(PIOCA,0xff);
  outport(PIOCB,0xff);
  outport(PIOCB,0xff);

  for (i=0;i<15;i++) InString[i]='\0';
  op_init_z1 (19200/1200, InString, 0);

  lk_init_keypad();
```

```
check=0x00;
while(1)
{
  check=0x00;
  inputa=inputb=inputc=inputlt=inputmt=0;
  inputa=menua();
  if (inputa==3) inputmt = menumtest();
  if ((inputa==1)||(inputa==2)) inputb=menub();
  if ((inputa==1)&&(inputb==5)) inputc=menultest();


  while((inputmt==1)||(inputmt==2))
  {
    if (inputmt==1)
    {
        sprintf(OutString,"1H");
        eCode=sendOp22 (1, OutString, strlen(OutString), 1);

        lk_printf("\x1be");
        lk_printf("\x1bp000Please Wait, Testing Output Mechanisms\n");
        lk_tdelay(2000);
        while (check!=0x01)
        {
            readme=inport(PIODA);
            check=readme&0x01;
        }
        check=0x00;

        inputmt = menumtest();
    }
    if (inputmt==2)
    {
        sprintf(OutString,"1I");
        eCode=sendOp22 (1, OutString, strlen(OutString), 1);

        lk_printf("\x1be");
        lk_printf("\x1bp000Please Wait, Testing Input Sensors\n");
        lk_tdelay(2000);
        while (check!=0x01)
        {
            readme=inport(PIODA);
            check=readme&0x01;
        }
        check=0x00;

        inputmt = menumtest();
    }
    if (inputmt==3) break;
  }


  while((inputb==1)||(inputb==2)||(inputb==3)||(inputb==4)||(inputb==6))
  {
    if (inputb==1)
```

```
{
  sprintf(OutString,"1A");
  eCode=sendOp22 (1, OutString, strlen(OutString), 1);

  lk_printf("\x1be");
  lk_printf("\x1bp000Please Wait, Left Box DOWN\n");
  lk_tdelay(2000);
  while (check!=0x01)
  {
    readme=inport(PIODA);
    check=readme&0x01;
  }
  check=0x00;

  inputb = menub();
}

if (inputb==2)
{
  sprintf(OutString,"1B");
  eCode=sendOp22 (1, OutString, strlen(OutString), 1);

  lk_printf("\x1be");
  lk_printf("\x1bp000Please Wait, Left Box UP\n");
  lk_tdelay(2000);
  while (check!=0x01)
  {
    readme=inport(PIODA);
    check=readme&0x01;
  }
  check=0x00;

  inputb = menub();
}

if (inputb==3)
{
  sprintf(OutString,"1C");
  eCode=sendOp22 (1, OutString, strlen(OutString), 1);

  lk_printf("\x1be");
  lk_printf("\x1bp000Please Wait, Primary Funnel DOWN\n");
  lk_tdelay(2000);
  while (check!=0x01)
  {
    readme=inport(PIODA);
    check=readme&0x01;
  }
  check=0x00;

  inputb = menub();
}

if (inputb==4)
{
```

```
    sprintf(OutString,"1D");
    eCode=sendOp22 (1, OutString, strlen(OutString), 1);

    lk_printf("\x1be");
    lk_printf("\x1bp000Please Wait, Primary Funnel UP\n");
    lk_tdelay(2000);
    while (check!=0x01)
    {
      readme=inport(PIODA);
      check=readme&0x01;
    }
    check=0x00;

    inputb = menub();
  }
  if (inputb==6)
  {
    break;
  }
}


while((inputc==1)||(inputc==2)||(inputc==4)||(inputc==5)||(inputc==6))
{
  if (inputc==1)
  {
    sprintf(OutString,"1G");
    eCode=sendOp22 (1, OutString, strlen(OutString), 1);

    lk_printf("\x1be");
    lk_printf("\x1bp000Please Wait, Single Pick-Up Mode\n");
    lk_tdelay(2000);
    while (check!=0x01)
    {
      readme=inport(PIODA);
      check=readme&0x01;
    }
    check=0x00;
    inputc = menultest();
  }

  if (inputc==2)
  {
    sprintf(OutString,"1J");
    eCode=sendOp22 (1, OutString, strlen(OutString), 1);

    lk_printf("\x1be");
    lk_printf("\x1bp000Please Wait, Single Drop-Off Mode\n");
    lk_tdelay(2000);
    while (check!=0x01)
    {
      readme=inport(PIODA);
      check=readme&0x01;
    }
    check=0x00;
```

```
  inputc = menultest();
}

if (inputc==3)
{
  break;
}

if (inputc==4)
{
  sprintf(OutString,"1E");
  eCode=sendOp22 (1, OutString, strlen(OutString), 1);

  lk_printf("\x1be");
  lk_printf("\x1bp000Please Wait, Testing Mult. PickUP Mode\n");
  lk_tdelay(2000);
  while (check!=0x01)
  {
    readme=inport(PIODA);
    check=readme&0x01;
  }
  check=0x00;
  inputc = menultest();
}

if (inputc==5)
{
  sprintf(OutString,"1F");
  eCode=sendOp22 (1, OutString, strlen(OutString), 1);

  lk_printf("\x1be");
  lk_printf("\x1bp000Please Wait, Testing Mult. DropOFF Mode\n");
  lk_tdelay(2000);
  while (check!=0x01)
  {
    readme=inport(PIODA);
    check=readme&0x01;
  }
  check=0x00;
  inputc = menultest();
}

if (inputc==6)
{
  sprintf(OutString,"1K");
  eCode=sendOp22 (1, OutString, strlen(OutString), 1);

  lk_printf("\x1be");
  lk_printf("\x1bp000Please Wait, Centering Arm Mode\n");
  lk_tdelay(2000);
  while (check!=0x01)
  {
    readme=inport(PIODA);
    check=readme&0x01;
  }
```

```
        check=0x00;
        inputc = menultest();
      }

  }
  }
}

/****************************************************************/

int menua()
{
  int ina,out;
  int lk_kxget();

  ina=0;
  out=0;
  while (out!=1)
  {
    lk_printf("\x1be");
    lk_printf("\x1bp000  MAIN Operating Menu\n");
    lk_printf("1. Leftside Operation\n");
    lk_printf("2. Rightside Operation\n");
    lk_printf("3. Test Opertation\n");
    while ((ina=lk_kxget(0))==-1);
    if ((ina==1)||(ina==2)||(ina==3)) out=1;
  }
  return ina;
}

/****************************************************************/

int menub()
{
  int inb,out;
  int lk_kxget();

  out=0;
  while(out!=1)
  {
    lk_printf("\x1be");
    lk_printf("\x1bp000LEFT SIDE Operation Menu\n");
    lk_printf("1. Box DOWN     4.  Funnel UP\n");
    lk_printf("2. Box UP       5.  Test\n");
    lk_printf("3. Funnel DOWN  6. Return to Main Menu");
    while ((inb=lk_kxget(0))==-1);
    if ((inb==1)||(inb==2)||(inb==3)||(inb==4)||
   (inb==5)||(inb==6)) out=1;
  }
  return inb;
}

/****************************************************************/

int menumtest()
```

```
{
  int intest,out;
  int lk_kxget();

  out=0;
  while(out!=1)
  {
    lk_printf("\x1be");
    lk_printf("\x1bp000Main Test Menu\n");
    lk_printf("1. Test all Output Drive Mechanisms\n");
    lk_printf("2. Test all Input Sensors\n");
    lk_printf("3. Return to Main Menu\n");
    while((intest=lk_kxget(0))==-1);
    if((intest==1)||(intest==2)||(intest==3)) out=1;
  }
  return intest;
}


/*************************************************************/

int menultest()
{
  int intest,out;
  int lk_kxget();

  out=0;
  while(out!=1)
  {
    lk_printf("\x1be");
    lk_printf("\x1bp000LeftSide Test Menu\n");
    lk_printf("1. Single PickUP    4. Mult. PickUP\n");
    lk_printf("2. Single DropOFF   5. Mult. DropOFF\n");
    lk_printf("3. Return to Main Menu 6. Center Arm\n");
    while((intest=lk_kxget(0))==-1);
    if((intest==1)||(intest==2)||(intest==3)||(intest==4)
      ||(intest==5)||(intest==6)) out=1;
  }
  return intest;
}

/*************************************************************/
```

```
/*******************************************************/
/*****                                            *****/
/*****        SLAVE PROGRAM Ver1.5dn              *****/
/*****                                            *****/
/*****          CONE MACHINE                      *****/
/*****                                            *****/
/*****  This program operates on a Little Giant Z-World   *****/
/*****  Controller called the Slave.  It takes direction from *****/
/*****  the Master Controller, and executes the appropriate *****/
/*****  function.  The program is able to access the status *****/
/*****  of 20 sensors, as well as, control the status of 16  *****/
/*****  relays.                                    *****/
/*****                                            *****/
/*****               9/23/96                      *****/
/*****                                            *****/
/*******************************************************/

#define KEYPAD_SIZE 40
#define LK_LINES 4
#define LK_COLS 40

void setup();
void initial();

void abort_check();

void right_grip_on();
void right_grip_off();
void lat_convey_lr_on();
void lat_convey_lr_off();
void lat_convey_rl_on();
void lat_convey_rl_off();
void right_st_fwd_on();
void right_st_fwd_off();
void left_stow_fwd_on();
void left_stow_fwd_off();
void left_arm_fwd_on();
void left_arm_fwd_off();
void left_arm_dwn_on();
void left_arm_dwn_off();
void left_grip_on();
void left_grip_off();
void pri_fun_down_on();
void pri_fun_down_off();
void pri_funnel_up_on();
void pri_funnel_up_off();
void mid_gate_on();
void mid_gate_off();
void stack_fwd_on();
void stack_fwd_off();
void stack_rev_on();
void stack_rev_off();
```

```
void left_box_down_on();
void left_box_down_off();
void left_box_up_on();
void left_box_up_off();

void fluid_cooler_on();
void fluid_cooler_off();

void left_box_down();
void left_box_up();
void pri_fun_down();
void pri_fun_up();

void test_pickup_w_psensors();
void test_dropf_w_psensors();

void pickup_series();
void dropf_series();

void center_left_arm();

void test_all_mech();
void test_all_sensors();

int check_sensor(char address, char bit);

int abort_sensor();

int left_stow_sensor();
int rt_stow_sensor();
int fwd_l_stack_sensor();
int fwd_r_stack_sensor();
int bck_l_stack_sensor();
int bck_r_stack_sensor();
int left_box_up_sensor();
int left_box_dn_sensor();
int left_arm_bp_sensor();
int left_arm_st_sensor();
int left_platfm_sensor();
int right_gate_sensor();
int mid_gate_l_sensor();
int mid_gate_r_sensor();

/**************************************************************/

void main()
{
  char OutString[15];
  char InString[15];
  char chvalue[15];
  char temp1,temp2;

  int index,cooler;
  char InCount, Received;
  char OutCount;
```

```
int i,eCode;

cooler = 1;

setup();
initial();

Reset_PBus;
Stall(3000);

lk_init_keypad();

outport(0xBA00,0x00);

for(i=0;i<15;i++) InString[i]='\0';
op_init_z1 (19200/1200, InString, 1);

while (1)
{
  if (check_opto_command()==1)
    {
      fluid_cooler_off();

      InString[strlen(InString)-2]='\0';
      strncpy (chvalue, (InString+2), 4);
      chvalue[2]='\0';
      switch(chvalue[0])
      {
        case '1':
          switch(chvalue[1])
          {
            case 'A':              /* inputa=1, inputc=1 */
              outport(0xBA00,0x00);
              left_box_down();
              outport(0xBA00,0x01);
              break;

            case 'B':              /* inputa=3, inputmt=1 */
              outport(0xBA00,0x00);
              left_box_up();
              outport(0xBA00,0x01);
              break;
            case 'C':              /* inputa=3, inputmt=2 */
              outport(0xBA00,0x00);
              pri_fun_down_on();
              lk_tdelay(4000);
              pri_fun_down_off();
              outport(0xBA00,0x01);
              break;

            case 'D':              /* inputa=1, inputb=4, inputlt=2 */
              outport(0xBA00,0x00);
              pri_funnel_up_on();
              lk_tdelay(4000);
              pri_funnel_up_off();
```

```
            outport(0xBA00,0x01);
            break;

          case 'E':            /* inputa=3, inputmt=2 */
            outport(0xBA00,0x00);
            pickup_series();
            outport(0xBA00,0x01);
            break;

          case 'F':            /* inputa=1, inputb=4, inputlt=2 */
            outport(0xBA00,0x00);
            dropf_series();
            outport(0xBA00,0x01);
            break;

          case 'G':            /*  inputa=1, inputc=1 */
            outport(0xBA00,0x00);
            test_pickup_w_psensors();
            outport(0xBA00,0x01);
            break;
          case 'H':            /* inputa=3, inputmt=1 */
            outport(0xBA00,0x00);
            test_all_mech();
            outport(0xBA00,0x01);
            break;
          case 'I':            /* inputa=3, inputmt=2 */
            outport(0xBA00,0x00);
            test_all_sensors();
            outport(0xBA00,0x01);
            break;

          case 'J':            /* inputa=1, inputb=4, inputlt=2 */
            outport(0xBA00,0x00);
            test_dropf_w_psensors();
            outport(0xBA00,0x01);
            break;
          case 'K':            /* inputa=1, inputlt=4 */
            outport(0xBA00,0x00);
            center_left_arm();
            outport(0xBA00,0x01);
            cooler = 1;
            break;

          case 'L':            /* inputa=1, inputlt=5 */
            outport(0xBA00,0x00);
            outport(0xBA00,0x01);
            cooler = 0;
            break;

        }
        break;
    }
    if (cooler == 0)
    {
       fluid_cooler_off();
```

```
        }
        else if (cooler == 1)
        {
          fluid_cooler_on();
        }

        for(i=0;i<15;i++) InString[i]='\0';
      }
   }
}

/************************************************************/

/* use LM9346 to reduce 12V input reads to 5 volts */
/* PIOCA sets port A command mode */
/* PIODA sets port A data mode */
/* PIOCB sets port B command mode */
/* PIODB sets port B data mode */

void setup()
{
  outport(0xB802,0xff);  /* mode control word set to mode 3 for H4 PIOCA */
  outport(0xB802,0xff);  /* I/O register control word set to all input */

  outport(0xB602,0xff);  /* mode control word set to mode 3 for H3 PIOCA */
  outport(0xB602,0xff);  /* I/O register control word set to all input */

  outport(0xB803,0xff);  /* mode control word set to mode 3 for H3 PIOCA */
  outport(0xB803,0xff);  /* I/O register control word set to all input */

  outport(0xB603,0xff);  /* mode control word set to mode 3 for H3 PIOCA */
  outport(0xB603,0xff);  /* I/O register control word set to all input */

  outport(0xBA02,0xff);  /* mode control word set to mode 3 for H5 PIOCA */
  outport(0xBA02,0x00);  /* I/O register control word set to all output */

  outport(0xBA03,0xff);  /* mode control word set to mode 3 for H5 PIOCB */
  outport(0xBA03,0x00);  /* I/O register control word set to all output */
}

/************************************************************/

void initial()
{
  int i;

  i = 0;
  for (i=0;i<8;i++)
  {
    Set_PBus_Relay(7,i,0);
    Set_PBus_Relay(6,i,0);
    Set_PBus_Relay(5,i,0);
    Set_PBus_Relay(3,i,0);
  }
```

```
  Set_PBus_Relay(6,2,1);
}

/*****************************************************************/
void center_left_arm()
{
  char temp2;
  int clock1,clock2,clock3;
  int okhigh;

  clock1 = clock2 = clock3 = 0;

  clock1 = clock();

  temp2 =  left_arm_st_sensor();

  if (temp2 == 0x00)
  {
    left_arm_dwn_on();

    okhigh = 0;
    while(okhigh < 5)
    {
      temp2 =  left_arm_st_sensor();
      if (temp2 > 0x00)
      {
        ++okhigh;
      }
      else okhigh = 0;

      clock2 = clock();
      clock3 = clock2 - clock1;

      if (clock3 >= 3)
      {
        left_arm_dwn_off();
        lk_tdelay(100);
        left_arm_fwd_on();

        okhigh = 0;
        while(okhigh < 10)
        {
          temp2 =  left_arm_st_sensor();

          if (temp2 > 0x00)
          {
            ++okhigh;
          }
          else okhigh = 0;
        }
        left_arm_fwd_off();
        break;
      }
    }
  }
```

```
  left_arm_dwn_off();
}

/*****************************************************************/

void abort_check()
{
  int temp1;

  temp1 = 0x00;
  temp1 =  abort_sensor();
  while (1)
  {
    if (temp1>0x00)
    {
      lk_tdelay(10);
      temp1 =  abort_sensor();
      if (temp1 > 0x00)
      {
        break;
      }
    }
    else
    {
      lk_tdelay(10);
      temp1 =  abort_sensor();
      if (temp1 == 0x00)
      {
        break;
      }
    }
  }

  if (temp1 > 0x00)
  {
    outport(0xBA00,0x01);
    main();
  }
}

/*****************************************************************/

void left_box_down()
{
  char temp1,temp2;
  int okhigh;

  okhigh = 0;
  while(okhigh < 10)
  {
    temp2 =  left_arm_st_sensor();
    if (temp2 > 0x00)
    {
      ++okhigh;
    }
```

```
    else okhigh = 0;
  }

  left_box_down_on();

  okhigh = 0;
  while(okhigh < 10)
  {
    temp1 =  left_box_dn_sensor();

    if (temp1 > 0x00)
    {
      ++okhigh;
    }
    else okhigh = 0;
  }
  left_box_down_off();
}

/******************************************************************/
void left_box_up()
{
  char temp1,temp2;
  int clock1,clock2,clock3;
  int okhigh;

  clock1 = clock2 = clock3 = 0;

  clock1 = clock();

  temp2 =  left_arm_st_sensor();

  if (temp2 == 0x00)
  {
    left_arm_dwn_on();

    okhigh = 0;
    while(okhigh < 10)
    {
      temp2 =  left_arm_st_sensor();
      if (temp2 > 0x00)
      {
        ++okhigh;
      }
      else okhigh = 0;

      clock2 = clock();
      clock3 = clock2 - clock1;

      if (clock3 >= 3)
      {
        left_arm_dwn_off();
        lk_tdelay(100);
        left_arm_fwd_on();
```

```
        okhigh = 0;
        while(okhigh < 5)
        {
          temp2 = left_arm_st_sensor();

          if (temp2 > 0x00)
          {
            ++okhigh;
          }
          else okhigh = 0;
        }
        left_arm_fwd_off();
        break;
      }
    }
  }
  left_arm_dwn_off();

  lk_tdelay(1000);

  left_box_up_on();

  okhigh = 0;
  while(okhigh < 5)
  {
    temp1 = left_box_up_sensor();

    if (temp1 > 0x00)
    {
      ++okhigh;
    }
    else okhigh = 0;
  }
  left_box_up_off();

}

/*******************************************************************/

void pickup_series()
{
  int i;
  i = 0;

  for (i=0;i<100;i++)
  {
    test_pickup_w_psensors();
  }
}

/*******************************************************************/
void dropf_series()
{
  int i;
  i=0;
```

```
  for (i=0;i<100;i++)
  {
    test_dropf_w_psensors();
  }
}

/****************************************************************/

void test_dropf_w_psensors()
{
  int temp1,temp2,temp3,temp4,temp5,temp6,temp7;
  int  side;


  temp5 = temp6 = temp7 = 0;

  temp1 = fwd_l_stack_sensor();
  while (1)
  {

    if (temp1>0x00)
    {
      lk_tdelay(10);
      temp1 = fwd_l_stack_sensor();
      if (temp1 > 0x00)
      {
        break;
      }
    }
    else
    {
      lk_tdelay(10);
      temp1 = fwd_l_stack_sensor();
      if (temp1 == 0x00)
      {
        break;
      }
    }
  }

  temp3 = fwd_r_stack_sensor();
  while (1)
  {
    if (temp3>0x00)
    {
      lk_tdelay(10);
      temp3 = fwd_r_stack_sensor();
      if (temp3 > 0x00)
      {
        break;
      }
    }
    else
    {
```

```
        lk_tdelay(10);
        temp3 = fwd_r_stack_sensor();
        if (temp3 == 0x00)
        {
          break;
        }
      }
    }

    side = 0;

    left_arm_fwd_on();

    if((temp1 == 0x00)&&(temp3 == 0x00))
    {
      stack_fwd_on();
      while((temp1 == 0x00)&&(temp3 == 0x00))
      {
        temp1 = fwd_l_stack_sensor();
        while (1)
        {
          if (temp1>0x00)
          {
            lk_tdelay(10);
            temp1 = fwd_l_stack_sensor();
            if (temp1 > 0x00)
            {
              break;
            }
          }
          else
          {
            lk_tdelay(10);
            temp1 = fwd_l_stack_sensor();
            if (temp1 == 0x00)
            {
              break;
            }
          }
        }

        temp3 = fwd_r_stack_sensor();
        while (1)
        {
          if (temp3>0x00)
          {
            lk_tdelay(10);
            temp3 = fwd_r_stack_sensor();
            if (temp3 > 0x00)
            {
              break;
            }
          }
          else
          {
```



```
      lk_tdelay(10);
      temp3 = fwd_r_stack_sensor();
      if (temp3 == 0x00)
      {
        break;
      }
    }
  }
}
stack_fwd_off();
lk_tdelay(100);

stack_rev_on();
lk_tdelay(50);
stack_rev_off();

lk_tdelay(10);

temp1 = fwd_l_stack_sensor();
while (1)
{
  if (temp1>0x00)
  {
    lk_tdelay(10);
    temp1 = fwd_l_stack_sensor();
    if (temp1 > 0x00)
    {
      break;
    }
  }
  else
  {
    lk_tdelay(10);
    temp1 = fwd_l_stack_sensor();
    if (temp1 == 0x00)
    {
      break;
    }
  }
}

temp3 = fwd_r_stack_sensor();
while (1)
{
  if (temp3>0x00)
  {
    lk_tdelay(10);
    temp3 = fwd_r_stack_sensor();
    if (temp3 > 0x00)
    {
      break;
    }
  }
  else
  {
```

```
            lk_tdelay(10);
            temp3 = fwd_r_stack_sensor();
            if (temp3 == 0x00)
            {
              break;
            }
          }
        }

        if((temp1 >= 0x00)&&(temp3 == 0x00))
        {
          side = 1;
        }
        else if ((temp1 == 0x00)&&(temp3 >= 0x00))
        {
          side = 2;

        }
        else if ((temp1 >= 0x00)&&(temp3 >= 0x00))
        {
          side = 1;
        }
        else
        {
          side = 0;
        }
      }

      else if((temp1 >= 0x00)&&(temp3 == 0x00))
      {
        side = 1;
      }

      else if((temp1 == 0x00)&&(temp3 >= 0x00))
      {
        side = 2;
      }

      else if((temp1 >= 0x00)&&(temp3 >= 0x00))
      {
        side = 1;
      }

      else
      {
        side = 0;
      }

      switch (side)
      {
        case 0: /*  no match occured, therefore an error resulted */
          break;

        case 1: /*  left cone stack operation */
          left_stow_fwd_off();
```

```
lk_tdelay(20);
right_st_fwd_on();

temp6 = rt_stow_sensor();
while(temp6 == 0x00)
{
  temp6 = rt_stow_sensor();
}


left_grip_on();
lk_tdelay(1000);

right_st_fwd_off();
lk_tdelay(200);

left_stow_fwd_on();

temp5 = left_stow_sensor();
while(temp5 == 0x00)
{
  temp5 = left_stow_sensor();
}

left_grip_off();
lk_tdelay(600);

lat_convey_rl_on();

temp7 = left_platfm_sensor();
while(temp7 == 0x00)
{
  temp7 = left_platfm_sensor();
}
lk_tdelay(1500);

lat_convey_rl_off();

break;


case 2: /*  right cone stack operation  */
  right_st_fwd_off();
  lk_tdelay(20);
  left_stow_fwd_on();

  temp5 = left_stow_sensor();
  while(temp5 == 0x00)
  {
    temp5 = left_stow_sensor();
  }

  right_grip_on();
  lk_tdelay(1000);
```

```
      left_stow_fwd_off();
      lk_tdelay(100);

      right_st_fwd_on();

      temp6 = rt_stow_sensor();
      while(temp6 == 0x00)
      {
        temp6 = rt_stow_sensor();
      }

      lk_tdelay(100);
      right_grip_off();
      lk_tdelay(300);

      lat_convey_rl_on();

      temp7 = left_platfm_sensor();
      while(temp7 == 0x00)
      {
        temp7 = left_platfm_sensor();
      }
      lk_tdelay(1500);

      lat_convey_rl_off();

      break;

  }

  left_arm_fwd_off();


}
/******************************************************************/
void test_pickup_w_psensors()
{
  int  temp1,temp2,temp3,temp4,temp5,temp6,temp7,temp8,
      temp9,temp10,temp11;

  int  side, okhigh, out;

  okhigh = 0;


  temp1 = left_arm_bp_sensor();
  temp2 = left_arm_st_sensor();
  temp3 = left_platfm_sensor();
  temp4 = mid_gate_l_sensor();
  temp5 = left_stow_sensor();
  temp6 = rt_stow_sensor();

  temp11 = right_gate_sensor();

  side = 0;
```

```
left_arm_dwn_on();


temp7 = fwd_l_stack_sensor();
while (1)
{
  if (temp7>0x00)
  {
    lk_tdelay(10);
    temp7 = fwd_l_stack_sensor();
    if (temp7 > 0x00)
    {
      break;
    }
  }
  else
  {
    lk_tdelay(10);
    temp7 = fwd_l_stack_sensor();
    if (temp7 == 0x00)
    {
      break;
    }
  }
}


temp8 = bck_l_stack_sensor();
while (1)
{
  if (temp8>0x00)
  {
    lk_tdelay(10);
    temp8 = bck_l_stack_sensor();
    if (temp8 > 0x00)
    {
      break;
    }
  }
  else
  {
    lk_tdelay(10);
    temp8 = bck_l_stack_sensor();
    if (temp8 == 0x00)
    {
      break;
    }
  }
}


temp9 = fwd_r_stack_sensor();
while (1)
{
```

```
  if (temp9>0x00)
  {
    lk_tdelay(10);
    temp9 = fwd_r_stack_sensor();
    if (temp9 > 0x00)
    {
      break;
    }
  }
  else
  {
    lk_tdelay(10);
    temp9 = fwd_r_stack_sensor();
    if (temp9 == 0x00)
    {
      break;
    }
  }
}


temp10 = bck_r_stack_sensor();
while (1)
{
  if (temp10>0x00)
  {
    lk_tdelay(10);
    temp10 = bck_r_stack_sensor();
    if (temp10 > 0x00)
    {
      break;
    }
  }
  else
  {
    lk_tdelay(10);
    temp10 = fwd_l_stack_sensor();
    if (temp10 == 0x00)
    {
      break;
    }
  }
}



if((temp7==0x00)&&(temp8==0x00)&&(temp9==0x00)&&(temp10==0x00))
{
  stack_fwd_on();

  while((temp8==0x00)&&(temp10==0x00))
  {
    temp8 = bck_l_stack_sensor();
    while (1)
    {
```

```
        if (temp8>0x00)
        {
          lk_tdelay(10);
          temp8 = bck_l_stack_sensor();
          if (temp8 > 0x00)
          {
            break;
          }
        }
        else
        {
          lk_tdelay(10);
          temp8 = bck_l_stack_sensor();
          if (temp8 == 0x00)
          {
            break;
          }
        }
      }

      temp10 = bck_r_stack_sensor();
      while (1)
      {
        if (temp10>0x00)
        {
          lk_tdelay(10);
          temp10 = bck_r_stack_sensor();
          if (temp10 > 0x00)
          {
            break;
          }
        }
        else
        {
          lk_tdelay(10);
          temp10 = fwd_l_stack_sensor();
          if (temp10 == 0x00)
          {
            break;
          }
        }
      }
    }
    stack_fwd_off();
    lk_tdelay(10);
    stack_rev_on();
    lk_tdelay(30);
    stack_rev_off();
  }


  temp7 = fwd_l_stack_sensor();
  while (1)
  {
    if (temp7>0x00)
```

```
  {
    lk_tdelay(10);
    temp7 = fwd_l_stack_sensor();
    if (temp7 > 0x00)
    {
      break;
    }
  }
  else
  {
    lk_tdelay(10);
    temp7 = fwd_l_stack_sensor();
    if (temp7 == 0x00)
    {
      break;
    }
  }
}


temp8 = bck_l_stack_sensor();
while (1)
{
  if (temp8>0x00)
  {
    lk_tdelay(10);
    temp8 = bck_l_stack_sensor();
    if (temp8 > 0x00)
    {
      break;
    }
  }
  else
  {
    lk_tdelay(10);
    temp8 = bck_l_stack_sensor();
    if (temp8 == 0x00)
    {
      break;
    }
  }
}


temp9 = fwd_r_stack_sensor();
while (1)
{
  if (temp9>0x00)
  {
    lk_tdelay(10);
    temp9 = fwd_r_stack_sensor();
    if (temp9 > 0x00)
    {
      break;
    }
```

```
    }
    else
    {
      lk_tdelay(10);
      temp9 = fwd_r_stack_sensor();
      if (temp9 == 0x00)
      {
        break;
      }
    }
  }


  temp10 = bck_r_stack_sensor();
  while (1)
  {
    if (temp10>0x00)
    {
      lk_tdelay(10);
      temp10 = bck_r_stack_sensor();
      if (temp10 > 0x00)
      {
        break;
      }
    }
    else
    {
      lk_tdelay(10);
      temp10 = fwd_l_stack_sensor();
      if (temp10 == 0x00)
      {
        break;
      }
    }
  }


  if((temp7==0x00)&&(temp8>0x00)&&(temp9==0x00)&&(temp10==0x00))
  {
    stack_fwd_on();
    while(temp7==0x00)
    {
      temp7=fwd_l_stack_sensor();
      while (1)
      {
        if (temp7>0x00)
        {
          lk_tdelay(10);
          temp7 = fwd_l_stack_sensor();
          if (temp7 > 0x00)
          {
            break;
          }
        }
        else
```

```
      {
        lk_tdelay(10);
        temp7 = fwd_l_stack_sensor();
        if (temp7 == 0x00)
        {
          break;
        }
      }
    }
  }
  stack_fwd_off();
  lk_tdelay(10);
  stack_rev_on();
  lk_tdelay(10);
  stack_rev_off();
  side=2;
}

else if((temp7==0x00)&&(temp8>0x00)&&(temp9==0x00)&&(temp10>0x00))
{
  side=1;
}

else if((temp7==0x00)&&(temp8==0x00)&&(temp9==0x00)&&(temp10>0x00))
{
  stack_fwd_on();
  while(temp9==0x00)
  {
    temp9 = fwd_r_stack_sensor();
    while (1)
    {
      if (temp9>0x00)
      {
        lk_tdelay(10);
        temp9 = fwd_r_stack_sensor();
        if (temp9 > 0x00)
        {
          break;
        }
      }
      else
      {
        lk_tdelay(10);
        temp9 = fwd_r_stack_sensor();
        if (temp9 == 0x00)
        {
          break;
        }
      }
    }
  }
  stack_fwd_off();
  lk_tdelay(10);
  stack_rev_on();
  lk_tdelay(10);
```

```
  stack_rev_off();
  side=1;
}

else if((temp7>0x00)&&(temp9==0x00))
{
  side=2;
}


else if((temp7==0x00)&&(temp9>0x00))
{
  side=1;
}

else if((temp7>0x00)&&(temp8>0x00)&&(temp9>0x00)&&(temp10>0x00))
{
  stack_rev_on();
  while((temp8>0x00)&&(temp10>0x00))
  {
    temp8 = bck_l_stack_sensor();
    while (1)
    {
      if (temp8>0x00)
      {
        lk_tdelay(10);
        temp8 = bck_l_stack_sensor();
        if (temp8 > 0x00)
        {
          break;
        }
      }
      else
      {
        lk_tdelay(10);
        temp8 = bck_l_stack_sensor();
        if (temp8 == 0x00)
        {
          break;
        }
      }
    }

    temp10 =bck_r_stack_sensor();
    while (1)
    {
      if (temp10>0x00)
      {
        lk_tdelay(10);
        temp10 = bck_r_stack_sensor();
        if (temp10 > 0x00)
        {
          break;
        }
      }
```

```
        else
        {
          lk_tdelay(10);
          temp10 = fwd_l_stack_sensor();
          if (temp10 == 0x00)
          {
            break;
          }
        }
      }
    }
    stack_rev_off();
    lk_tdelay(10);
    stack_fwd_on();
    lk_tdelay(225);
    stack_fwd_off();

    side=1;
  }

  else
  {
    side=0;
  }



  switch(side)
  {
    case 0:
      break;

    case 1:
      right_st_fwd_off();
      lk_tdelay(20);
      left_stow_fwd_on();

      okhigh = 0;
      while(okhigh < 10)
      {
        temp5 = left_stow_sensor();
        if (temp5 > 0x00)
        {
          ++okhigh;
        }
        else okhigh = 0;
      }


      okhigh = 0;
      while(okhigh < 10)
      {
        temp1 = left_arm_bp_sensor();
        if (temp1 > 0x00)
```

```
  {
    ++okhigh;
  }
  else okhigh = 0;
}

left_arm_dwn_off();
lk_tdelay(100);
left_arm_fwd_on();

okhigh = 0;
while(okhigh < 10)
{
  temp2 = left_arm_st_sensor();
  if (temp2 > 0x00)
  {
    ++okhigh;
  }
  else okhigh = 0;
}

lat_convey_lr_on();


okhigh = 0;
while(okhigh < 10)
{
  temp3 = left_platfm_sensor();
  if (temp3 > 0x00)
  {
    ++okhigh;
  }
  else okhigh = 0;
}


mid_gate_on();

left_arm_fwd_off();
lk_tdelay(50);

left_arm_dwn_on();

okhigh = 0;
while(okhigh < 10)
{
  temp4 = mid_gate_l_sensor();
  if (temp4 > 0x00)
  {
    ++okhigh;
  }
  else okhigh = 0;
}

lat_convey_lr_off();
```

```
  mid_gate_off();
  lk_tdelay(200);

  left_grip_on();
  lk_tdelay(800);

  left_stow_fwd_off();
  lk_tdelay(50);
  right_st_fwd_on();

  okhigh = 0;
  while(okhigh < 10)
  {
    temp6 = rt_stow_sensor();
    if (temp6 > 0x00)
    {
      ++okhigh;
    }
    else okhigh = 0;
  }

  left_grip_off();
  lk_tdelay(800);

  left_arm_dwn_off();

  break;


case 2:
  left_stow_fwd_off();
  lk_tdelay(20);
  right_st_fwd_on();

  okhigh = 0;
  while(okhigh < 10)
  {
    temp6 = rt_stow_sensor();
    if (temp6 > 0x00)
    {
      ++okhigh;
    }
    else okhigh = 0;
  }


  okhigh = 0;
  while(okhigh < 10)
  {
    temp1 = left_arm_bp_sensor();
    if (temp1 > 0x00)
    {
      ++okhigh;
    }
```

```
  else okhigh = 0;
}

left_arm_dwn_off();
lk_tdelay(100);
left_arm_fwd_on();

okhigh = 0;
while(okhigh < 10)
{
  temp2 = left_arm_st_sensor();
  if (temp2 > 0x00)
  {
    ++okhigh;
  }
  else okhigh = 0;
}

lat_convey_lr_on();


okhigh = 0;
while(okhigh < 10)
{
  temp3 = left_platfm_sensor();
  if (temp3 > 0x00)
  {
    ++okhigh;
  }
  else okhigh = 0;
}

left_arm_fwd_off();
lk_tdelay(50);

left_arm_dwn_on();

okhigh = 0;
while(okhigh < 10)
{
  temp11 = right_gate_sensor();
  if (temp11 > 0x00)
  {
    ++okhigh;
  }
  else okhigh = 0;
}

lat_convey_lr_off();


right_grip_on();
lk_tdelay(800);

right_st_fwd_off();
```

```
        lk_tdelay(50);
        left_stow_fwd_on();

        okhigh = 0;
        while(okhigh < 10)
        {
          temp5 = left_stow_sensor();
          if (temp5 > 0x00)
          {
            ++okhigh;
          }
          else okhigh = 0;
        }

        right_grip_off();
        lk_tdelay(300);

        left_arm_dwn_off();

        break;

    }
}
/*******************************************************************/

int left_stow_sensor()
{
  char num,check,readme;
  int temp;

  abort_check();

  temp = 0;
  num = 0xff;
  readme = inport(0xB800);
  check = num&readme;
  temp = check&0x01;

  return temp;
}


/*******************************************************************/

int rt_stow_sensor()
{
  char num,check,readme;
  int temp;

  abort_check();

  temp = 0;
  num = 0xff;
  readme = inport(0xB800);
  check = num&readme;
```

```
  temp = check&0x02;

  return temp;
}

/******************************************************************/

int fwd_l_stack_sensor()
{
  char num,check,readme;
  int temp;

  abort_check();

  temp = 0;
  num = 0xff;
  readme = inport(0xB800);
  check = num&readme;
  temp = check&0x04;

  return temp;
}

/******************************************************************/
int fwd_r_stack_sensor()
{
  char num,check,readme;
  int temp;

  abort_check();

  temp = 0;
  num = 0xff;
  readme = inport(0xB800);
  check = num&readme;
  temp = check&0x08;

  return temp;
}

/******************************************************************/

int bck_l_stack_sensor()
{
  char num,check,readme;
  int temp;

  abort_check();

  temp = 0;
  num = 0xff;
  readme = inport(0xB800);
  check = num&readme;
```

```
  temp = check&0x10;

  return temp;
}


/*****************************************************************/
int bck_r_stack_sensor()
{
  char num,check,readme;
  int temp;

  abort_check();

  temp = 0;
  num = 0xff;
  readme = inport(0xB800);
  check = num&readme;
  temp = check&0x20;

  return temp;
}


/*****************************************************************/

int left_box_up_sensor()
{
  char num,check,readme;
  int temp;

  abort_check();

  temp = 0;
  num = 0xff;
  readme = inport(0xB800);
  check = num&readme;
  temp = check&0x40;

  return temp;
}


/*****************************************************************/
int left_box_dn_sensor()
{
  char num,check,readme;
  int temp;

  abort_check();

  temp = 0;
  num = 0xff;
  readme = inport(0xB800);
  check = num&readme;
```

```
  temp = check&0x80;

  return temp;
}

/*****************************************************************/
int left_arm_bp_sensor()
{
  char num,check,readme;
  int temp;

  abort_check();

  temp = 0;
  num = 0xff;
  readme = inport(0xB801);
  check = num&readme;
  temp = check&0x04;

  return temp;
}

/*****************************************************************/
int left_arm_st_sensor()
{
  char num,check,readme;
  int temp;

  abort_check();

  temp = 0;
  num = 0xff;
  readme = inport(0xB801);
  check = num&readme;
  temp = check&0x40;

  return temp;
}

/*****************************************************************/
int left_platfm_sensor()
{
  char num,check,readme;
  int temp;
  abort_check();

  temp = 0;
  num = 0xff;
  readme = inport(0xB600);
  check = num&readme;
  temp = check&0x01;
```

```
  return temp;
}


/*****************************************************************/
int right_gate_sensor()
{
  char num,check,readme;
  int temp;

  abort_check();

  temp = 0;
  num = 0xff;
  readme = inport(0xB600);
  check = num&readme;
  temp = check&0x10;

  return temp;
}


/*****************************************************************/
int mid_gate_l_sensor()
{
  char num,check,readme;
  int temp;

  abort_check();

  temp = 0;
  num = 0xff;
  readme = inport(0xB600);
  check = num&readme;
  temp = check&0x40;

  return temp;
}


/*****************************************************************/
int mid_gate_r_sensor()
{
  char num,check,readme;
  int temp;

  abort_check();

  temp = 0;
  num = 0xff;
  readme = inport(0xB601);
  check = num&readme;
  temp = check&0x01;

  return temp;
```

```
}

/*****************************************************************/
int abort_sensor()
{
  char num,check,readme;
  int temp;

  temp = 0;
  num = 0xff;
  readme = inport(0xB601);
  check = num&readme;
  temp = check&0x04;
  return temp;
}

/*****************************************************************/

void right_grip_on()
{
  abort_check();
  Set_PBus_Relay(7,0,1);
}

/***************************************************************/

void right_grip_off()
{
  abort_check();
  Set_PBus_Relay(7,0,0);
}

/***************************************************************/

void lat_convey_lr_on()
{
  abort_check();
  Set_PBus_Relay(7,1,1);
}

/***************************************************************/

void lat_convey_lr_off()
{
  abort_check();
  Set_PBus_Relay(7,1,0);
}

/***************************************************************/

void lat_convey_rl_on()
{
  abort_check();
  Set_PBus_Relay(7,2,1);
}
```

```
/***************************************************************/

void lat_convey_rl_off()
{
  abort_check();
  Set_PBus_Relay(7,2,0);
}

/***************************************************************/

void right_st_fwd_on()
{
  abort_check();
  Set_PBus_Relay(7,3,1);
}

/***************************************************************/

void right_st_fwd_off()
{
  abort_check();
  Set_PBus_Relay(7,3,0);
}

/***************************************************************/

void left_stow_fwd_on()
{
  abort_check();
  Set_PBus_Relay(7,4,1);
}

/***************************************************************/

void left_stow_fwd_off()
{
  abort_check();
  Set_PBus_Relay(7,4,0);
}

/***************************************************************/

void left_arm_fwd_on()
{
  abort_check();
  Set_PBus_Relay(7,5,1);
}

/***************************************************************/

void left_arm_fwd_off()
{
  abort_check();
  Set_PBus_Relay(7,5,0);
```

```
}

/****************************************************************/

void left_arm_dwn_on()
{
  abort_check();
  Set_PBus_Relay(6,0,1);
}

/****************************************************************/

void left_arm_dwn_off()
{
  abort_check();
  Set_PBus_Relay(6,0,0);
}

/****************************************************************/

void left_grip_on()
{
  abort_check();
  Set_PBus_Relay(6,3,1);
}

/****************************************************************/

void left_grip_off()
{
  abort_check();
  Set_PBus_Relay(6,3,0);
}

/****************************************************************/

void pri_fun_down_on()
{
  abort_check();
  Set_PBus_Relay(6,4,1);
}

/****************************************************************/

void pri_fun_down_off()
{
  abort_check();
  Set_PBus_Relay(6,4,0);
}

/****************************************************************/

void pri_funnel_up_on()
{
  abort_check();
```

```
  Set_PBus_Relay(6,5,1);
}

/****************************************************************/

void pri_funnel_up_off()
{
  abort_check();
  Set_PBus_Relay(6,5,0);
}

/****************************************************************/

void mid_gate_on()
{
  abort_check();
  Set_PBus_Relay(5,0,1);
}

/****************************************************************/

void mid_gate_off()
{
  abort_check();
  Set_PBus_Relay(5,0,0);
}
/****************************************************************/

void stack_fwd_on()
{
  abort_check();
  Set_PBus_Relay(5,1,1);
}

/****************************************************************/

void stack_fwd_off()
{
  abort_check();
  Set_PBus_Relay(5,1,0);
}

/****************************************************************/

void stack_rev_on()
{
  abort_check();
  Set_PBus_Relay(5,2,1);
}

/****************************************************************/

void stack_rev_off()
{
  abort_check();
```

```
  Set_PBus_Relay(5,2,0);
}

/***************************************************************/

void fluid_cooler_on()
{
  abort_check();
  Set_PBus_Relay(6,2,1);
}

/***************************************************************/

void fluid_cooler_off()
{
  abort_check();
  Set_PBus_Relay(6,2,0);
}

/***************************************************************/

void left_box_down_on()
{
  abort_check();
  Set_PBus_Relay(5,3,1);
}

/***************************************************************/

void left_box_down_off()
{
  abort_check();
  Set_PBus_Relay(5,3,0);
}

/***************************************************************/

void left_box_up_on()
{
  abort_check();
  Set_PBus_Relay(5,4,1);
}

/***************************************************************/

void left_box_up_off()
{
  abort_check();
  Set_PBus_Relay(5,4,0);
}

/***************************************************************/

void test_all_mech()
{
```

```
right_grip_on();
lk_tdelay(2000);

right_grip_off();
lk_tdelay(1000);

lat_convey_lr_on();
lk_tdelay(2000);

lat_convey_lr_off();
lk_tdelay(1000);

lat_convey_rl_on();
lk_tdelay(2000);

lat_convey_rl_off();
lk_tdelay(1000);

right_st_fwd_on();
lk_tdelay(2500);

right_st_fwd_off();
lk_tdelay(1000);

left_stow_fwd_on();
lk_tdelay(2500);

left_stow_fwd_off();
lk_tdelay(1000);

left_arm_fwd_on();
lk_tdelay(1500);

left_arm_fwd_off();
lk_tdelay(1000);

left_arm_dwn_on();
lk_tdelay(1500);

left_arm_dwn_off();
lk_tdelay(1000);
```

```
  left_grip_on();
  lk_tdelay(2000);

  left_grip_off();
  lk_tdelay(1000);

  pri_fun_down_on();
  lk_tdelay(1000);

  pri_fun_down_off();
  lk_tdelay(1000);

  pri_funnel_up_on();
  lk_tdelay(6000);

  pri_funnel_up_off();
  lk_tdelay(1000);

  mid_gate_on();
  lk_tdelay(5000);

  mid_gate_off();
  lk_tdelay(2000);

  stack_fwd_on();
  lk_tdelay(1000);

  stack_fwd_off();
  lk_tdelay(1000);

  stack_rev_on();
  lk_tdelay(1000);

  stack_rev_off();
}

/*******************************************************************/

void test_all_sensors()
{
  char temp;
```

```
temp=0x00;
while(temp==0x00)
{
  printf("waiting for left_stow_sensor to go high\n");
  temp = left_stow_sensor();
  if(temp>0x00)
  {
    printf("left_stow_sensor is HIGH!!!\n");
    lk_tdelay(5000);
  }
}
  printf("waiting for rt_stow_sensor to go high\n");


printf("waiting for rt_stow_sensor to go high\n");
temp=0x00;
while(temp==0x00)
{
  temp = rt_stow_sensor();
  if(temp==0x02)
  {
    temp = rt_stow_sensor();
    printf("rt_stow_sensor is HIGH!!!\n");
    lk_tdelay(5000);
  }
}

temp=0x00;
while(temp==0x00)
{
  printf("waiting for fwd_l_stack_sensor to go high\n");
  temp = fwd_l_stack_sensor();
  if(temp==0x04)
  {
    printf("fwd_l_stack_sensor is HIGH!!!\n");
    lk_tdelay(5000);
  }
}

temp=0x00;
while(temp==0x00)
{
  printf("waiting for fwd_r_stack_sensor to go high\n");
  temp = fwd_r_stack_sensor();
  if(temp==0x08)
  {
    printf("fwd_r_stack_sensor is HIGH!!!\n");
    lk_tdelay(5000);
  }
}

temp=0x00;
while(temp==0x00)
{
  printf("waiting for bck_l_stack_sensor to go high\n");
```

```
    temp = bck_l_stack_sensor();
    if(temp==0x10)
    {
      printf("bck_l_stack_sensor is HIGH!!!\n");
      lk_tdelay(5000);
    }
  }

  temp=0x00;
  while(temp==0x00)
  {
    printf("waiting for bck_r_stack_sensor to go high\n");
    temp = bck_r_stack_sensor();
    if(temp==0x20)
    {
      printf("bck_r_stack_sensor is HIGH!!!\n");
      lk_tdelay(5000);
    }
  }

  temp=0x00;
  while(temp==0x00)
  {
    printf("waiting for left_box_up_sensor to go high\n");
    temp = left_box_up_sensor();
    if(temp==0x40)
    {
      printf(" left_box_up_sensor is HIGH!!!\n");
      lk_tdelay(5000);
    }
  }

  temp=0x00;
  while(temp==0x00)
  {
    printf("waiting for left_box_dn_sensor to go high\n");
    temp = left_box_dn_sensor();
    if(temp==0x80)
    {
      printf(" left_box_dn_sensor is HIGH!!!\n");
      lk_tdelay(5000);
    }
  }

  temp=0x00;
  while(temp==0x00)
  {
    printf("waiting for left_arm_bp_sensor to go high\n");
    temp = left_arm_bp_sensor();
    if(temp==0x04)
    {
      printf("left_arm_bp_sensor is HIGH!!!\n");
      lk_tdelay(5000);
    }
  }
```

```
temp=0x00;
while(temp==0x00)
{
  printf("waiting for left_arm_st_sensor to go high\n");
  temp = left_arm_st_sensor();
  if(temp==0x40)
  {
    printf("left_arm_st_sensor is HIGH!!!\n");
    lk_tdelay(5000);
  }
}

temp=0x00;
while(temp==0x00)
{
  printf("waiting for left_platfm_sensor to go high\n");
  temp = left_platfm_sensor();
  if(temp==0x01)
  {
    printf("left_platfm_sensor is HIGH!!!\n");
    lk_tdelay(5000);
  }
}

temp=0x00;
while(temp==0x00)
{
  printf("waiting for right_gate_sensor to go high\n");
  temp = right_gate_sensor();
  if(temp==0x10)
  {
    printf("right_gate_sensor is HIGH!!!\n");
    lk_tdelay(5000);
  }
}

temp=0x00;
while(temp==0x00)
{
  printf("waiting for mid_gate_l_sensor to go high\n");
  temp = mid_gate_l_sensor();
  if(temp==0x40)
  {
    printf("mid_gate_l_sensor is HIGH!!!\n");
    lk_tdelay(5000);
  }
}
  temp=0x00;
while(temp==0x00)
{
  printf("waiting for mid_gate_r_sensor to go high\n");
  temp = mid_gate_r_sensor();
  if(temp==0x01)
  {
    printf("mid_gate_r_sensor is HIGH!!!\n");
```

```
        lk_tdelay(5000);
      }
    }
    printf("Sensor test program complete\n");
}
```