

California AHMCT Program
University of California at Davis
California Department of Transportation

**DEVELOPMENT OF SUBSYSTEMS FOR
AN AUTOMATED CONE PLACEMENT
AND RETRIEVAL MACHINE**

Peter K. Tseng
James P. Siacunco
Wilderich A. White
Steven A. Velinsky

AHMCT Research Report
UCD-ARR-96-06-01-01

Interim Report of Contract
DOT 65X938 CONE PLACEMENT

June 1, 1996

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle DEVELOPMENT OF SUBSYSTEMS FOR AN AUTOMATED CONE PLACEMENT AND RETRIEVAL MACHINE		5. Report Date June 1996	
		6. Performing Organization Code	
7. Author(s) Peter K. Tseng, James Siacunco, Wilderich White, Steven A. Velinsky		8. Performing Organization Report No.	
9. Performing Organization Name and Address AHMCT Research Center UCD Dept of Mech & Aero Engineering Davis, California 95616-5294		10. Work Unit No. (TRAIS)	
		11. Contract or Grant RTA-65X938	
12. Sponsoring Agency Name and Address California Department of Transportation P. O. Box 942873, MS 83 Sacramento, CA 94273-0001		13. Type of Report and Period Covered Interim Report March - May 1996	
		14. Sponsoring Agency Code	
15. Supplementary Notes This study was conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration, under the research project entitled "Continued Development of an Automated Machine for Highway Cone Placement and Retrieval"			
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 time and efficiency. The ACM will minimize the exposure of workers to fast moving traffic by having all mechanisms be controlled from within the confines of the truck cab. This report discusses the development of the ACM while emphasizing the design of the retrieval, placement, and stowage subsystems, the operating control system, and the hydraulic drive system. The design process that includes the generation of 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 miniature controller to integrate and activate the hydraulic powered ACM subsystems in predetermined sequences to effectively perform cone handling operations.			
17. Key Words Automation, Robotics, Highway Maintenance, Traffic Cone, Highway Safety, Control Systems, Hydraulic		18. Distribution Statement No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.	
20. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 254	22. Price

DISCLAIMER/DISCLOSURE

"The research reported herein was performed as part of the Advanced Highway Maintenance and Construction Technology Program (AHMCT), within the Department of Mechanical and Aeronautical Engineering at the University of California, Davis and the Division of New Technology and Research of 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. This report does not constitute a standard, specifications or regulation."

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 time and efficiency. The ACM will minimize the exposure of workers to fast moving traffic by having all mechanisms be controlled from within the confines of the truck cab.

This report discusses the development of the ACM while emphasizing the design of the retrieval, placement, and stowage subsystems, the operating control system, and the hydraulic drive system. The design process that includes the generation of 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 miniature controller to integrate and activate the hydraulic powered ACM subsystems in predetermined sequences to effectively perform cone handling operations.

EXECUTIVE SUMMARY

This report documents the development of the Automated Cone Machine (ACM) at the Advanced Highway and Maintenance 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 traffic 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 multi-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 an enormous cone carrying capacity, it can only pick and place 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 highway operations 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 for a bulky rotating 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 will 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.

TABLE OF CONTENTS

ABSTRACT	v
EXECUTIVE SUMMARY	vii
TABLE OF CONTENTS	ix
LIST OF FIGURES	xiii
LIST OF TABLES	xvii
CHAPTER 1: INTRODUCTION	1
1.1 Literature Search	3
1.2 Caltrans Traffic Cones	7
1.3 Current Caltrans Methods	8
1.4 Evaluation of Existing Methods	14
1.5 Problem Description and Objectives	15
CHAPTER 2: SPECIFICATIONS OF THE ACM	17
2.1 Functional Specifications	17
2.2 General Descriptions of the Automated Cone Machine	20
2.3 General Descriptions of the ACM Operational Procedures	25
CHAPTER 3: DESIGN AND DEVELOPMENT OF THE CONE RETRIEVAL AND DEVELOPMENT SYSTEM	35
3.1 Concept Development for the ACM Retrieval System	35
3.2 Selection of Concepts	44
3.3 Break Away Arm Operational Description	47
3.4 Initial Designs for the Dispensing of Cones	51
3.5 Selection of the Dispensing Method	56
3.6 Drop Box Redesigns	68
CHAPTER 4: TESTING AND MODIFICATION OF THE CONE RETRIEVAL AND DEVELOPMENT SYSTEM	63

4.1 Introduction	63
4.2 Strength Analysis	63
4.3 Improvements of Current Design	66
4.4 Testing of the Retrieval System	69
CHAPTER 5: DESIGN AND DEVELOPMENT OF THE FUNNEL SYSTEM	75
5.1 Introduction	75
5.2 The Primary Funnel Component	75
5.3 The Secondary Component	76
5.4 Testing of the Funnel System	78
CHAPTER 6: DESIGN AND DEVELOPMENT OF THE CONE STOWAGE SYSTEM	83
6.1 Introduction	83
6.2 Important Criterion for the Evaluation of Concepts	83
6.3 The Automated Cone Stowage System	88
6.4 Other Trade-Off Concepts	93
6.5 Evaluation of Conceptual Designs	97
CHAPTER 7: THE ACM POWER DELIVERY SYSTEM	101
7.1 Selection of the Power Delivery System	101
7.2 Design Evolution of the Hydraulics	103
CHAPTER 8: THE COORDINATED CONTROL SYSTEM	109
8.1 General Description	109
8.2 Controller Hardware and Software	110
8.3 Development of the ACM Control Code	114
8.4 The Control Scheme	117
CHAPTER 9: CONCLUSIONS AND RECOMMENDATIONS	121
9.1 Conclusions	121

9.2 Recommendations	120
REFERENCES	124
APPENDIX A: CALCULATIONS	125
APPENDIX B: DETAILED DRAWINGS FOR RETRIEVAL SYSTEM	147
APPENDIX C: DETAILED DRAWINGS FOR STOWAGE SYSTEM	178
APPENDIX D: FIRST PHASE PSEUDO CODE	222
APPENDIX E: SECOND PHASE PSEUDO CODE	245

LIST OF FIGURES

Figure 1.1	Traffic Cone Retriever	4
Figure 1.2	The Baliseur Cone Picker	5
Figure 1.3	Cone Wheel Dispenser and Collector	6
Figure 1.4	Lane Closure Configuration	10
Figure 1.5	Cone Body Vehicle	11
Figure 1.6	Cone Body with Crew Workers	12
Figure 1.7	Cone Body with Crew Workers	12
Figure 2.1	The Automated Cone Machine	19
Figure 2.2	The Primary Funnel Configuration	20
Figure 2.3	The Secondary Funnel Configuration	21
Figure 2.4	The Integrated Dispensing and Retrieval Configuration	22
Figure 2.5	The Lateral Conveyor System	23
Figure 2.6	The Automated Cone Stowage System	24
Figure 2.7	Configuration A	26
Figure 2.8	Configuration B	27
Figure 2.9	Desired Orientation of Traffic Cone for Retrieval	29
Figure 2.10a	Free Gate Option for Cones Between 0 and 180 Degrees	30
Figure 2.10b	Free Gate Allows Cone to Pass Underneath	30
Figure 2.11	Rigid Gate Option for Cones Between 180 and 360 Degrees	31
Figure 2.12	Locked Gate Causes Traffic Cone to Straighten	32
Figure 2.13	Locked Gate Stands Traffic Cone	32
Figure 2.14	Retrieval of Standing Cones	34
Figure 3.1	Three Prong Concept pick up sequence with base first	36
Figure 3.2	Three Prong Concept pick up sequence tip first	37
Figure 3.3	Cone Base Retrieval Concept	39

Figure 3.4	Retrieval using Contoured Surface	41
Figure 3.5	Double Retrieval Arm	42
Figure 3.6	Break Away Arm	43
Figure 3.7	Break Away Arm Cone Retriever	58
Figure 3.8	Side View of Break Away Concept	50
Figure 3.9	Top View of Break Away Concept	50
Figure 3.10	Rear View of Break Away Concept	51
Figure 3.11	Sliding Plate Concept	52
Figure 3.12	Conveyor Chute Dispenser	53
Figure 3.13	Drop Chute with Wheels	54
Figure 3.14	Drop Box with Stabilizing Wheels	56
Figure 3.15	Rubber Flaps Used for Dispensing Cones	59
Figure 3.16	Rubber Flaps Bent Rearward	59
Figure 3.17	IDRC Using Nylon Buffers	60
Figure 4.1	Side View of Side Bar and Retaining Door	67
Figure 4.2	End View of Side Bar and Retaining Door	68
Figure 4.3	Advanced Timing Elements	69
Figure 4.4	Addition to Poker Arm	71
Figure 4.5	Modified Retaining Door	72
Figure 4.6	Retrieval Arm in Ready Position	74
Figure 4.7	Retrieval Arm After Stripping Cone	74
Figure 5.1	Top View of Cone Truck with Funnel System	76
Figure 5.2	Side View of Cone Truck with Funnel System	77
Figure 5.3	Back View of Cone Truck with Funnel System	77
Figure 5.4	Adjustable Funnel Parameters	79
Figure 6.1	Longitudinal Conveyor Assembly	84
Figure 6.2	Top View of the Available Space in the LCS	85

Figure 6.3	Top View of the Location of the Stowage System	86
Figure 6.4	Allocated Space for the Traffic Cone Stowage System	87
Figure 6.5	Top View of the Automated Cone Stowage System	89
Figure 6.6	Gripper Mechanisms on the ACSS	90
Figure 6.7	Rotational Motion Caused by the Linkage System	91
Figure 6.8	The Rotating Stowage Assembly	94
Figure 6.9	The Swivel Stowage Unit	95
Figure 6.10	The Rotating Swivel System in Retrieval Mode	96
Figure 7.1	First Hydraulic Schematic	103
Figure 7.2	Second Hydraulic Schematic	104
Figure 7.3	Current Hydraulic Schematic	105
Figure 7.4	Hydraulic Distribution Box	106
Figure 8.1	Zworld Little Giant Miniature Controller	111
Figure 8.2	Zworld Keypad Display Module	112
Figure 8.3	Zworld Relay6 Expansion Board	113
Figure 8.4	Zworld IOE-DGL96 Expansion Board	113
Figure A.1	Reference Drawing for Calculation 4.1	131
Figure A.2	Reference Drawing for Calculation 4.2	136
Figure A.3	Reference Drawing for Calculation 4.2	136
Figure A.4	Reference Drawing for Calculation 4.2	137
Figure A.5	Reference Drawing for Calculation 4.2	137

LIST OF TABLES

Table 1.1	Physical Properties of Traffic Cones	8
Table 3.1	Trade-offs for Retrieval Designs	45
Table 3.2	Trade-offs Table for Dispensing Concepts	57
Table 3.3	Test Results of Dispensing	61
Table 4.1	Test Results of Retrieval	70
Table 4.2	Laboratory Test Results of Retrieval	73
Table 5.1	Funnel Test Results on First Run	78
Table 5.2	Funnel Test Results on Second Run	80
Table 5.3	Funnel Test Results on Following Run with Tipping Bar	80
Table 6.1	Trade-Off Table for Conceptual Designs	99
Table 7.1	Trade-off Table of Power Delivery	102
Table 8.1	Zworld Input Designations	115
Table 8.2	Zworld Output Designations	115
Table 8.3	Operating Scenarios	116

CHAPTER 1 INTRODUCTION

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 common method used worldwide. Current lane closure operations in many of the California districts make use of a vehicle known as the cone body. While placing cones from the tailgate of a pick up truck is a common practice, 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 heavy duty full-sized trucks. 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 thesis is to develop 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.

1.1 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 be 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.

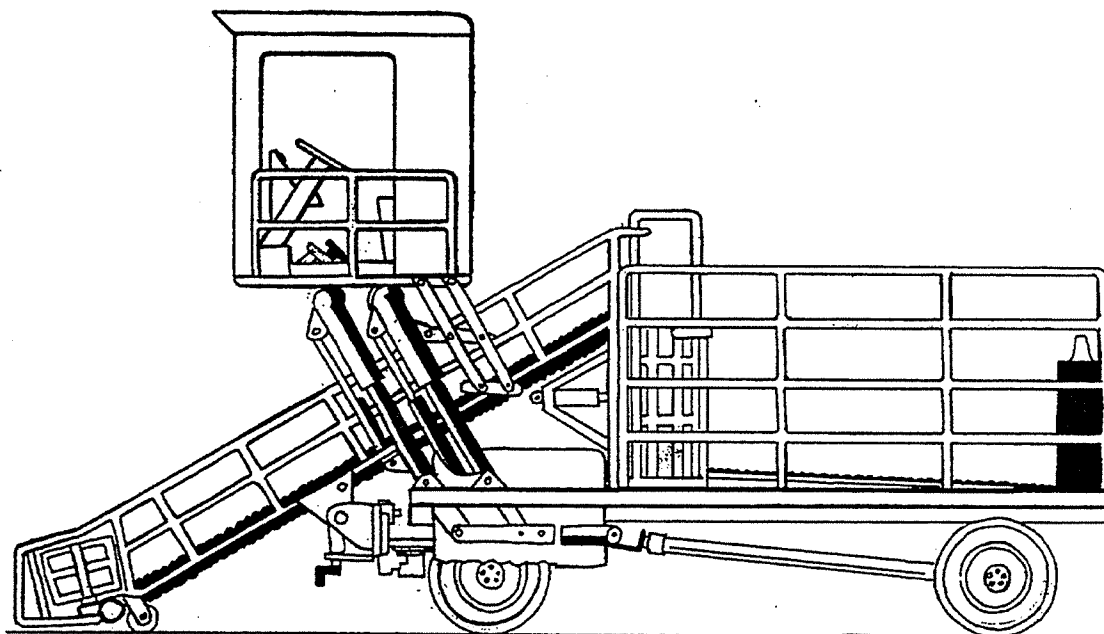


Figure 1.1 *Traffic Cone Retriever (from Fig. 1 of patent 3750900)*

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.

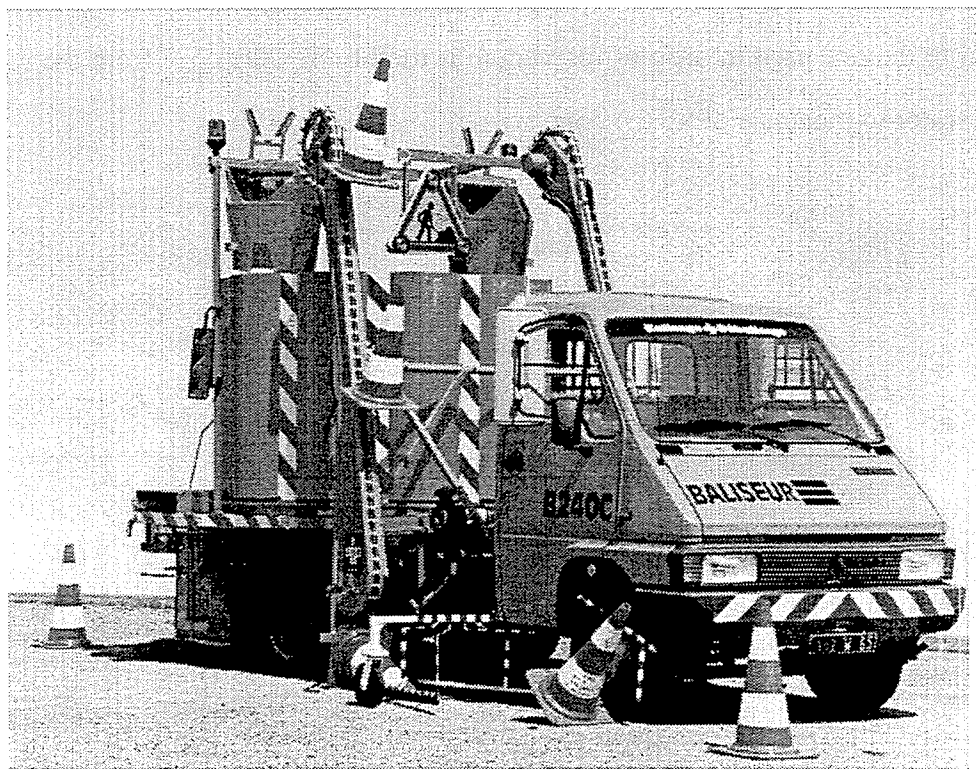


Figure 1.2 *The Baliseur Cone Picker (from SEP advertisement)*

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.

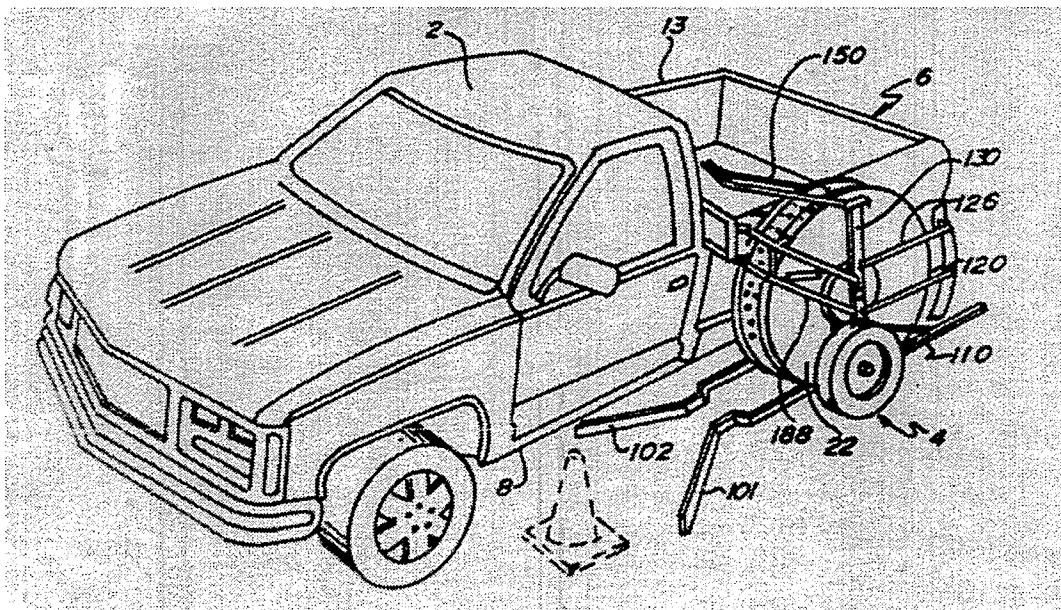


Figure 1.3 Cone Wheel Dispenser and Collector (from Fig. 1 of patent 5054648)

1.2 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 obtain a wide selection 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 Properties	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)

1.3 Current Caltrans Methods

1.3.1 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 right side 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.

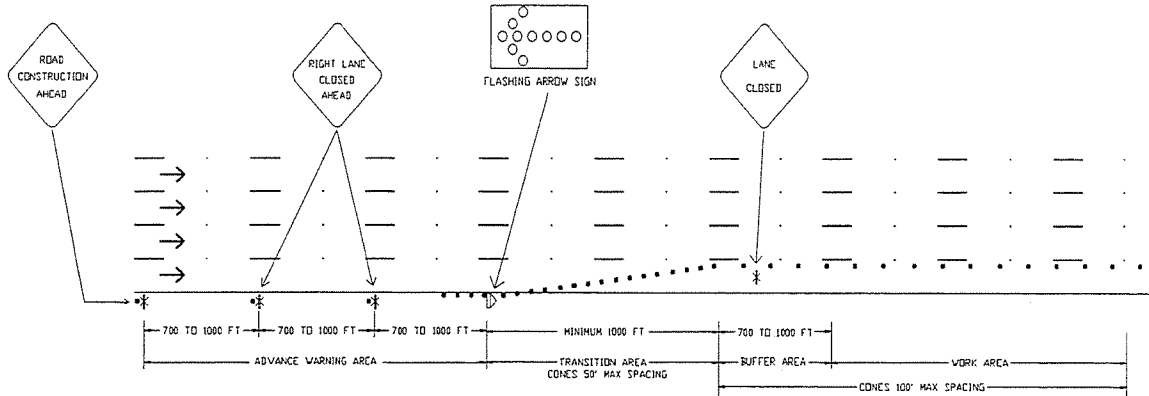


Figure 1.4 Lane Closure Configuration (from Caltrans Traffic Manual, 1990)

1.3.2 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.

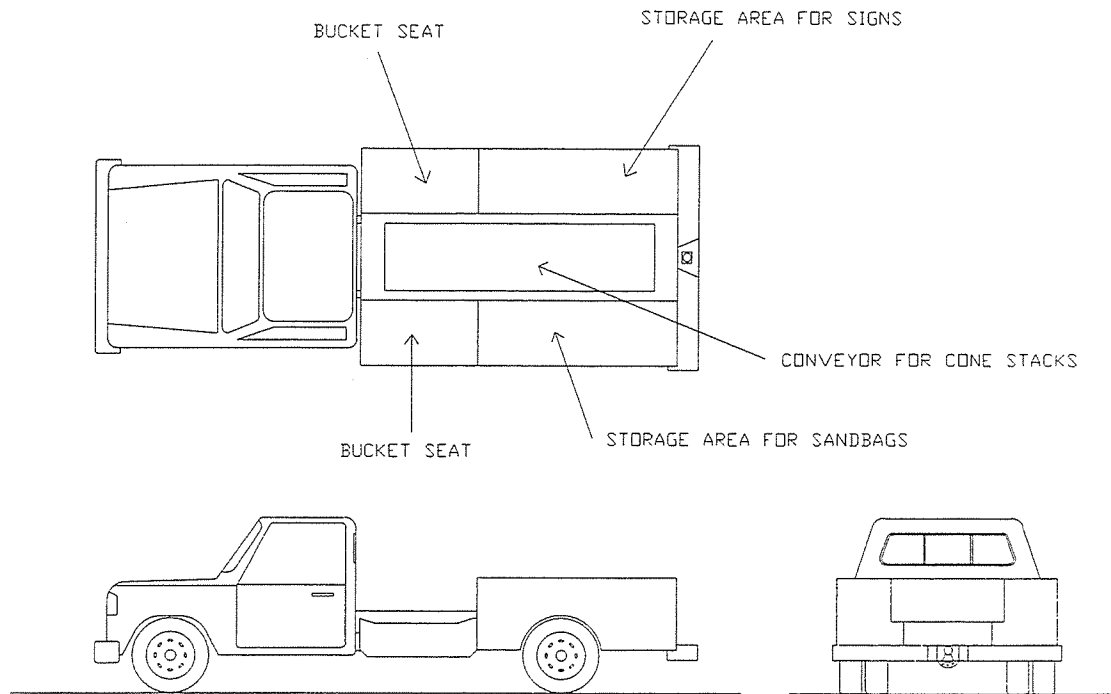


Figure 1.5 *Cone body vehicle*

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 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. Dual communication between the vehicle driver and the worker in the bucket is emphasized in cone retrieval to ensure accurate pick up positioning.

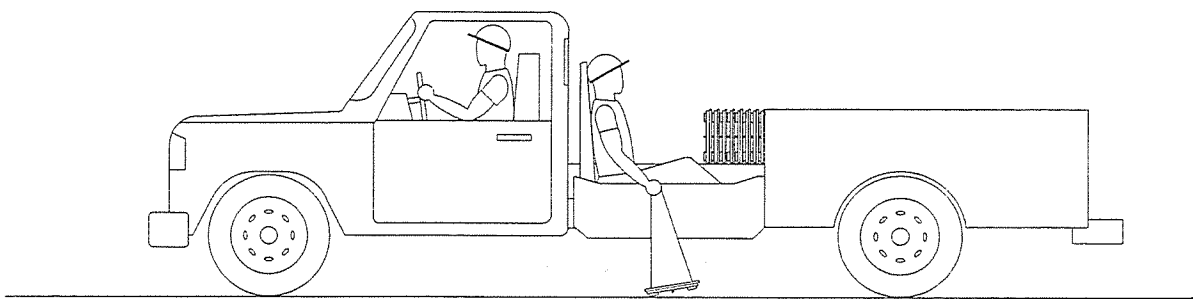


Figure 1.6 *Cone body vehicle with crew workers (side view)*

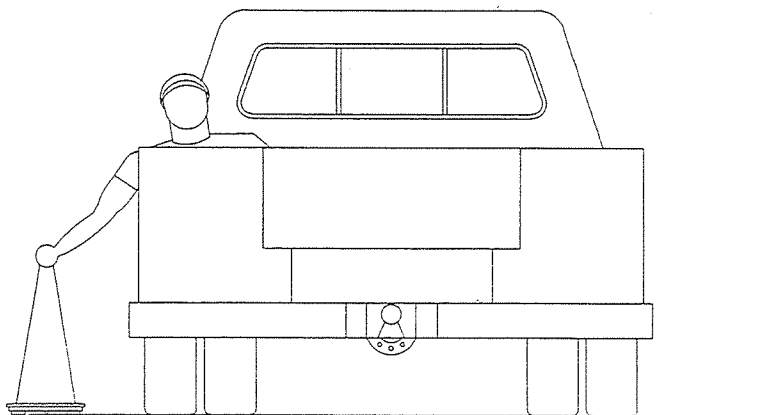


Figure 1.7 *Cone body with crew workers (rear view)*

1.3.3 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 vehicle's 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 increase 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.

1.4 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. The Cone Wheel does not satisfy functional requirements because it simply cannot retrieve cones that have fallen and the mechanisms are susceptible to jamming. Since the operator of the cones 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.

1.5 Problem Description and Objectives

The investigation of commercially available machines has shown that none of the existing automated mechanisms 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 an incredibly hazardous environment and are required to endure potentially injurious repetitive motion. Thus, 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. This report contains the functional specifications for the complete automated system and the design and development of the Automated Cone Stowage System and the Coordinated Control Unit.

CHAPTER 2 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.

2.1.1 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

2.1.2 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.

2.1.3 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.

2.1.5 Traffic Cones

The ACM has a minimum storage capacity of eighty traffic cones on its large 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.

2.1.4 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.

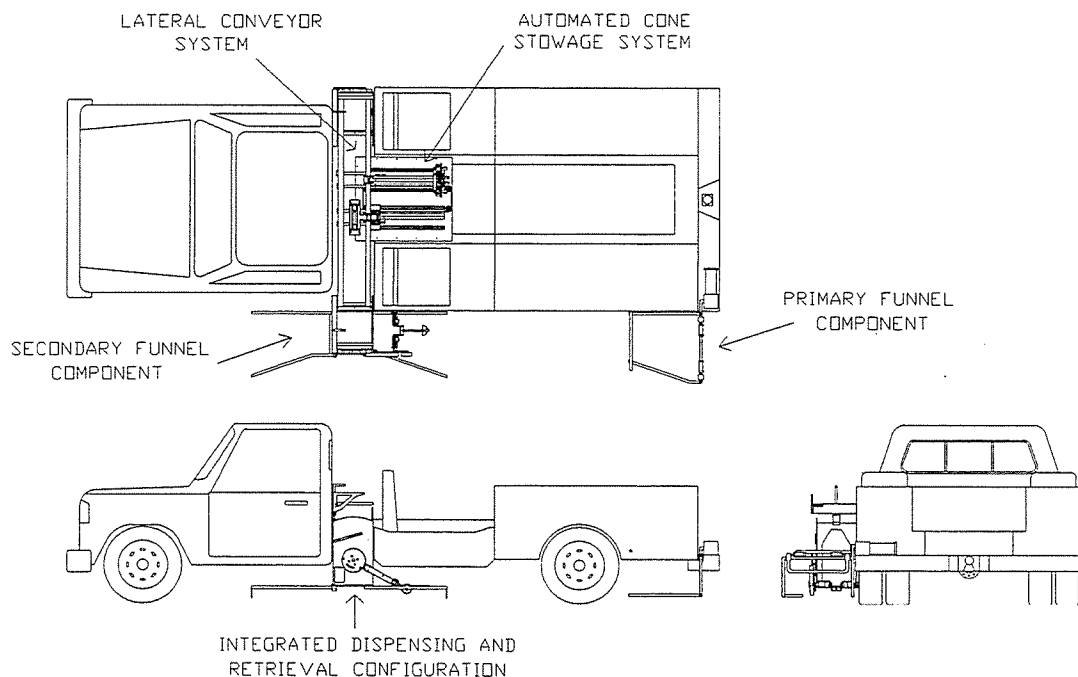


Figure 2.1 *The Automated Cone Machine*

2.2 General Description of the Automated Cone Machine

2.2.1 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 cables placed at the ends of the rods prevent traffic cones from getting jammed between the rods and the road.

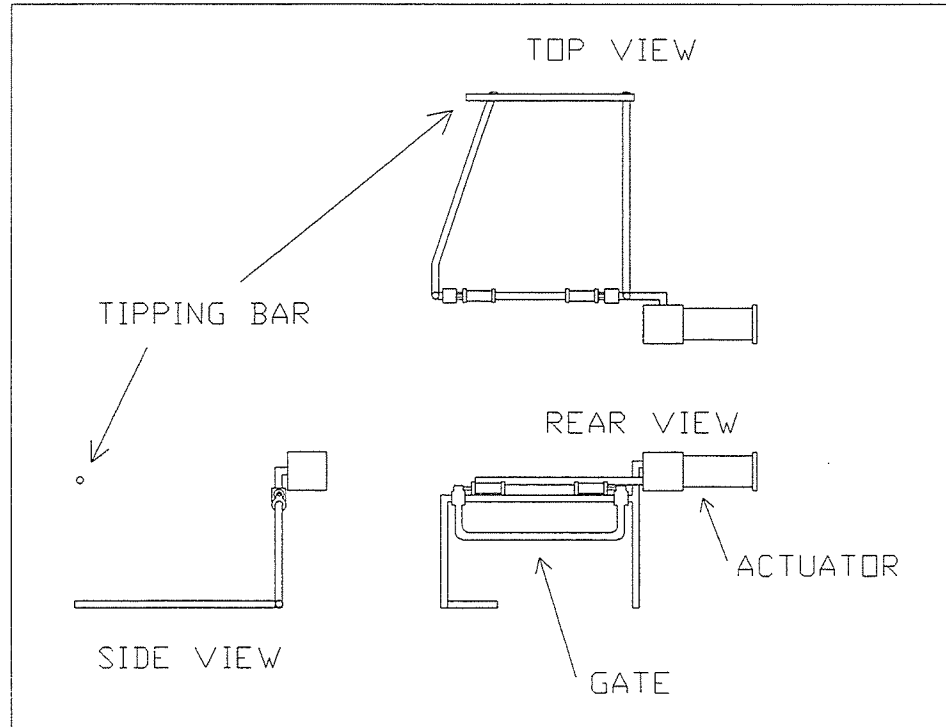


Figure 2.2 *The Primary Funnel Component of the Funnel System*

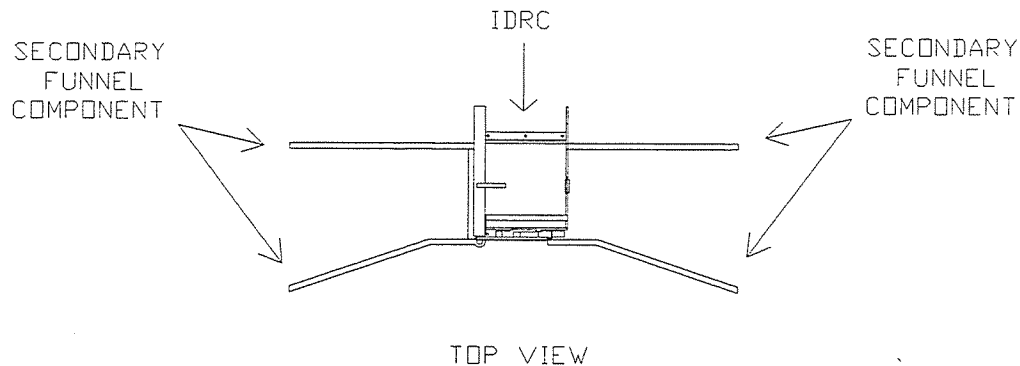


Figure 2.3 *The Secondary Funnel Component of the Funnel System*

2.2.2 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.

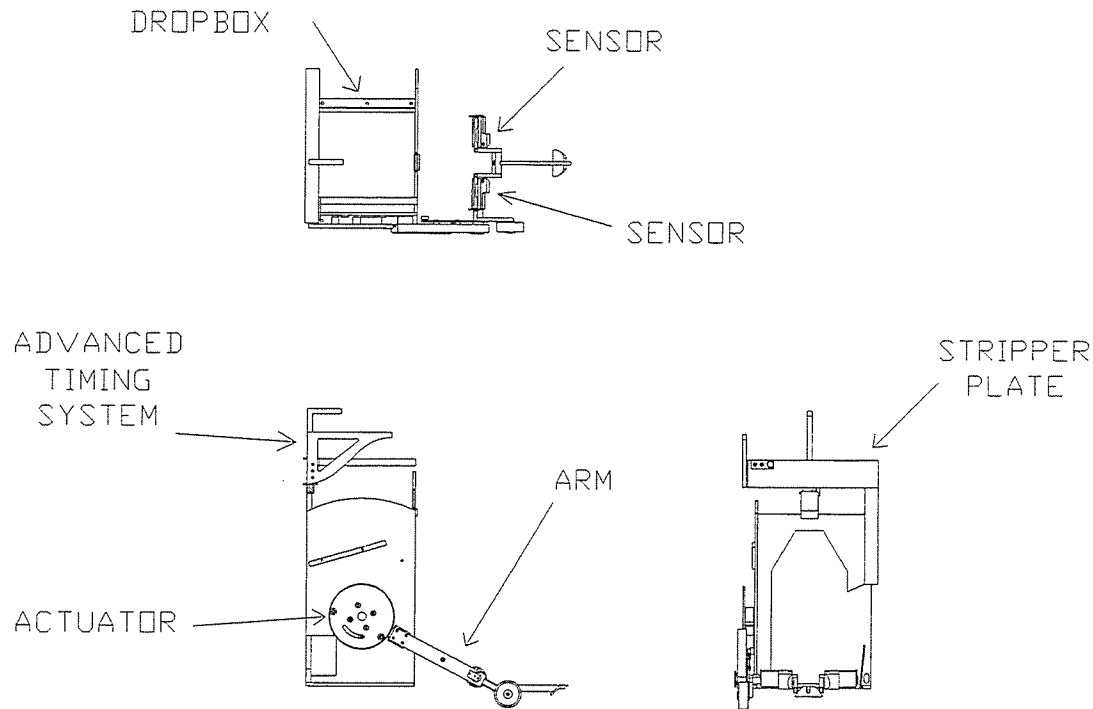


Figure 2.4 *The Integrated Dispensing and Retrieval Configuration*

2.2.3 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.

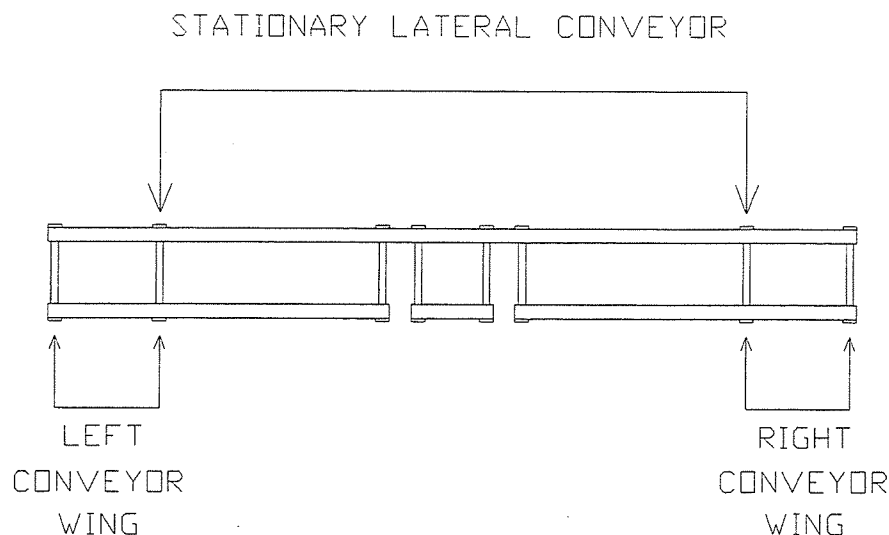


Figure 2.5 *The Lateral Conveyor System*

2.2.4 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 press against the inside surfaces 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.

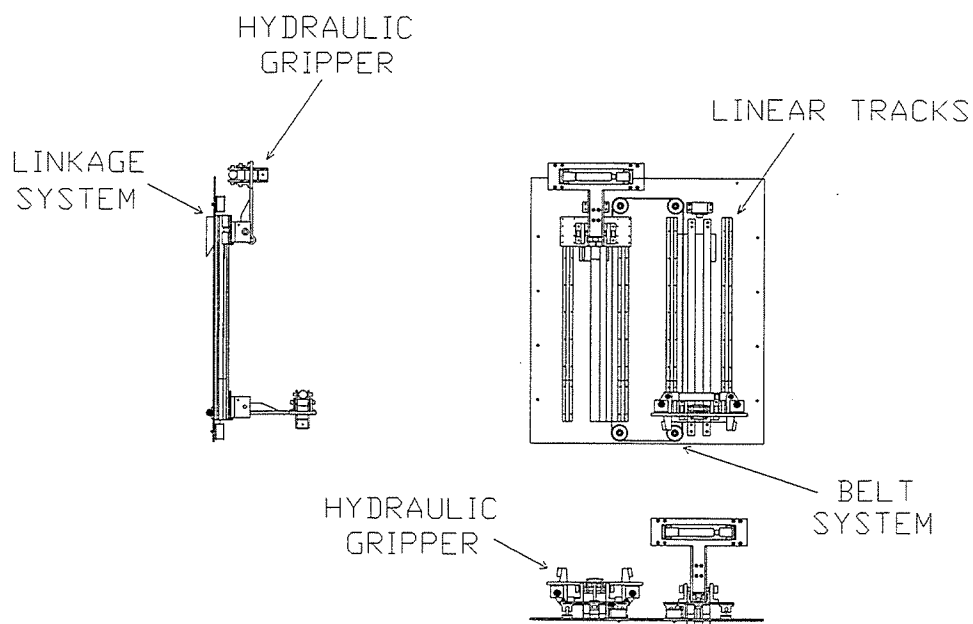


Figure 2.6 *The Automated Cone Stowage System*

2.2.5 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.

2.3 General Descriptions of ACM Operational Procedures

2.3.1 Preoperational 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 detailed 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 be 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.

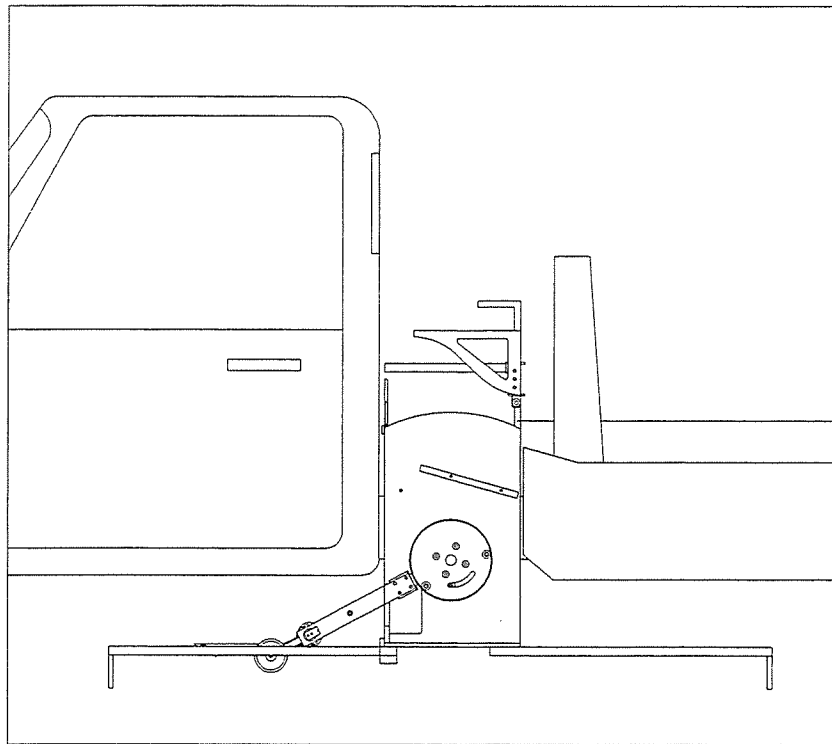


Figure 2.7 *Configuration A*

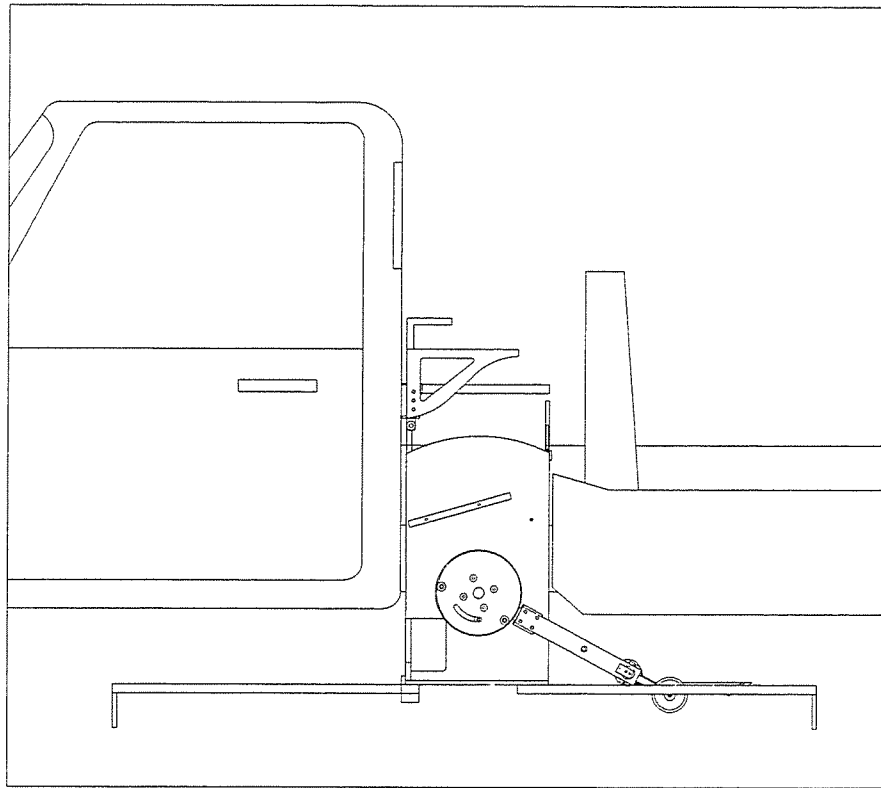


Figure 2.8 *Configuration B*

2.3.2 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.

2.3.3 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. Figures 2.10 and 2.11 show the decisions that the driver must make in order to effectively use the PFC.

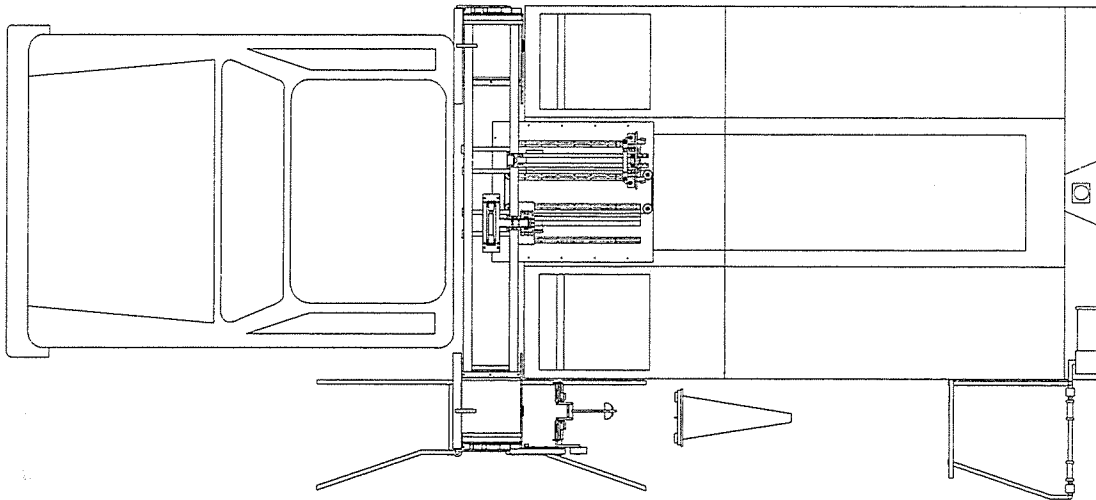


Figure 2.9 *Desired orientation of traffic cone for retrieval*

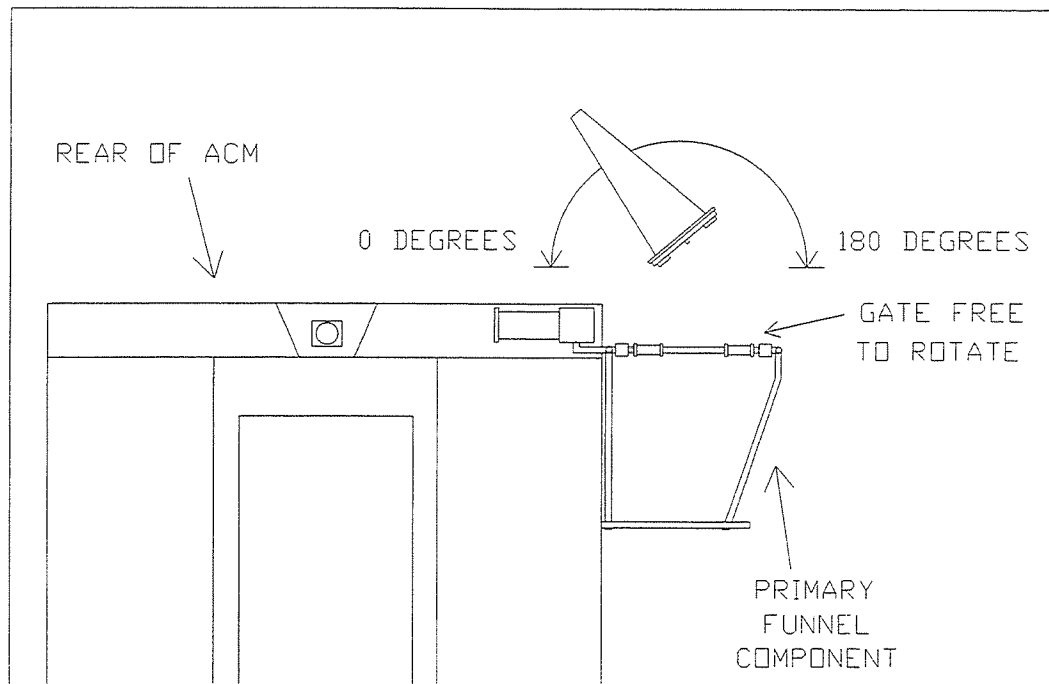


Figure 2.10a *Free gate option for cones situated between 0 and 180 degrees*

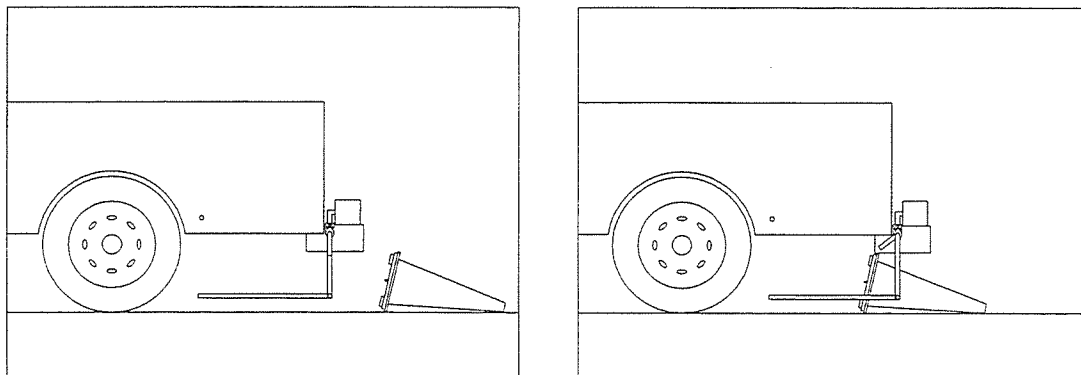


Figure 2.10b *Free gate allows cone to pass underneath*

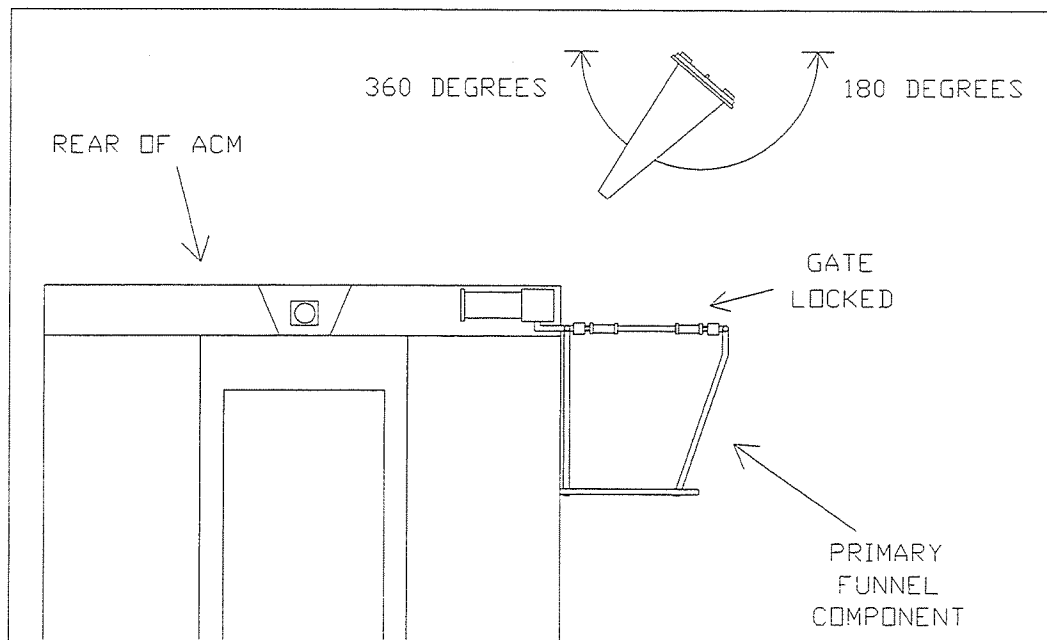


Figure 2.11 *Rigid gate option for cones situated between 180 and 360 degrees*

Figures 2.10a and 2.10b 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 2.11 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.

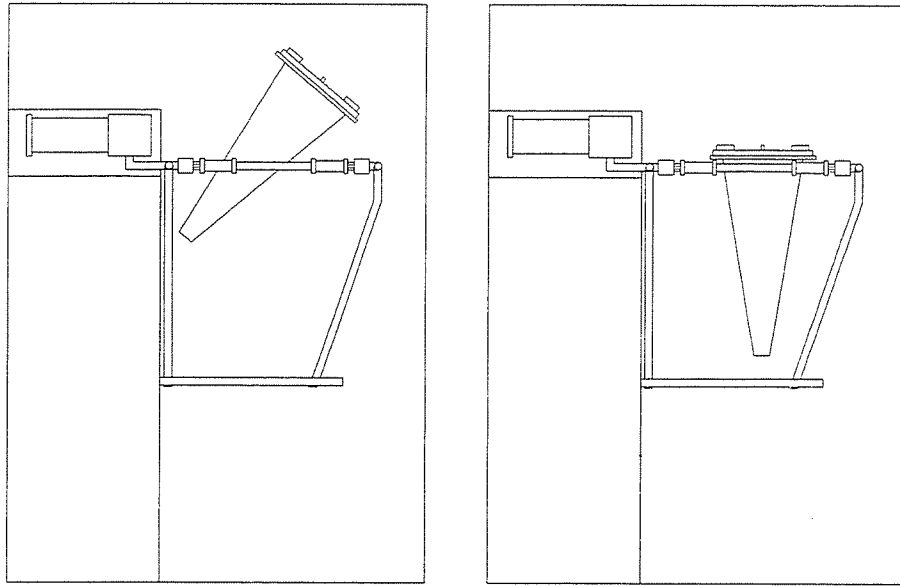


Figure 2.12 *Locked gate causes traffic cone to straighten*

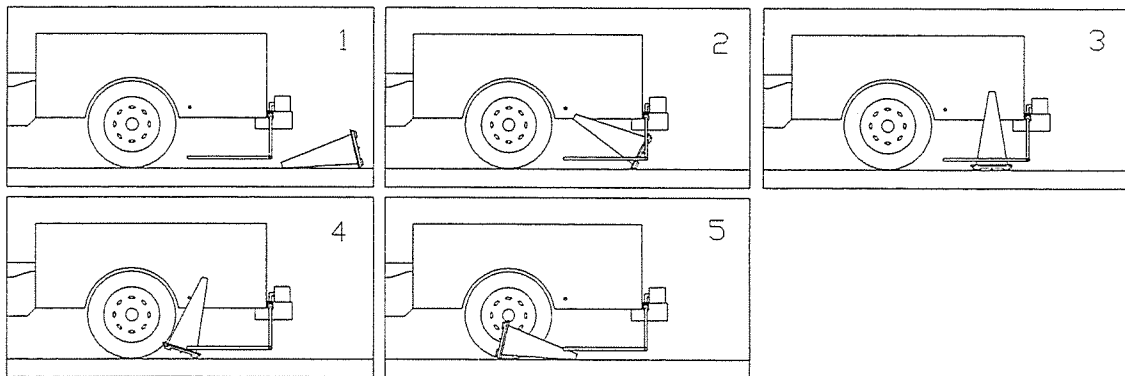


Figure 2.13 *Locked gate stands traffic cone and tipping bar topples it into desired base first orientation*

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.

2.3.4 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.

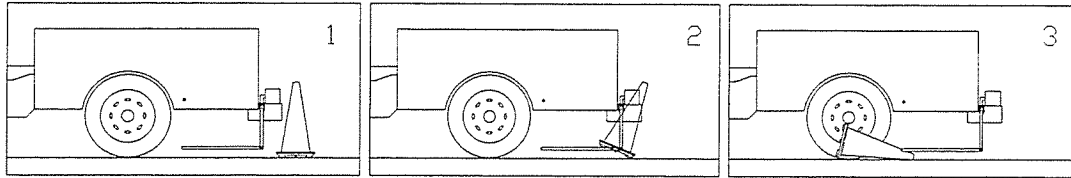


Figure 2.14 *Retrieval of standing cones*

CHAPTER 3 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.

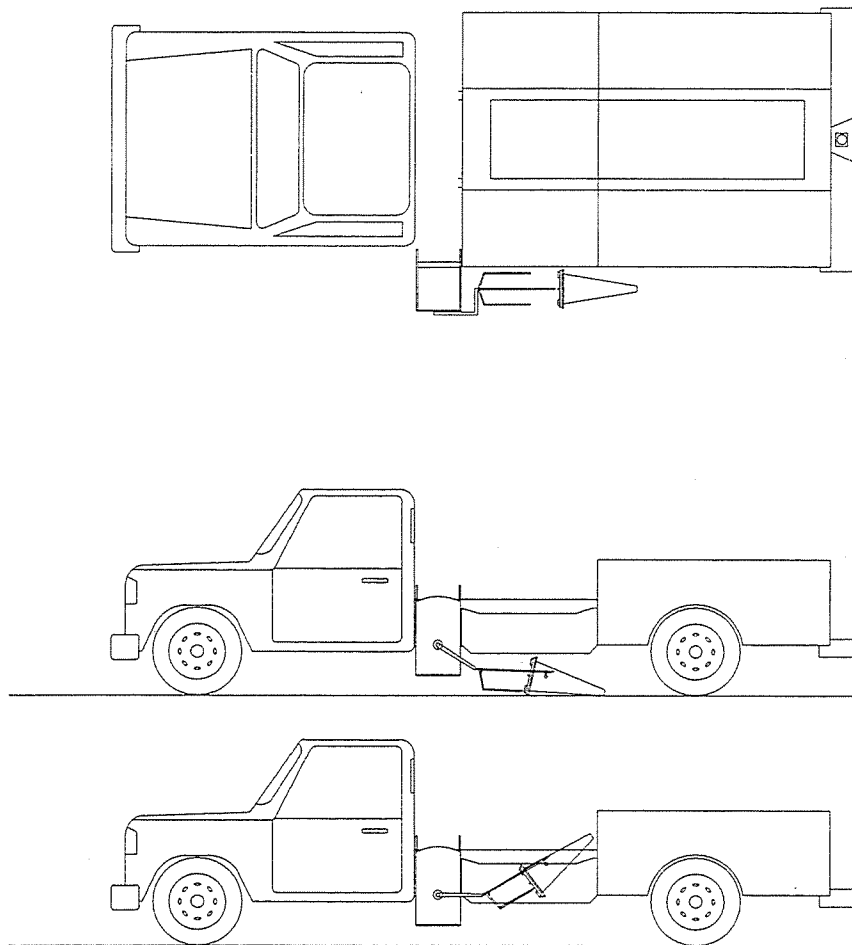


Figure 3.1 *Three Prong Concept pick up sequence with cone base first*

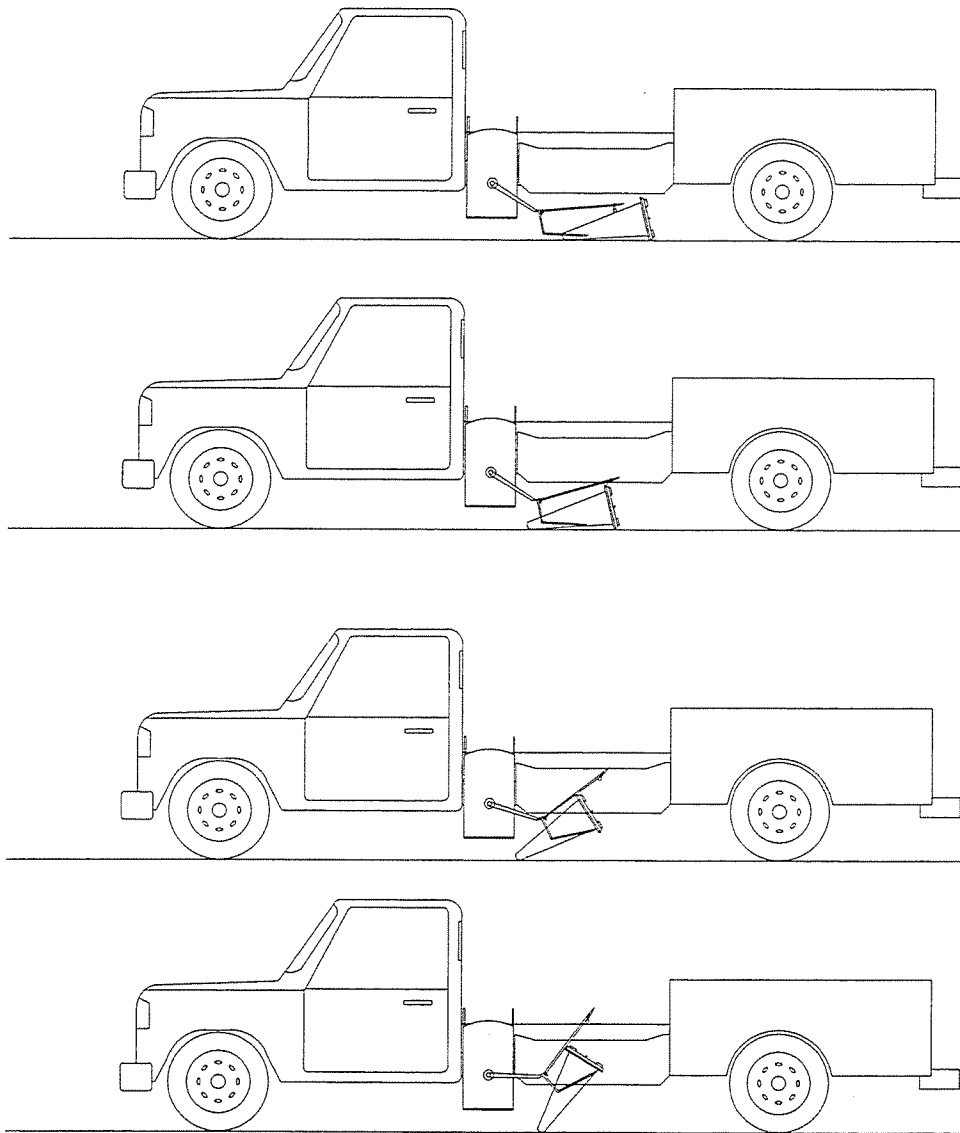


Figure 3.2 *Three Prong Concept pick up sequence tip first*

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.

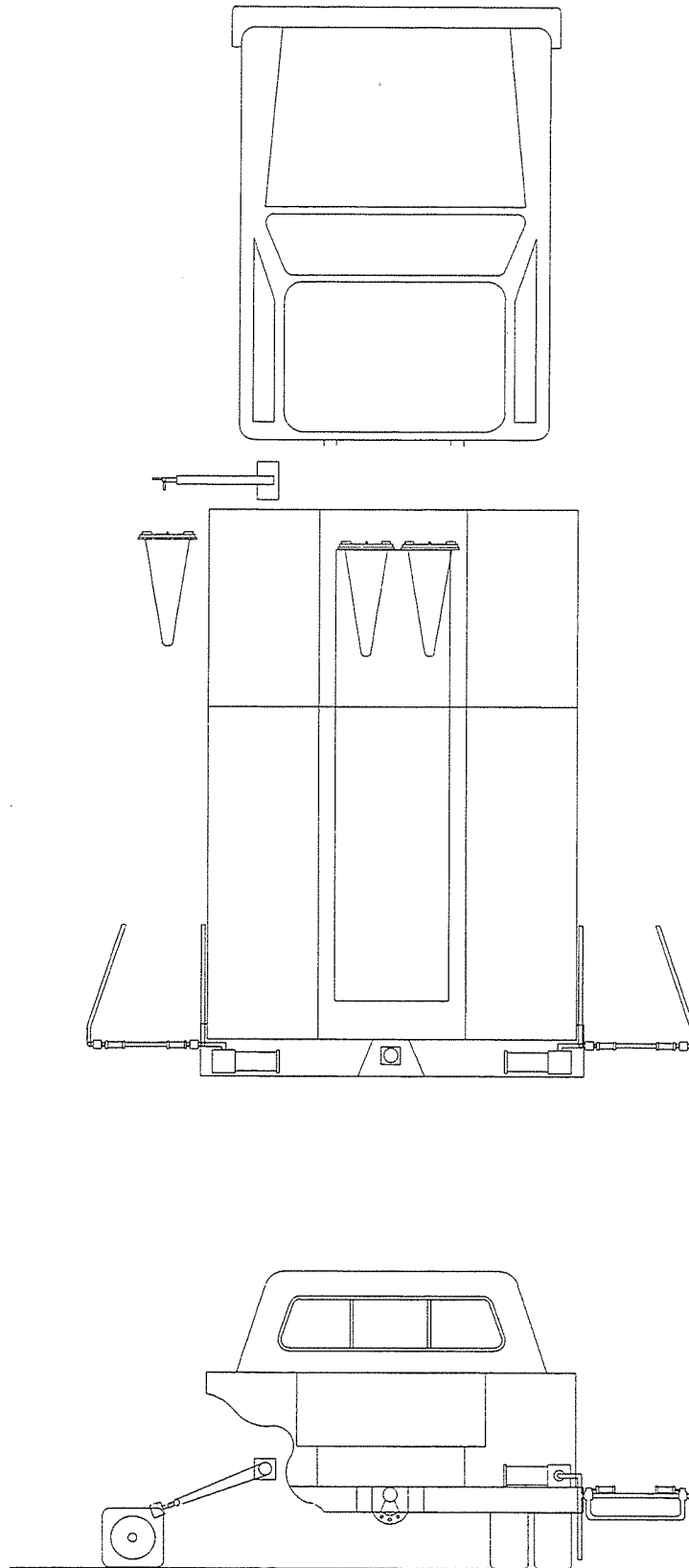


Figure 3.3 *Cone Base Retrieval Concept (cut away back view)*

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 than 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.

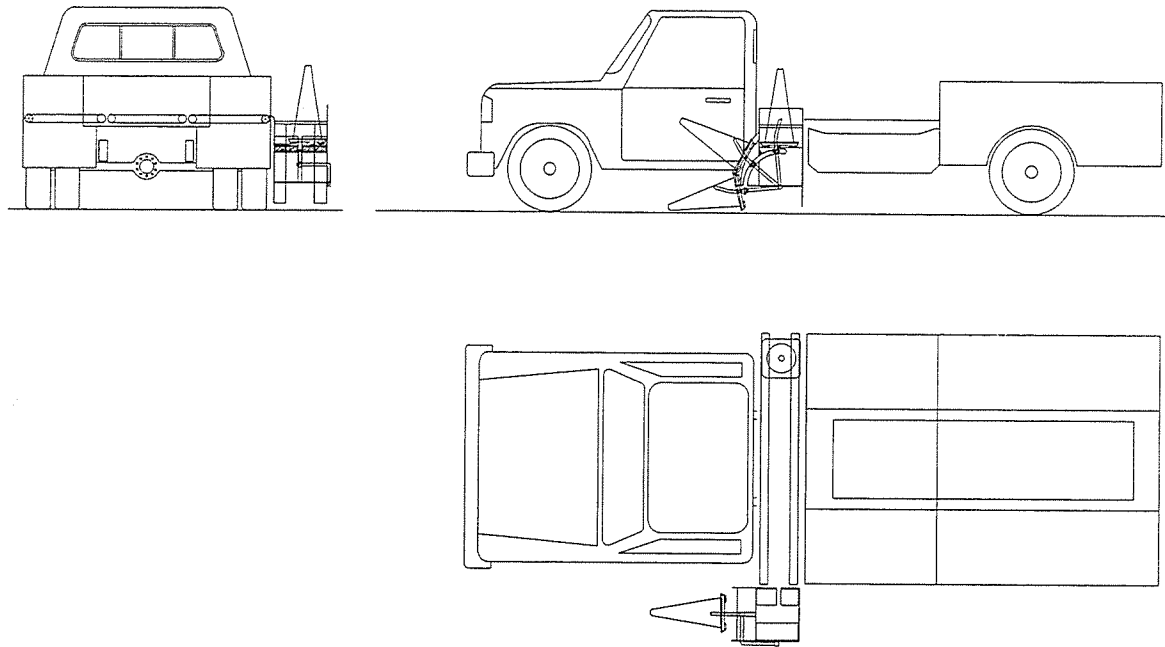


Figure 3.4 *Retrieval using Contoured Surface*

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.

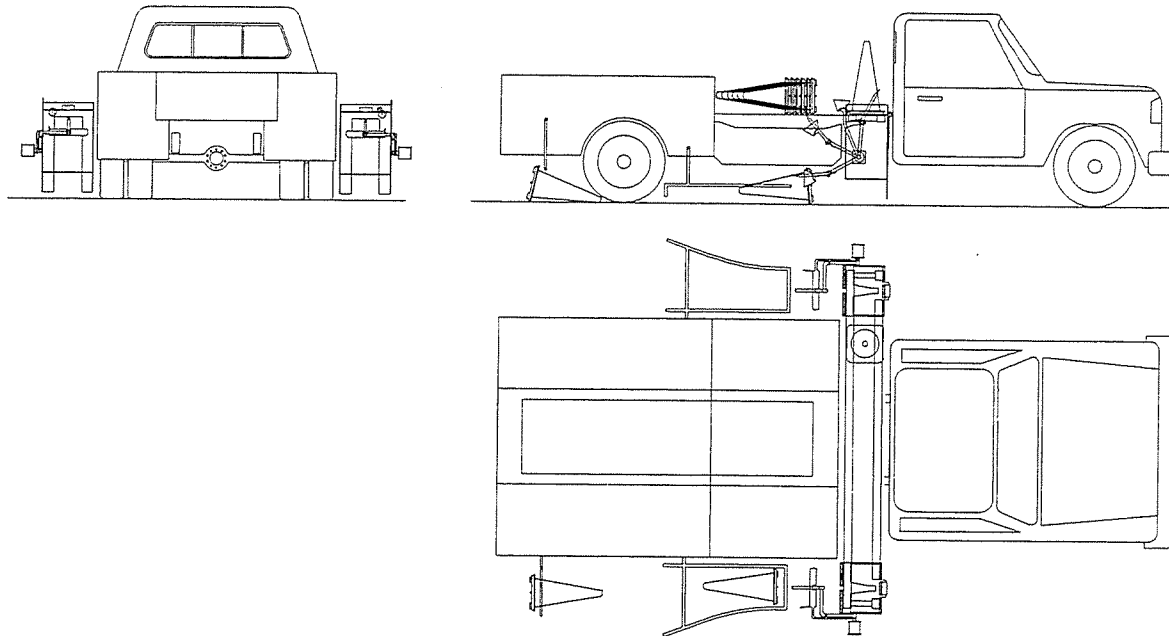


Figure 3.5 *Double Retrieval Arm*

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.

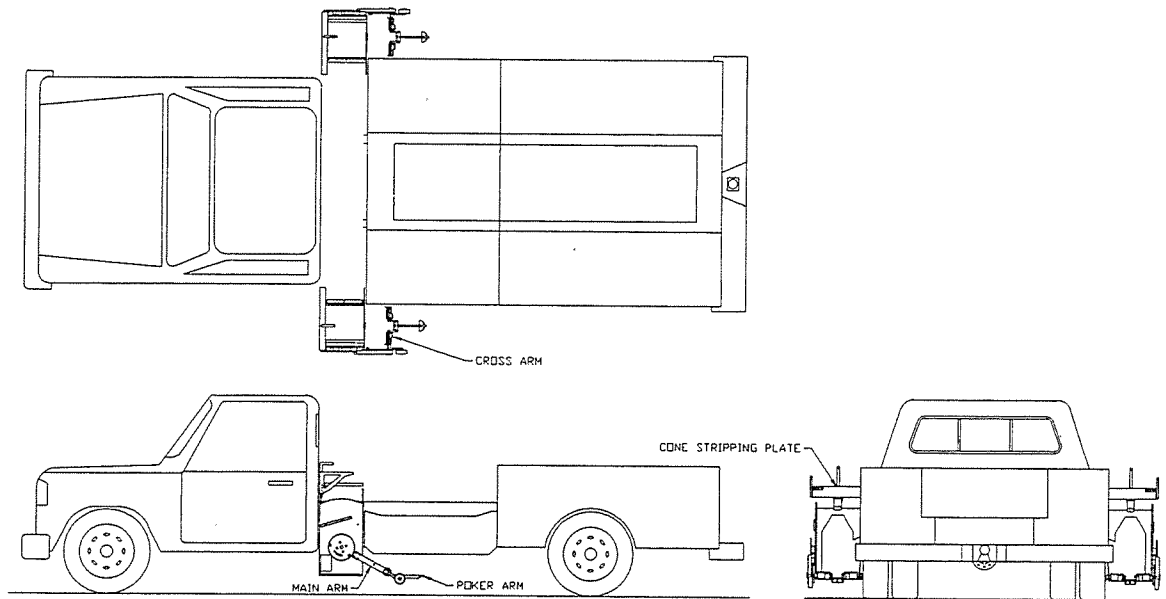


Figure 3.6 Break Away Arm

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.

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

Table 3.1 Trade-offs for Retrieval Designs

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 positioned being restricted by a retaining spring that can be seen in Figure 3.8.

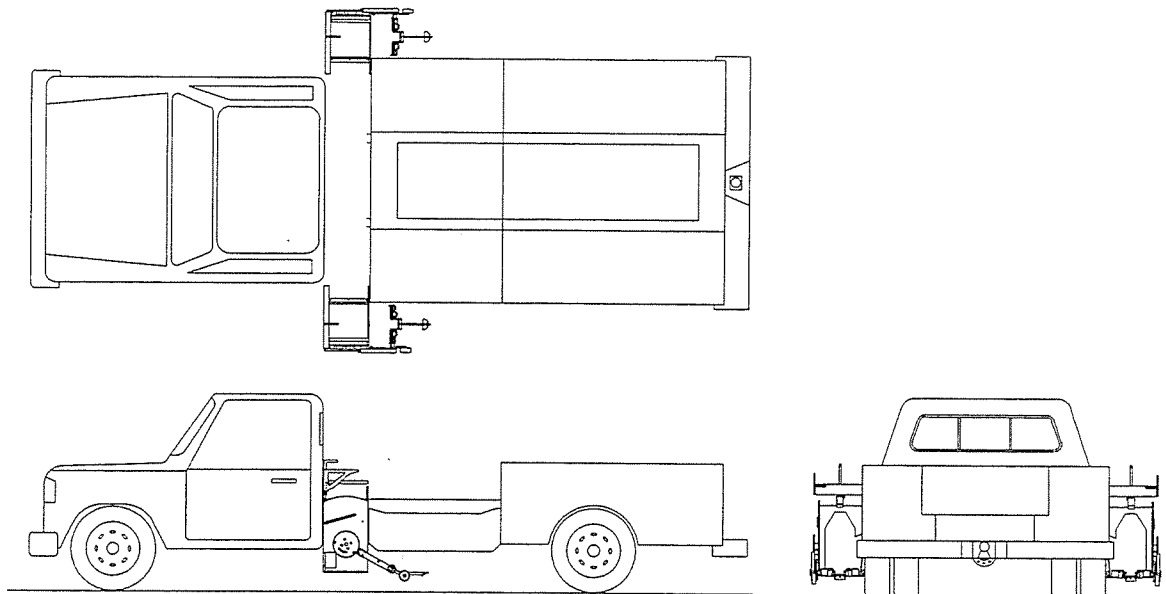


Figure 3.7 *Break Away Arm Cone Retriever*

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.

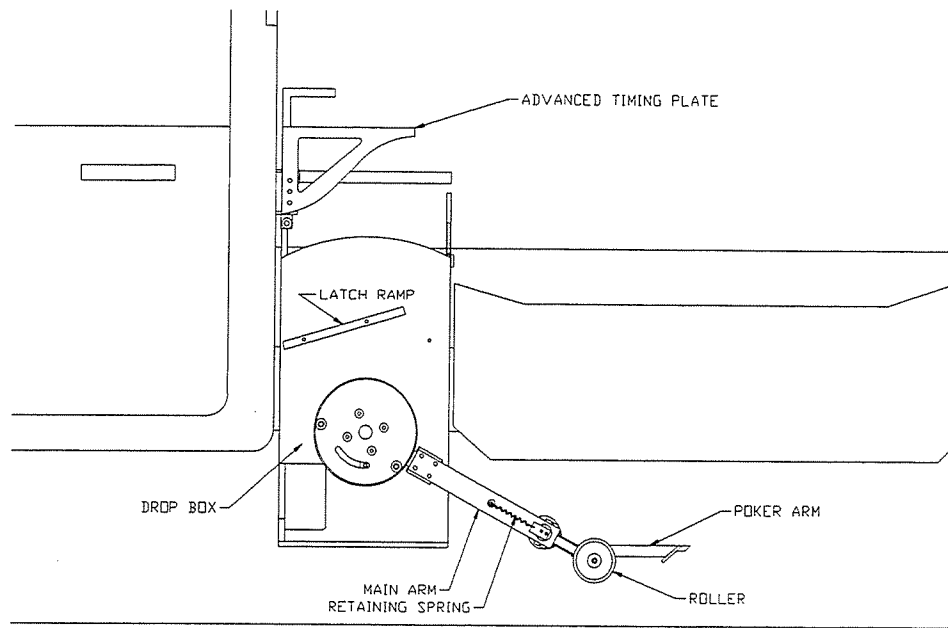


Figure 3.8 *Side View of Break Away Concept*

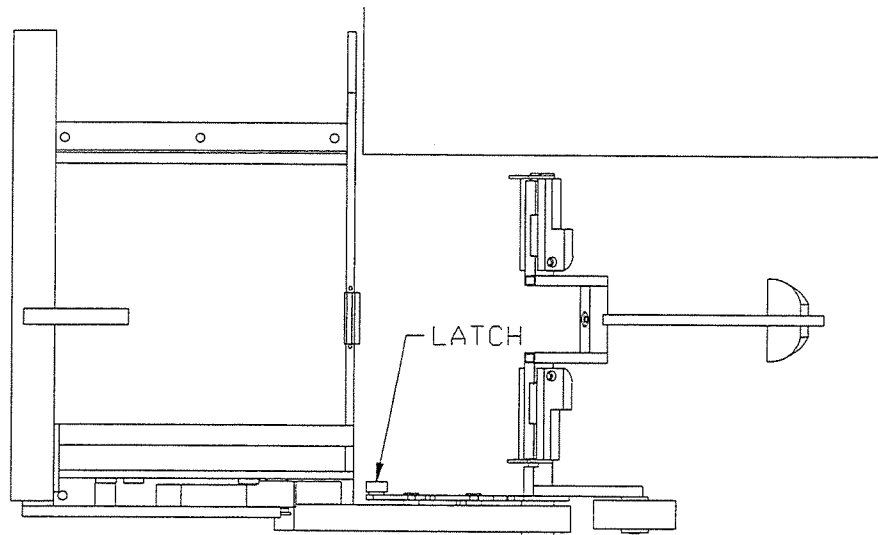


Figure 3.9 *Top View of Break Away Concept*

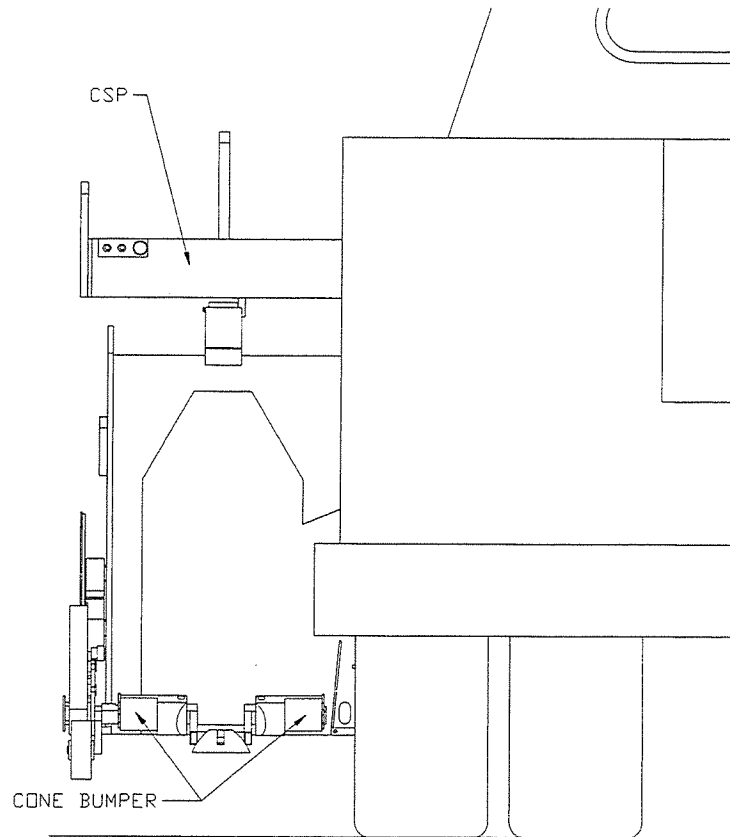


Figure 3.10 *Rear View of Break Away Concept*

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 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.

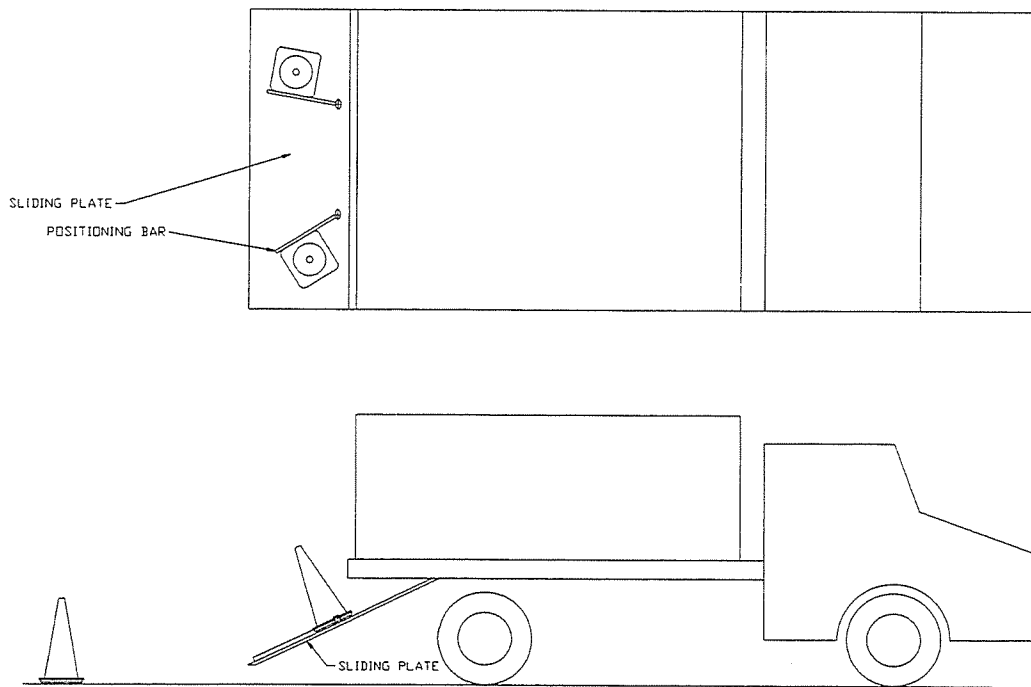


Figure 3.11 *Sliding Plate Concept*

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.

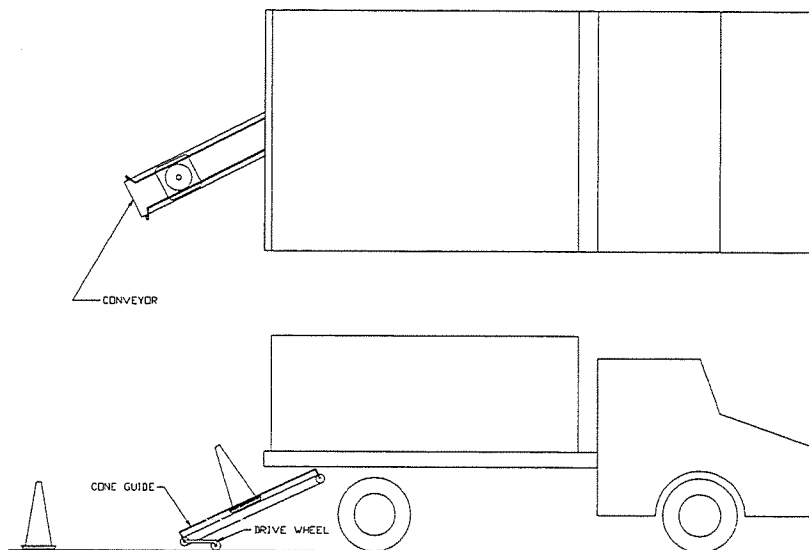


Figure 3.12 *Conveyor Chute Dispenser*

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.

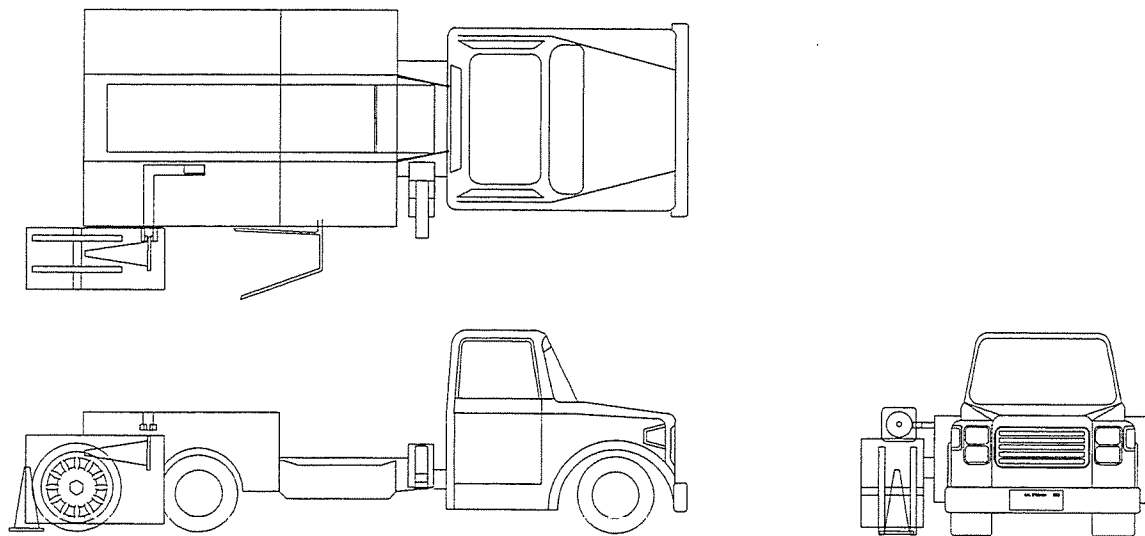


Figure 3.13 *Drop Chute with Wheels*

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.

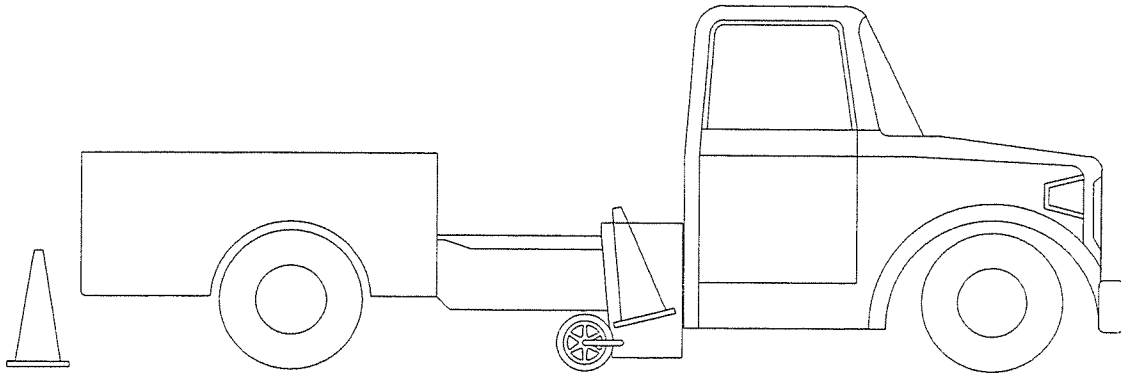


Figure 3.14 *Drop Box with Stabilizing Wheels*

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.

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 bkwr	3	0	0	0	0
4. Pick/Place opposite side moving bkwr	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

Table 3.2 Trade-off Table for Dispensing Concepts

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 or 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.

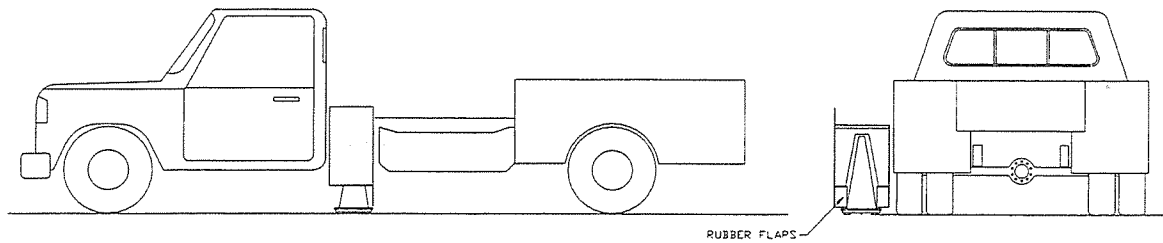


Figure 3.15 *Rubber Flaps Used for Dispensing Cones*

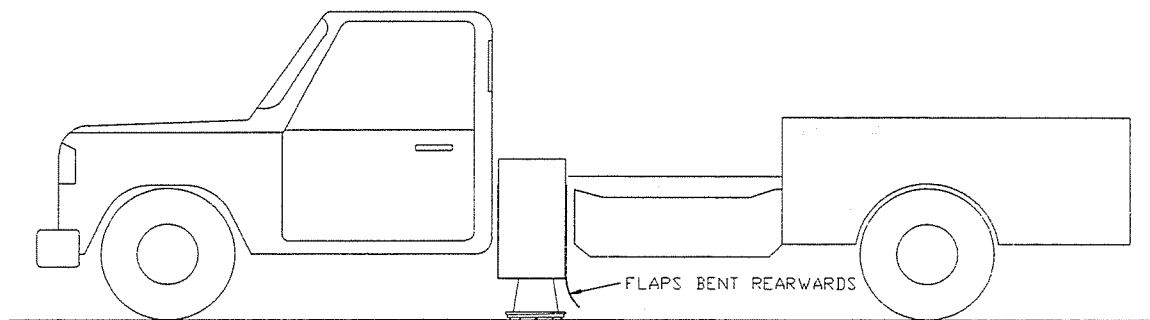


Figure 3.16 *Rubber Flaps Bent Rearward*

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.

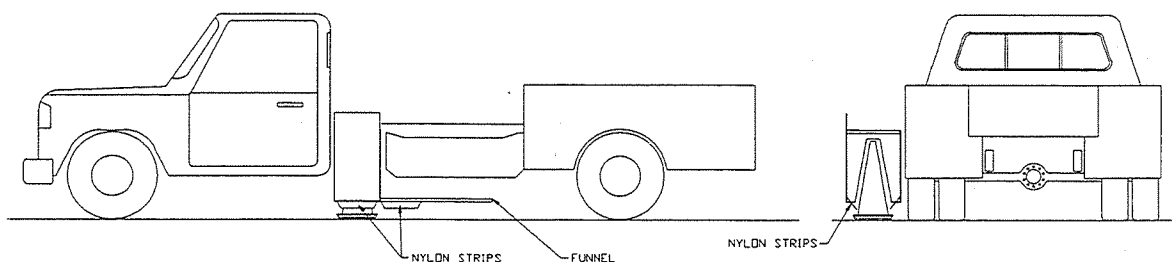


Figure 3.17 IDRC Using Nylon Buffers

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

Table 3.3 *Test Results of Dispensing*

CHAPTER 4 TESTING AND MODIFICATION OF THE CONE RETRIEVAL AND DEVELOPMENT 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 4940 MPa (716 psi) making nearly any material suitable for use (see Appendix A Calc4-1). 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. From Calc4-2, the cross member takes 797 N (179 lbf) of 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 483 MPa (70 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 35.

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 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.

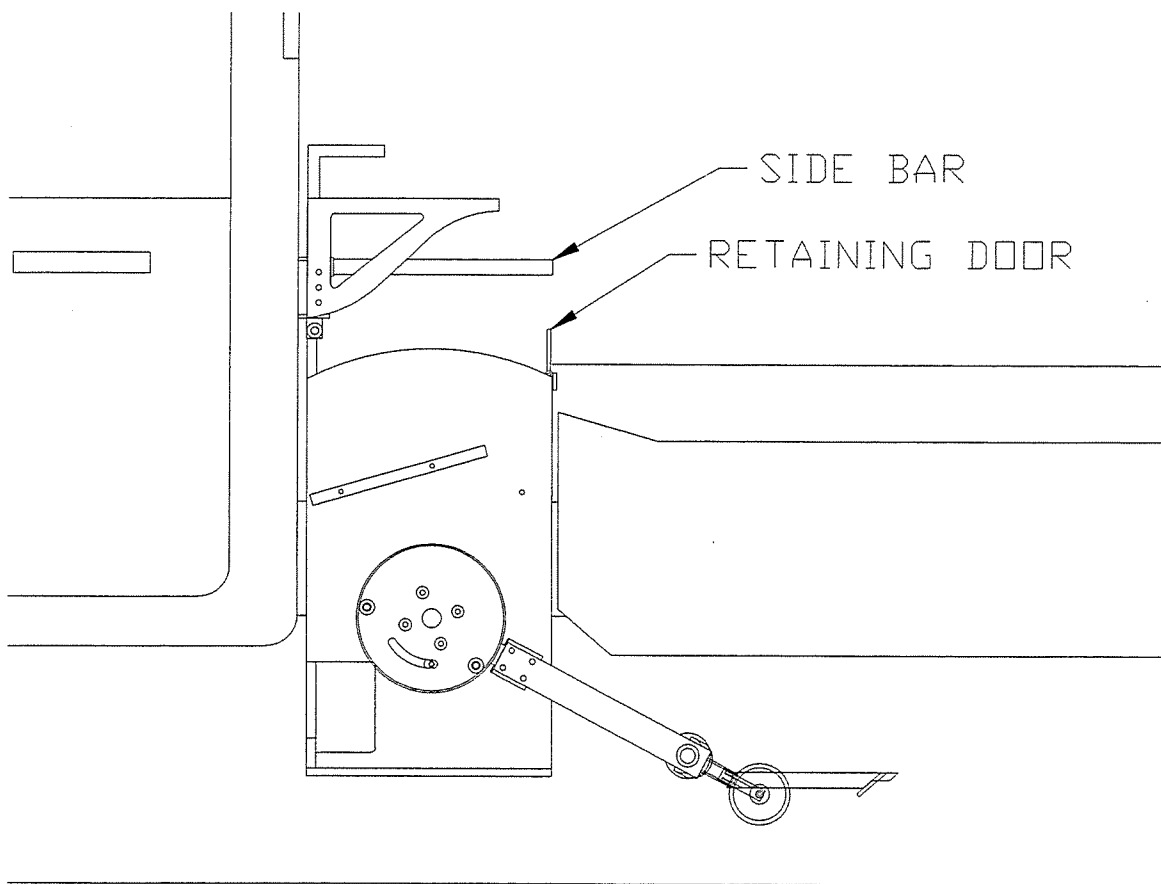


Figure 4.1 *Side View of Side Bar and Retaining Door*

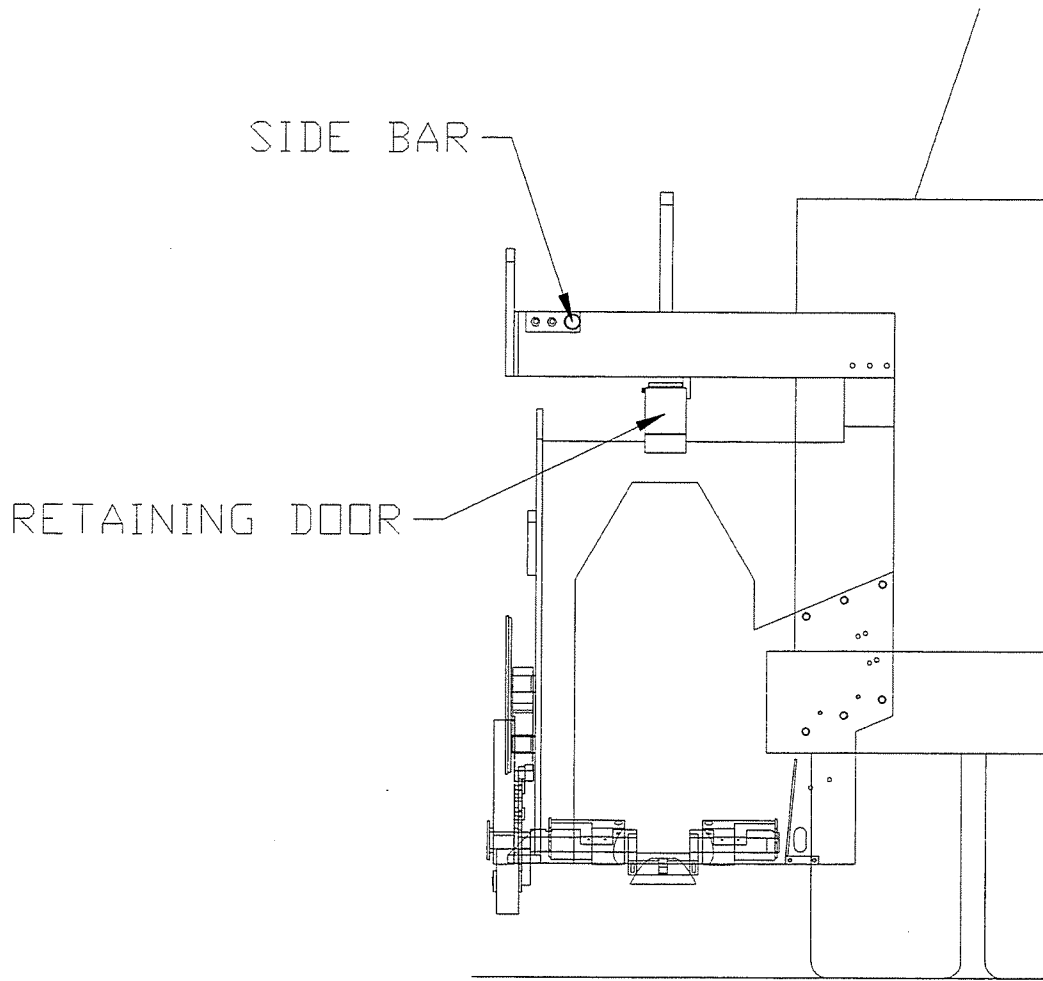


Figure 4.2 *End View of Side Bar and Retaining Door*

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.

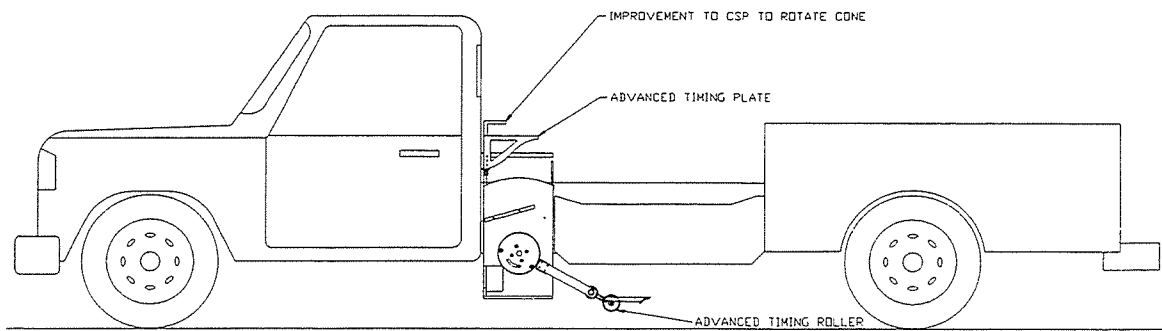


Figure 4.3 *Advanced Timing Elements*

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.

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

Table 4.1 *Test Results of Retrieval*

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.

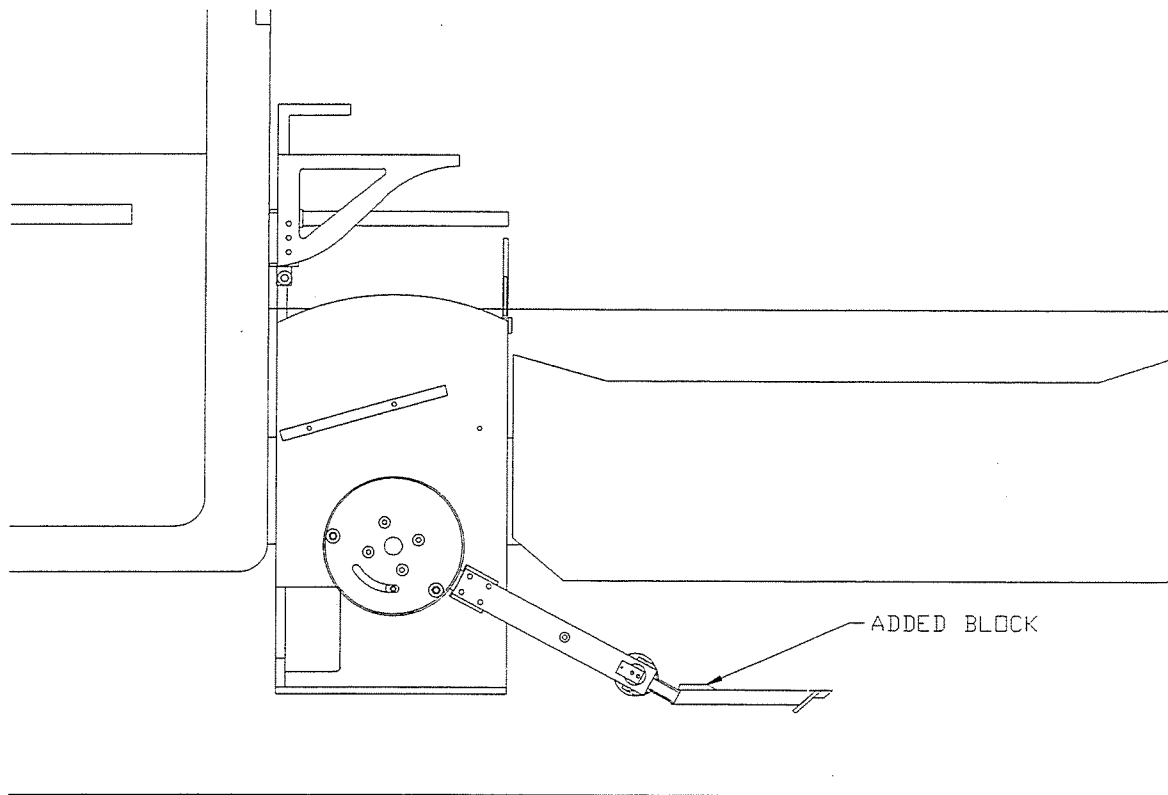


Figure 4.4 *Addition to Poker Arm*

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.

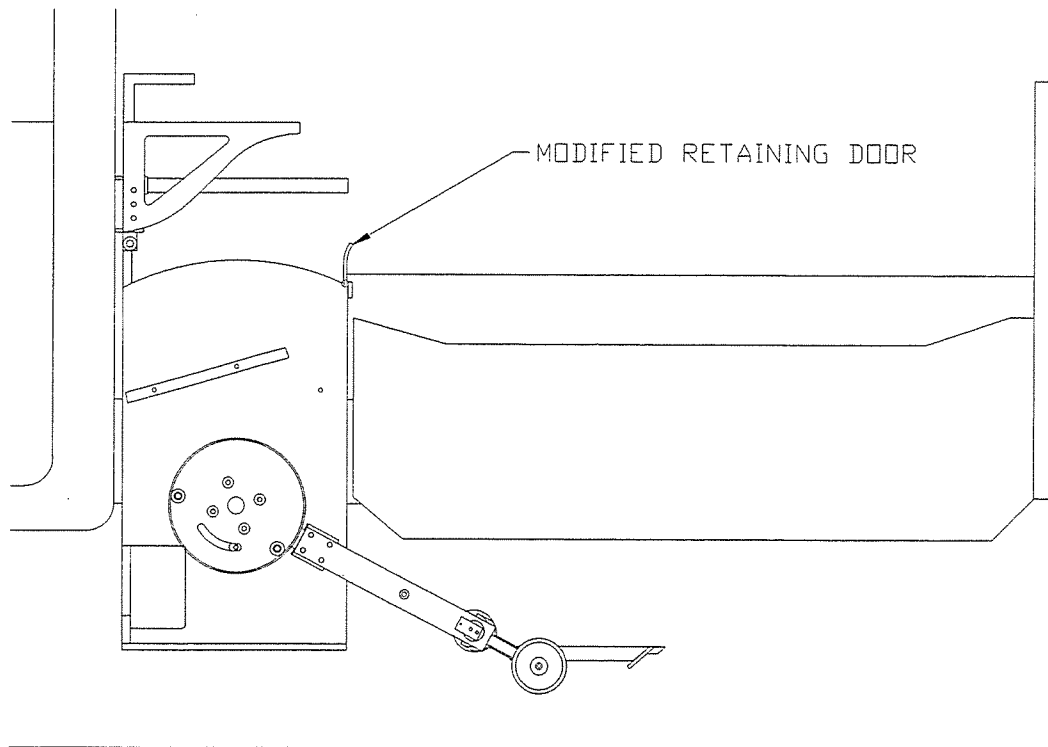


Figure 4.5 *Modified Retaining Door*

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%

Table 4.2 *Laboratory Test Results of Retrieval*

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.

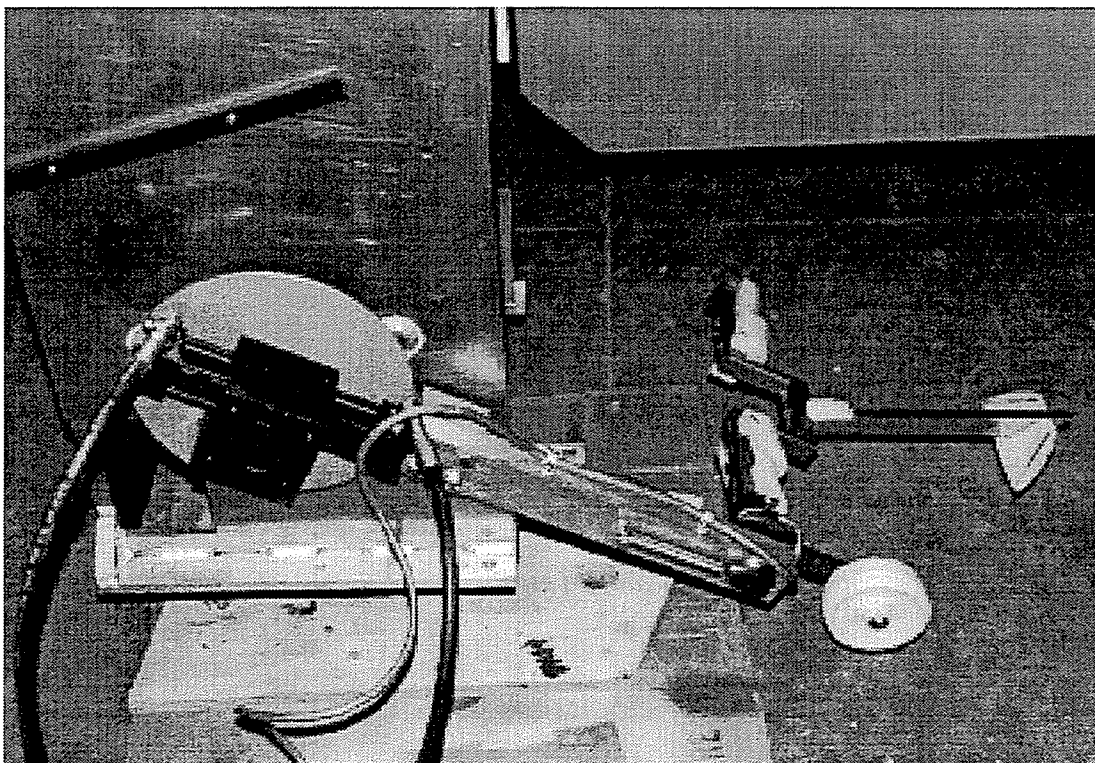


Figure 4.6 *Retrieval Arm in Ready Position*

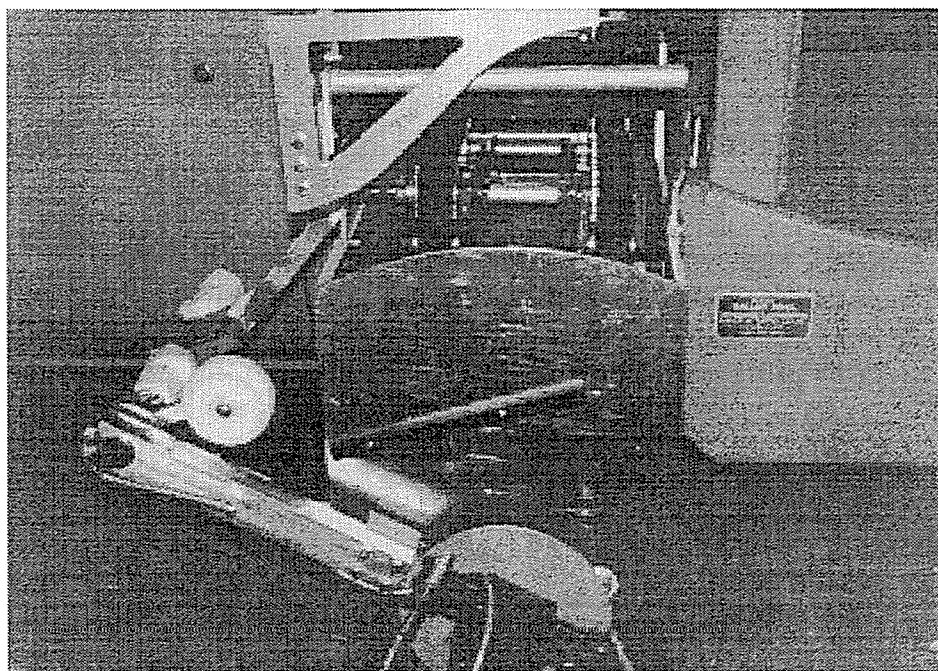


Figure 4.7 *Retrieval Arm After Stripping Cone*

CHAPTER 5 THE DESIGN AND DEVELOPMENT OF THE FUNNEL SYSTEM

5.1 Introduction

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 cone into a single base first orientation. The initial portion of this frame is used to coerce 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.

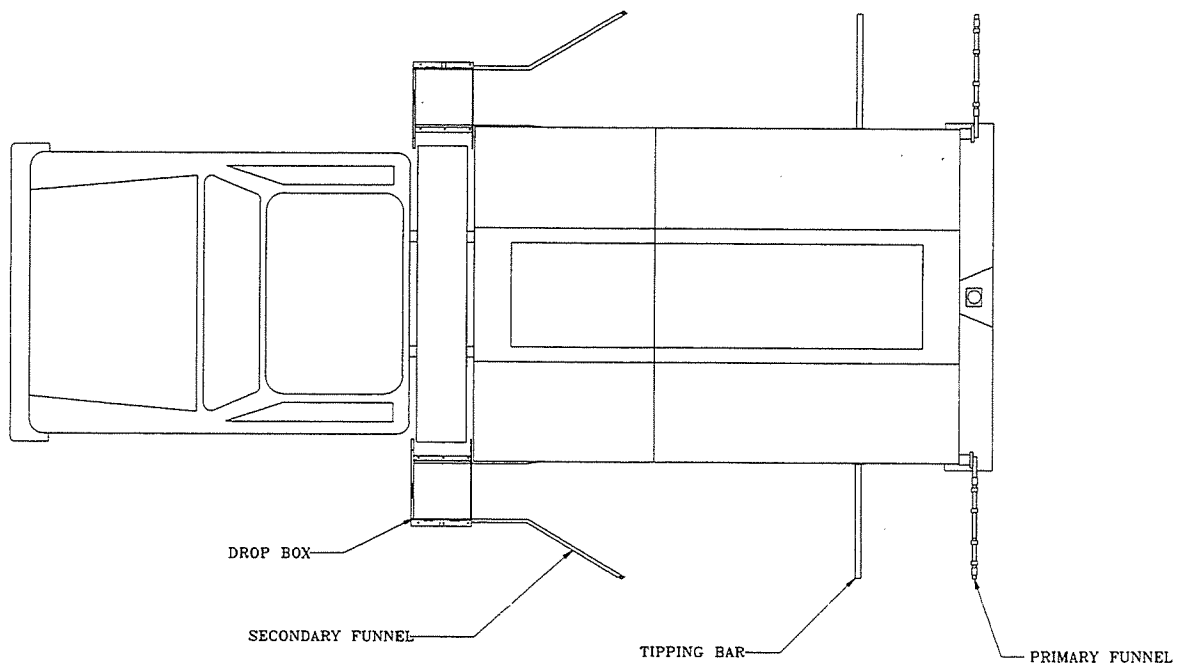


Figure 5.1 *Top view of Cone Truck with Funnel System*

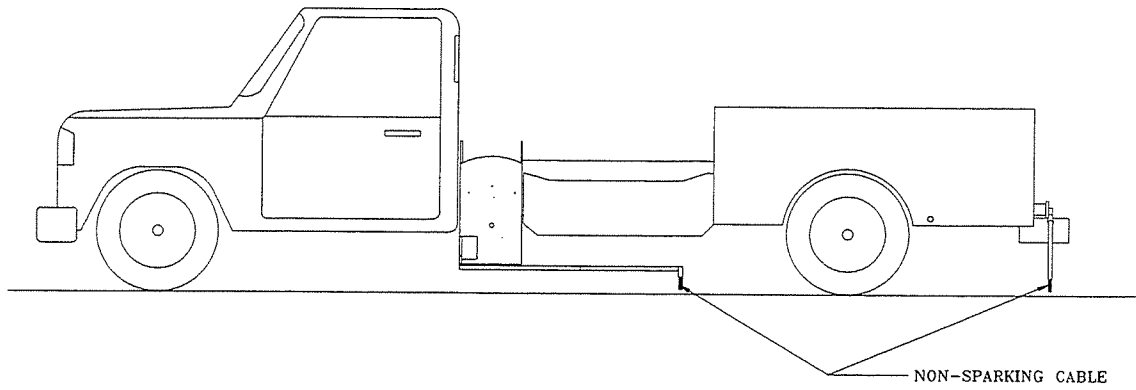


Figure 5.2 *Side view of Cone Truck with Funnel System*

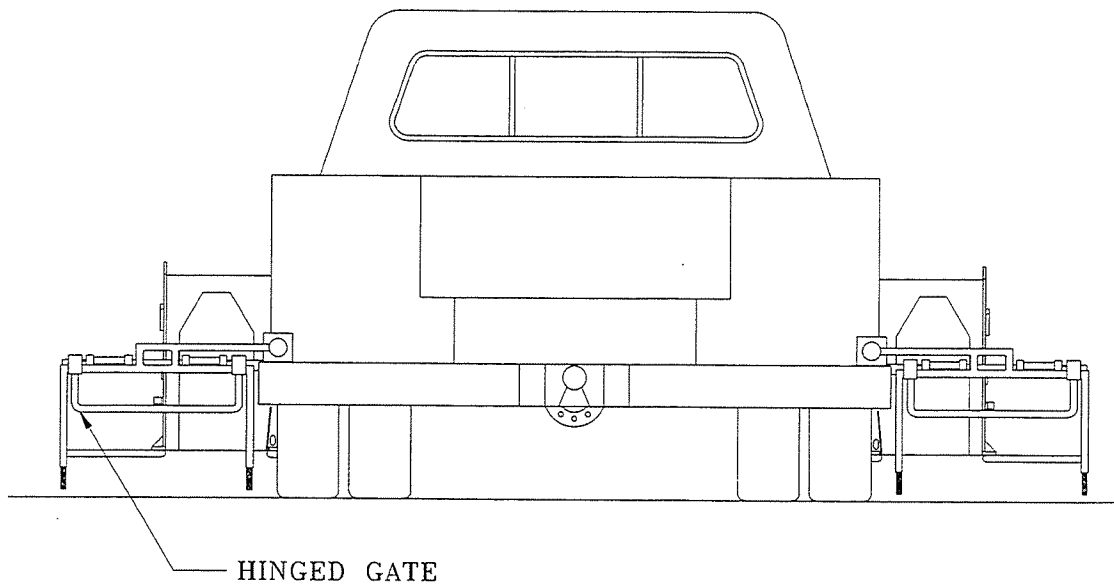


Figure 5.3 *Back view of Cone Truck with Funnel System*

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

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%

Table 5.1 *Funnel Test Results on First Run*

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.

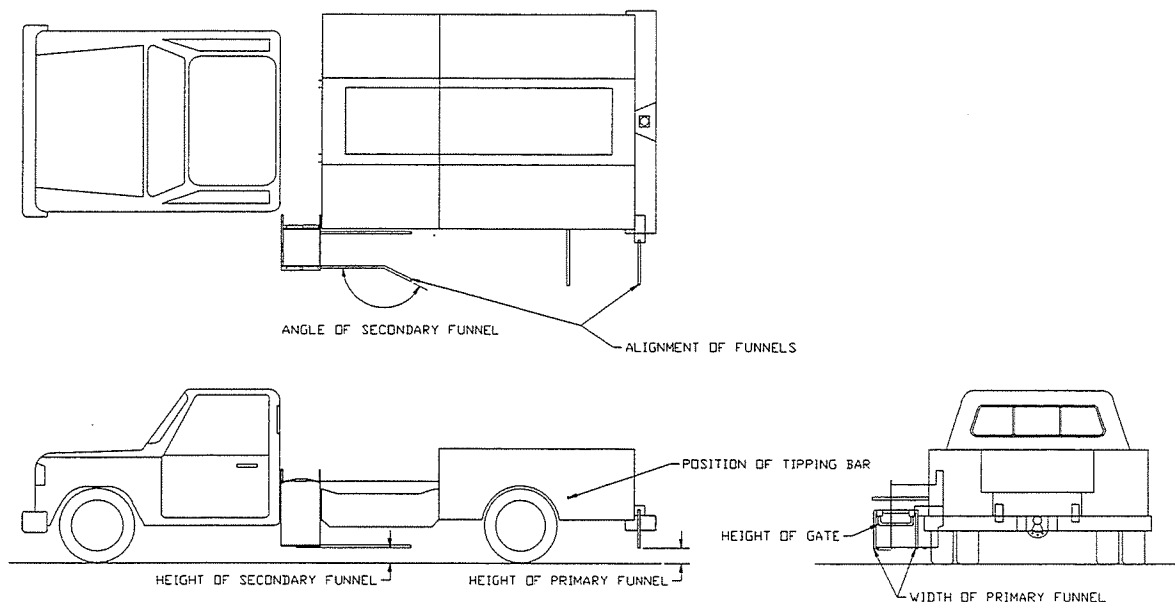


Figure 5.4 *Adjustable Funnel Parameters*

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%

Table 5.2 *Funnel Test Results On Second Run*

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.

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%

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

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.

CHAPTER 6 CONCEPTUAL DESIGN AND DEVELOPMENT OF THE AUTOMATED CONE STOWAGE SYSTEM

6.1 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.

6.2 Important Criterion for the Evaluation of Concepts

6.2.1 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 6.1, 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.

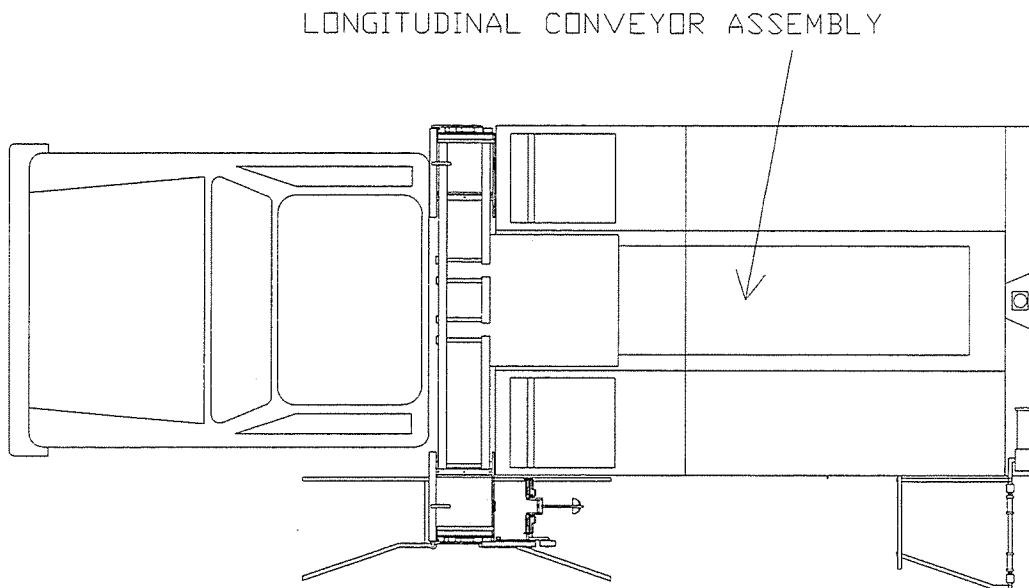


Figure 6.1 *Longitudinal conveyor assembly*

6.2.2 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 6.2. 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 6.3 shows the allowable space located in the LCS and the interface between the stowage system and the two adjoining systems.

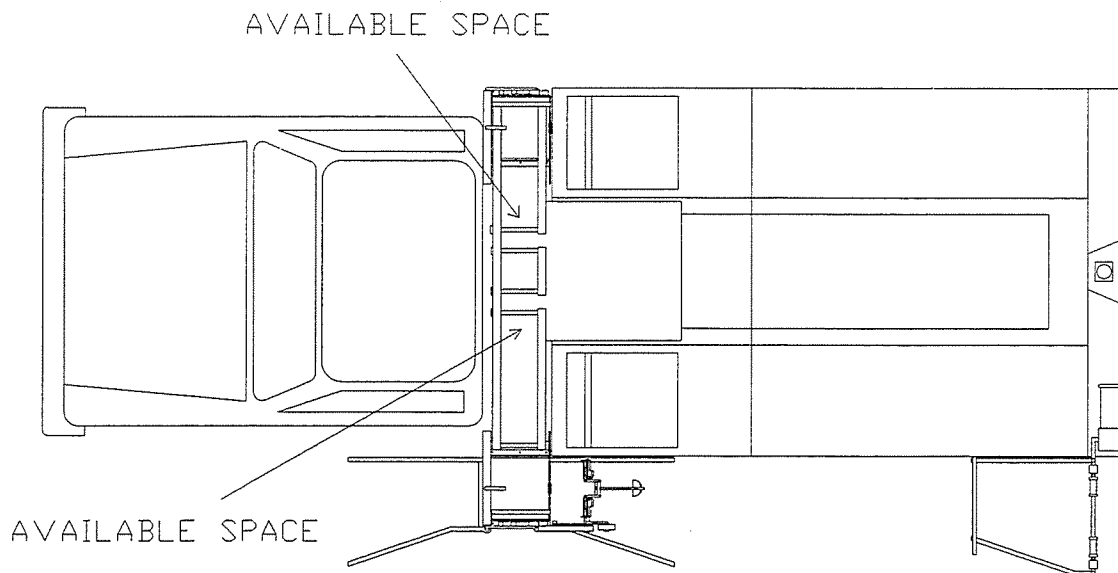


Figure 6.2 *Top view of the available space in the LCS*

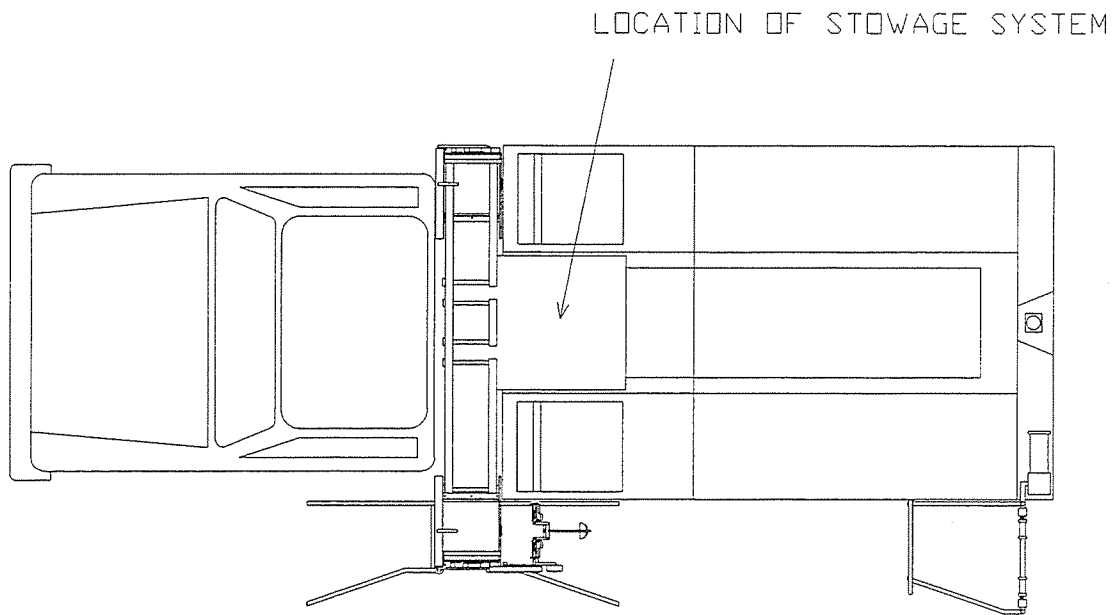


Figure 6.3 *Top view of the location of the stowage system*

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 6.4 shows a side view of the location for the stowage system.

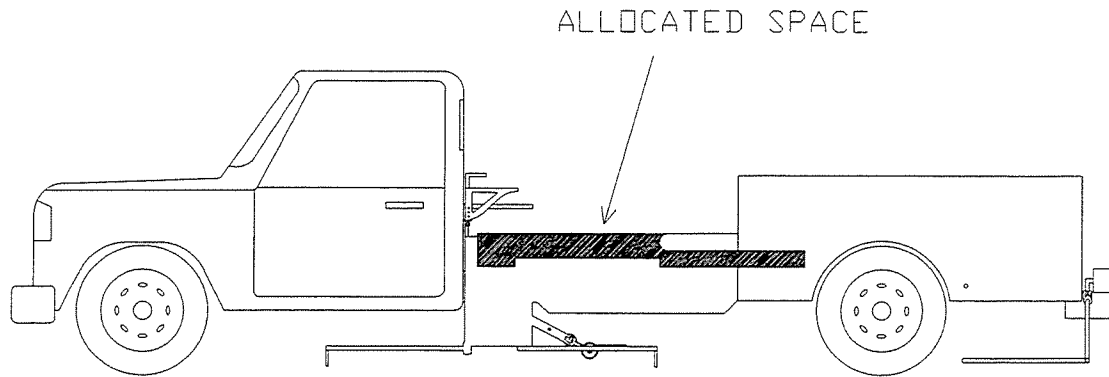


Figure 6.4 *Side View of the allocated space for the traffic cone stowage system*

6.2.3 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.

6.3 The Automated Cone Stowage System

6.3.1 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 6.5.

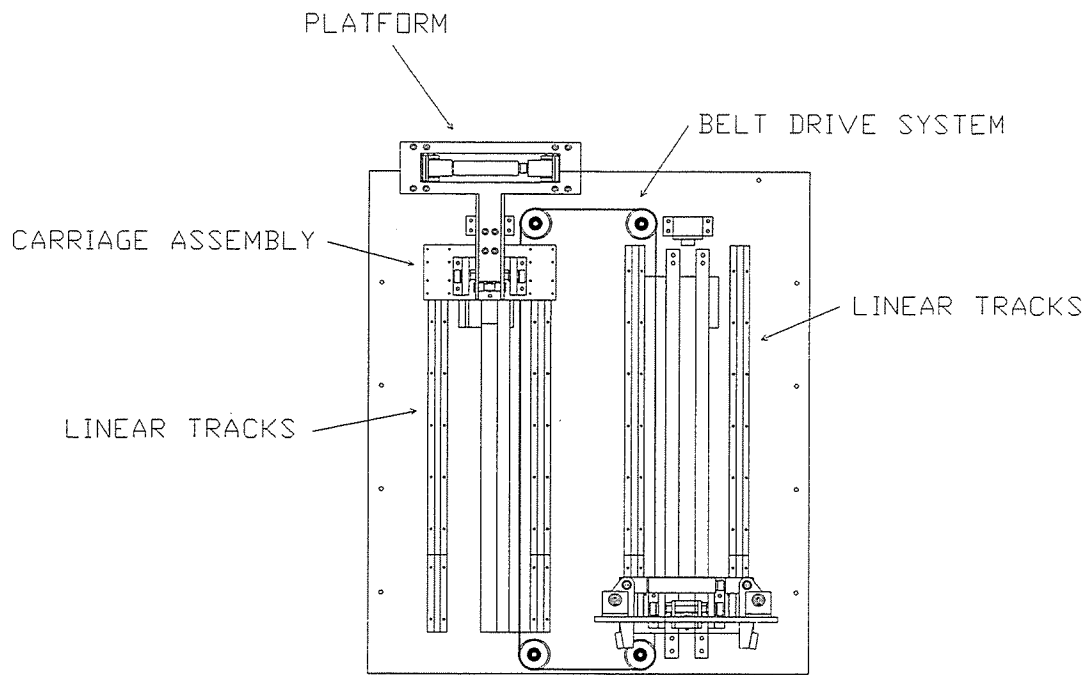


Figure 6.5 *Top view of the Automated Cone Stowage System*

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 6.6. 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.

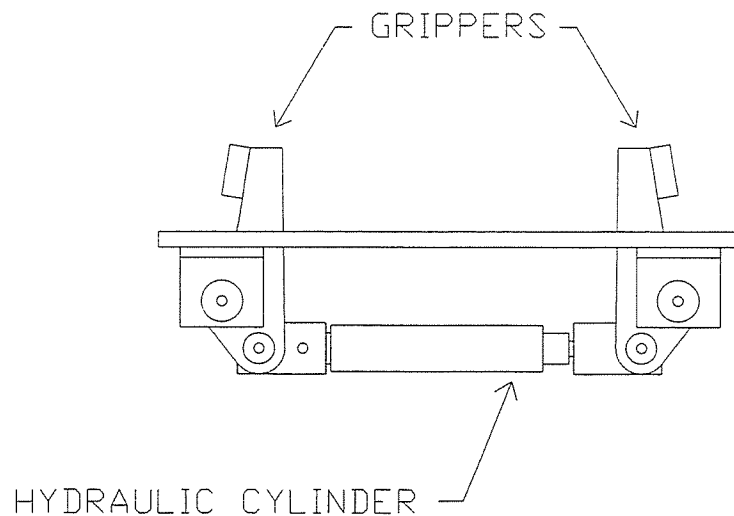


Figure 6.6 *Gripper mechanisms on the ACSS*

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 6.7, 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.

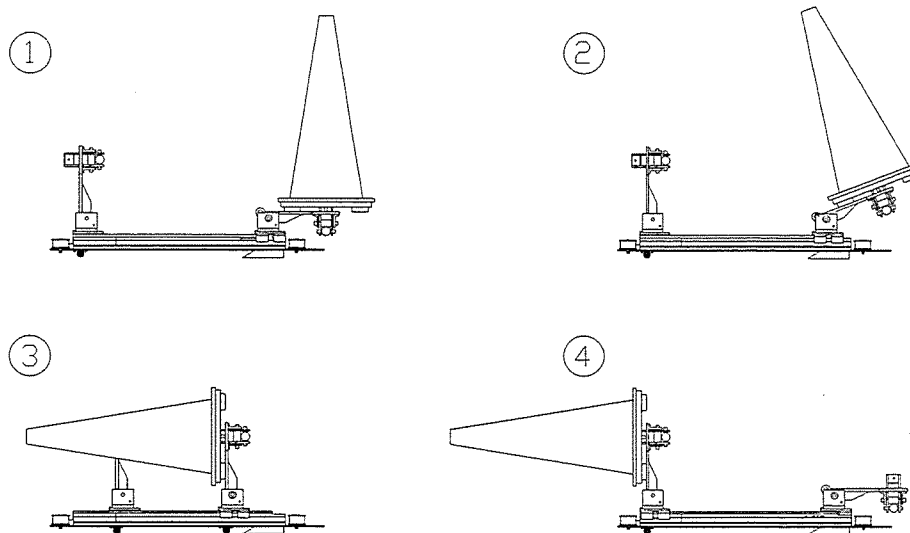


Figure 6.7 *Rotational motion caused by the linkage system*

6.3.2 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.

6.4 Other Trade-Off Concepts

6.4.1 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 6.8. 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.

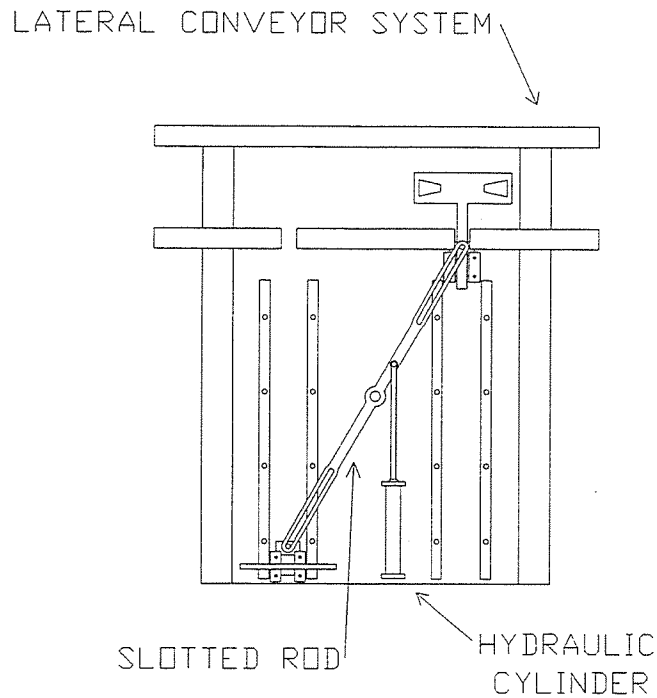


Figure 6.8 *The Rotating Stowage Assembly*

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.

6.4.2 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 6.9, simply uses the conveyor assembly itself to rotate and to transport two cones at a time.

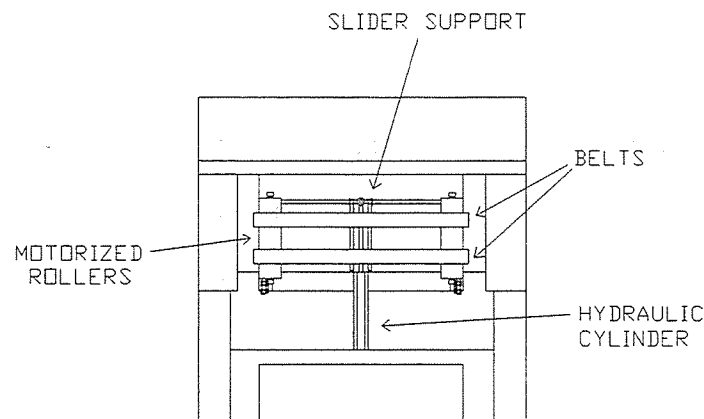


Figure 6.9 *The Swivel Stowage Unit*

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 6.10. Once properly placed into the two stowage stacks, the grippers are closed and the traffic cones are released.

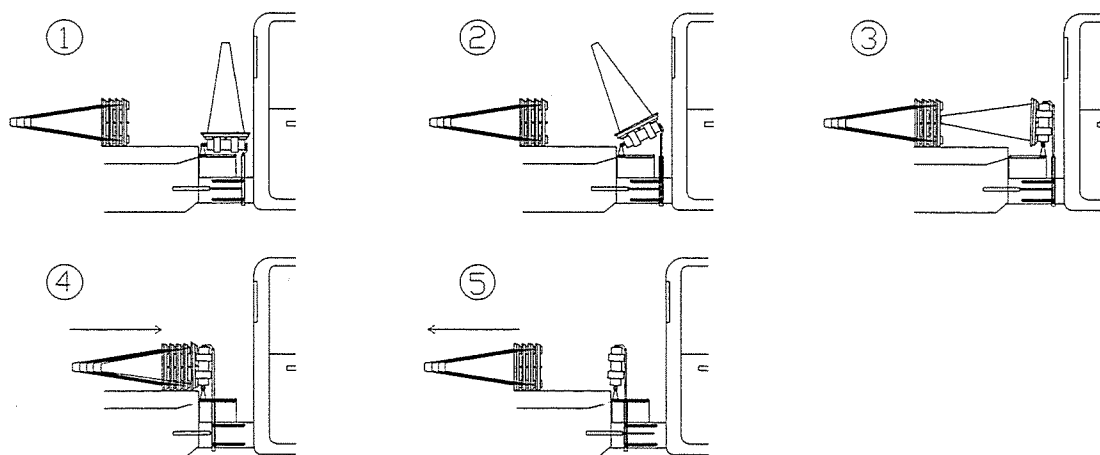


Figure 6.10 *The Rotating Swivel System in retrieval mode*

6.5 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 6.1, 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 6.1 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

CHAPTER 7 THE ACM 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.

7.1 Selection of Power Delivery System

The operation of the Automated Cone Machine can be powered by 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.

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 7.1.

FACTORS	WEIGHTING	POWER		
	FACTOR	TYPES		
		HYDRAULIC	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

Table 7.1 *Trade-Off Table of Power Delivery*

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 7.1). 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.

7.2 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 4.1. 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.

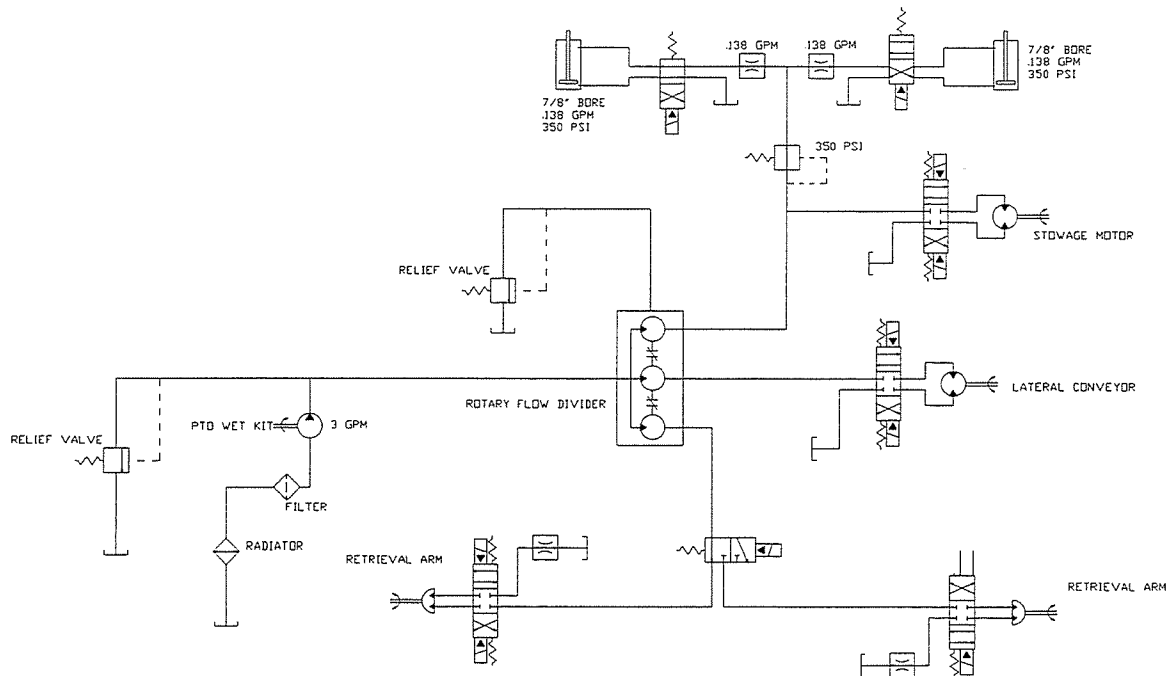


Figure 7.1 *First Hydraulic Schematic*

The next design uses conventional flow dividers (see Figure 7.2). In order to ensure that there are no any 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.

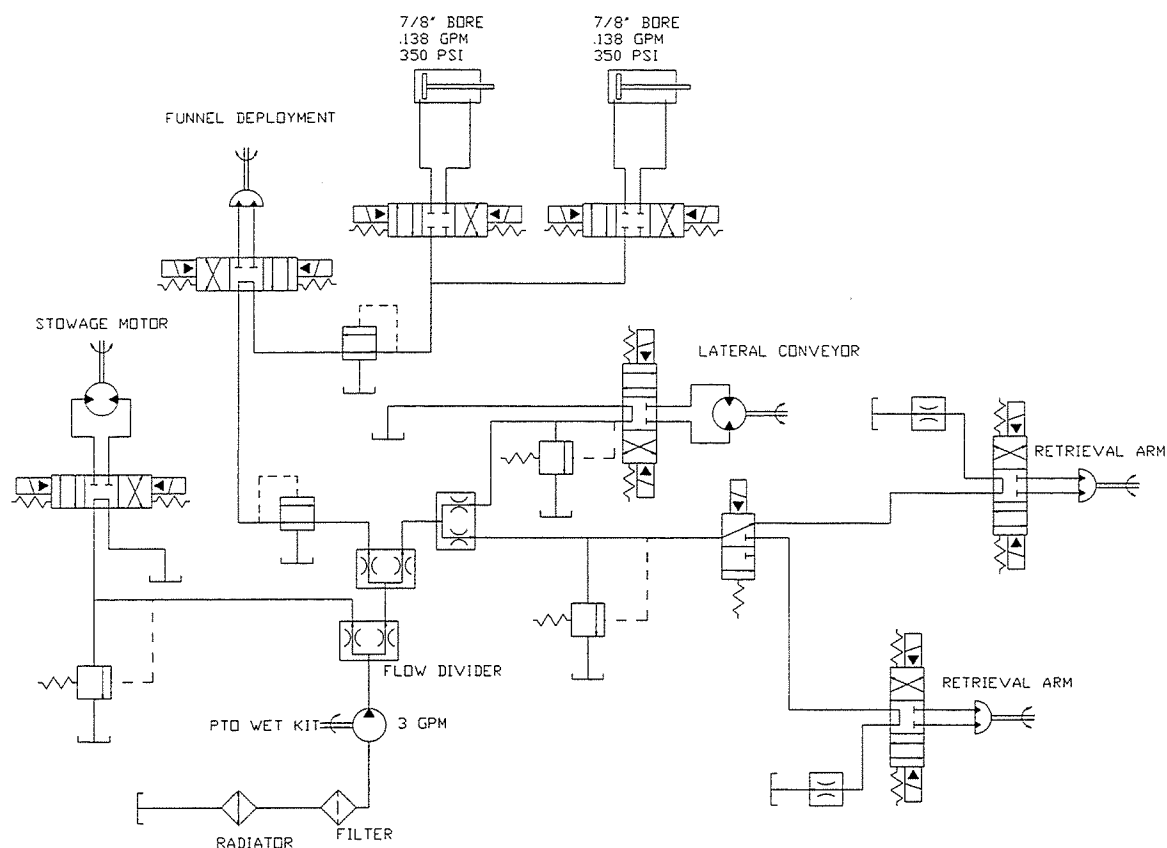


Figure 7.2 *Second Hydraulic Schematic*

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 7.3.

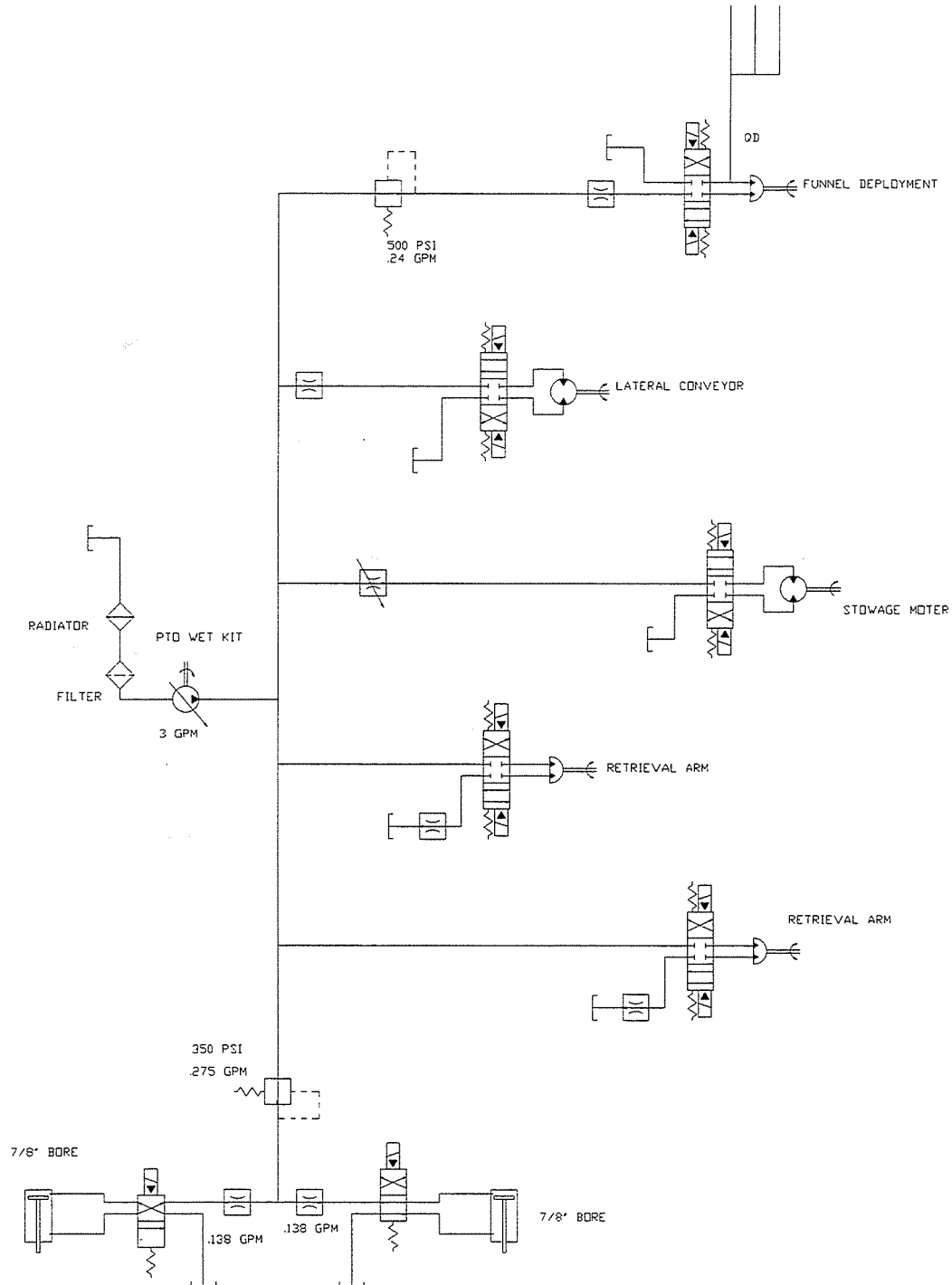


Figure 7.3 *Current Hydraulic Schematic*

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 7.4 below shows the distribution box for all of the hydraulic valves of the circuit.

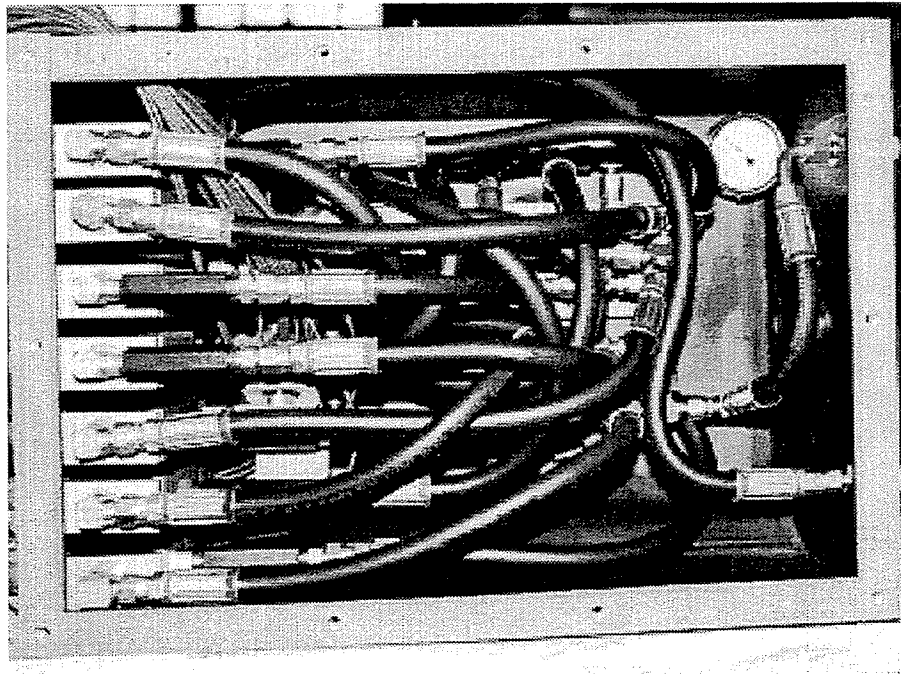


Figure 7.4 *Hydraulic Distribution Box*

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 minor 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.

CHAPTER 8 COORDINATED CONTROL UNIT

8.1 General Description

The Coordinated Control Unit (CCU) integrates and controls the various systems of the Automated Cone Machine (ACM) to effectively perform the retrieval and deployment of traffic cones on the highway. The CCU allows the driver to activate the Funnel System (FS), the Integrated Dispensing and Retrieval Configuration (IDRC), the Lateral Conveyor System (LCS), and the Automated Cone Stowage System (ACSS) in predetermined sequences depending on the type of cone operation involved. The CCU utilizes a set of directives that revolve around the cone retrieval, cone deployment, and lane maintenance operations. The CCU is located in the left bucket seat area and consists of a Zworld Little Giant miniature controller and several expansion boards. While the main unit is stationary in the bucket area, a remote keypad controller can be used both inside and outside of the truck cab during actual operations and during maintenance testing.

8.2 Controller Hardware and Software

The CCU utilizes the Zworld Little Giant miniature controller and the Dynamic C software development system to operate the numerous systems of the Automated Cone Machine (ACM). The Little Giant is capable of processing the commands of the ACM driver and sequentially powering certain systems in order to perform the desired operation. Additional expansion boards for the Little Giant are necessary to process the many inputs and outputs of the ACM systems. The Zworld Relay6 expansion board serves as a simple means of adding relays to the Little Giant control system while the IOE-DGL96 expansion board provides access to an additional number of digital inputs and outputs.

8.2.1 The Zworld Little Giant

The Zworld Little Giant is a miniature controller designed for data collection and control applications. The Little Giant is very compact, measuring 142 x 122 mm (5.6 x 4.8 in), and is shown in Figure 8.1. The main features of this controller include a parallel port, four serial ports, six counter timers, eight high-current, high-voltage digital outputs, liquid crystal display interface, and analog inputs and outputs. The 16-bit parallel port is used as either two 8-bit ports or 16 individual inputs and/or outputs while the four serial ports support communications at 57,600 baud. Two of the six counters generate the baud rate for the serial ports while the other four are capable of supplying periodic output or monitoring external inputs. The high-current, high-voltage digital outputs control inductive loads and can sink up to 400 mA per channel at 35-40 volts inductive, or 50-100 volts non-inductive. The liquid crystal interface supports the Zworld Keyboard Display Modules as well as a variety of other character and graphic displays. The analog input and output channels can yield up to 10,000 samples per second and are accompanied by an on-board 2.5 volt reference and a temperature sensor.

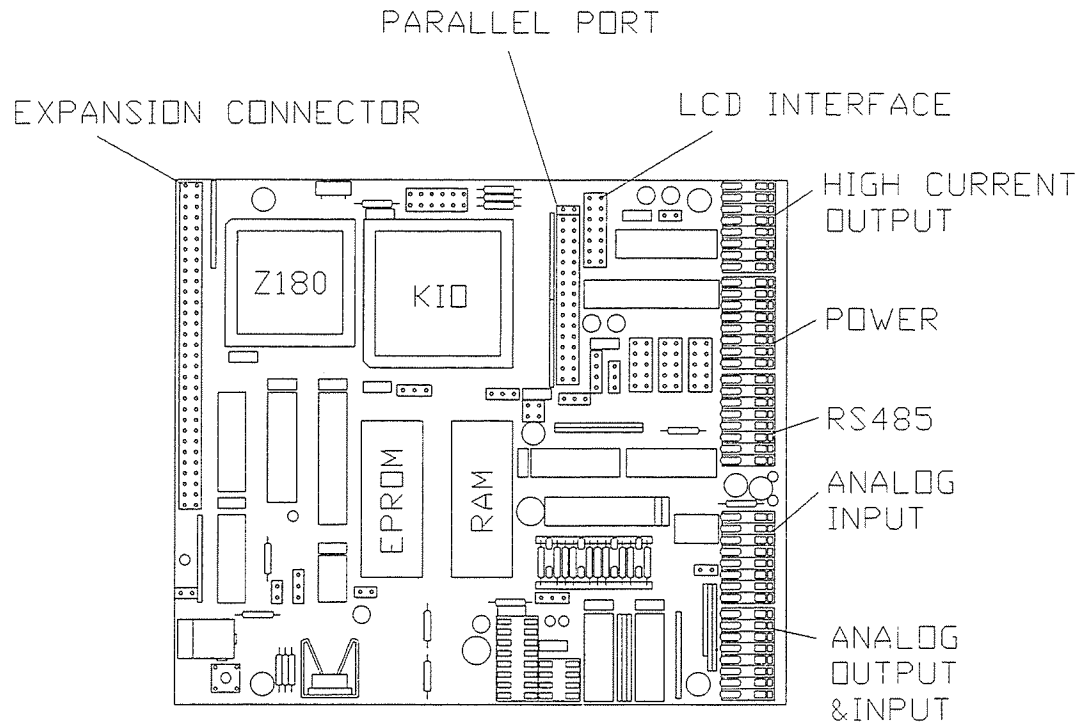


Figure 8.1 *Zworld Little Giant miniature controller*

8.2.2 The Zworld Keyboard Display Module

The Zworld Keyboard Display Module (KDM) 4x40 provides a means of user interface for the control system. As shown in Figure 8.2, the KDM features a 4-line by 40 character liquid crystal display, a 4 by 10 keypad, and a full enclosure with keypad overlay and protective mask. A portion of the keypad is allocated for control decisions made by the driver during the various cone picking and placing operations while the remaining keys are used to monitor and control individual systems of the ACM. This flexibility allows testing of both individual and integrated systems during routine maintenance.

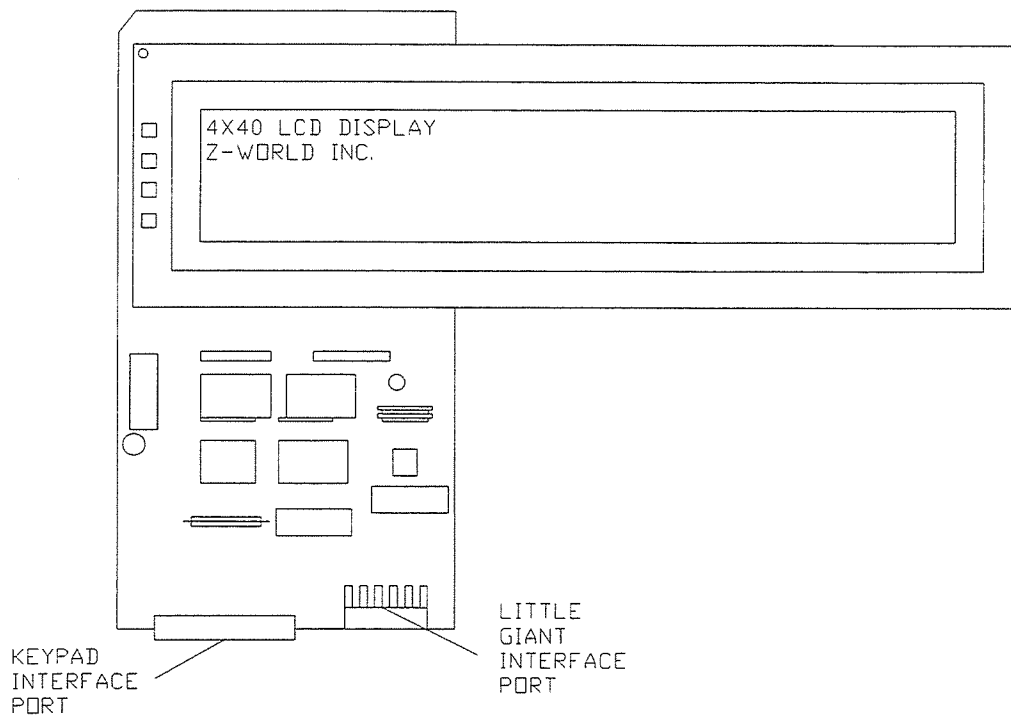


Figure 8.2 *Zworld Keypad Display Module*

8.2.3 The Zworld Expansion Boards

The Zworld Expansion Boards provide simple ways to extend the capabilities of the core Zworld system. The Relay6 Boards, shown in Figure 8.3, measure 89 x 72 mm (2.2 x 2.8 in) and contain six high powered relays that are individually controllable. They feature linkable ports, maximum switching voltage of 24 VDC at 10 amps, and LED status indicators. The IOE-DGL96, shown in Figure 8.4, measures 89 x 119 x 18 mm (3.5 x 4.7 x 0.7 in) and provides 96 individual channels that can be used as an input or an output. Since a large number of sensors and switches are used to deliver digital inputs, this board is essential for complete system control of the ACM. Up to four of these boards can be stacked on top of the Little Giant to expand the control system to a total of 384 inputs and outputs.

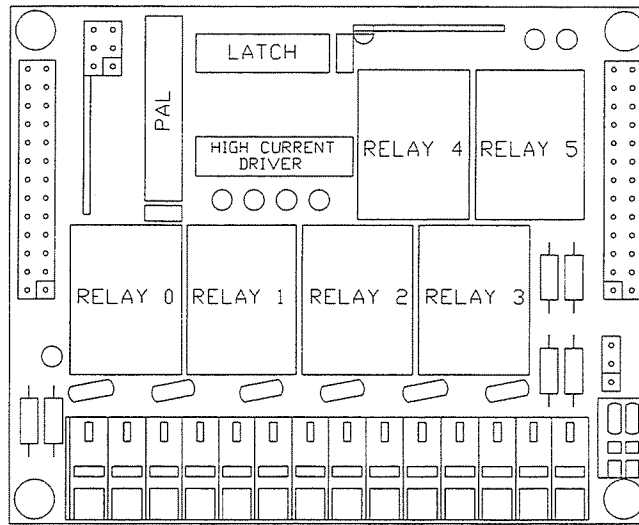


Figure 8.3 *Zworld Relay6 Expansion Board*

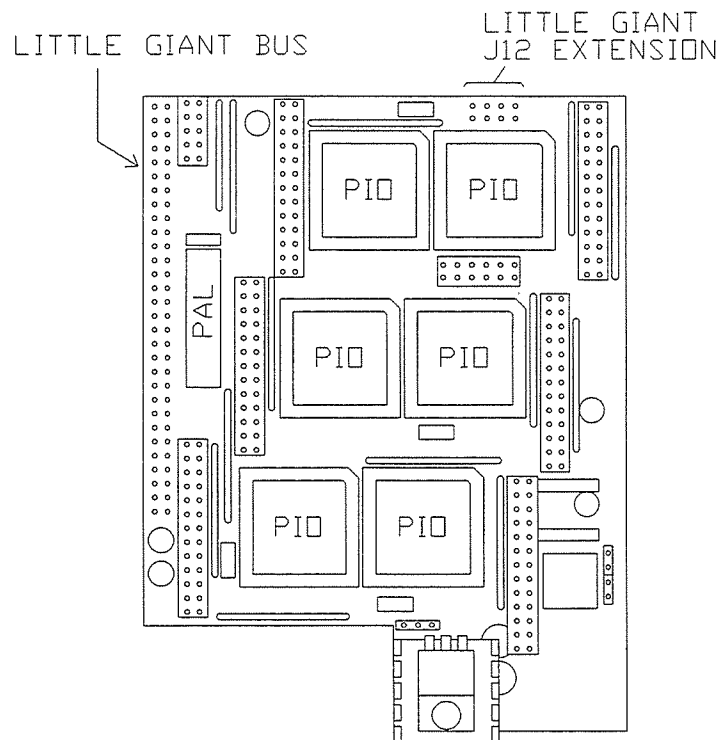


Figure 8.4 *Zworld IOE-DGL96 Expansion Board*

8.3 Development of the ACM Control Code

In order to construct a control program for the Automated Cone Machine (ACM), it was necessary to develop a pseudo code that would determine the inputs and the outputs of the ACM and the proper activation sequences of the numerous subsystems. Since a wide variety of cone placement and retrieval operations are required on the road surface, it was important to identify which systems were to be activated for every scenario. Flow charts were then used to clearly map out the proper sequence of events and to build the framework for the second phase of the program development.

8.3.1 Inputs and Outputs of the ACM Control System

The inputs and the outputs of the ACM control system were identified for several reasons. With a large number of sensors, switches, motors, and actuators, designating the inputs and outputs with a number system proved to simplify the creation of activation sequences for the various operating scenarios. With a table of input and output designations, it was easier to specify the parameters of the necessary relays and to match the proper hardware with the Zworld controller. The inputs and outputs are shown in Table 8.1 and Table 8.2 respectively.

Table 8.1 *Zworld Input Designations*

1.	Left Stowage Sensor	14.	Right Arm Bumper Switch #2
2.	Right Stowage Sensor	15.	Left Arm Stow Position
3.	Forward Left Stack Sensor	16.	Right Arm Stow Position
4.	Forward Right Stack Sensor	17.	Left Platform Switch
5.	Backward Left Stack Sensor	18.	Right Platform Switch
6.	Backward Right Stack Sensor	19.	Left Gate Switch #1
7.	Left Dropbox Up Limit Switch	20.	Left Gate Switch #2
8.	Left Dropbox Down Limit Switch	21.	Right Gate Switch #1
9.	Right Dropbox Up Limit Switch	22.	Right Gate Switch #2
10.	Right Dropbox Down Limit Switch	23.	Middle Gate Leftside Switch #1
11.	Left Arm Bumper Switch #1	24.	Middle Gate Leftside Switch #2
12.	Left Arm Bumper Switch #2	25.	Middle Gate Rightside Switch #1
13.	Right Arm Bumper Switch #1	26.	Middle Gate Rightside Switch #2

Table 8.2 *Zworld Output Designations*

1.	Right Gripper	11.	Funnel Deployment
2.	Lateral Conveyor Direction #1	12.	Funnel Retraction
3.	Lateral Conveyor Direction #2	13.	Middle Gate
4.	Stowage Motor Direction #1	14.	Advance Stack Forward
5.	Stowage Motor Direction #2	15.	Advance Stack Backward
6.	Left Retrieval Arm Direction #1	16.	Left Dropbox Down
7.	Left Retrieval Arm Direction #2	17.	Left Dropbox Up
8.	Right Retrieval Arm Direction #1	18.	Right Dropbox Down
9.	Right Retrieval Arm Direction #2	19.	Right Dropbox Up
10.	Left Gripper	20.	Funnel Gate

8.3.2 First Phase Pseudo Code

Since the ACM must perform a variety of duties during a typical cone placement and retrieval operation, it was necessary to identify and detail the different operating scenarios that would require subsystem integration and sequencing. It was determined that thirteen operating scenarios were essential for the cone placement, retrieval, and maintenance procedures. These scenarios are listed below in Table 8.3.

Table 8.3 *Operating Scenarios*

1.	Left Side Retrieval w/ Cone Tip First
2.	Left Side Retrieval w/ Cone Standing or Base First
3.	Right Side Retrieval w/ Cone Tip First
4.	Right Side Retrieval w/ Cone Standing or Base First
5.	Left Side Placement Single Cone
6.	Right Side Placement Single Cone
7.	Left Side Placement Series w/ 25 Foot Spacing
8.	Left Side Placement Series w/ 50 Foot Spacing
9.	Left Side Placement Series w/ 100 Foot Spacing
10.	Right Side Placement Series w/ 25 Foot Spacing
11.	Right Side Placement Series w/ 50 Foot Spacing
12.	Right Side Placement Series w/ 100 Foot Spacing
13.	Stow

With these scenarios identified and the inputs and outputs of the control system designated, it was possible to construct a simple flow chart for each individual scenario with details as to which inputs needed to be read and which outputs needed to be activated. These flow charts, located in Appendix 1, provided frameworks so that the activation of ACM subsystems could be adequately sequenced. Once this was completed, it was possible to devise a first phase pseudo code that provided a basic text version of the multiple flow charts. This allowed the sequences to be broken in segments so that common procedures among different operating scenarios could be identified. This first phase pseudo code is located in Appendix 2.

8.3.3 Second Phase Pseudo Code

A second phase pseudo code was developed using a combination of the flow charts and the first phase pseudo code. This pseudo code transformed the structure of the first phase into a code format as shown in Appendix 3. Segments of ACM operational instructions were formed into function blocks and logical decisions involving inputs and outputs were converted into

simple computer language statements. The second phase pseudo code also allowed the addition of a driver interface. Several menus were created to direct the driver through a decision tree and to provide complete control during the various traffic cone operations. This second phase pseudo code provided the framework to develop a code compatible with the Dynamic C software system to effectively control the integrated systems of the ACM.

8.3.4 Control Code

Using the second phase pseudo code as a guide, it was possible to construct a control code based on the Dynamic C software system that could be processed by the Zworld Little Giant and its expansion boards. After wiring the subsystems of the ACM to selected expansion boards, the Zworld Little Giant was able to execute the control code, interface with the driver, read the digital signals of the sensor and switch inputs, and initiate the necessary sequence of subsystem activation. The structure of the code was based on function blocks that provided instructions for sequences that were common to many operation scenarios.

8.4 The Control Scheme

The Coordinated Control Unit (CCU) is activated by a series of menus that appears on the Keyboard Display Module and allows the driver to selectively interface with the systems of the ACM. Menu A and Menu B give the driver the opportunity to designate whether the operation will occur on the left or right side of the vehicle and whether the mechanisms should be deployed in placement, retrieval, or lane maintenance mode. After the driver has selected from these two menus, the CCU begins one of four deployment procedures. If the left side option and the placement option are selected, the left side Integrated Dispensing and Retrieval Configuration (IDRC) is deployed, the Lateral Conveyor System (LCS) is activated, the left retrieval arm is placed in an upward position, and the middle gate located underneath the LCS is opened. Likewise, if the right side option is selected with the placement option, components on the right side of the vehicle will activate in the fashion described above. If any other

permutations of the options are selected, the CCU will initiate one of the two remaining deployment procedures. If the leftside option and either the retrieval or maintenance option are selected, the left IDRC and the Primary Funnel Configuration (PFC) will be deployed, the LCS will be activated, and the left retrieval arm will be situated in the down position. Selecting the right side option yields a similar deployment procedure with the right side components going into motion instead of those on the left side.

Once the deployment procedures are completed the CCU initiates one of three functions depending on the driver response from Menu B. If the placement option was selected from Menu B, the CCU activates a procedure that consists of three additional menus. Menu C allows the driver to pick from three distance separation selections of 25, 50, and 100 feet and a single cone drop selection. If any of the three distance separation selections are chosen, the CCU will proceed to Menu E. This menu gives the driver the options of initiating or terminating the placement of a series of traffic cones, returning to Menu C, and stowing the deployed systems of the present ACM configuration. When the option of initiating the placement of cones is selected, the ACSS becomes active and the logic routines that determine which cone is to be taken from the cone stacks are executed. Constant reading from a distance counter prompts the CCU to release cones on to the moving timing belts of the LCS and towards the IDRC for placement on to the road surface. If the single drop selection is chosen, the CCU goes to Menu F and driver is given active control of placing individual cones by pressing a release button. A similar ACSS routine is executed as described above. Other options in Menu F are returning to Menu C and exiting through a system stow procedure.

If the retrieval option was chosen from Menu B, the CCU begins a function that primes the ACSS, deploys the PFC, and allows the driver to enter the general orientation of the cone to be picked up. Priming the ACSS is accomplished by reading the digital signals emitted from the sensors located at the front end of the cone stack. Depending on the combination of the four sensor signals, the ACSS will activate its grippers and move the main conveyor until the cone stack is properly positioned. Menu D has the options of reconfiguring the PFC to accommodate

cones that are lying tip first, base first, and standing upright and the option of stowing the deployed systems. As the driver selects from these different cone orientations, the gate located on the PFC will activate. If the cones to be picked up are oriented tip first, the driver selection will prompt the CCU to lock the gate and make it rigid. For cones that are situated base first or standing upright, the CCU will inactive the locking mechanism and allow it to swing freely.

If the lane maintenance option is selected from Menu B, the CCU will execute a function that will follow Menu G. This menu gives the driver the options of retrieving, placing, and recycling a traffic cone. The first two options simply call the routines described earlier in this chapter. Both the retrieval and placement routines contain the preparatory functions that allow the proper spacing for stowing and removing cones from the ACSS. The recycle option causes the CCU to follow a routine similar to the retrieval function except that the configuration of ACM systems is slightly altered. By dropping the wing mechanism located in the LCS, the retrieved cone will fall through the IDRC and back onto the road surface. This allows correctly positioned fallen cones to be redeposited in the desired upright orientation.

CHAPTER 9 CONCLUSIONS AND RECOMMENDATIONS

9.1 Conclusions

This thesis discusses the multiple developmental stages involved in the design of the Automated Cone Machine (ACM). Current methods and mechanisms used to place and retrieve traffic cones are presented to establish the direction that was taken towards the generation of overall conceptual designs. The previous chapters include general descriptions of the individual systems that constitute the ACM as well as more detailed descriptions of the stowage system and the control system. The generation of multiple stowage system concepts and the impartial trade-off process provide a logical means of selecting the most effective design while identifying the strengths and weaknesses of each design. Likewise, the development of the control system, as presented in Chapter 8 and in several of the appendices, is also presented to show the step by step approach used to convert functional procedures of the ACM into actual software code.

The overall ACM design was divided into individual systems in order to allow simultaneous development and testing to occur as parts and equipment were obtained. Modifications and improvements were accomplished easier and faster by using this subsystem approach. Since the cone placement and retrieval procedures for the ACM required the activation of several subsystems in a determined sequence, the approach of independent systems greatly assisted the development of the ACM control scheme and code.

9.2 Recommendations

After initial prototypes of the Integrated Dispensing and Retrieval Configuration (IDRC) were tested both in the laboratory and on the road surface, this concept of cone deployment and retrieval was proven with reliability. Two areas of improvement are apparent. The first improvement can be made by routing the electrical wires from the switches down through the retrieval arm. This rewiring will allow the poker arm to attach and disconnect more easily. The second improvement can be made by using an alternate method for how the cross member and

poker arm are returned to its ready position. When the retrieval arm rotates down to the ready position, the cross member and the poker arm need to be returned to the ready position, currently accomplished using a retaining spring. This method is sufficient for this prototypical stage but a more refined and less bulky approach, would be more appropriate for the next generation design.

After initial prototype testing was conducted on the Automated Cone Stowage System (ACSS), it was determined that while the ACSS displayed the desired motion needed to rotate and transport the traffic cones, several modifications to the original design were necessary to increase robustness. More extensive durability and reliability testing is required to effectively identify the areas that require some alterations.

Many of the required modifications on the ACSS were due to the unexpectedly high friction forces that were present when the carriage assemblies were in motion. Two main factors contributed to this problem. First, the tolerances of the linear bearing blocks were larger than expected and this discrepancy caused the rail and carriage system to have some binding problems. The second factor lending to this binding problem was the location of the belt attachment on the carriage assembly. Since the linkage mechanism had to be located directly in the middle of the carriage assembly, the belt attachment was designed to be placed slightly off the centerline so that it could be installed in its entirety. This pulling force imbalance only contributed to the problem of high bearing tolerances.

Several modifications were utilized to alleviate these friction forces. The rails and the bearing blocks were carefully realigned using a frame that constrained their lateral movement. A fifth idler pulley was also introduced to force the timing belt to contact a greater number of teeth on two of the four pulleys. This addition effectively increased the torque provided by the hydraulic motor of this system. These simple modifications proved to help the sliding action of the carriage assemblies and allow the ACSS to perform at expected speeds. Other recommended modifications to decrease these friction forces are to find a more suitable bearing system, possibly using roller or ball bearings instead of sleeve bearings, and to counteract the imbalance

of pulling force by cutting the belt and reattaching the ends to the middle of the carriage assemblies.

A second area of reconsideration are the cylinders used to activate the gripper mechanisms. Since the chosen cylinders were double acting, they required two hydraulic lines for total control. With the required rotational and transitional motion, the routing of hydraulic lines to these cylinders was difficult. Replacing these cylinders with single acting spring loaded ones would reduce the number of necessary lines for this system and make the task of routing lines much easier.

In general, the hydraulics prove to be reliable but several considerations are evident. While the distribution box is necessary to ensure that the correct hydraulic components are connected in the proper sequence, a manifold can accomplish the same task in a more compact space. After further testing, a better understanding of the power requirements will determine the necessary specifications for the construction of a manifold.

While the control scheme and code for operating the ACM is both basic and flexible, some modifications are anticipated. Since the integration of systems requires considerably accurate timing and the powering of systems relies on hydraulic fluid of variable temperature, some discrepancies between expected and actual activation times are expected. The code framework for the Coordinated Control Unit is also flexible to accommodate changes in operating procedures and sequences. Some investigation is recommended to determine whether there are other control systems that are more suitable for the needs of the ACM control system.

The development of the ACM and the testing of the systems both individually and collectively have proven that replacing manual methods of cone placement and retrieval with automated technology is feasible and practical. While this ACM prototype has shown some need for modification and improvement, the basic concepts of cone handling have been established and confirmed. After further field testing and optimization phases are complete, the ACM can prove to be both reliable and valuable.

REFERENCES

California Department of Transportation, 1992, Traffic Manual, State of California Department of Transportation Publication Distribution Unit, CA

Crandall, S. H., Dahl, N. C., Lardner, T. J., 1978, An Introduction to the Mechanics of Solids, Second Edition with SI units, McGraw-Hill, NY

Editors of *Hydraulics & Pneumatics*, 1994, Fluid Power Handbook & Directory, Penton Publishing, OH

Henke, R. W., 1983, Fluid Power Systems & Circuits, Penton Publishing, OH

Meriam, J.L., Kraige, L.G., 1987, Engineering Mechanics, DYNAMICS, John Wiley & Sons, NY

Merritt, H. E., 1967, Hydraulic Control Systems. John Wiley & Sons, NY

Munoz, D., 1995-96, *Berendson Fluid Power Inc.*, Vendor Consultation

Popov, E. P., 1990, Engineering Mechanics of Solids, Prentice Hall, New Jersey

Shigley, J. E., Mischke, C. R., 1989, Mechanical Engineering Design, Fifth Edition, McGraw-Hill, NY

Slater, R. E., 1993, Highway Statistics, Federal Highway Administration

Ulrich, K. T., Eppinger, S. D., 1995, Product Design and Development, McGraw-Hill, NY

APPENDIX A CALCULATIONS

Calculation 4.1

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

Poker Arm

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

Calculation 4.1 (Cont.)

find reaction forces Ra and Rb

$$\begin{array}{l} \text{sum of vertical} \\ \text{forces} \end{array} \quad Ra + Rb := mc \left(9.81 \cdot \frac{m}{\text{sec}^2} + ay \right) \quad \square$$

sum of moments about point Force Ra is exerted

$$-(Ra + Rb) \cdot (4.97 \cdot \text{in}) + Rb \cdot (4.97 \cdot \text{in} + 7.91 \cdot \text{in}) := 0 \quad \square$$

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

$$-(11.95 \cdot \text{lbf}) \cdot (4.97 \cdot \text{in}) + Rb \cdot (4.97 \cdot \text{in} + 7.91 \cdot \text{in}) := 0 \quad \square$$

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

$$Rb = 4.611 \cdot \text{lbf}$$

$$-(Ra + Rb) \cdot (4.97 \cdot \text{in}) + Rb \cdot (4.97 \cdot \text{in} + 7.91 \cdot \text{in}) = 0 \quad \square$$

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

$$Ra = 7.339 \cdot \text{lbf}$$

Calculation 4.1 (Cont.)

Strength of Poker Arm

Moment of Inertia

$$I := \frac{1}{12} \cdot w \cdot h^3 \quad I = 0.042 \cdot \text{in}^4$$

distance from neutral axis to
farthest fibers of component

$$c := \frac{h}{2} \quad c = 0.5 \cdot \text{in}$$

due to symmetry

angle between horizontal
and poker arm orientation

$$\tau := 98 \cdot \text{deg}$$

Moment on Poker Arm

$$M := l \cdot Rb \cdot \sin(\tau)$$

$$M = 49.087 \cdot \text{in} \cdot \text{lbf}$$

Calculation 4.1 (Cont.)

Treating Poker arm as a simple beam

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

$$\sigma = 589.048 \cdot \text{psi}$$

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

length of thinner tip piece of
poker arm

$$l := 1.634 \cdot \text{in}$$

Height of thinner thinner piece
of poker arm

$$h := .5 \cdot \text{in}$$

Moment of inertia of thinner
piece of poker arm

$$I := \frac{1}{12} \cdot w \cdot h^3 \quad I = 0.005 \cdot \text{in}^4$$

Moment of thinner piece of
poker arm

$$M := l \cdot Rb \cdot \sin(\tau)$$

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

$$\sigma = 716.283 \cdot \text{psi}$$

Drawing for Calculation 4.1

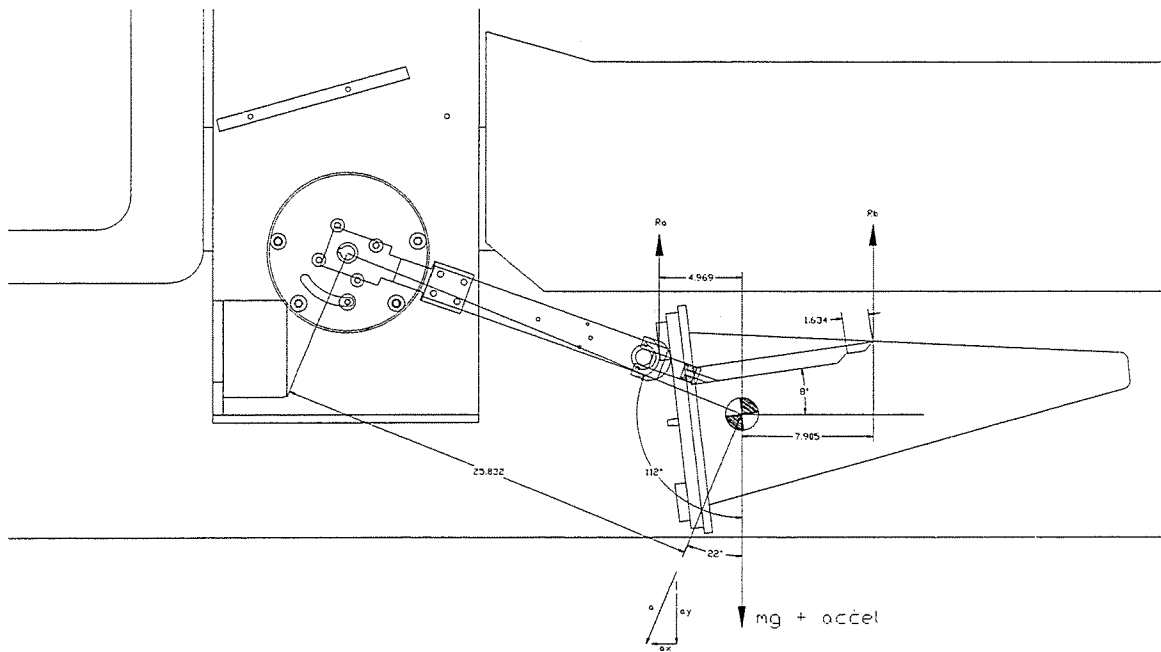


Figure A.1 *Reference Drawing for Calculation 4.1*

Calculation 4.2

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

Cross Member Calculations

Impact of Cone Onto Cross Member at 10 MPH

relative velocity of cone to truck	$v := 10 \cdot \text{mph}$
kinetic energy	$T := \frac{1}{2} \cdot m_c \cdot v^2 \quad T = 45.324 \cdot \text{kg} \cdot \text{m}^2 \cdot \text{sec}^{-2}$
observed energy absorption of cone	$EA := \frac{82}{84}$
amount of energy transmitted to cross arm as cone hits it	$En := (1 - EA) \cdot T$ $En = 1.0791 \cdot \text{kg} \cdot \text{m}^2 \cdot \text{sec}^{-2}$

Calculation 4.2 (Cont.)

assuming cross arm acts like a spring

potential 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

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

$$\text{assume rectangular cross section with length} \quad L := 8.875 \cdot \text{in}$$

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

width $w := 1 \cdot \text{in}$

thickness $h := .5 \cdot \text{in}$

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

At weak point of cross member

1-direction along cross member

2-direction perpendicular to cross member

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

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

Calculation 4.2 (Cont.)

$$I_2 = 0.0416 \cdot \text{in}^4$$

$$I_{12} := 0 \cdot \text{in}^4$$

$$I := -\frac{I_1 - I_2}{2} \cdot \sin(2 \cdot \theta) + I_{12} \cdot \cos(2 \cdot \theta)$$

$$I = 0.0135 \cdot \text{in}^4$$

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

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

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

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

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

$$F = 179.1785 \cdot \text{lbf}$$

$$x = 0.1066 \cdot \text{in}$$

$$F_1 := F \cdot \cos(\theta) \quad F_1 = 158.2052 \cdot \text{lbf}$$

$$F_2 := F \cdot \sin(\theta) \quad F_2 = 84.1192 \cdot \text{lbf}$$

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

Calculation 4.2 (Cont.)

The bending moment about the 2-direction

$$M2 := F1 \cdot X \quad M2 = 18.8865 \cdot \text{m} \cdot \text{lbf}$$

$$M1 := F2 \cdot X \quad M1 = 10.0422 \cdot \text{m} \cdot \text{lbf}$$

Bending stress

$$\sigma_1 := \frac{M1 \cdot \frac{h}{2}}{I1} \quad \sigma_1 = 1.1008 \cdot 10^4 \cdot \text{psi}$$

$$\sigma_2 := \frac{M2 \cdot \frac{w}{2}}{I2} \quad \sigma_2 = 8.9463 \cdot 10^3 \cdot \text{psi}$$

Drawing for Calculation 4.2

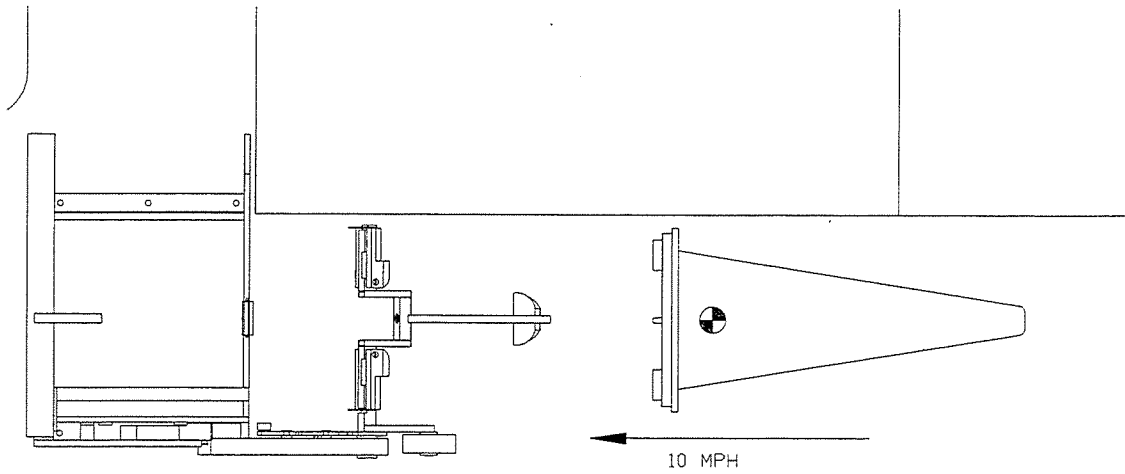


Figure A.2 *Reference Drawing for Calculation 4.2*

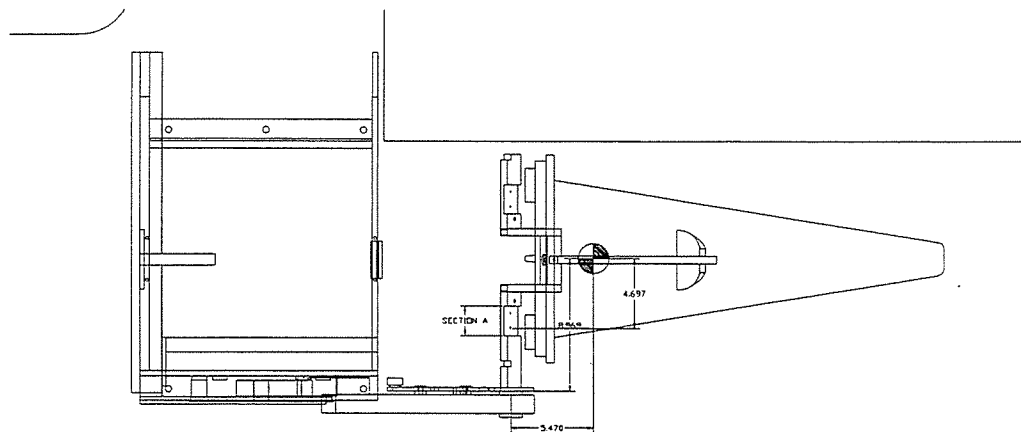


Figure A.3 *Reference Drawing for Calculation 4.2*

Drawing for Calculation 4.2

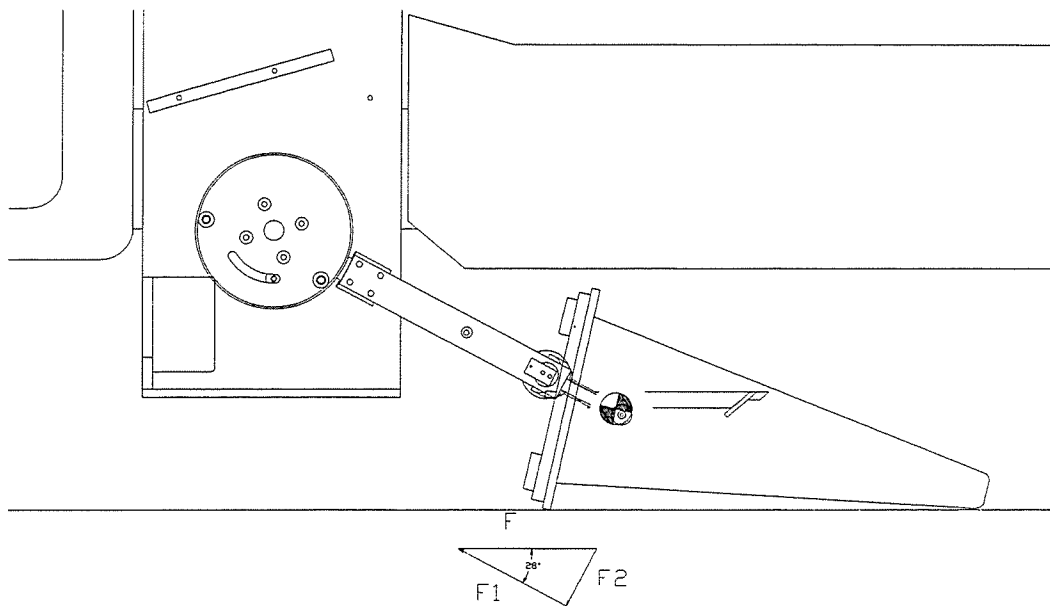


Figure A.4 *Reference Drawing for Calculation 4.2*

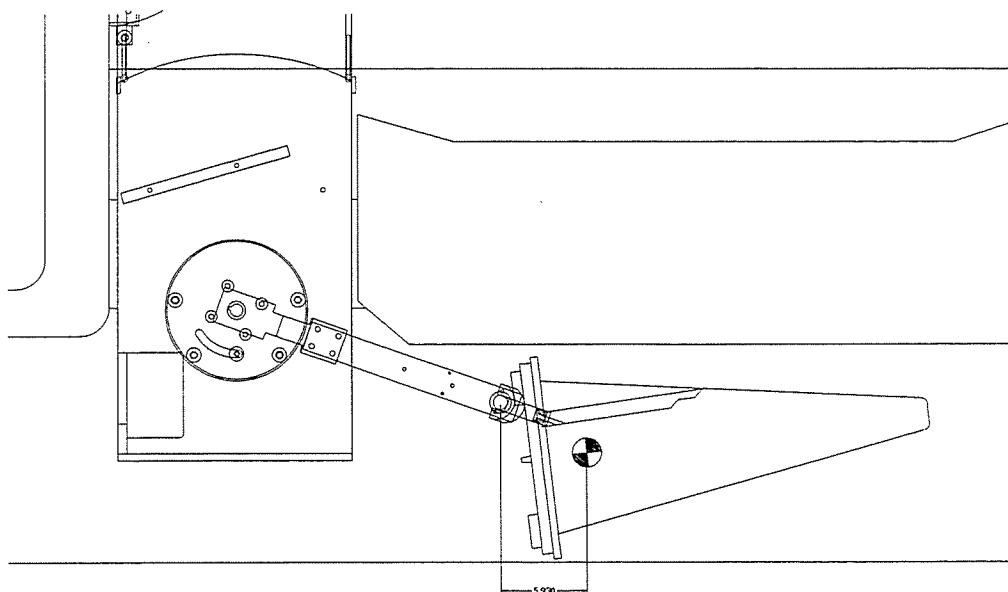


Figure A.5 *Reference Drawing for Calculation 4.2*

Calculation 4.3

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

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	$\theta := 28 \cdot \text{deg}$
thickness at weak point	$th := .5 \cdot \text{in}$
base at weak point	$b := 1 \cdot \text{in}$
constant for torsion calculation	$\psi := .246 \quad (\text{p.208, Popov, 1990})$
distance to C.M. of cone from pivot point	$dc := 5 \cdot \text{in}$
distance from poker arm to weak point	$dp = 4.7 \cdot \text{in}$
from Calc3-20	$I_x := .00898 \cdot \text{in}^4 \quad I_y := .0416 \cdot \text{in}^4$

Calculation 4.3 (Cont.)

Force generated from lifting cone

$$F := mc \cdot (a + g) \quad F = 12.099 \cdot \text{lbf}$$

$$\text{Force in X-direction} \quad F_x := F \cdot \sin(\theta) \quad F_x = 5.68 \cdot \text{lbf}$$

$$\text{Force in Y-direction} \quad F_y := F \cdot \cos(\theta) \quad F_y = 10.683 \cdot \text{lbf}$$

Torsion on cross member

$$M_t := F \cdot d_c \quad M_t = 60.497 \cdot \text{in} \cdot \text{lbf}$$

Shear stress due to torsion (Popov, 1990)

$$\tau := \frac{M_t}{\psi \cdot b \cdot t^2} \quad \tau = 983.686 \cdot \text{psi}$$

Bending stresses due to lifting

$$M_x := F_x \cdot d_p \quad M_x = 26.697 \cdot \text{in} \cdot \text{lbf}$$

$$M_y := F_y \cdot d_p \quad M_y = 50.21 \cdot \text{in} \cdot \text{lbf}$$

distance from neutral axis to point of interest in y-dir $c_y = .25 \text{ in}$

distance from neutral axis to point of interest in x-dir $c_x = .5 \text{ in}$

$$\sigma_x := \frac{M_y \cdot c_y}{I_x} \quad \sigma_x = 1.398 \cdot 10^3 \cdot \text{psi}$$

$$\sigma_y := \frac{M_x \cdot c_x}{I_y} \quad \sigma_y = 320.882 \cdot \text{psi}$$

Superposition Principle states that all stress can be added together

Due to torsion:	$\sigma_x = 0$	Due to bending:	$\sigma_x = 1398 \text{ psi}$
	$\sigma_y = 0$		$\sigma_y = 321 \text{ psi}$
	$\tau = 984 \text{ psi}$		$\tau = 0$

$$\begin{aligned} \text{maximum stress} \\ \sigma_{\max} &:= \frac{\sigma_x + \sigma_y}{2} + \sqrt{\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + \tau^2} \\ \sigma_{\max} &= 1.981 \cdot 10^3 \cdot \text{psi} \end{aligned}$$

Calculation 4.4

velocity of vehicle	$v := 10 \cdot \text{mph}$	
distance between cones	$d := 50 \cdot \text{ft}$	
cycle time interval	$t := \frac{d}{v}$	$t = 3.409 \cdot \text{sec}$
mass of cone	$m_c := 10 \cdot \text{lb}$	
angular velocity of arm	$\omega := 3.14159 \cdot \frac{\text{rad}}{\text{sec}}$	
angular accel of arm	$\alpha := 3.14159 \cdot \frac{\text{rad}}{\text{sec}^2}$	
radius from actuator to C.M. of cone	$r_c := 25.8 \cdot \text{in}$	
radius from actuator to cross member	$r_{cm} := 19 \cdot \text{in}$	
length of main arm	$l := 15 \cdot \text{in}$	
accel of cone	$a_c := \alpha \cdot r_c$	$a_c = 81.053 \cdot \frac{\text{in}}{\text{sec}^2}$
accel of cross member	$a_{cm} := \alpha \cdot r_{cm}$	$a_{cm} = 59.69 \cdot \frac{\text{in}}{\text{sec}^2}$
approximate mass of cross member		
volume of cross member	$\text{Vol} := 1 \cdot \text{in} \cdot 1 \cdot \text{in} \cdot 16 \cdot \text{in}$	
	$\text{Vol} = 16 \cdot \text{in}^3$	
density of steel	$\rho := .283 \cdot \frac{\text{lb}}{\text{in}^3}$	
mass of cross member	$m_{cm} := \text{Vol} \cdot \rho$	$m_{cm} = 4.528 \cdot \text{lb}$

Calculation 4.4 (Cont.)

Static load of cross member and cone on main arm

$$P_s := g \cdot (m_{cm} + m_c)$$

$$P_s = 14.528 \cdot \text{lbf}$$

Dynamic loads of cross member and cone arm

$$P_d := a_c \cdot m_c + a_{cm} \cdot m_{cm}$$

$$P_d = 2.799 \cdot \text{lbf}$$

Total load, static and dynamic

$$P := P_s + P_d$$

$$P = 17.327 \cdot \text{lbf}$$

Bending on main arm

maximum load when arm is parallel to ground

bending moment $M_b := P \cdot l$

$$M_b = 259.911 \cdot \text{in} \cdot \text{lbf}$$

Torsion on arm

distance from C.M. of cone and
cross member to main arm pivot

$$d_c := 8 \cdot \text{in}$$

$$M_t := P \cdot d_c$$

$$M_t = 138.619 \cdot \text{in} \cdot \text{lbf}$$

Calculation 4.4 (Cont.)

height of beam $hb := 2 \cdot \text{in}$

thickness of beam $tb := 1.25 \cdot \text{in}$

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

Bending stress on main arm

$$\sigma_b := \frac{Mb \cdot \frac{hb}{2}}{I} \quad \sigma_b = 311.893 \cdot \text{psi}$$

Torsional stress on main arm

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

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

$$\tau = 145.915 \cdot \text{psi}$$

Calculation 4.4 (Cont.)

Stresses from bending

$$\sigma_b = 395 \text{ psi}$$

$$\sigma_x = 0 \text{ psi}$$

$$\tau = 0 \text{ psi}$$

Stresses from torsion

$$\sigma_b = 0 \text{ psi}$$

$$\sigma_x = 0 \text{ psi}$$

$$\tau = 146 \text{ psi}$$

Superposition Principal allows for the addition of stresses
total stresses

$$\sigma_b = 311.893 \cdot \text{psi}$$

$$\sigma_x := 0 \cdot \text{psi}$$

$$\tau = 145.915 \cdot \text{psi}$$

$$\sigma_{\max} := \frac{\sigma_b + \sigma_x}{2} + \sqrt{\left(\frac{\sigma_b - \sigma_x}{2}\right)^2 + \tau^2}$$

$$\sigma_{\max} = 369.512 \cdot \text{psi}$$

Calculation 4.5

velocity of vehicle	$v := 10 \text{ mph}$	
distance between cones	$d := 50 \text{ ft}$	
cycle time interval	$t := \frac{d}{v}$	$t = 3.409 \text{ sec}$
mass of cone	$m_c := 10 \text{ lb}$	
angular velocity of arm	$\omega := 3.14159 \frac{\text{rad}}{\text{sec}}$	
angular accel of arm	$\alpha := 3.14159 \frac{\text{rad}}{\text{sec}^2}$	
radius from actuator to C.M. of cone	$r_c := 25.8 \text{ in}$	
radius from actuator to cross member	$r_{cm} := 19 \text{ in}$	
radius from actuator to C.M. of main arm	$r_{ma} := 12.75 \text{ in}$	
radius from actuator to end of arm mount	$r_{am} := 6.5 \text{ in}$	
accel of main arm	$a_{ma} := \alpha \cdot r_{ma}$	$a_{ma} = 40.055 \cdot \frac{\text{in}}{\text{sec}^2}$
accel of cone	$a_c := \alpha \cdot r_c$	$a_c = 81.053 \cdot \frac{\text{in}}{\text{sec}^2}$
accel of cross member	$a_{cm} := \alpha \cdot r_{cm}$	$a_{cm} = 59.69 \cdot \frac{\text{in}}{\text{sec}^2}$

Calculation 4.5 (Cont.)

approximate mass of cross member

volume of cross member $\text{Vol} := 1 \cdot \text{in} \cdot 1 \cdot \text{in} \cdot 16 \cdot \text{in}$
 $\text{Vol} = 16 \cdot \text{in}^3$

density of steel $\rho_s := .283 \frac{\text{lb}}{\text{in}^3}$

mass of cross member $\text{mcm} := \text{Vol} \cdot \rho_s$ $\text{mcm} = 4.528 \cdot \text{lb}$

approximate mass of main arm

volume of main arm $\text{Vol} := 1.25 \cdot \text{in} \cdot 2 \cdot \text{in} \cdot 15 \cdot \text{in}$
 $\text{Vol} = 37.5 \cdot \text{in}^3$

density of aluminum $\rho_a := .100 \frac{\text{lb}}{\text{in}^3}$

mass of cross member $\text{mma} := \text{Vol} \cdot \rho_a$ $\text{mma} = 3.75 \cdot \text{lb}$

Calculation 4.5 (Cont.)

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

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

$$P_s = 18.278 \cdot \text{lbf}$$

Dynamic loads of cross member and cone arm

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

$$P_d = 3.188 \cdot \text{lbf}$$

Total load, static and dynamic

$$P := P_s + P_d$$

$$P = 21.466 \cdot \text{lbf}$$

Bending on main arm

maximum load when arm is parallel to ground

bending moment $M_b := P \cdot ram$

$$M_b = 139.532 \cdot \text{in} \cdot \text{lbf}$$

Torsion on arm

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

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

$$M_t = 138.619 \cdot \text{in} \cdot \text{lbf}$$

Calculation 4.5 (Cont.)

height of mount $hm := 1.5 \text{ in}$

thickness of mount $tm := 1.065 \text{ in}$

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

Bending stress on main arm

$$\sigma_b := \frac{Mb \cdot \frac{hm}{2}}{I} \quad \sigma_b = 349.375 \text{ psi}$$

Torsional stress on main arm

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

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

$$\tau = 352.712 \text{ psi}$$

Stresses from bending

$$\sigma_b = 349 \text{ psi}$$

$$\sigma_x = 0 \text{ psi}$$

$$\tau = 0 \text{ psi}$$

Stresses from torsion

$$\sigma_b = 0 \text{ psi}$$

$$\sigma_x = 0 \text{ psi}$$

$$\tau = 352 \text{ psi}$$

Superposition Principal allows for the addition of stresses
total stresses

$$\sigma_b = 349.375 \text{ psi}$$

$$\sigma_x := 0 \text{ psi}$$

$$\tau = 352.712 \text{ psi}$$

$$\sigma_{\max} := \frac{\sigma_b + \sigma_x}{2} + \sqrt{\left(\frac{\sigma_b - \sigma_x}{2}\right)^2 + \tau^2}$$

$$\sigma_{\max} = 568.288 \text{ psi}$$

Calculation 5.1

HYDRAULIC POWER REQUIREMENTS

Lateral conveyors

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

$$\text{Power1} := Q \cdot \text{press} \quad \text{Power1} = 0.408 \cdot \text{hp}$$

Funnel Actuator

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

$$\text{Power2} := Q \cdot \text{press} \quad \text{Power2} = 0.07 \cdot \text{hp}$$

Stowage

Motor

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

$$\text{Power3} := Q \cdot \text{press} \quad \text{Power3} = 1.021 \cdot \text{hp}$$

Retrieval

Actuator

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

$$\text{Power4} := Q \cdot \text{press} \quad \text{Power4} = 0.343 \cdot \text{hp}$$

Stowage

Cylinders

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

$$\text{Power5} := Q \cdot \text{press} \quad \text{Power5} = 0.056 \cdot \text{hp}$$

Total Power

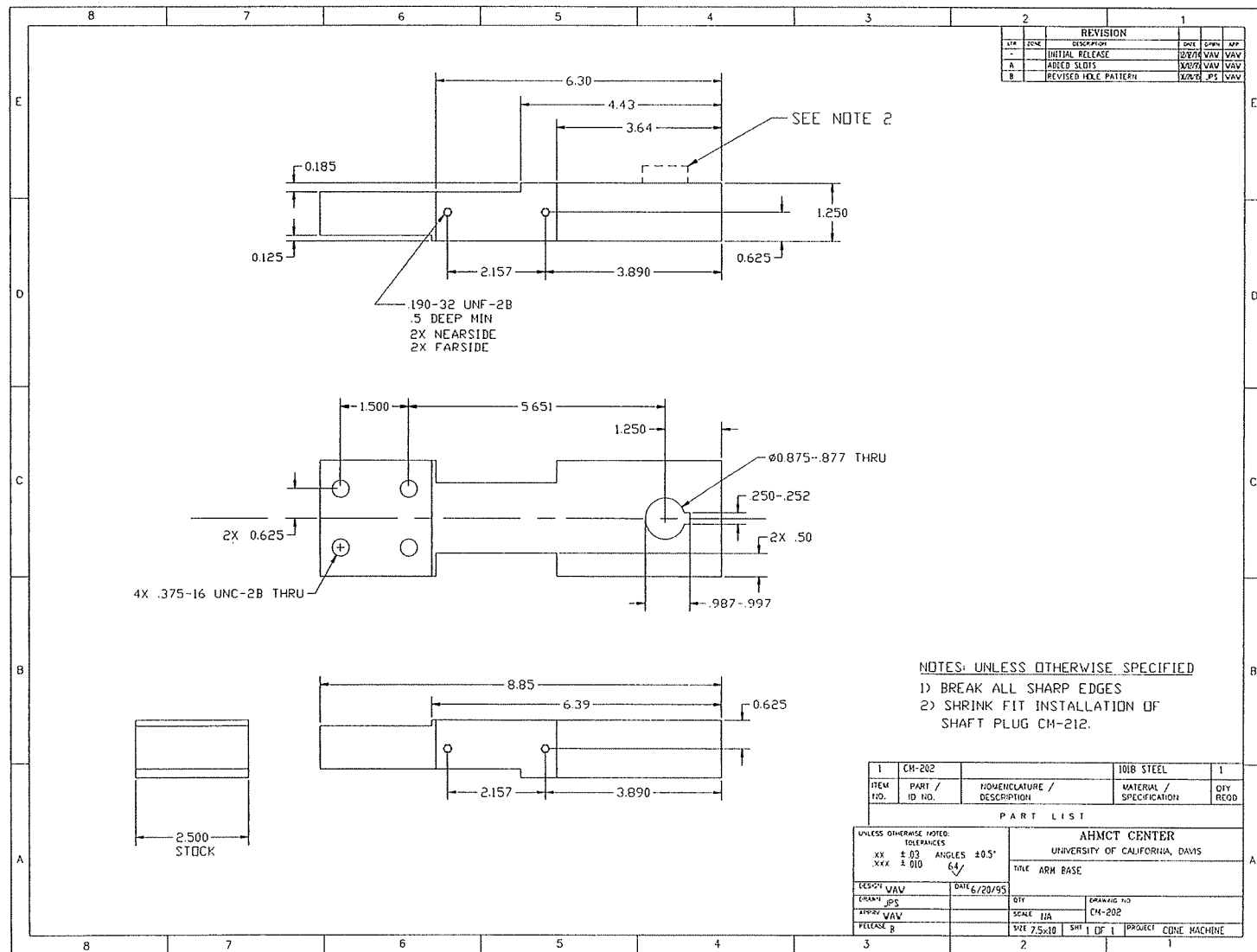
$$\text{Power} := \text{Power1} + \text{Power2} + \text{Power3} + \text{Power4} + \text{Power5}$$

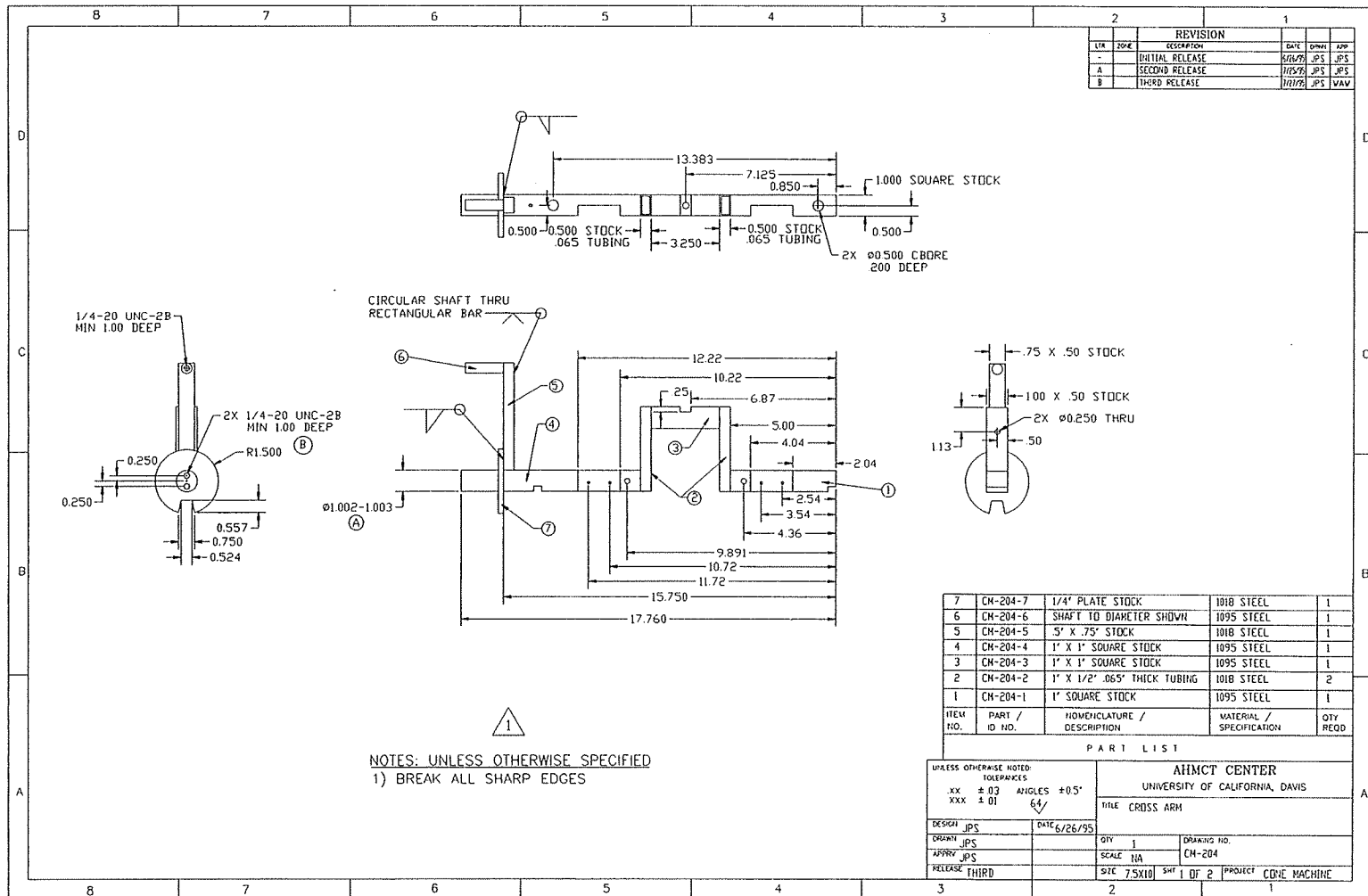
$$\text{Power} = 1.898 \cdot \text{hp}$$

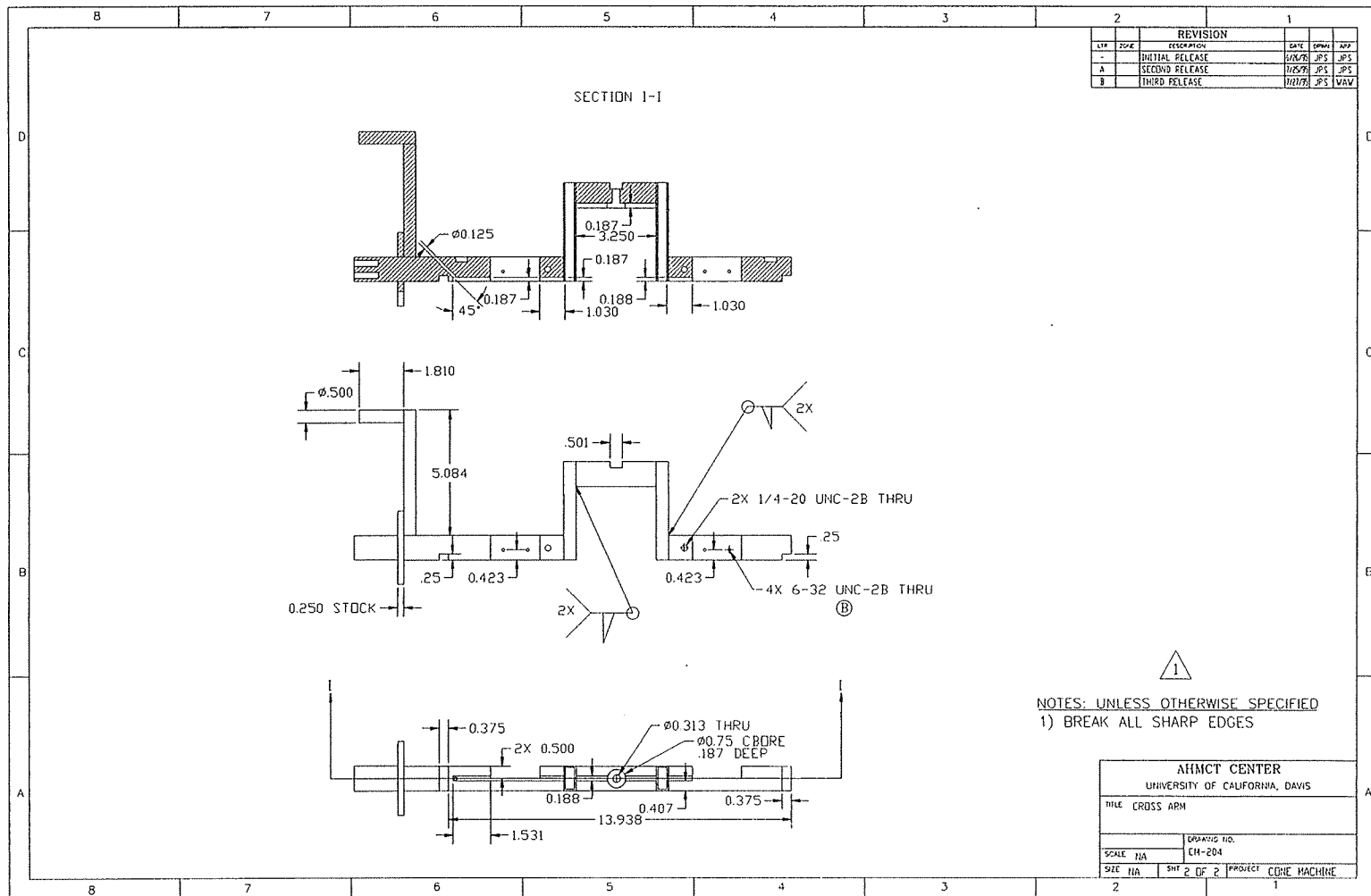
$$\text{Power} = 1.416 \cdot 10^3 \cdot \text{watt}$$

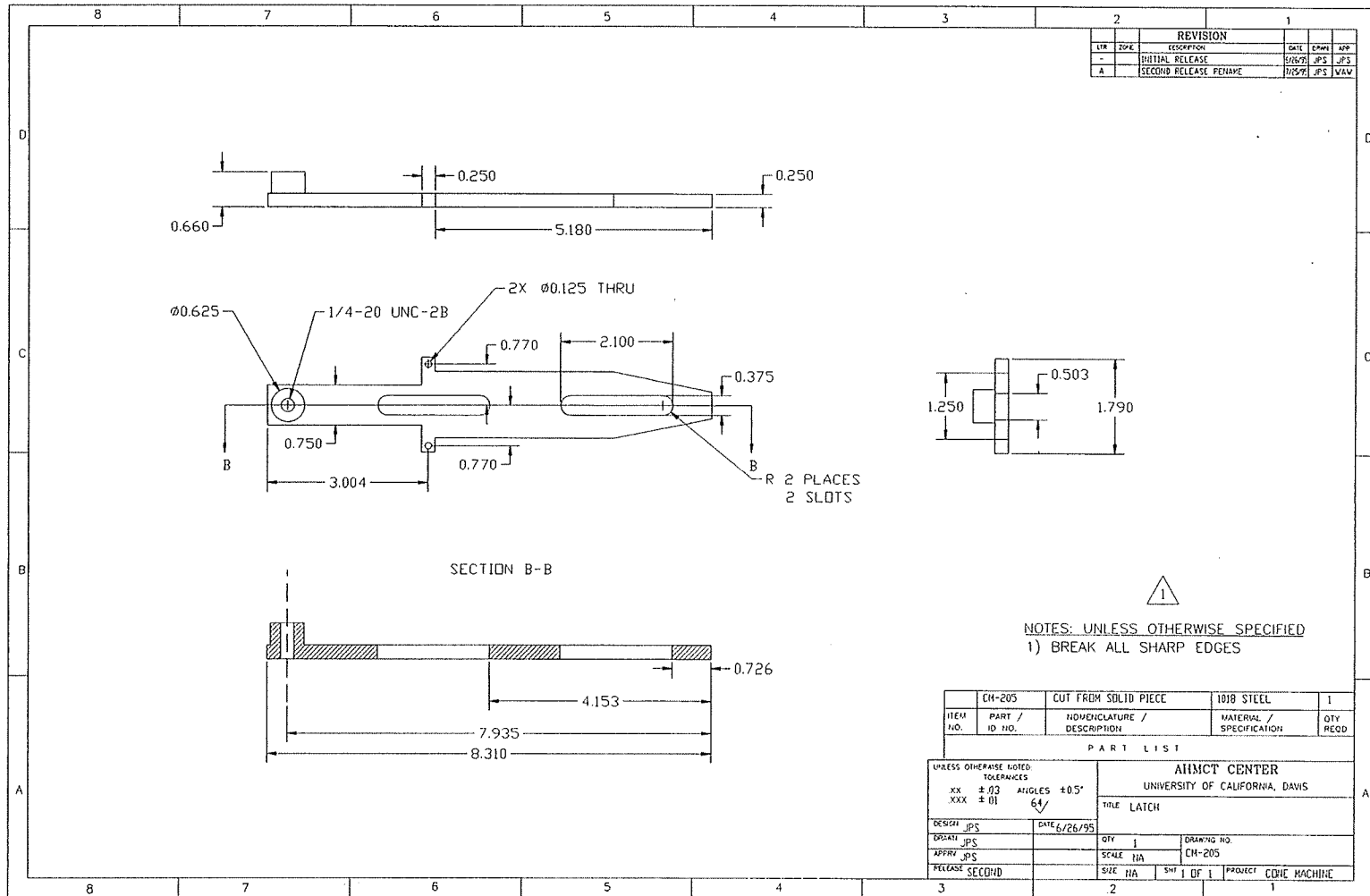
APPENDIX B DETAILED DRAWINGS FOR RETRIEVAL SYSTEM**RETRIEVAL SYSTEM DRAWING LIST**

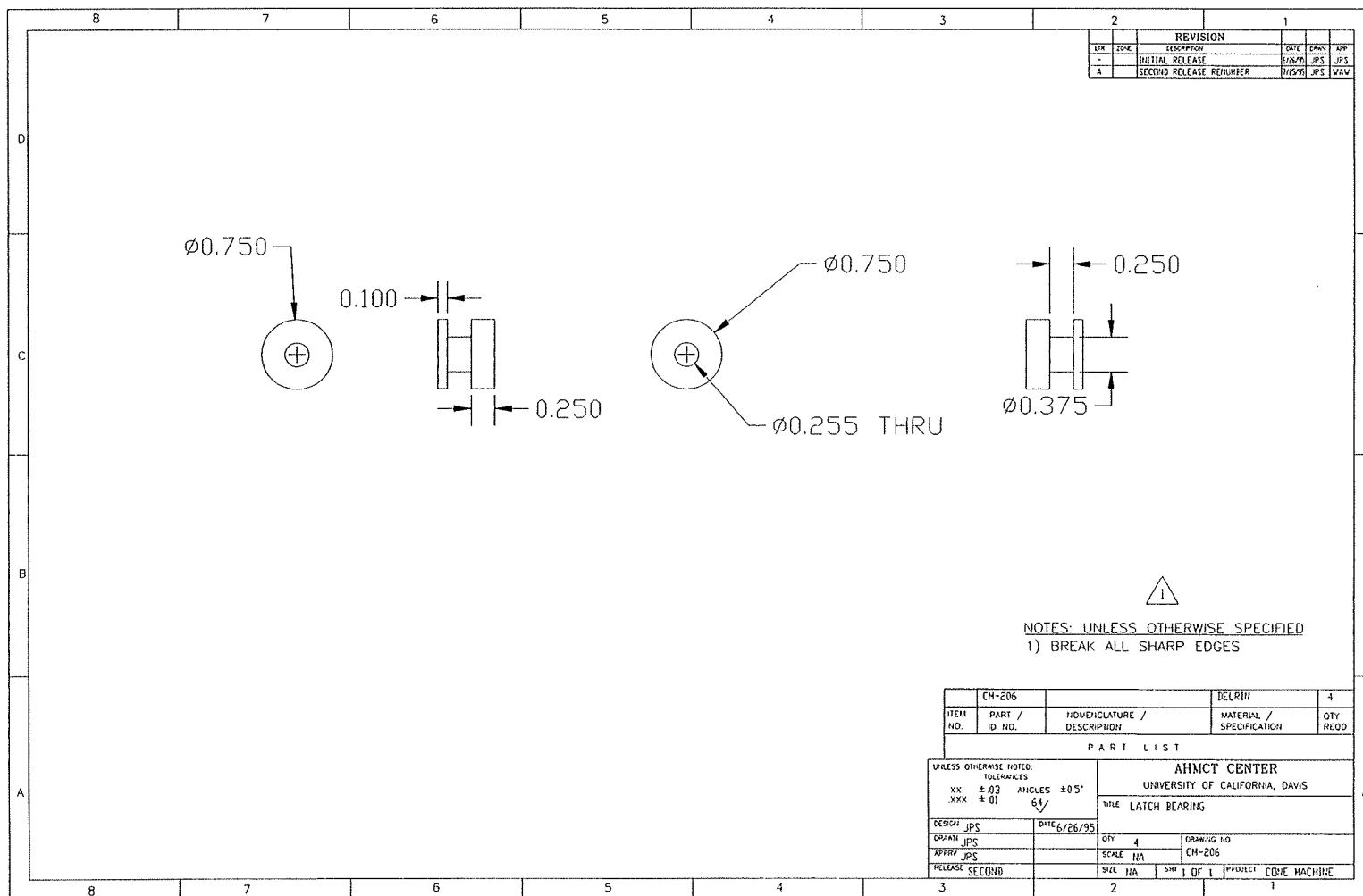
<u>DWG NO.</u>	<u>DESCRIPTION</u>
CM-202	ARM BASE
CM-203	MAIN ARM
CM-204	CROSS ARM
CM-205	LATCH
CM-206	LATCH BEARING
CM-208	SWITCH MOUNT
CM-209	BUMPER RETAINING PLATE
CM-210	CONE BUMPER
CM-211	SPRING MOUNT
CM-213	POKER ARM
CM-214	POKER ARM SEMI-CIRCLE
CM-215	LATCH ROLLER
CM-301	STRIPPER PLATE
CM-310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

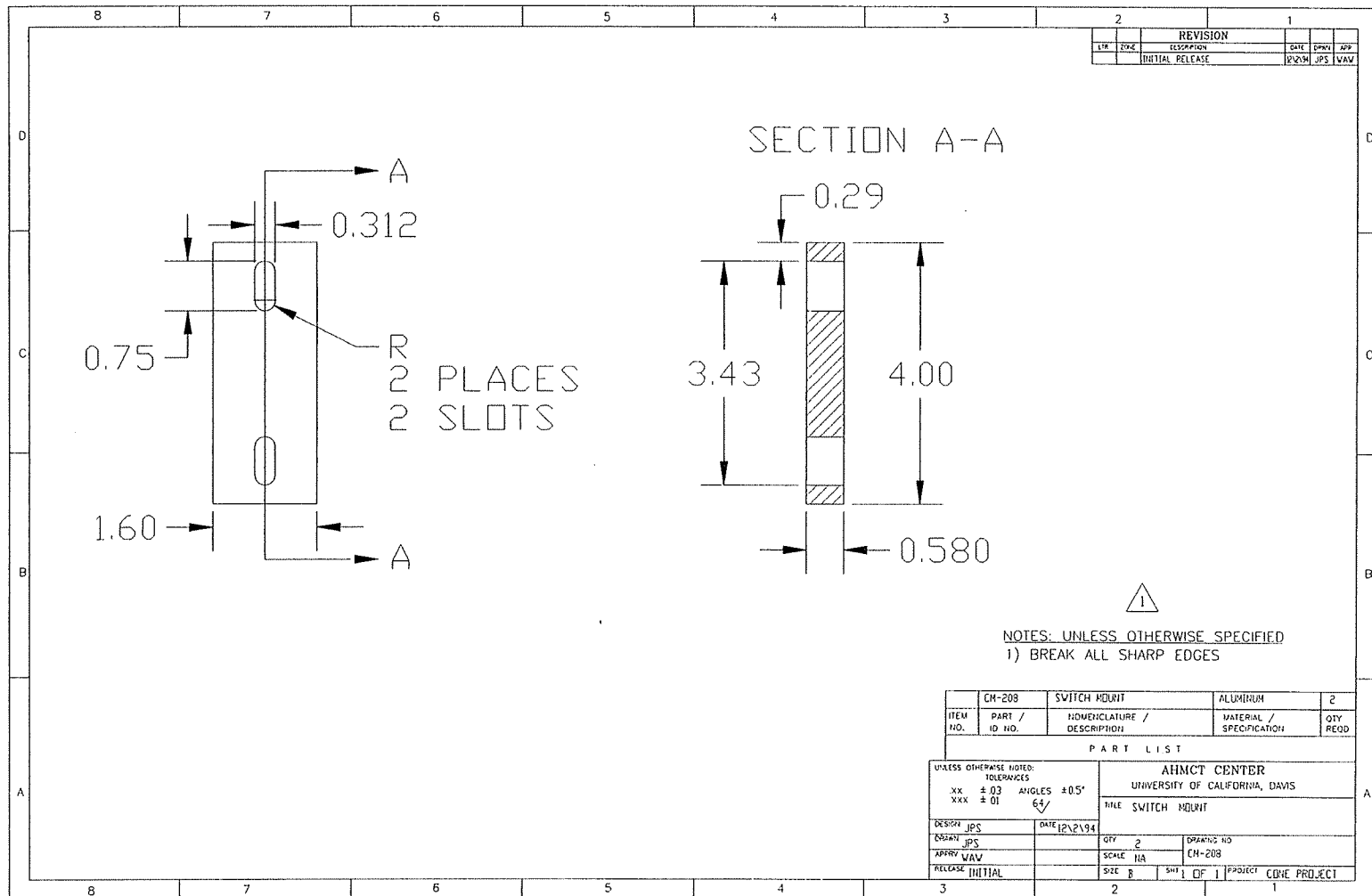


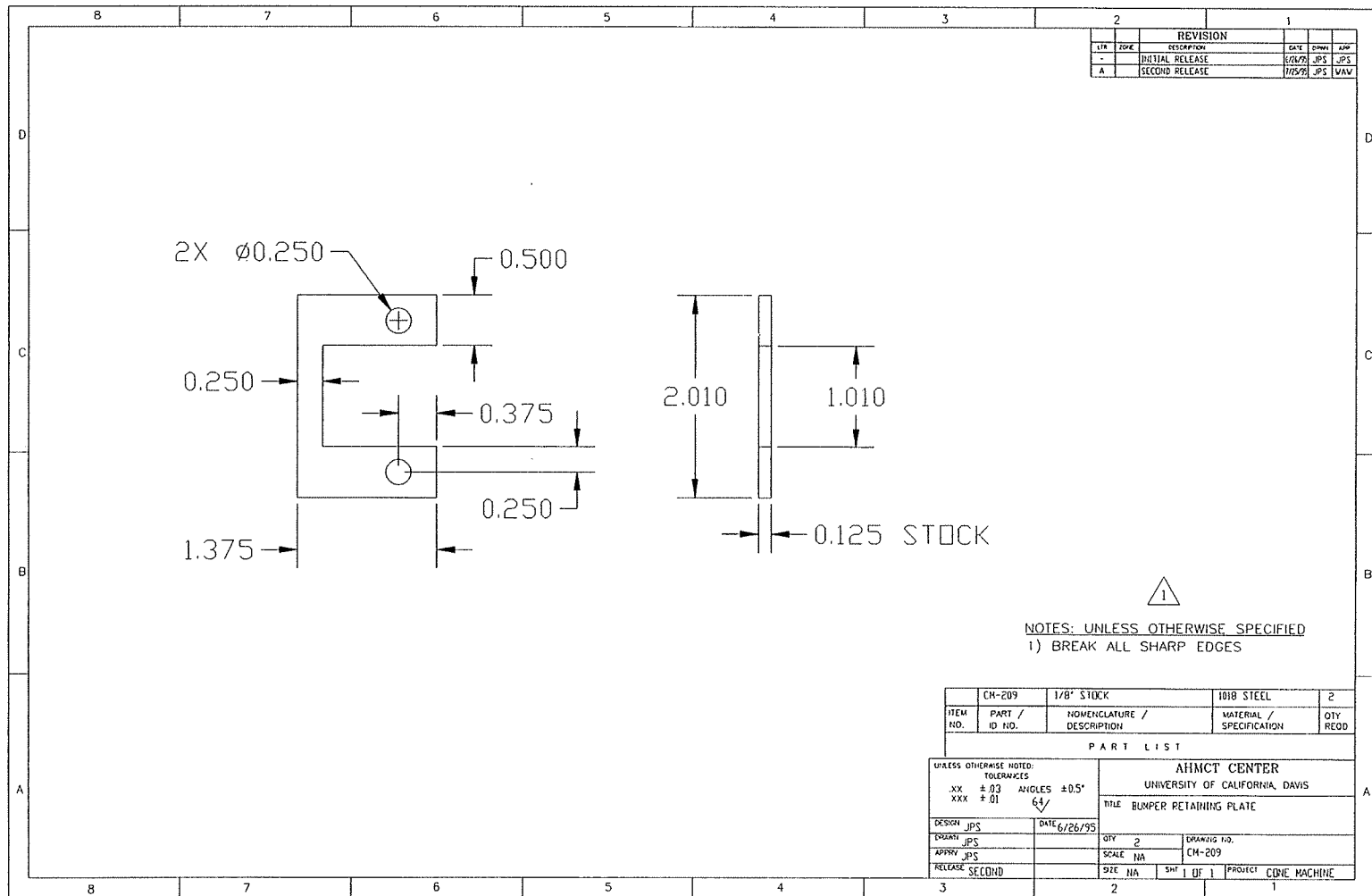


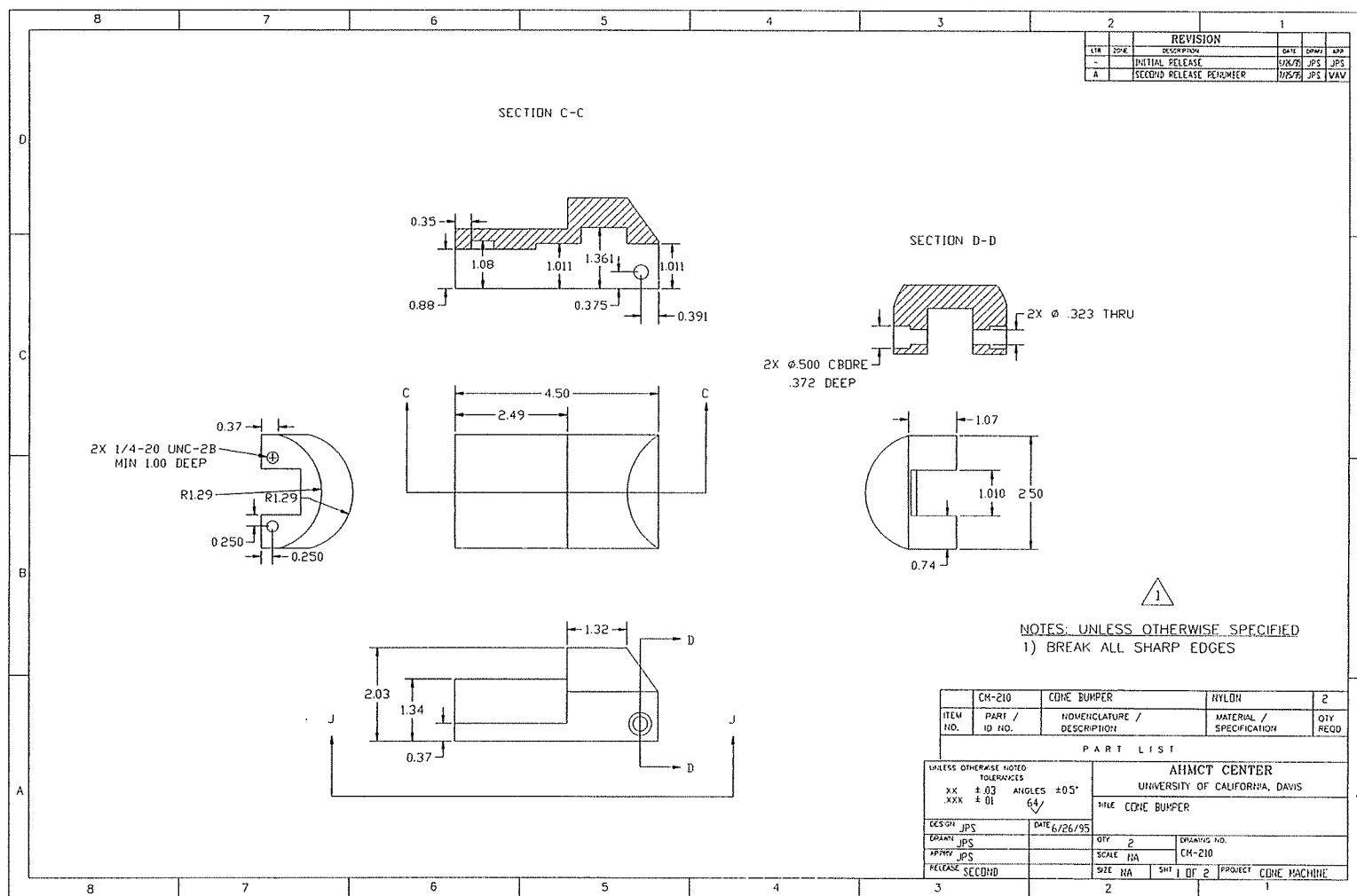


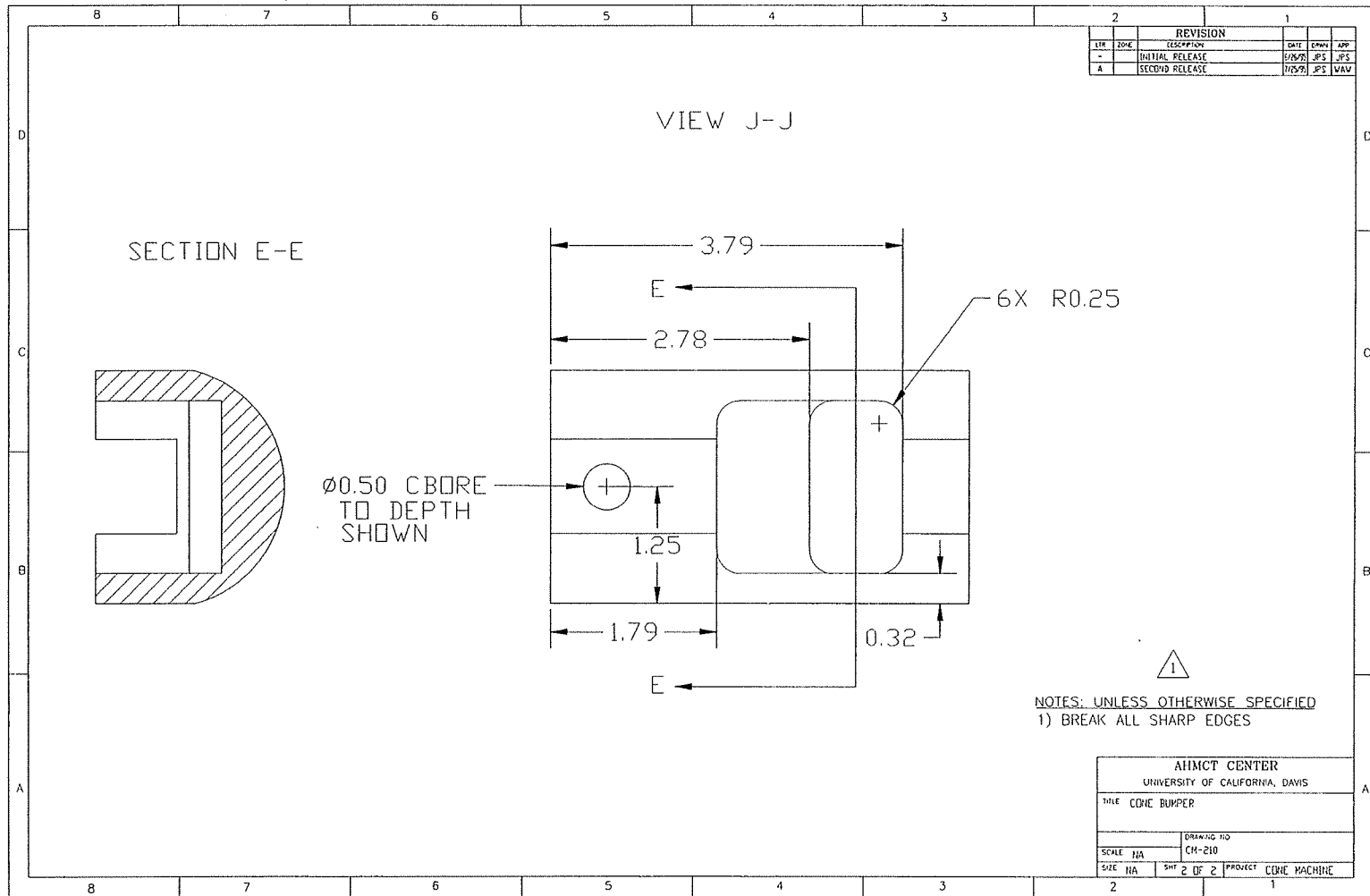


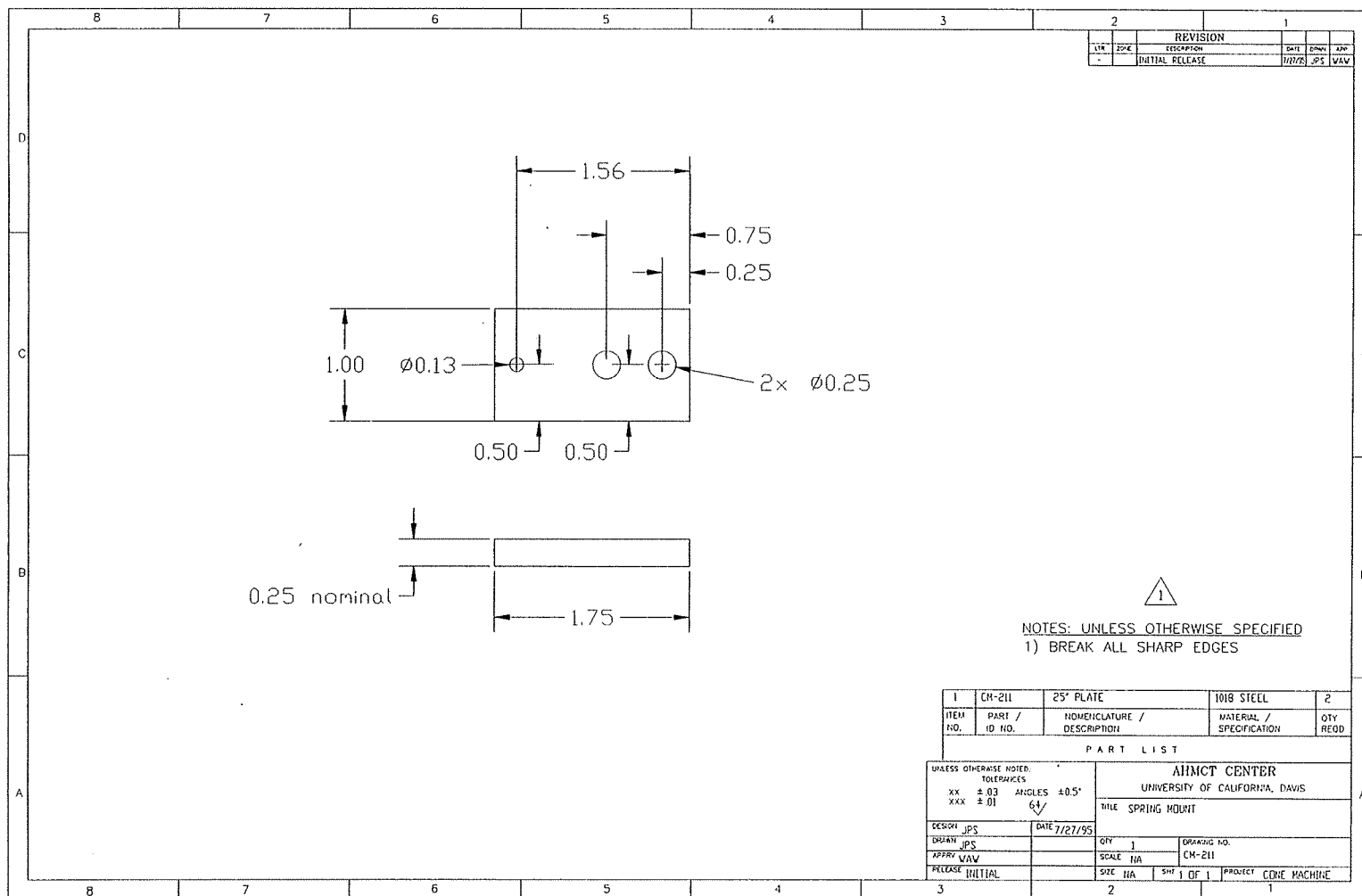


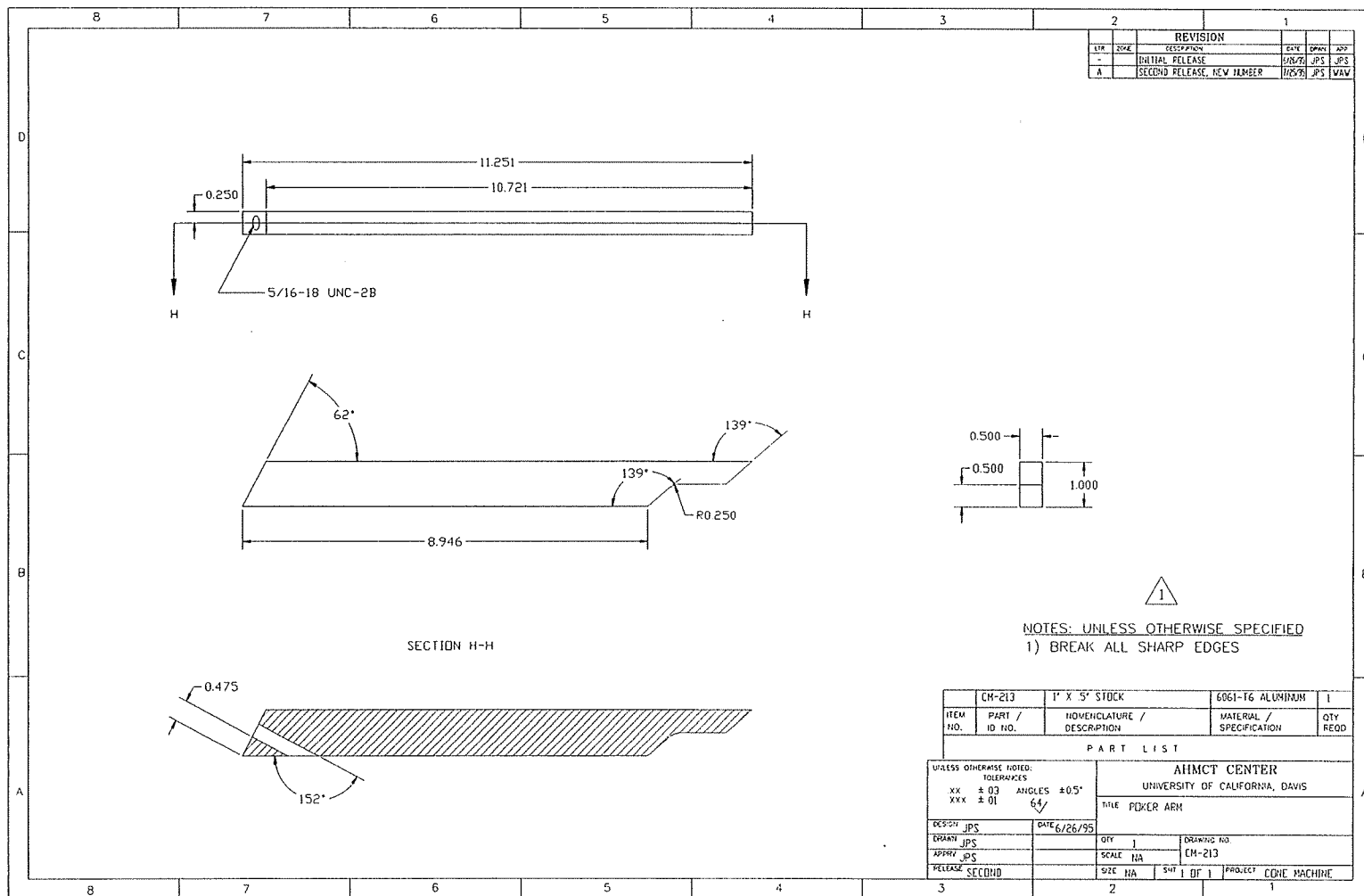


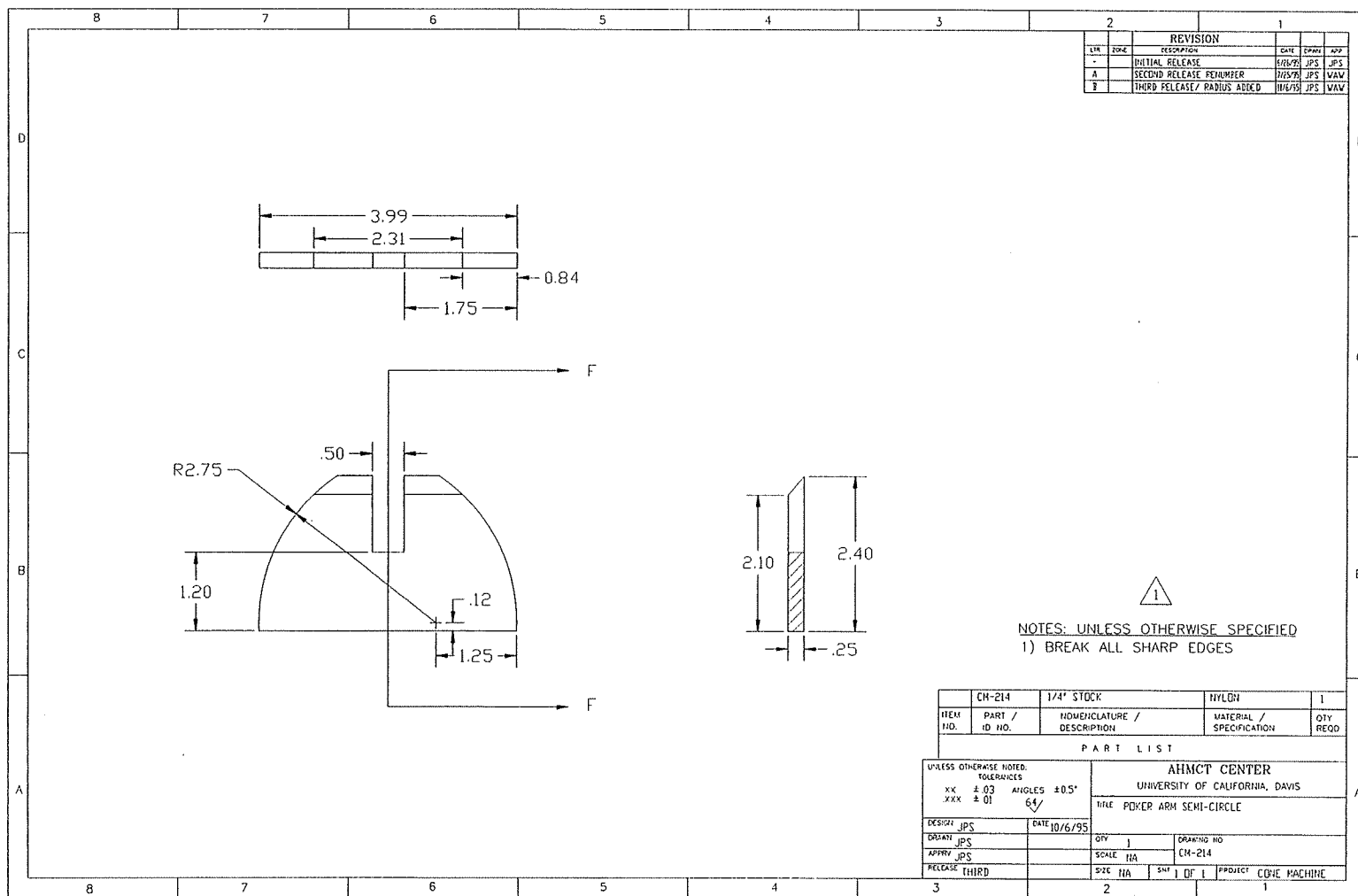


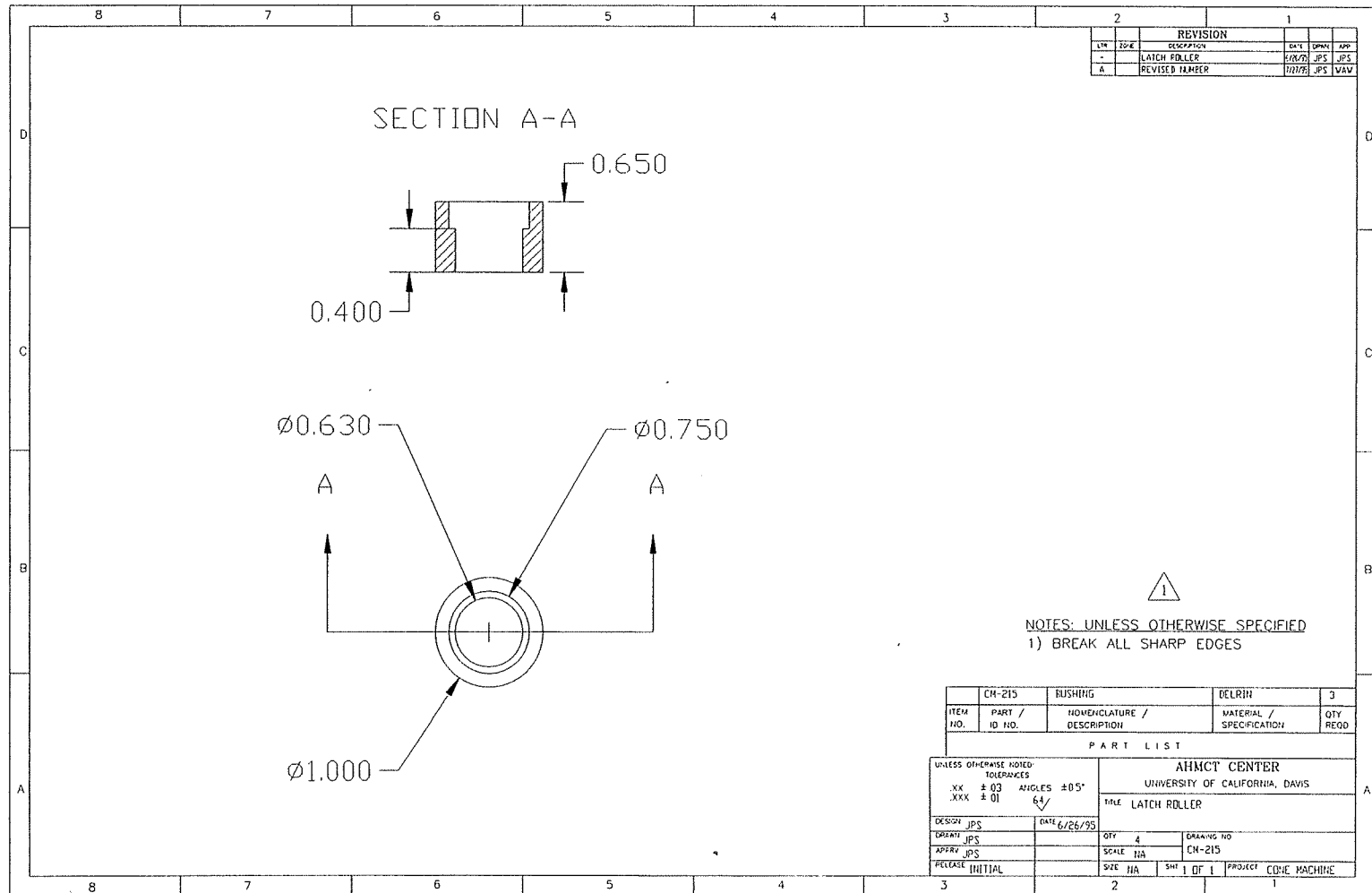


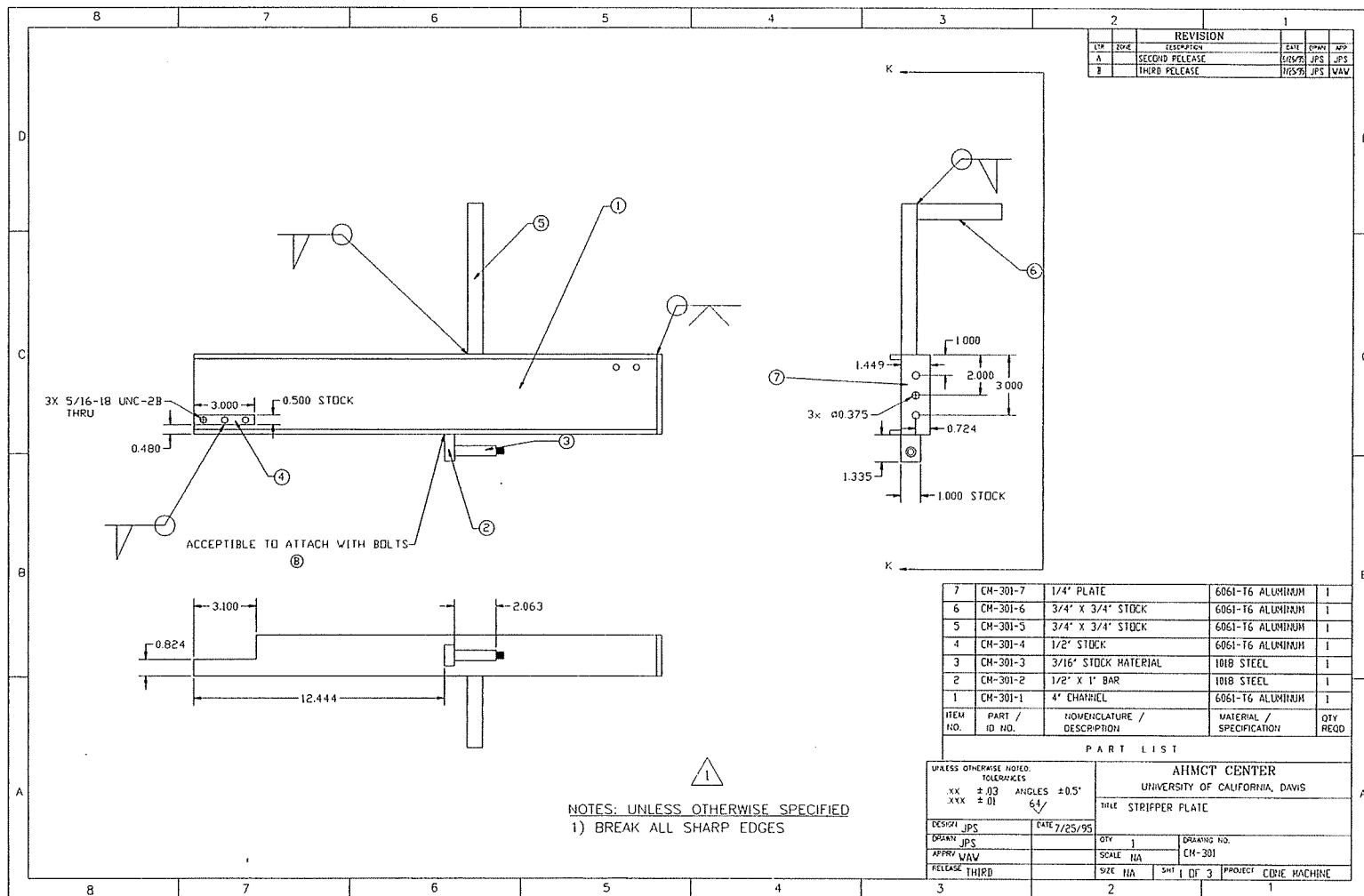


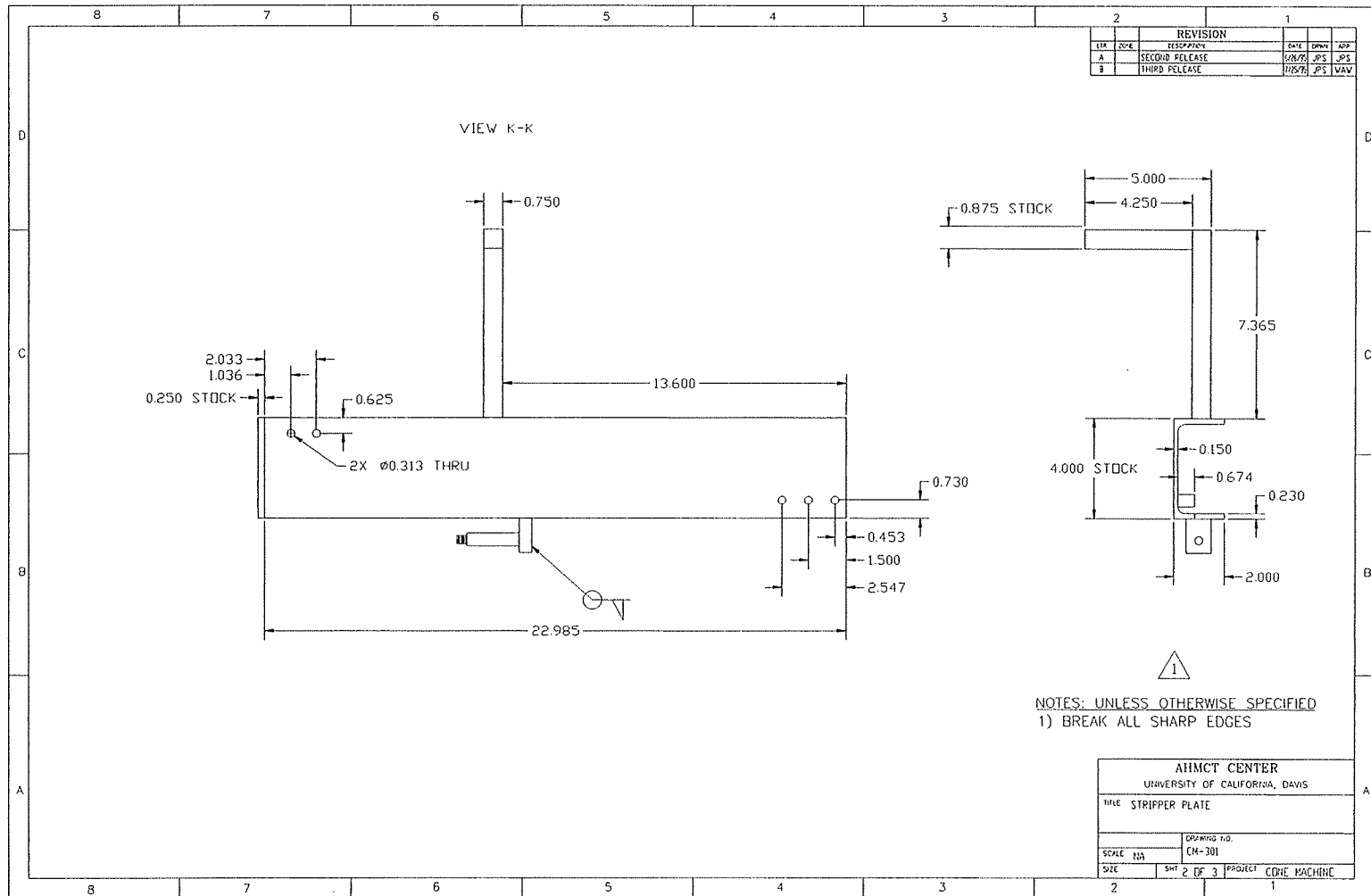


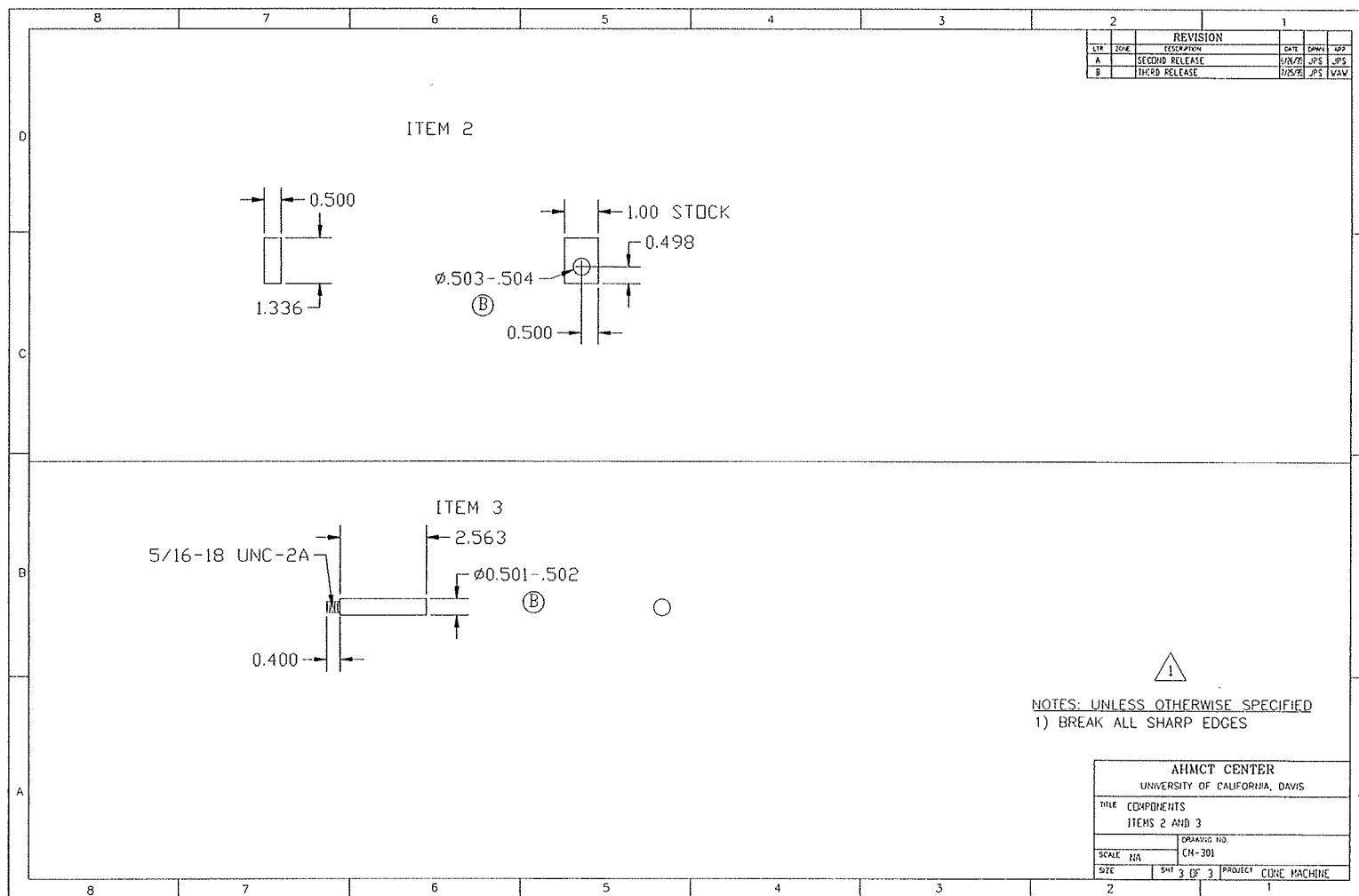


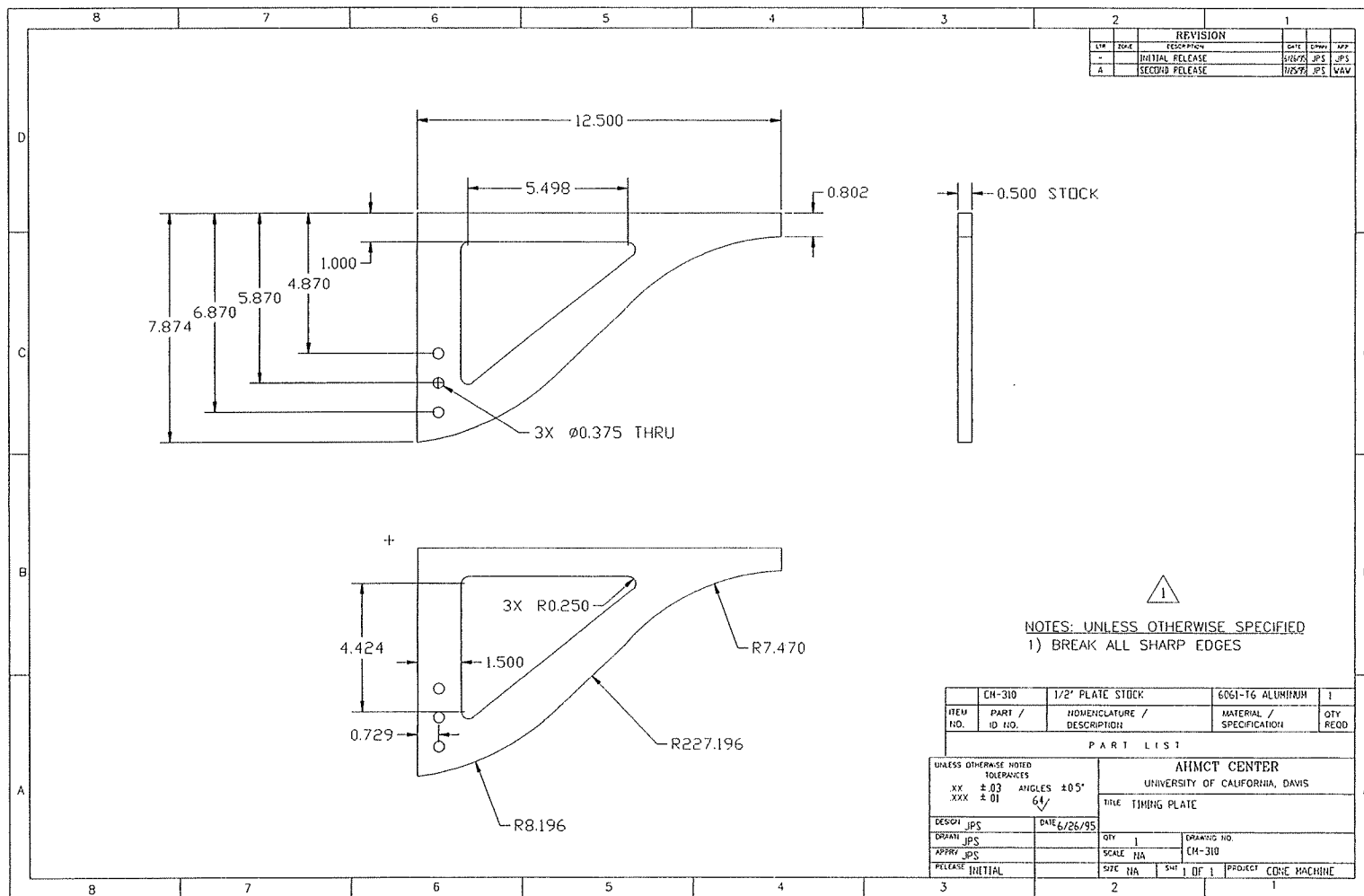


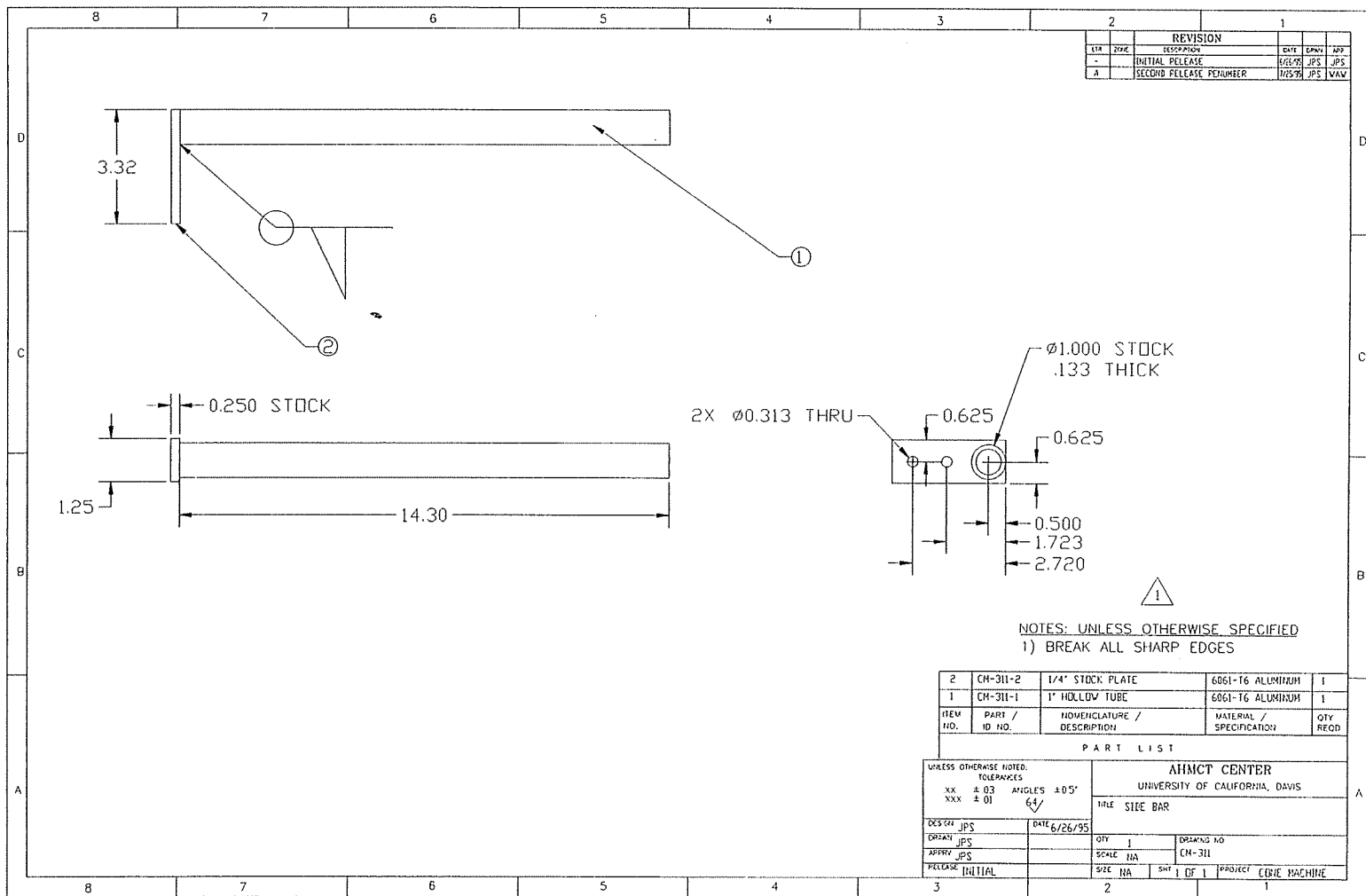


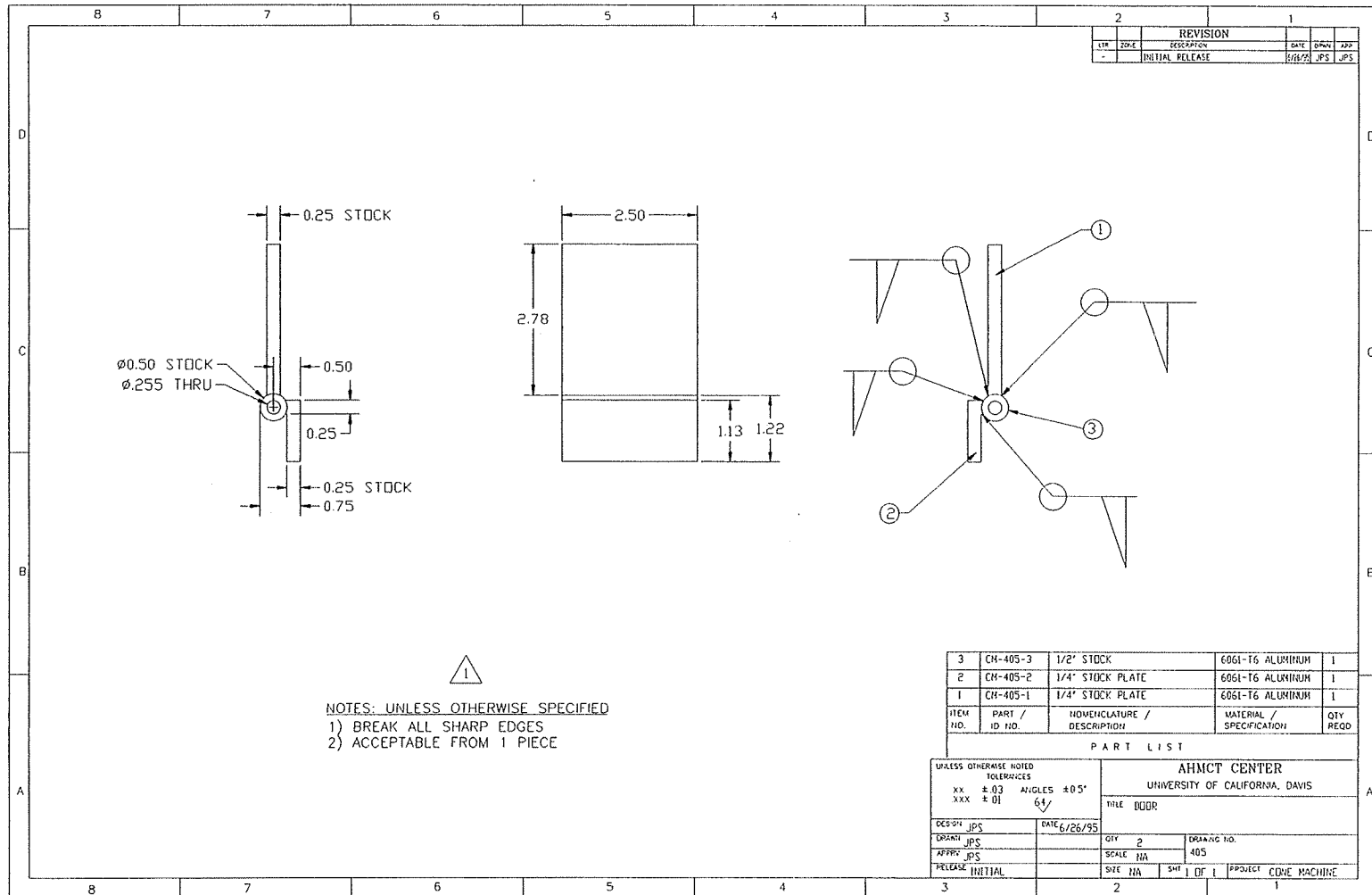


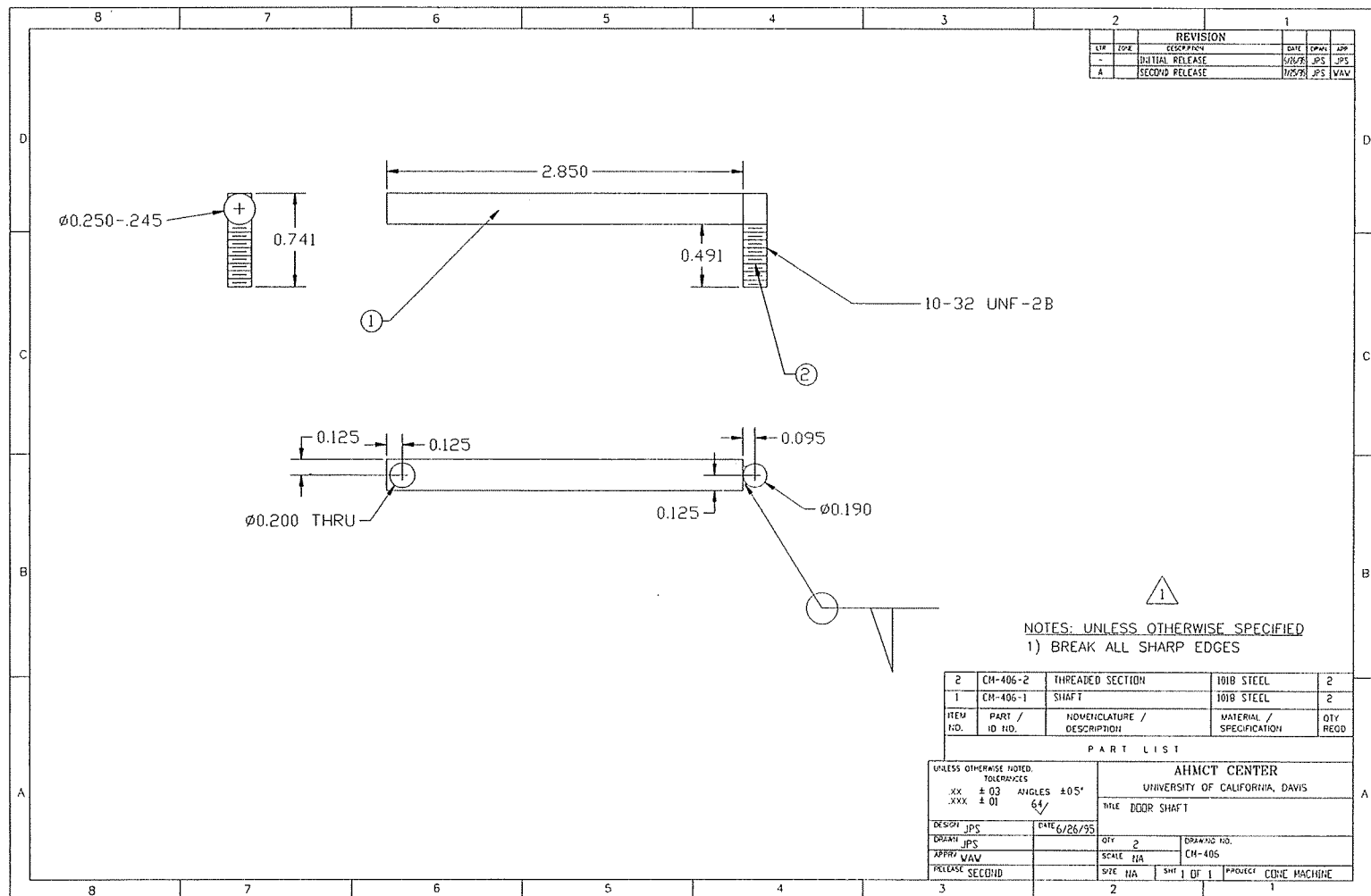


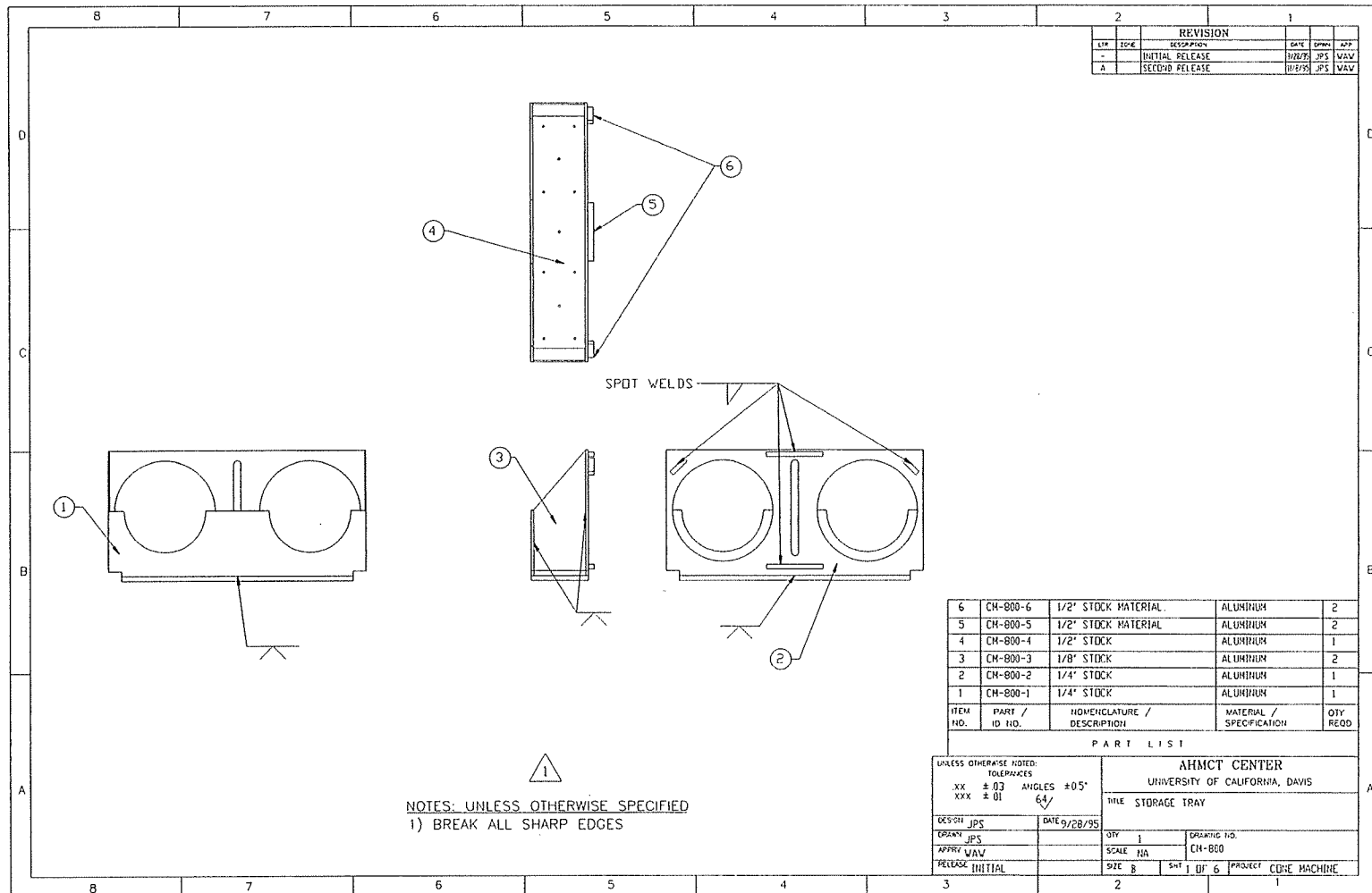


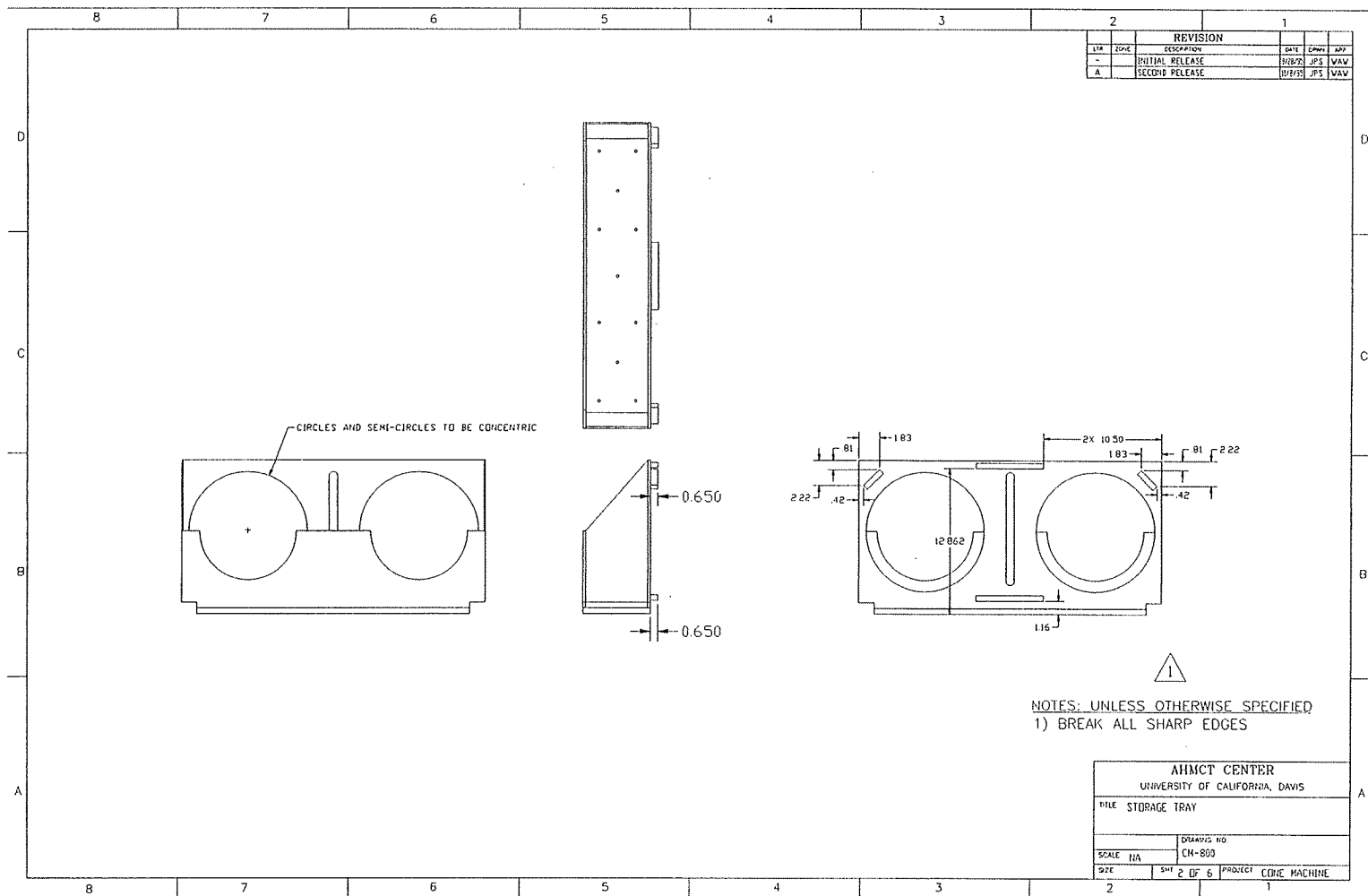


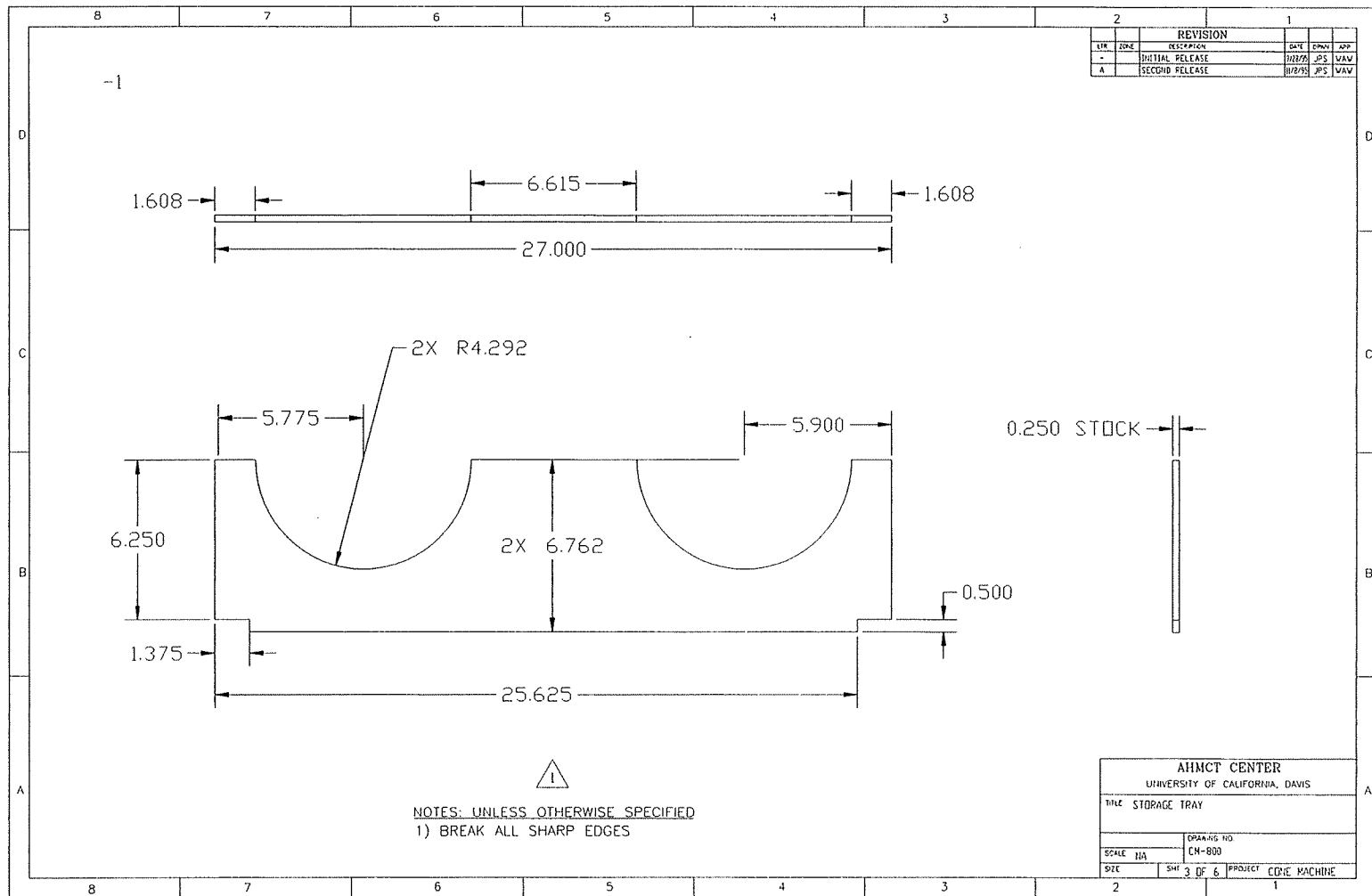


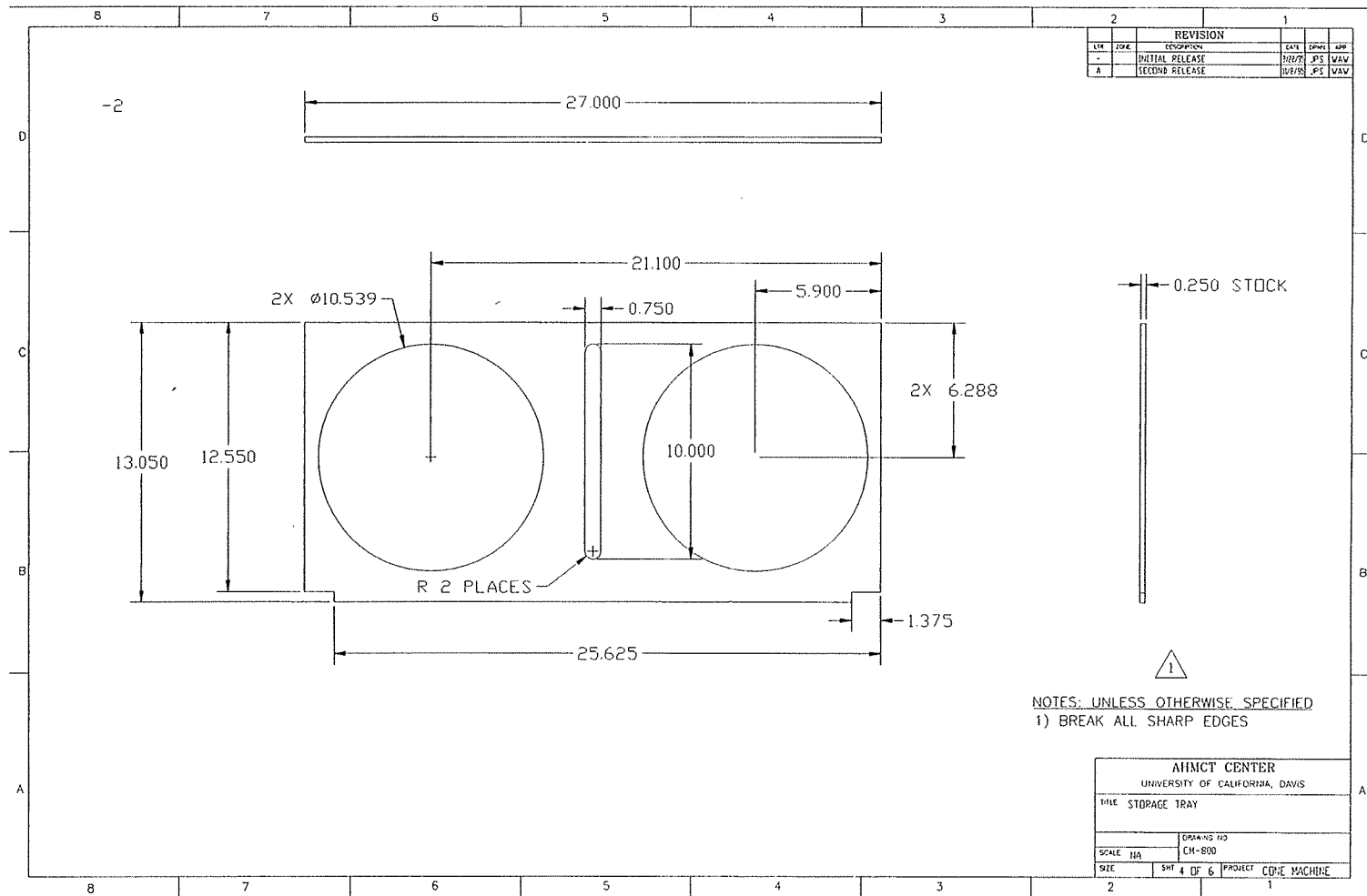


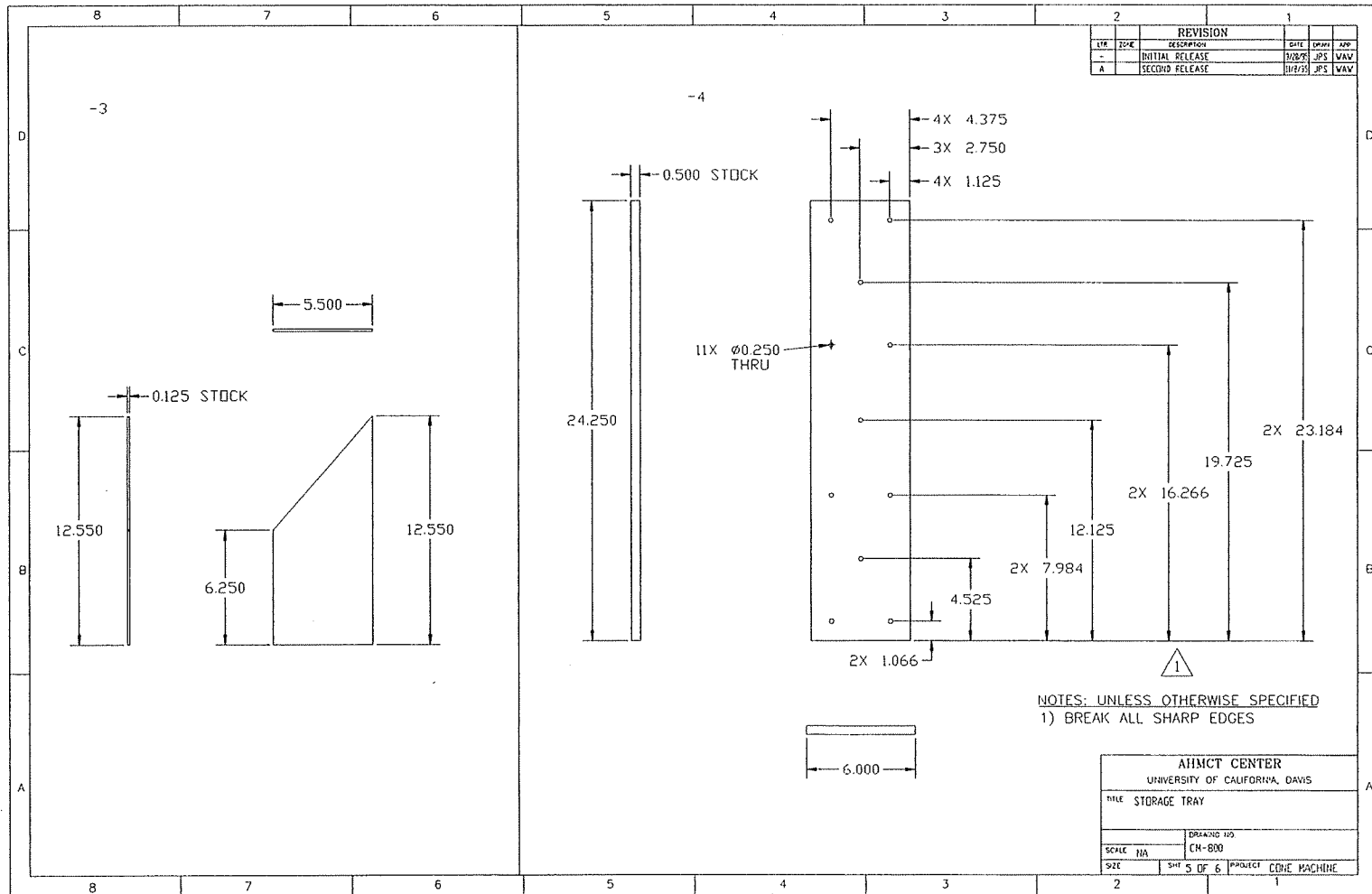


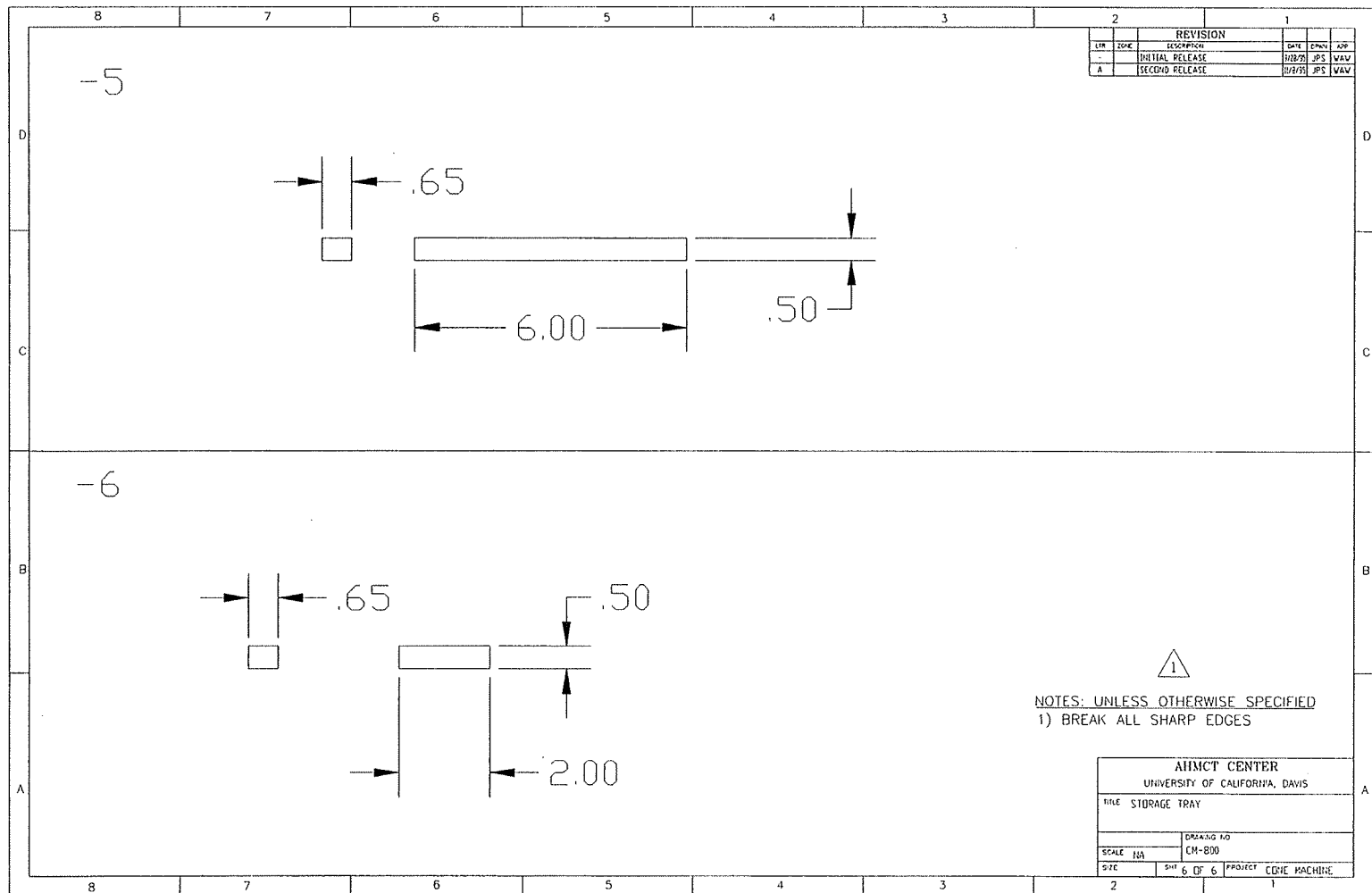


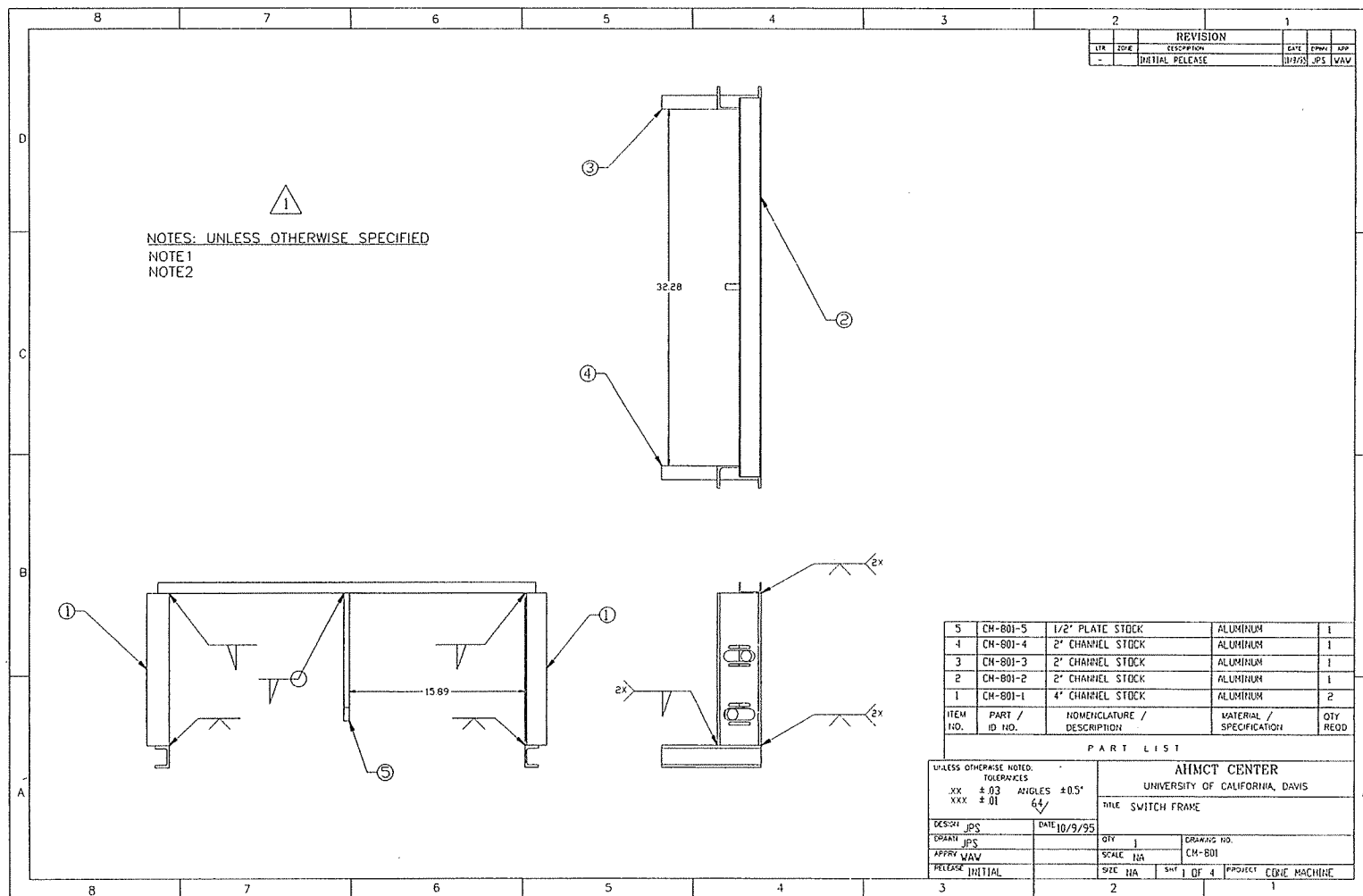


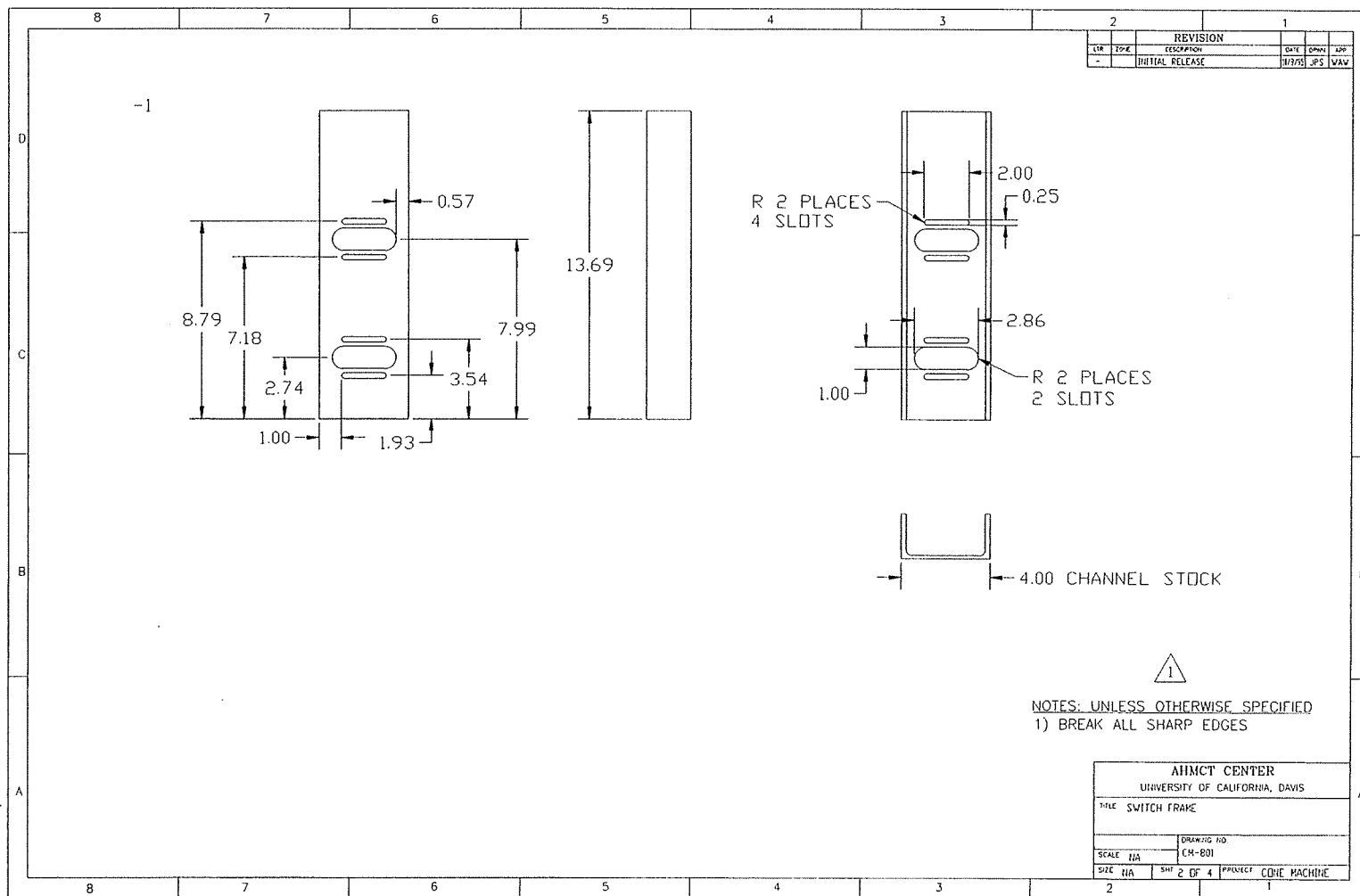


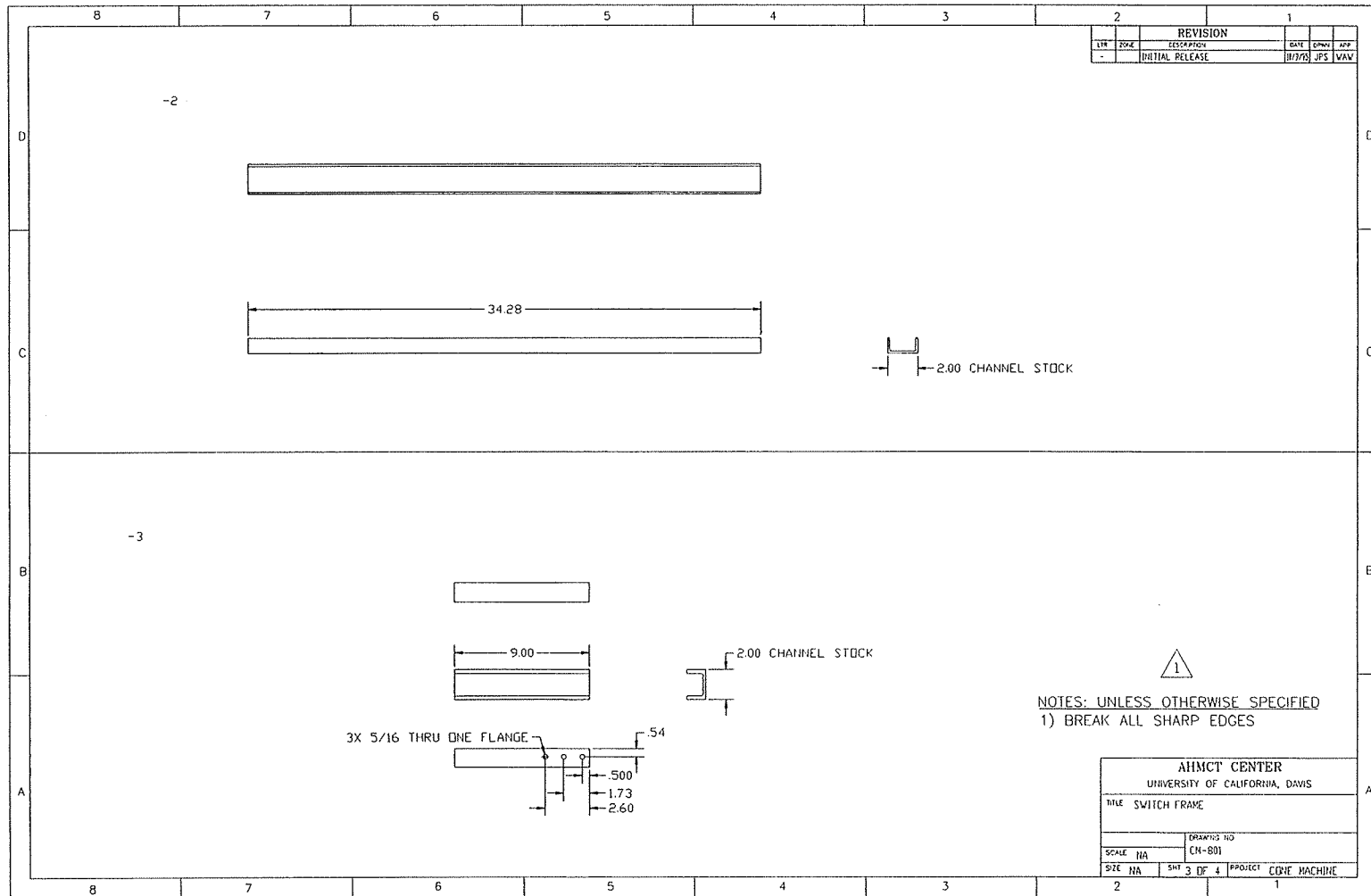


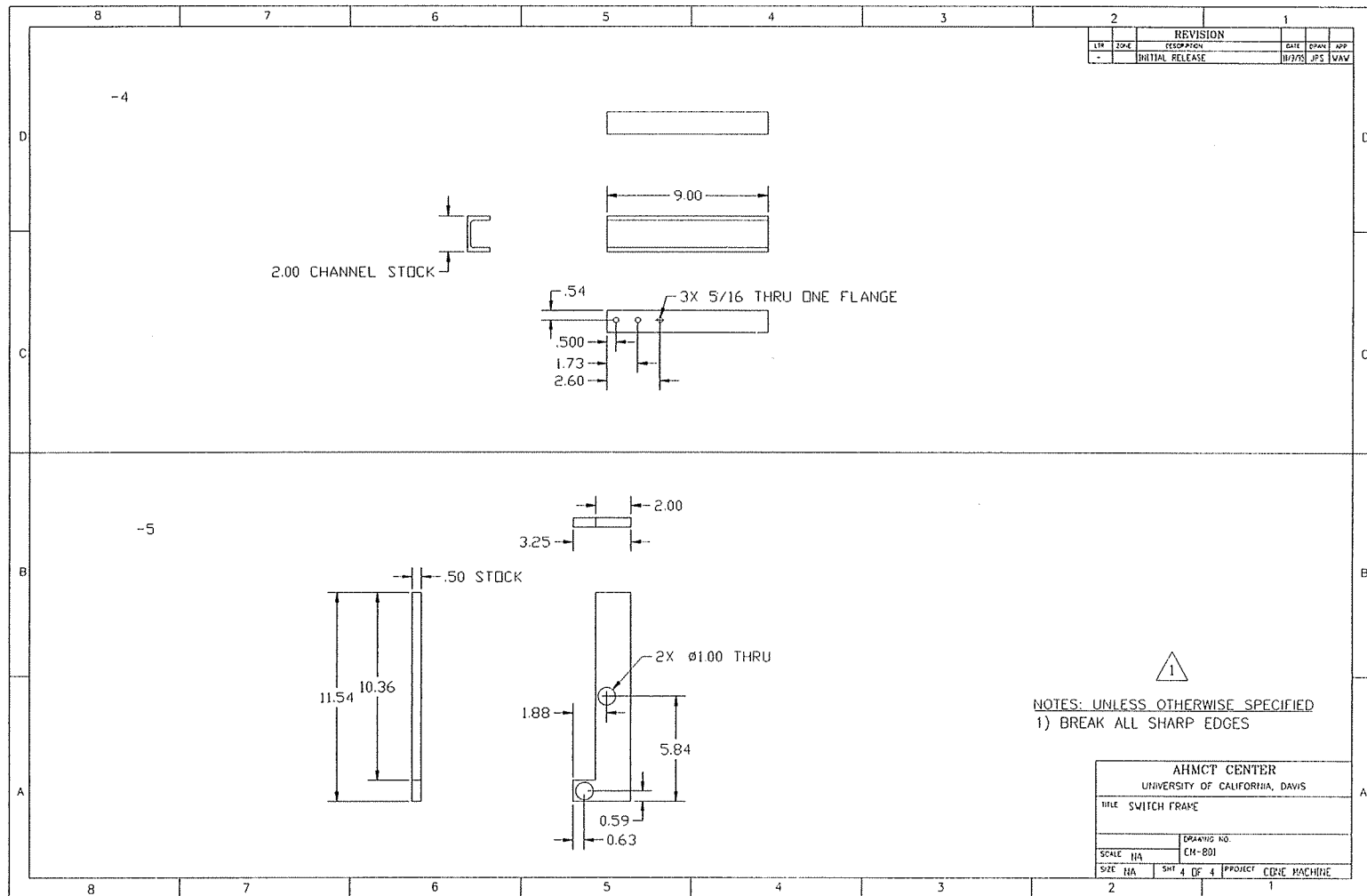








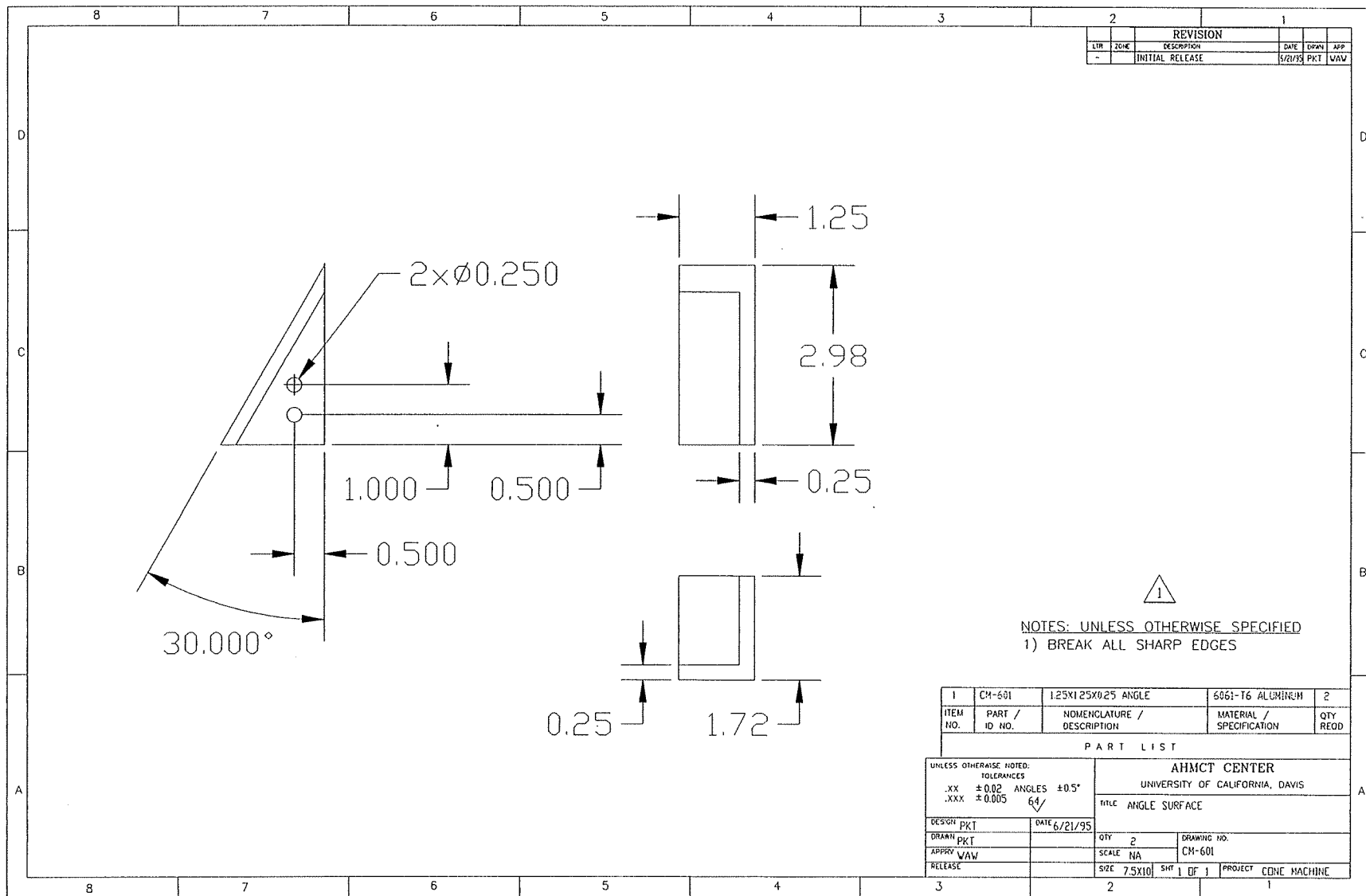


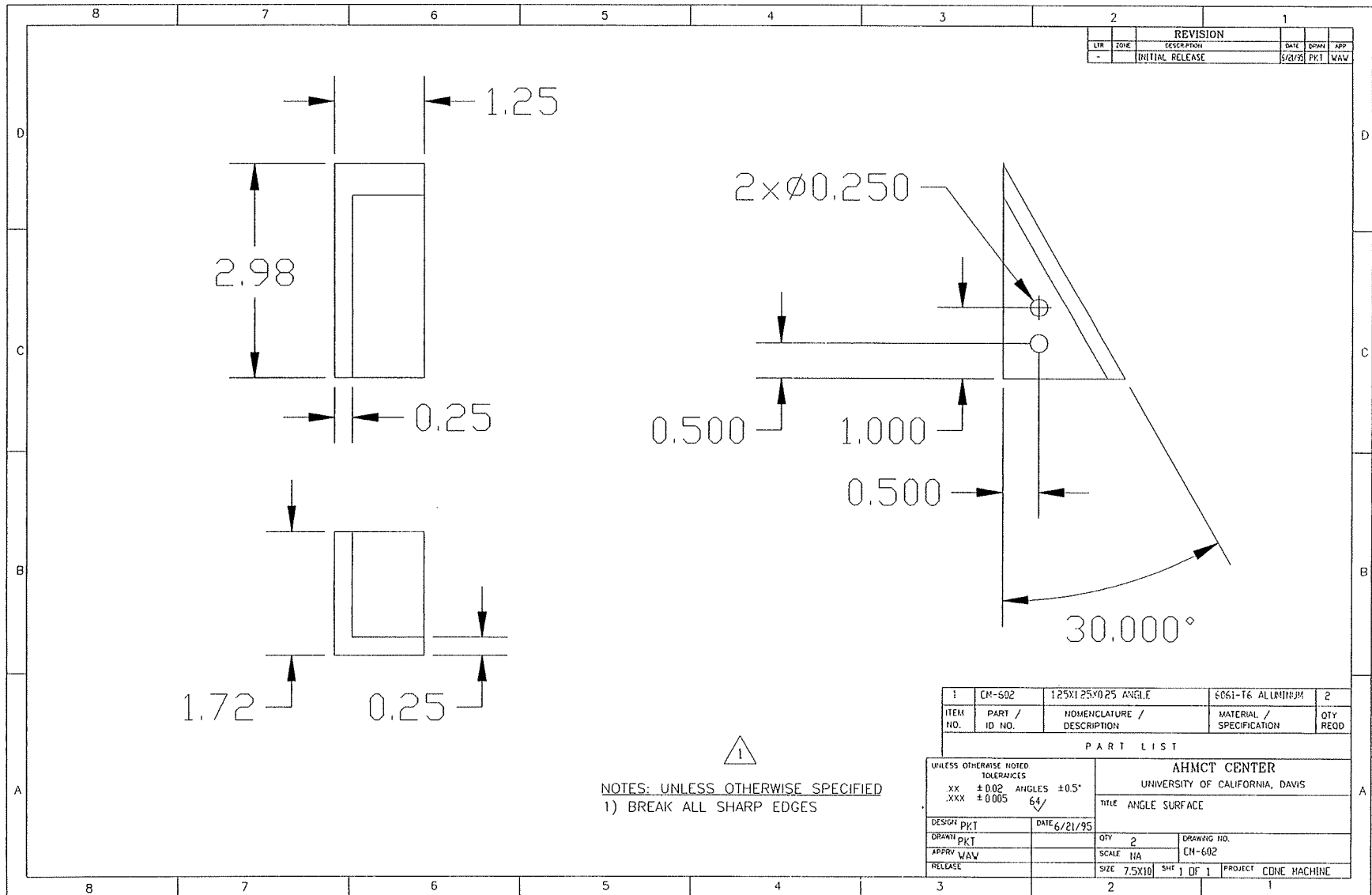


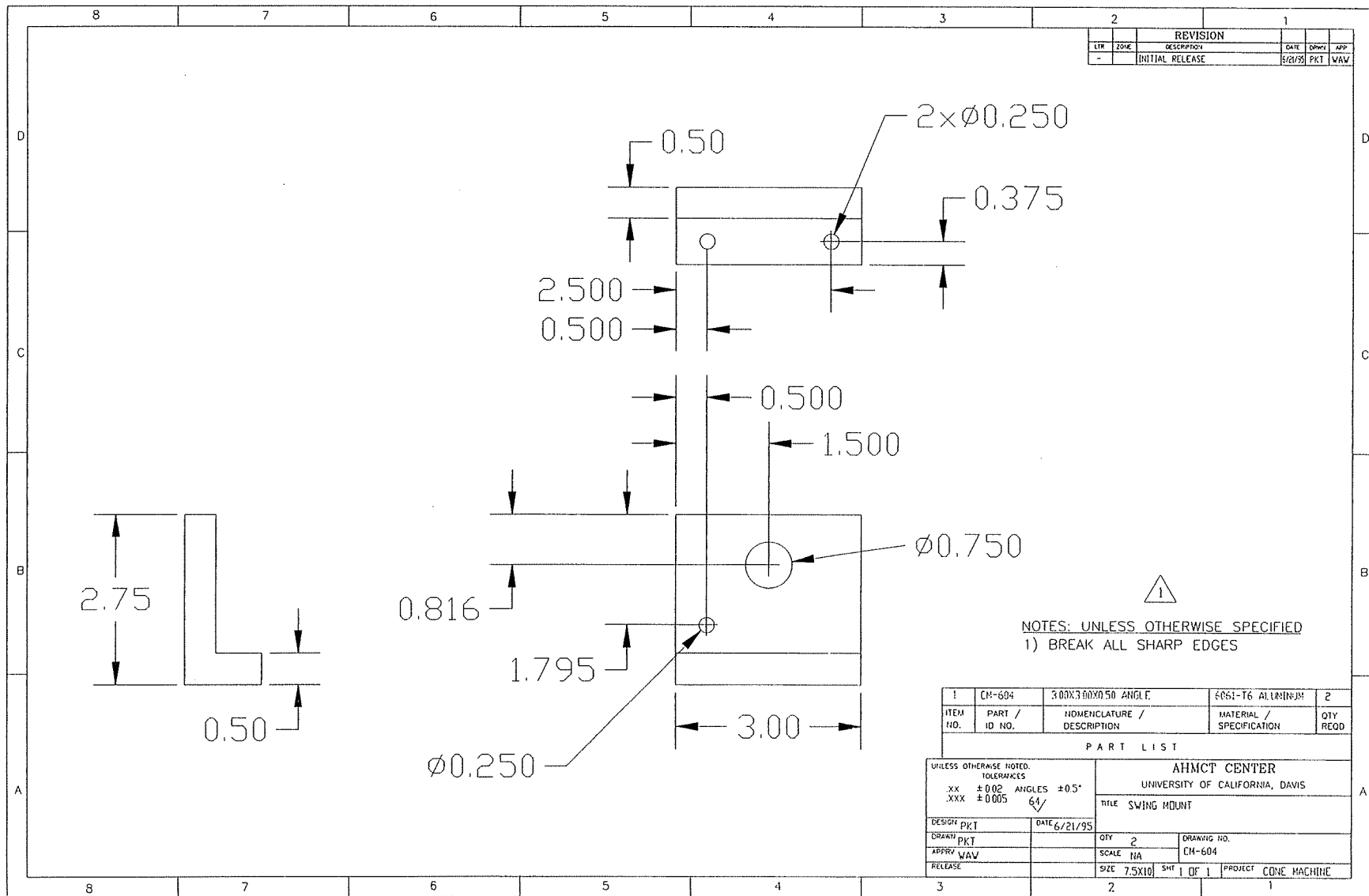
APPENDIX C DETAILED DRAWINGS FOR STOWAGE SYSTEM

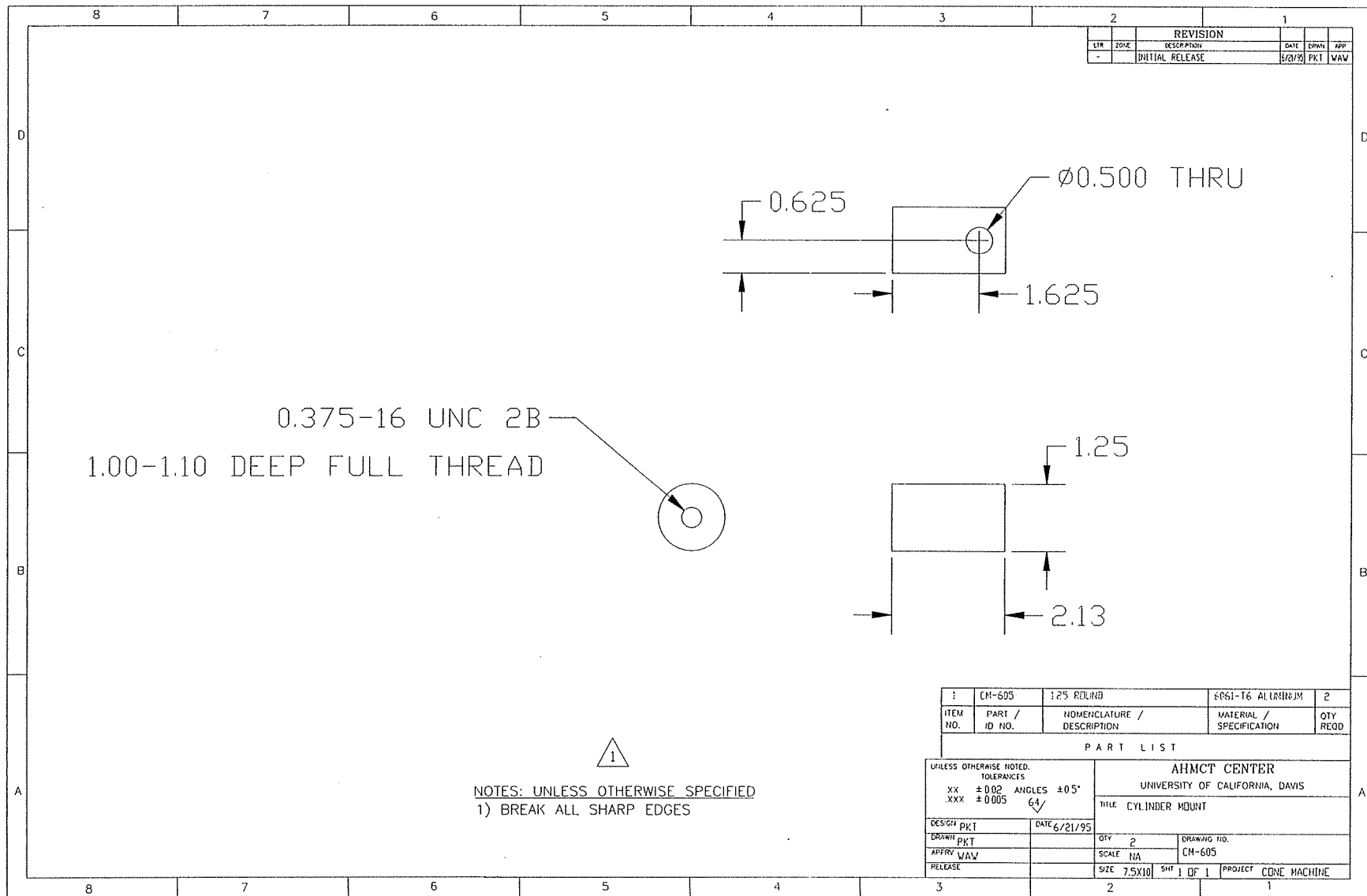
STOWAGE SYSTEM DRAWING LIST

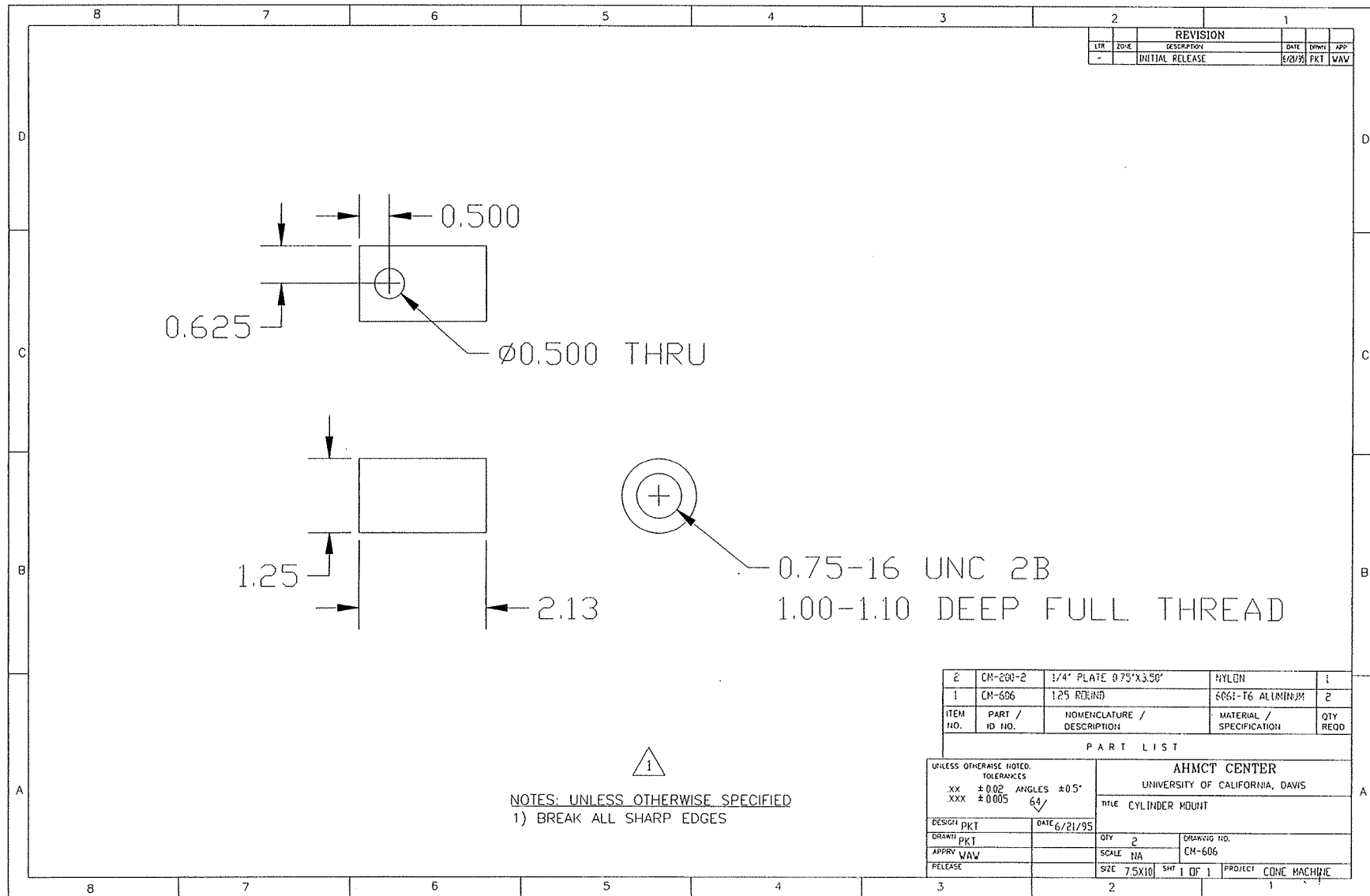
<u>DWG NO.</u>	<u>DESCRIPTION</u>
CM-601	ANGLE SURFACE
CM-602	ANGLE SURFACE
CM-603	SWING MOUNT
CM-604	SWING MOUNT
CM-605	CYLINDER MOUNT
CM-606	CYLINDER MOUNT
CM-607	MOUNT SHAFT
CM-608	BELT MOUNT
CM-609	SWING STOP
CM-610	GRIP SPACER
CM-611	MOUNT BRACKET
CM-612	SLEEVE WELDMENT
CM-613	SLEEVE PLATE
CM-614	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

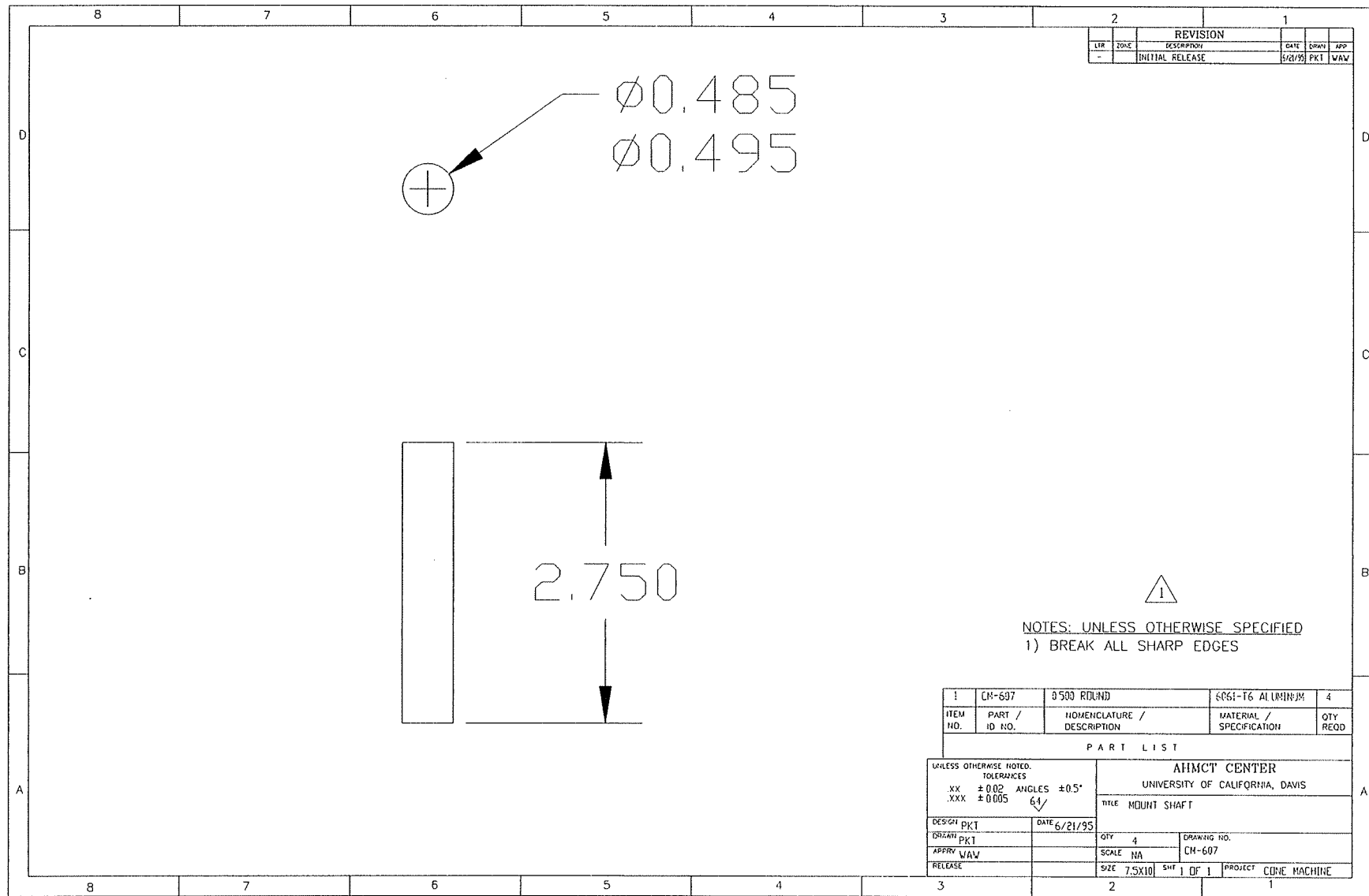


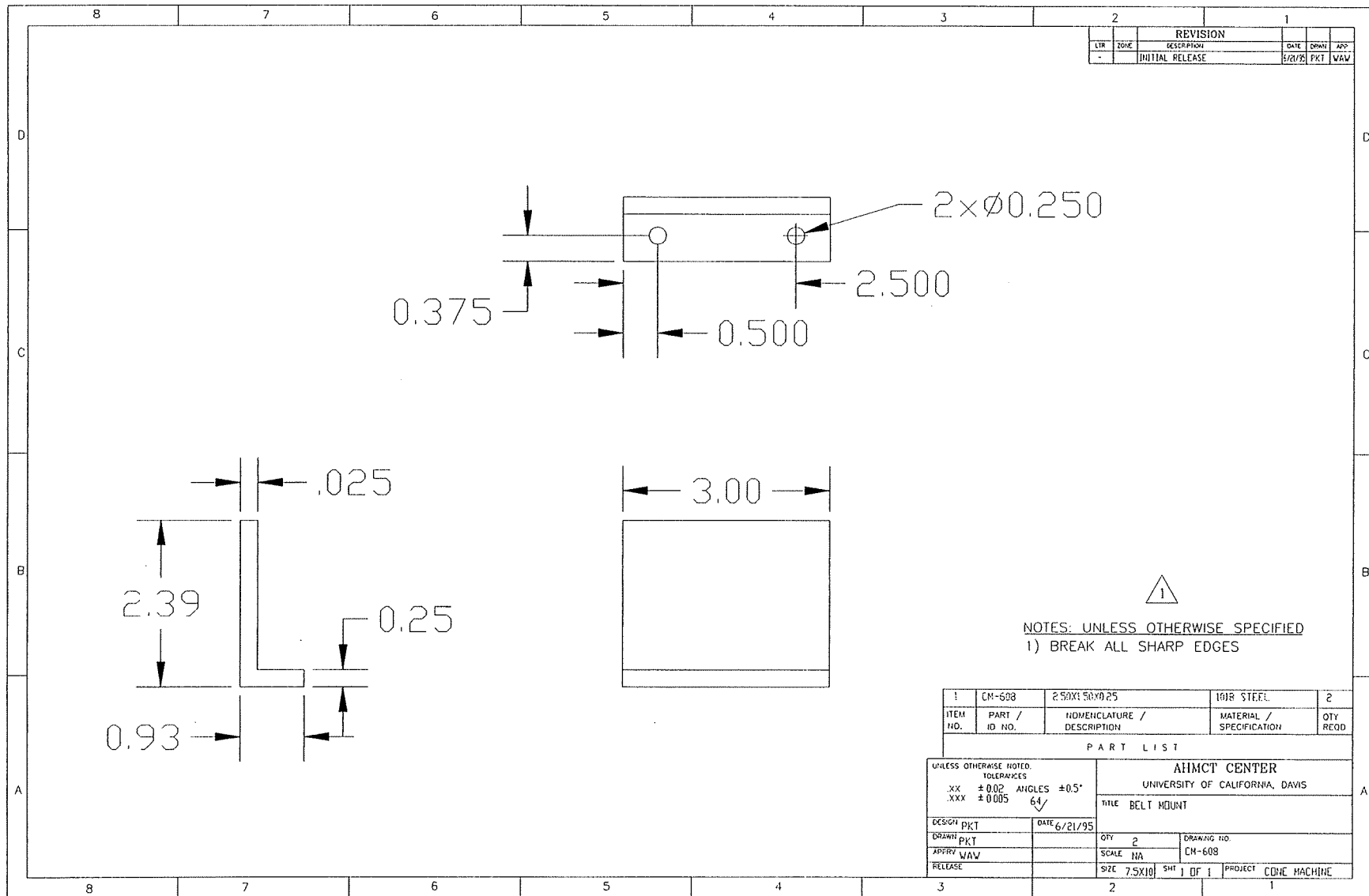


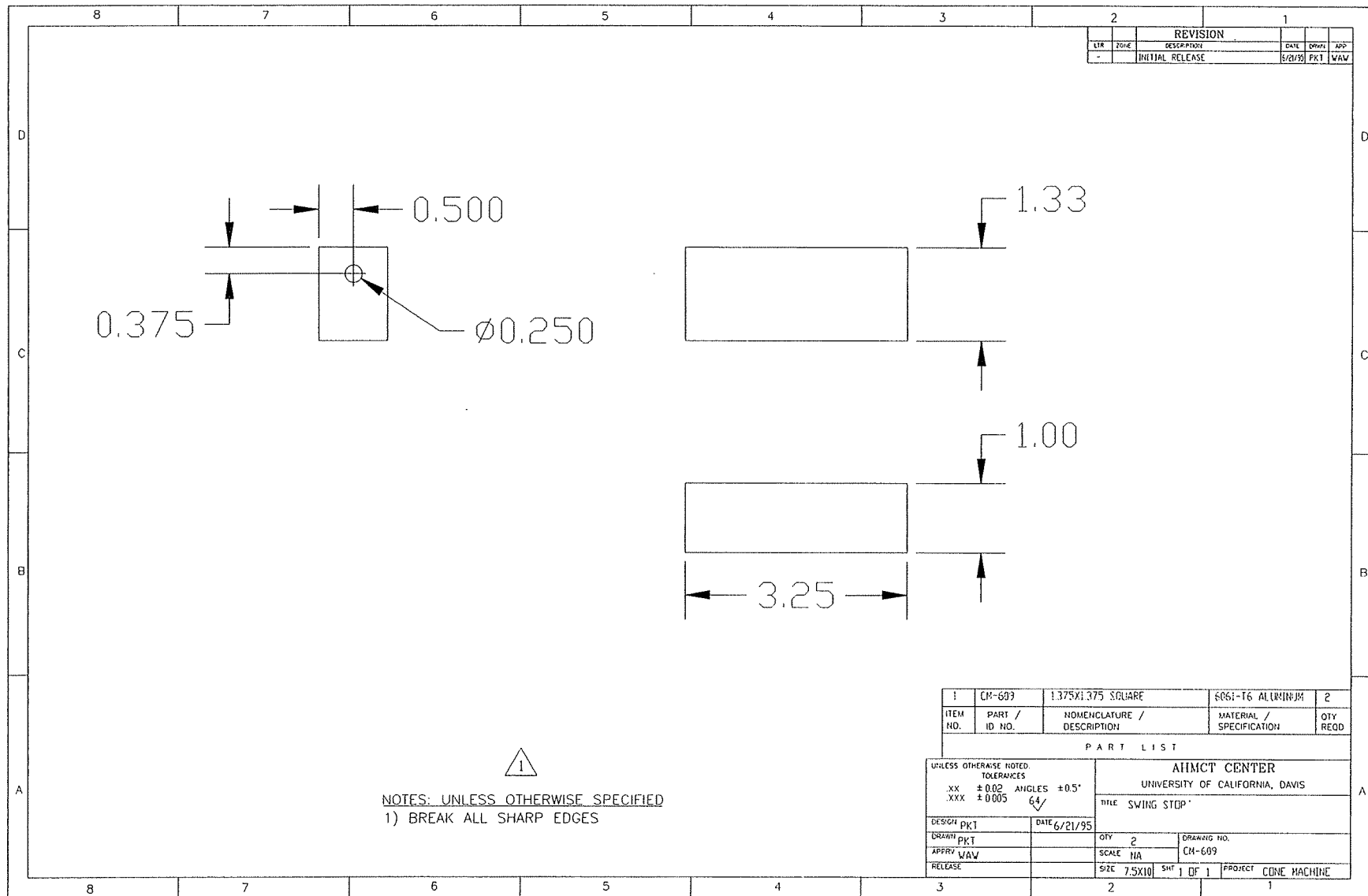


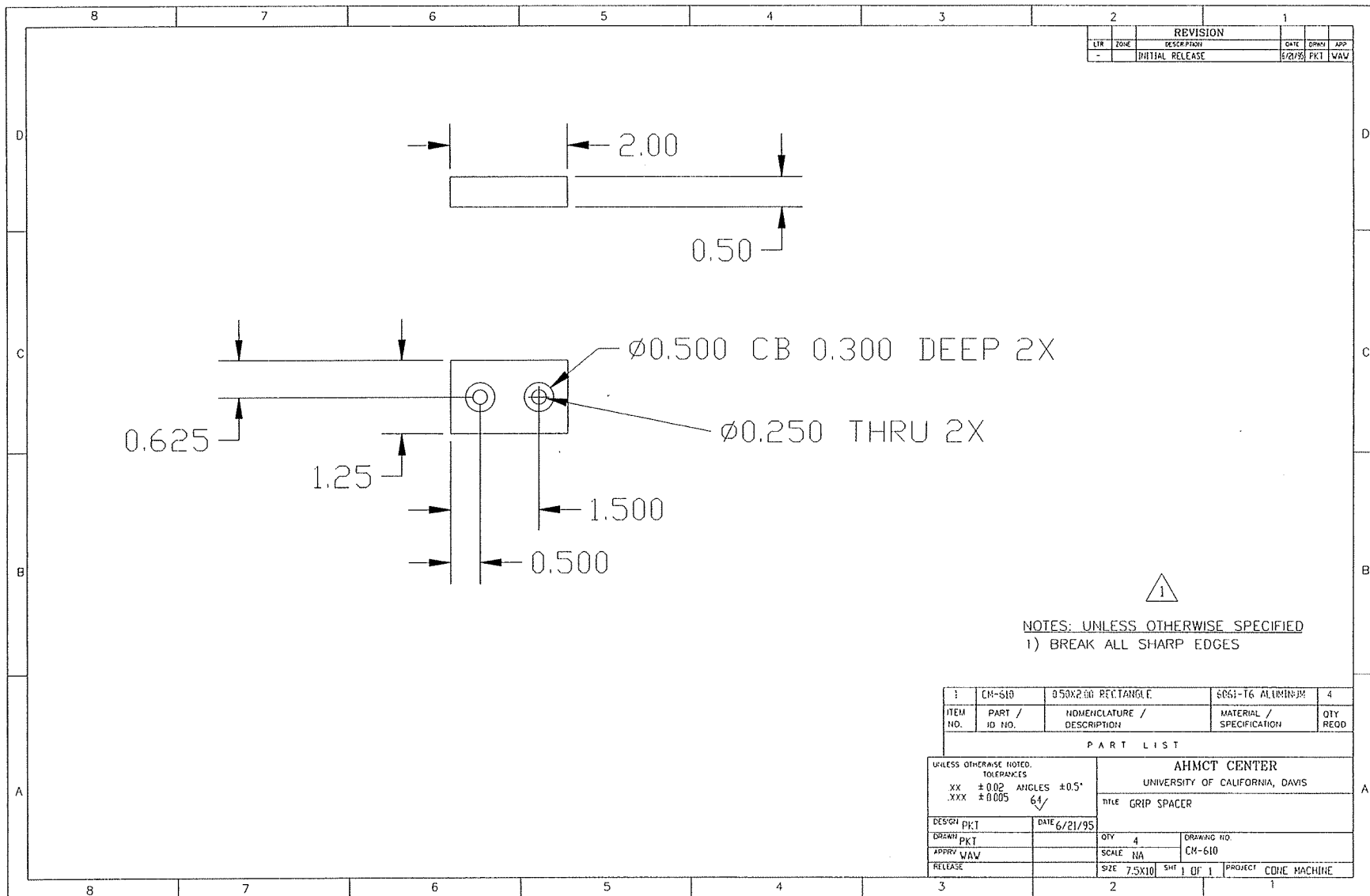


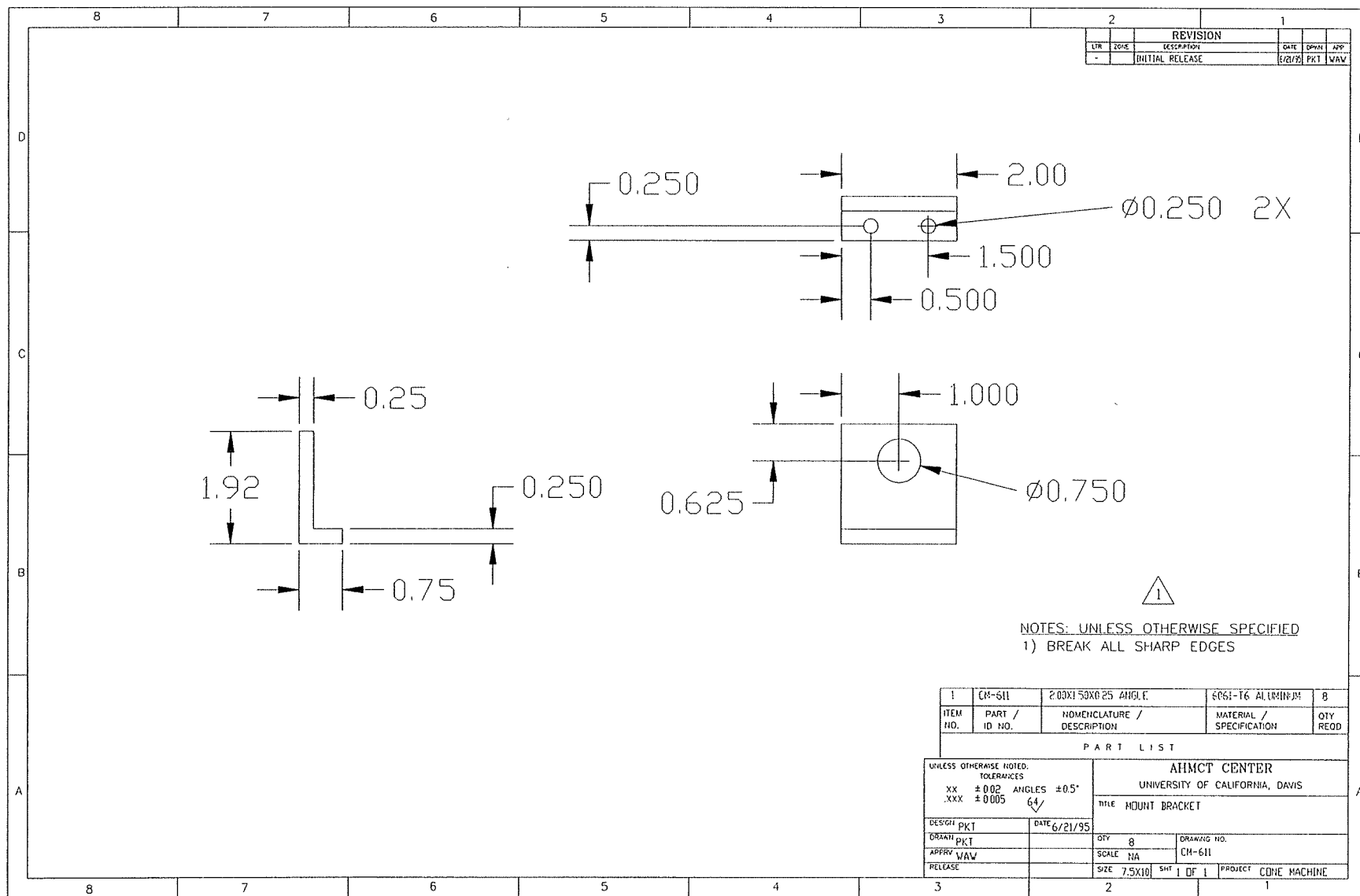


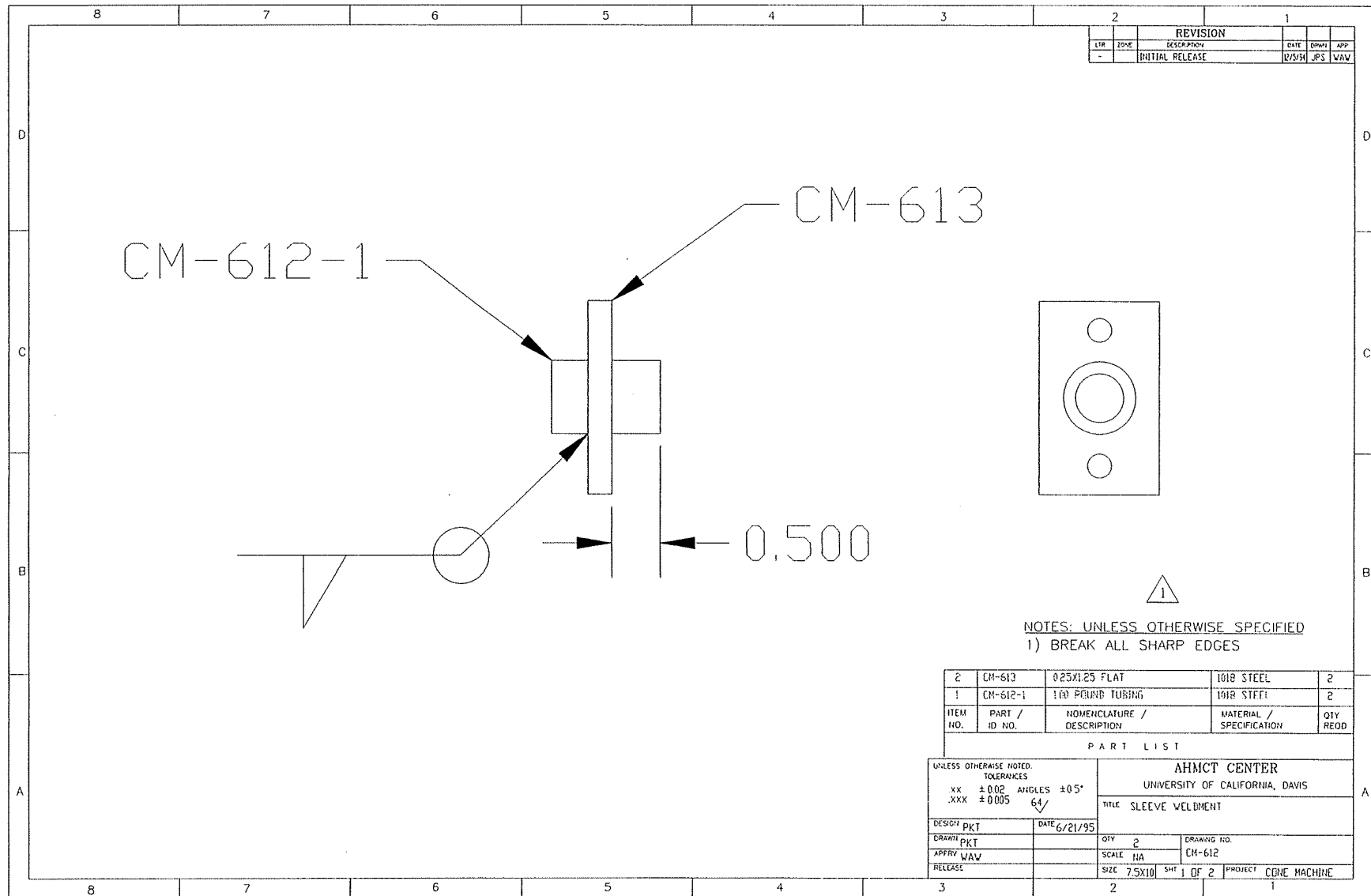


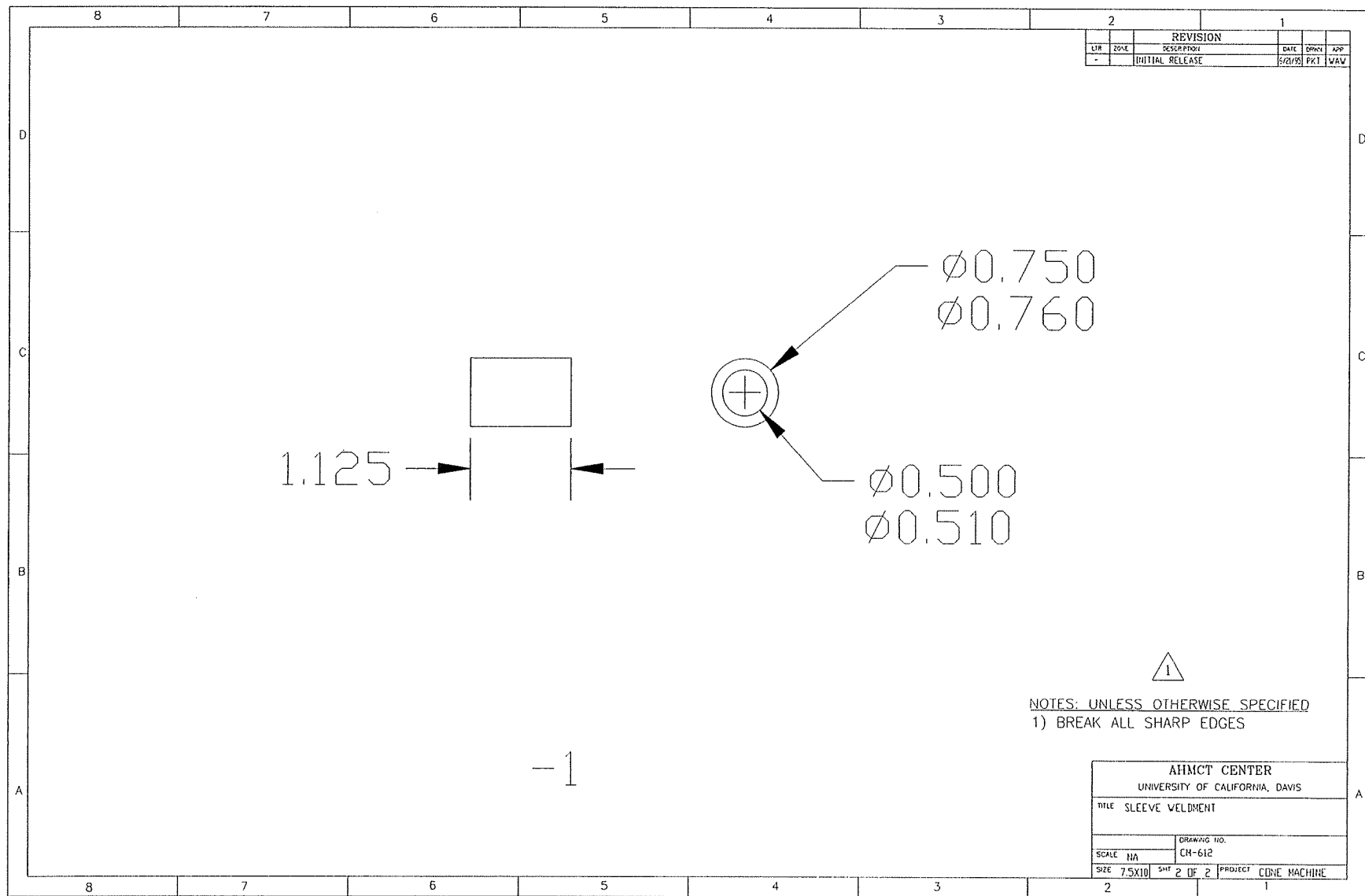


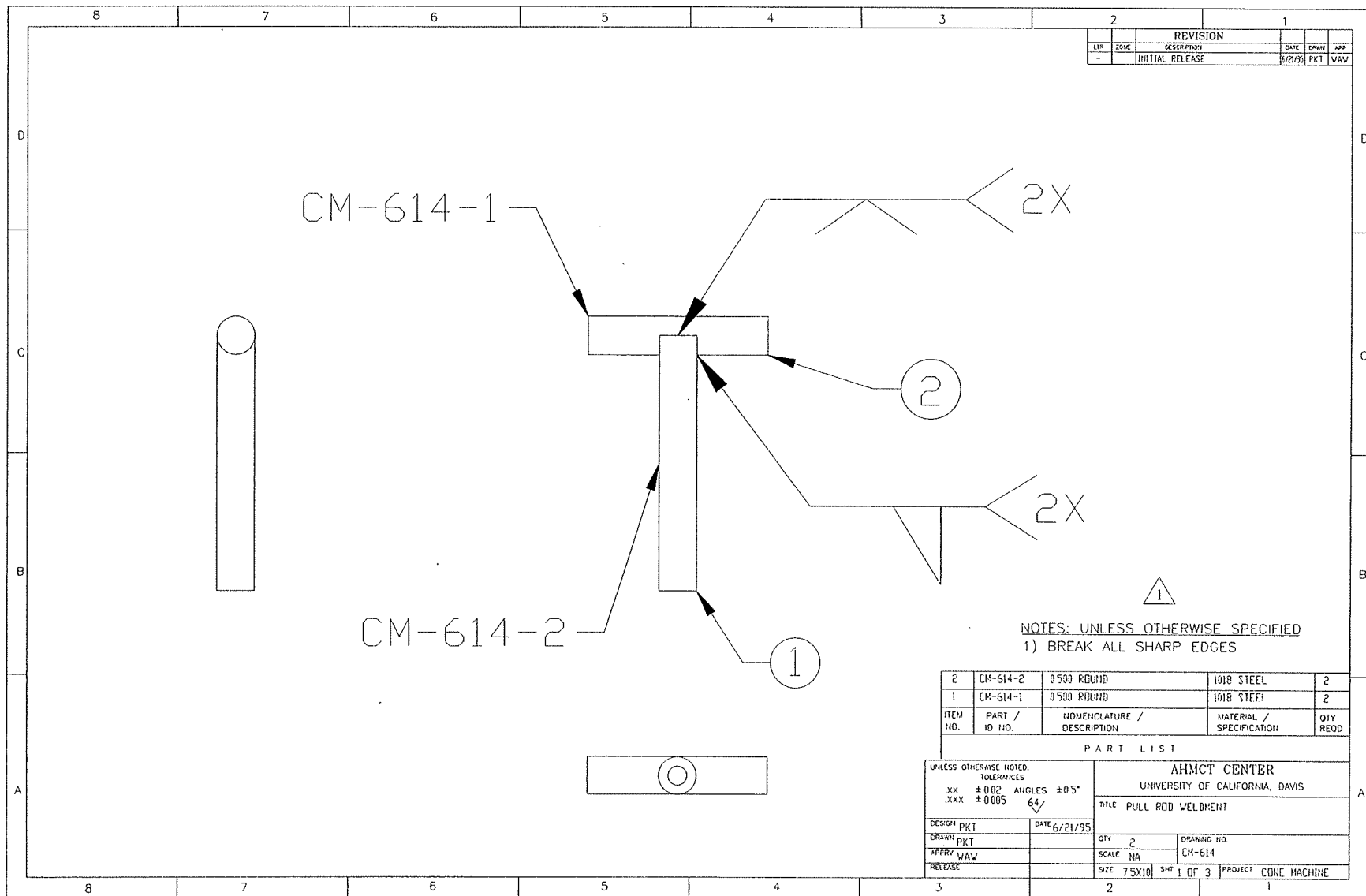


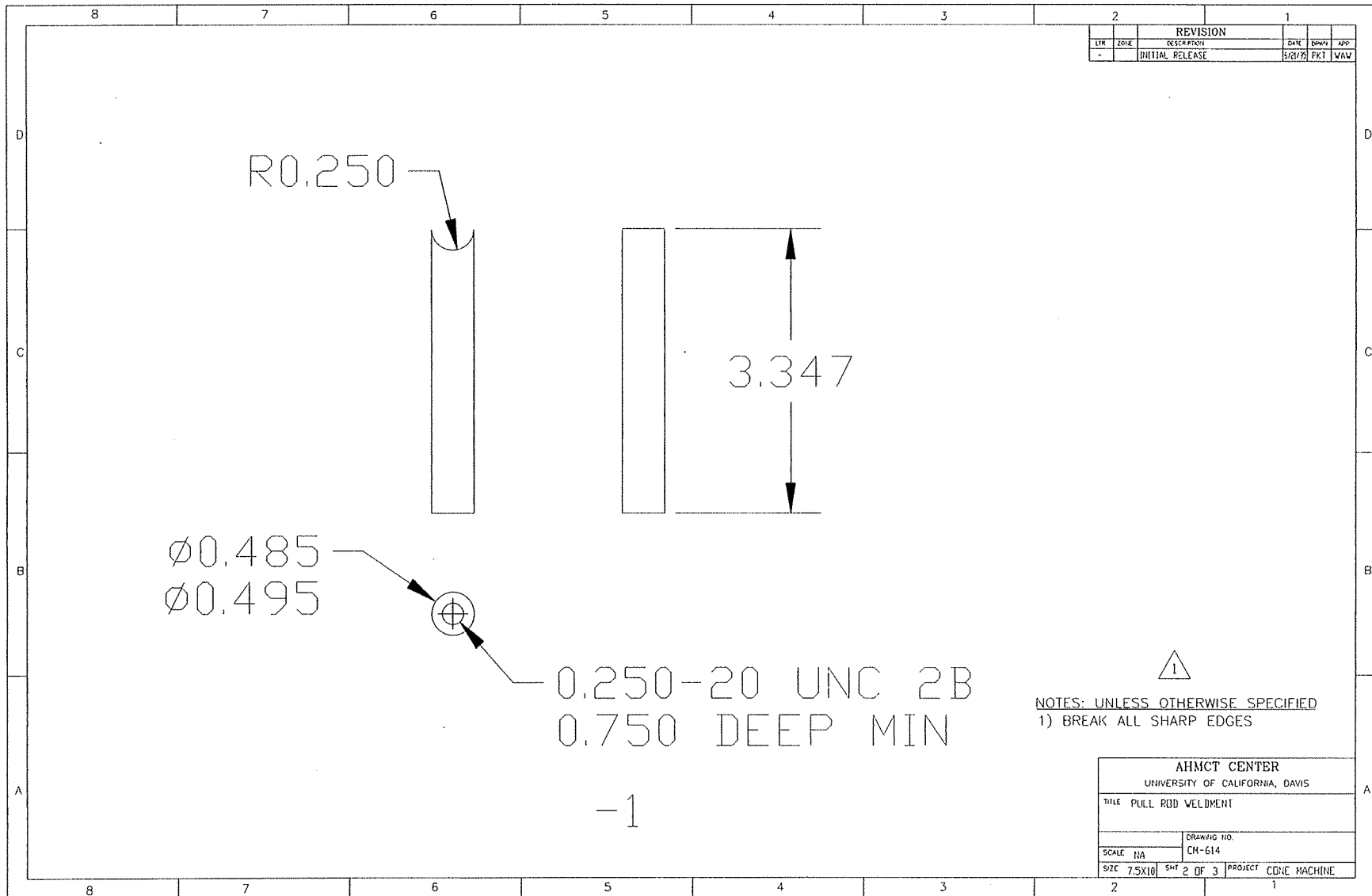


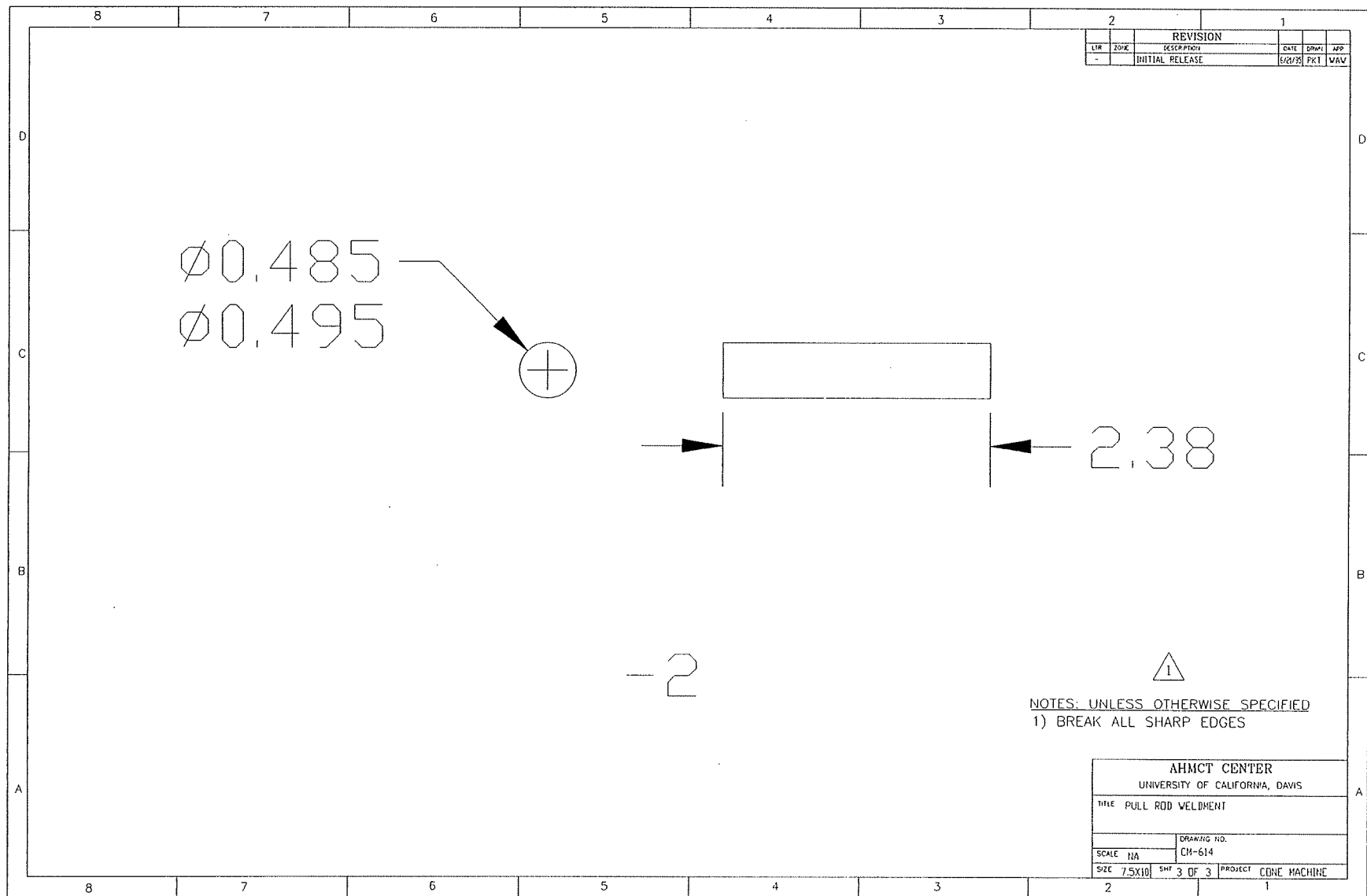


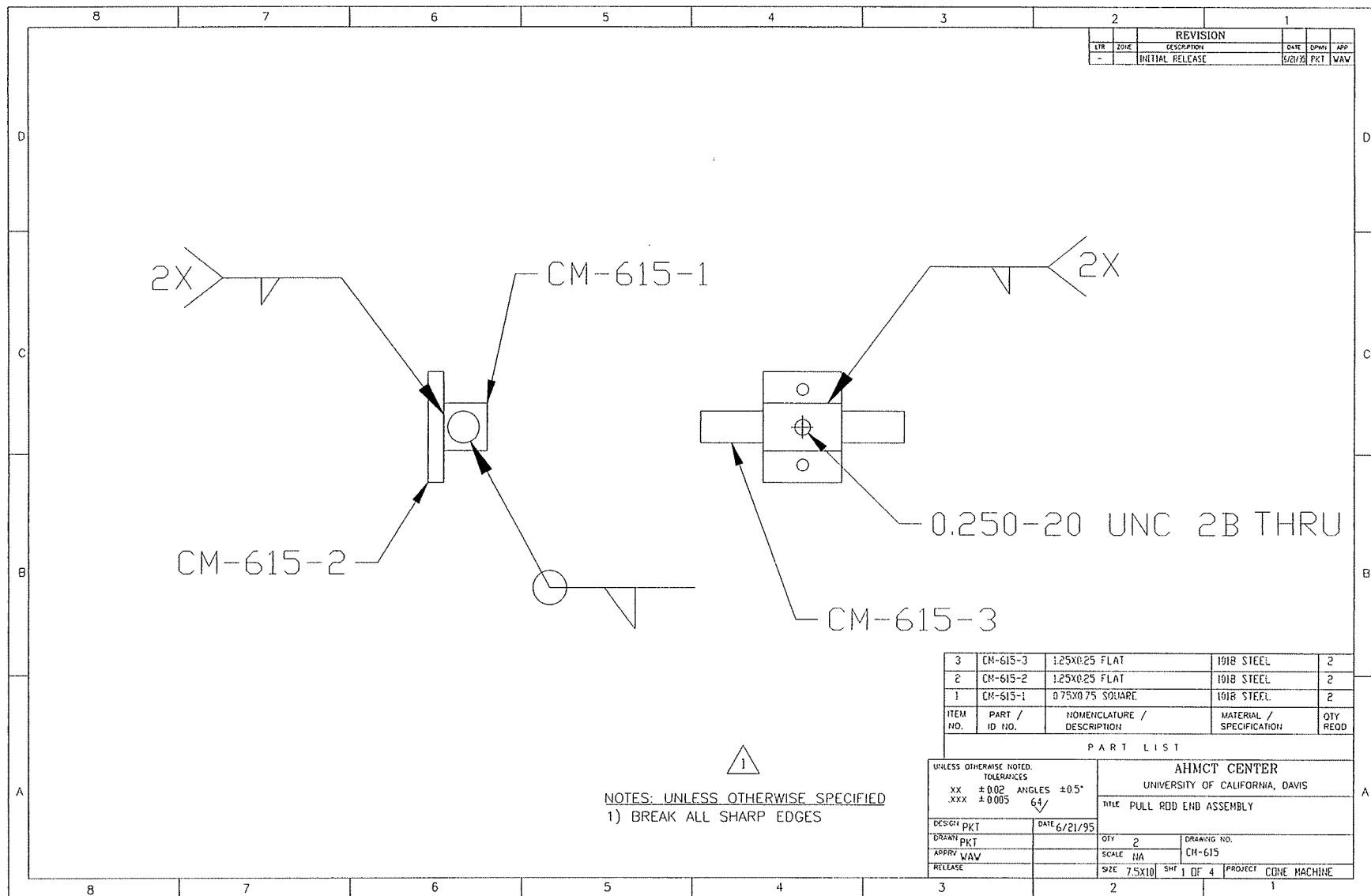


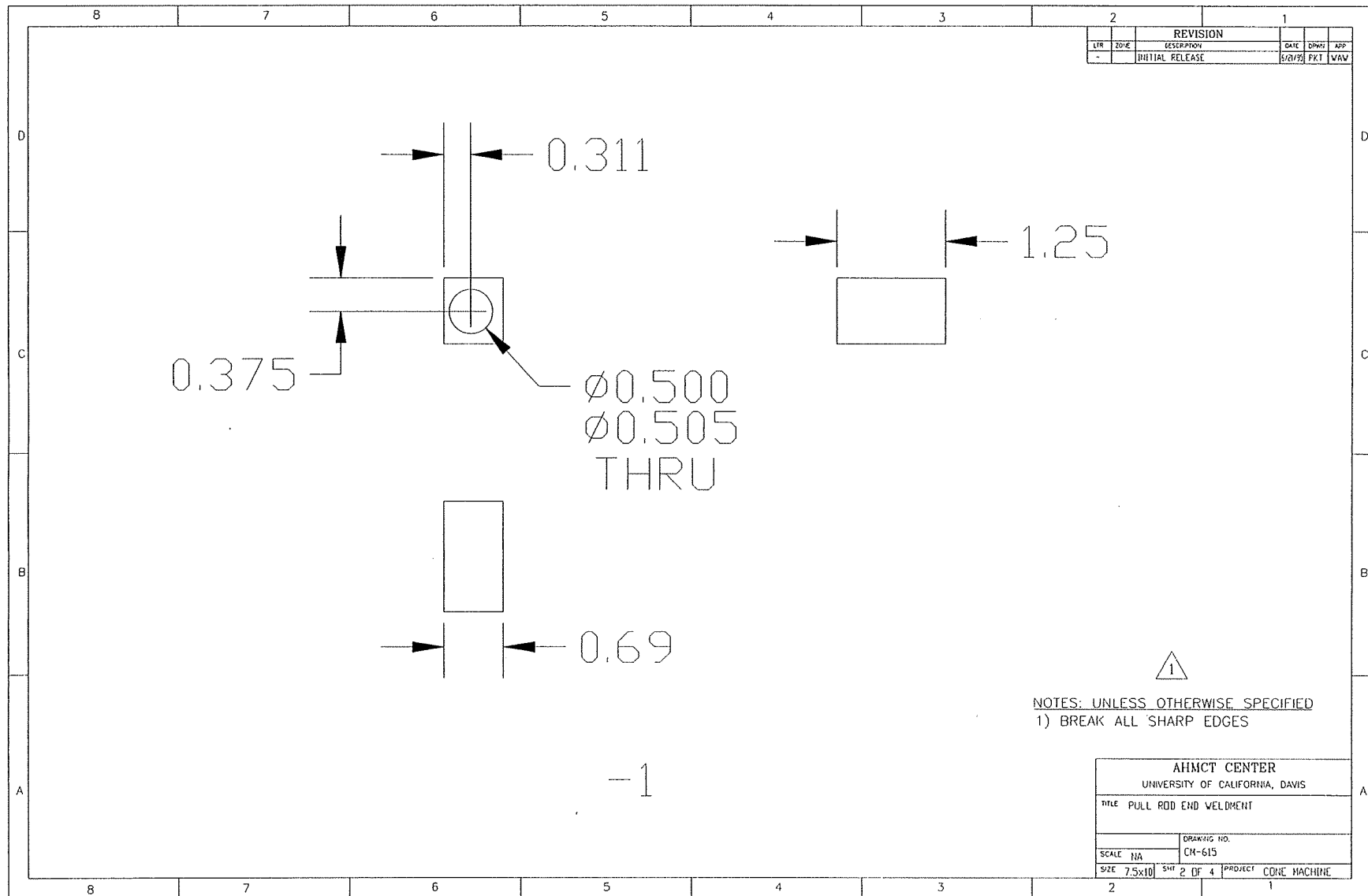


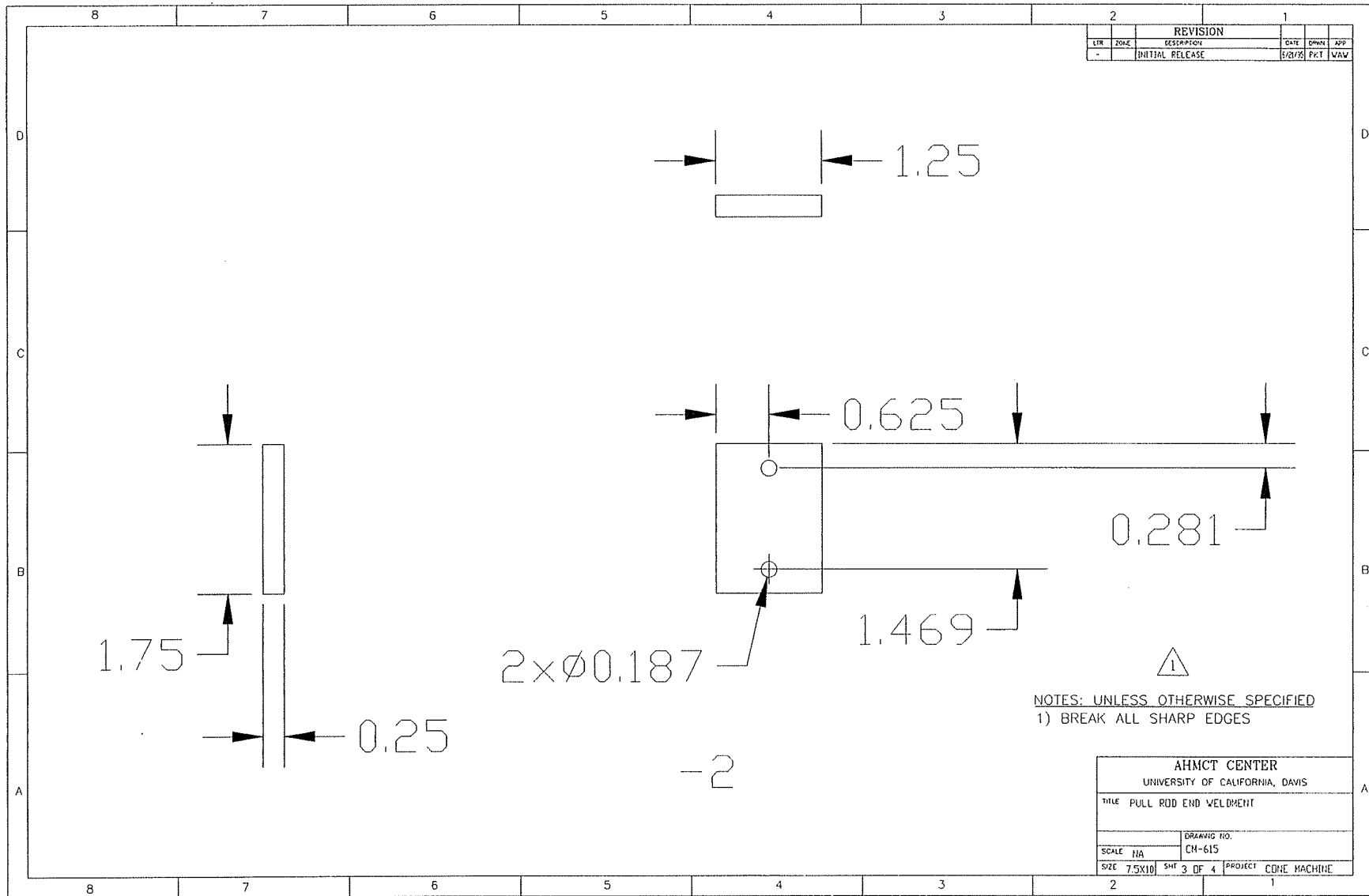


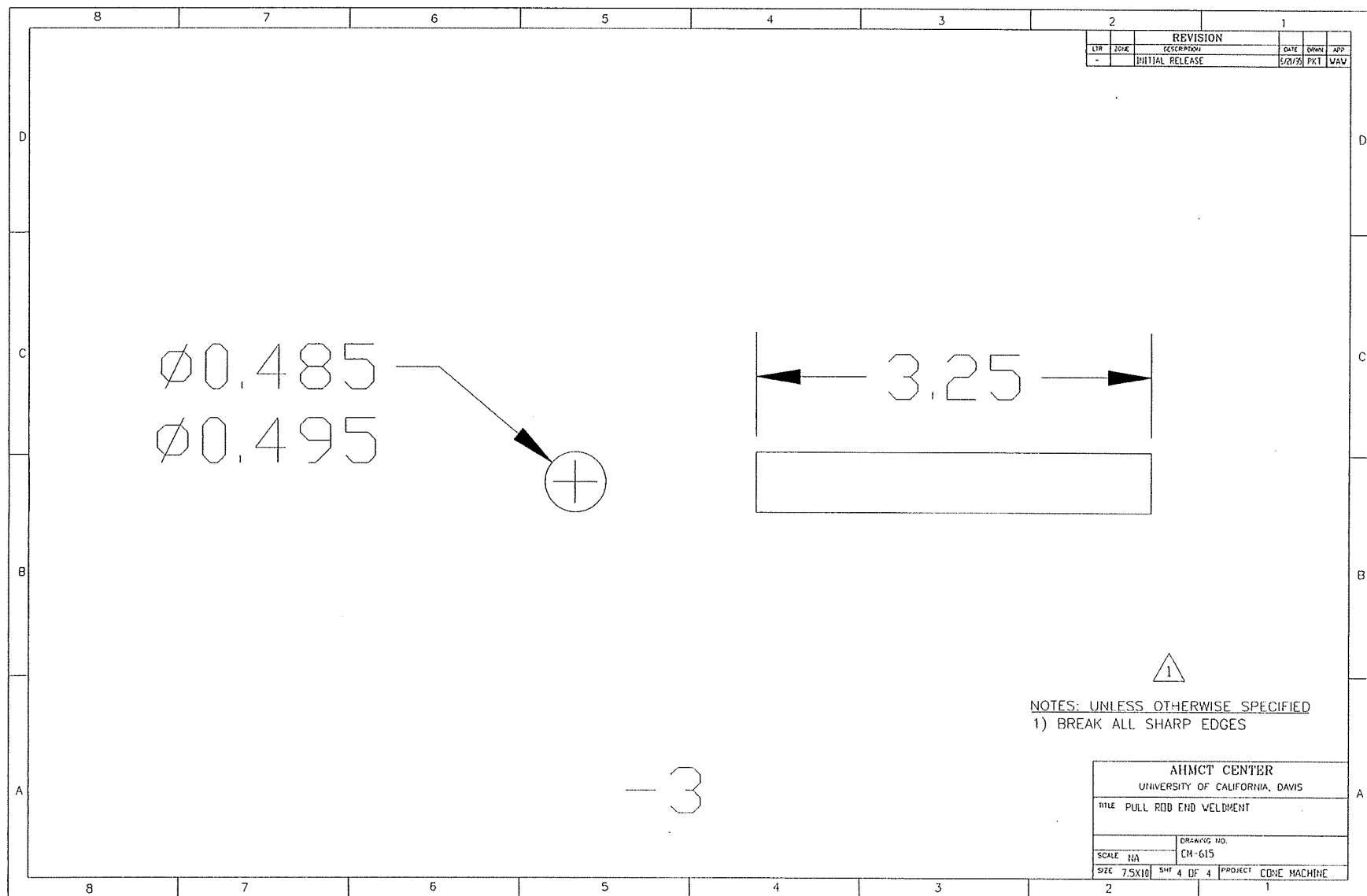


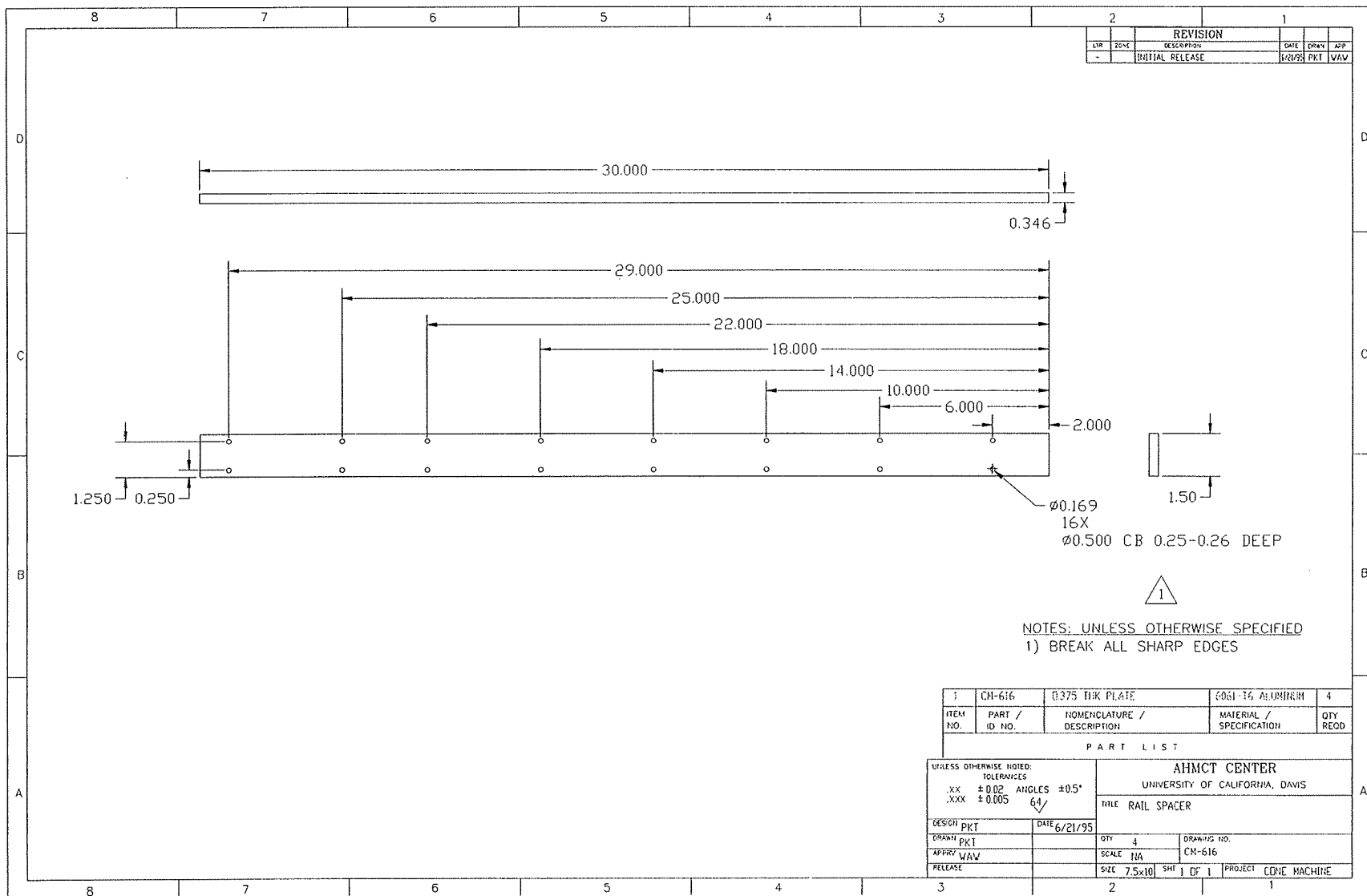


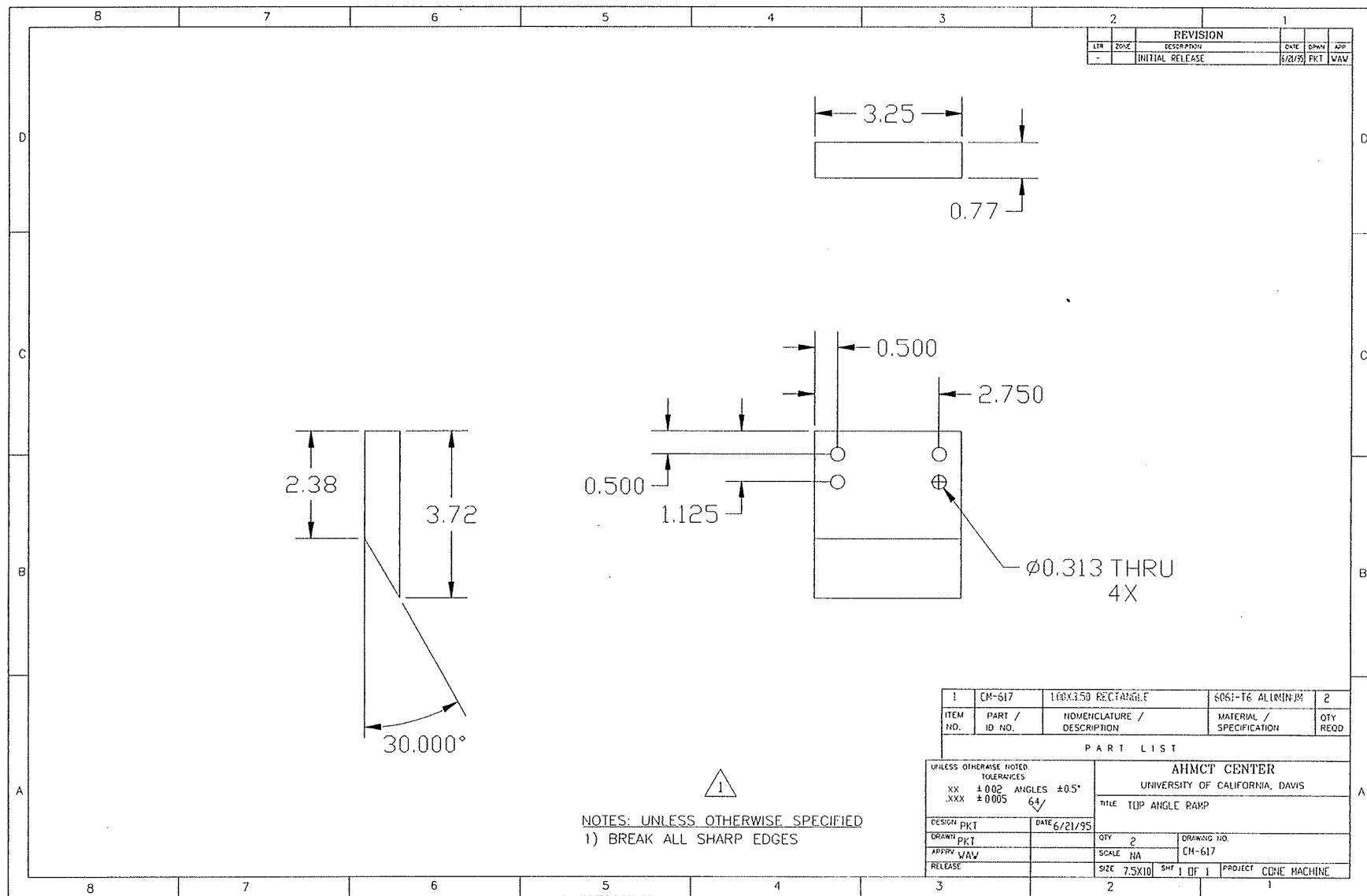


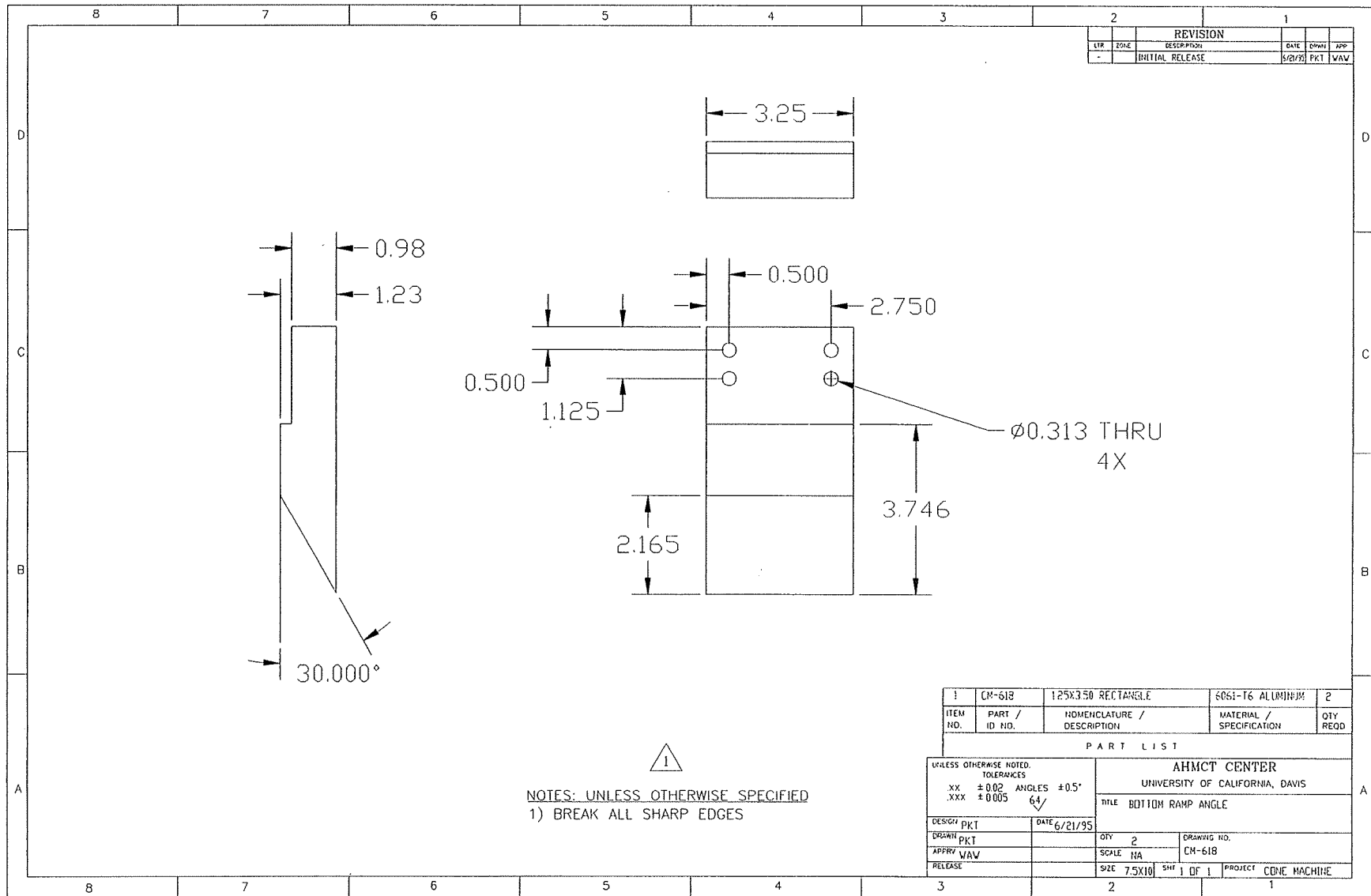


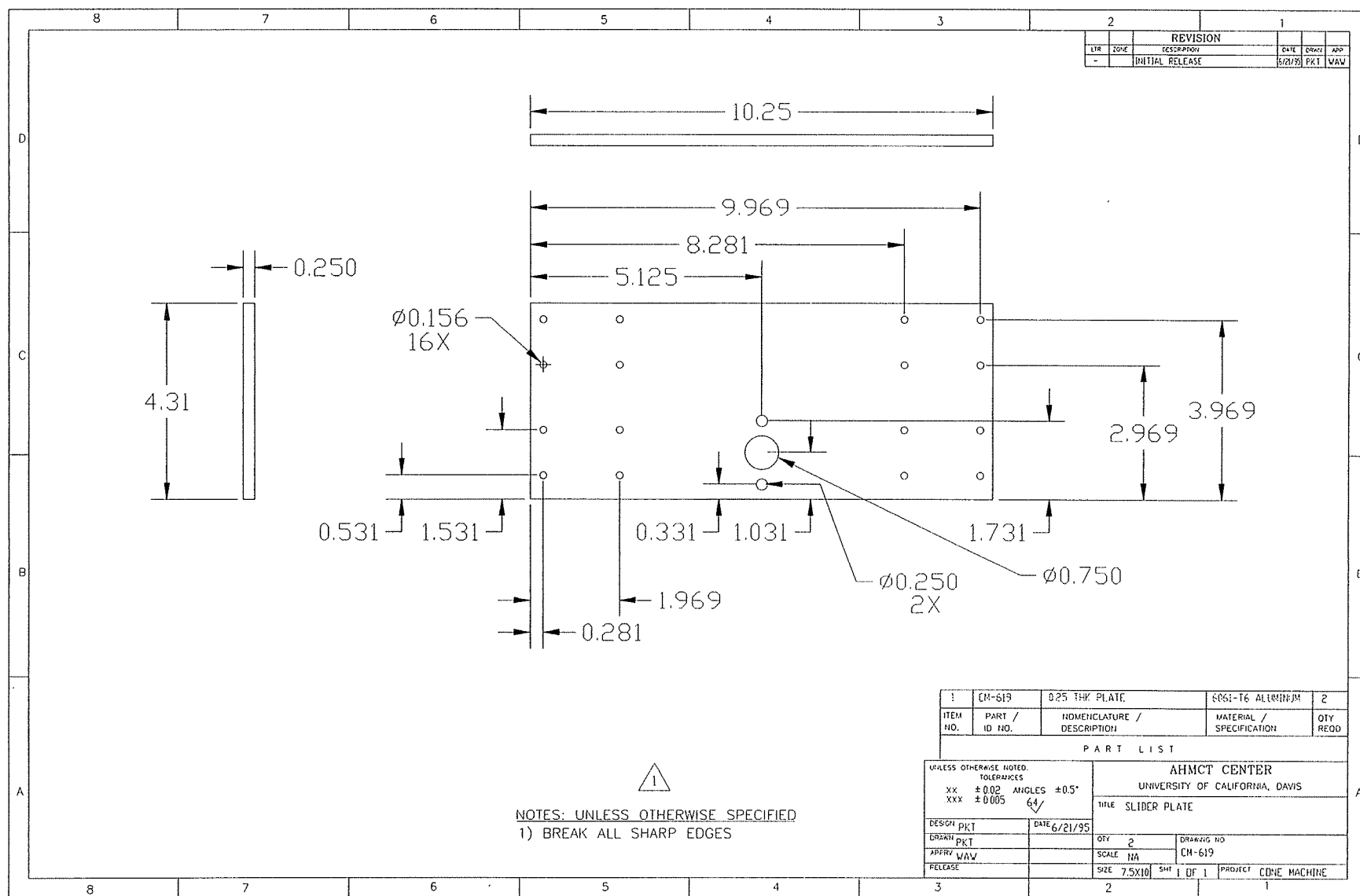


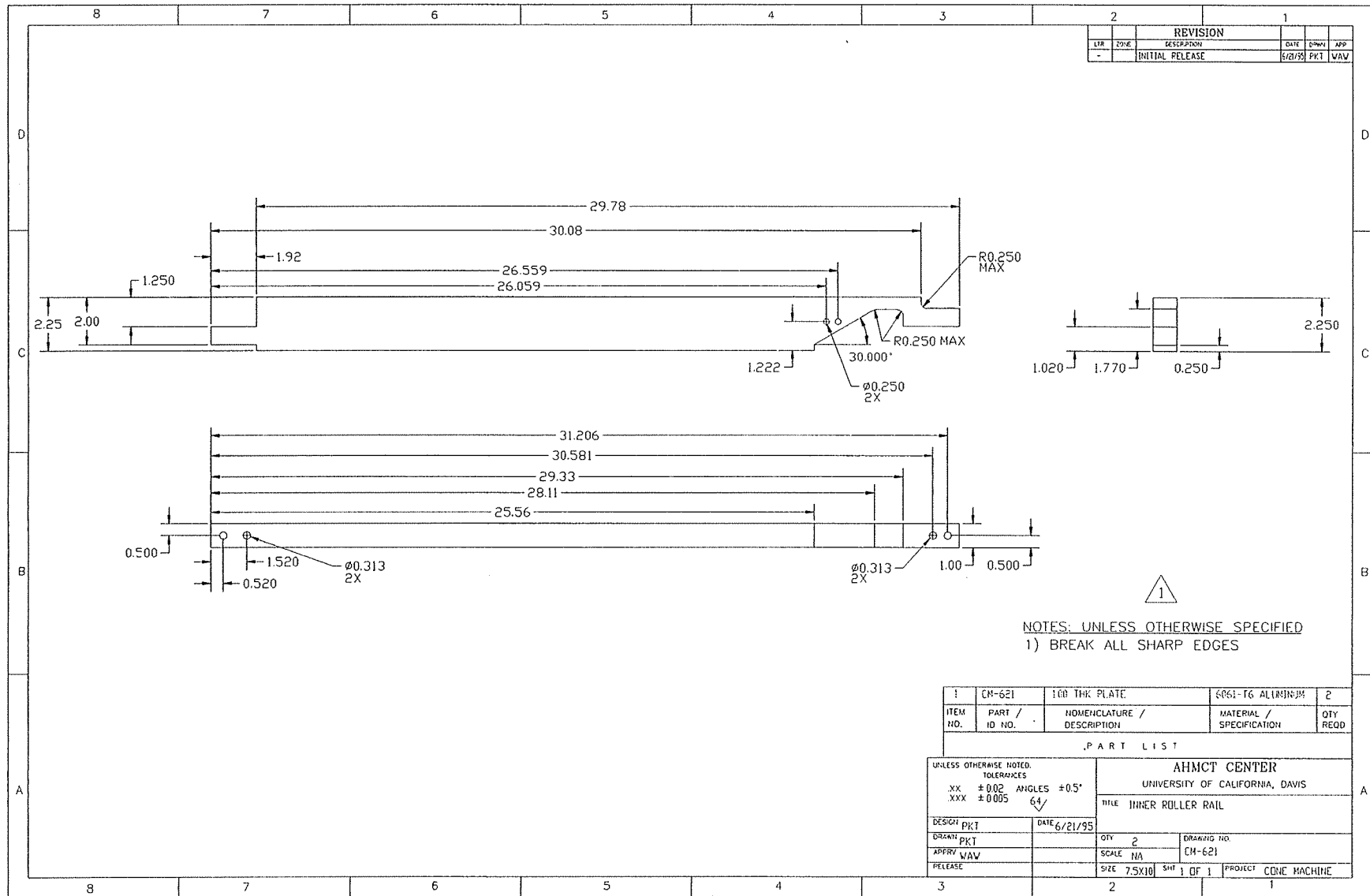


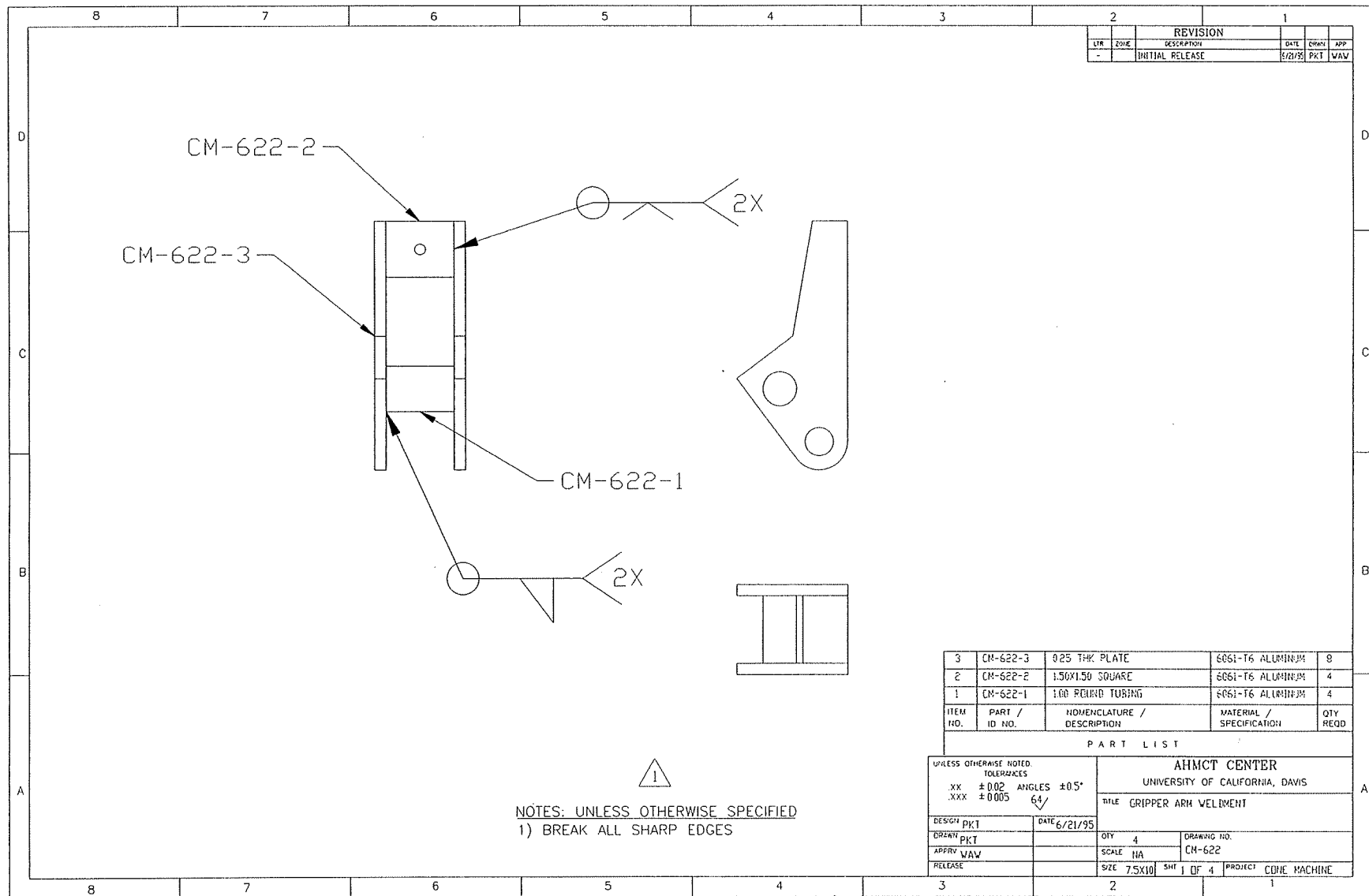


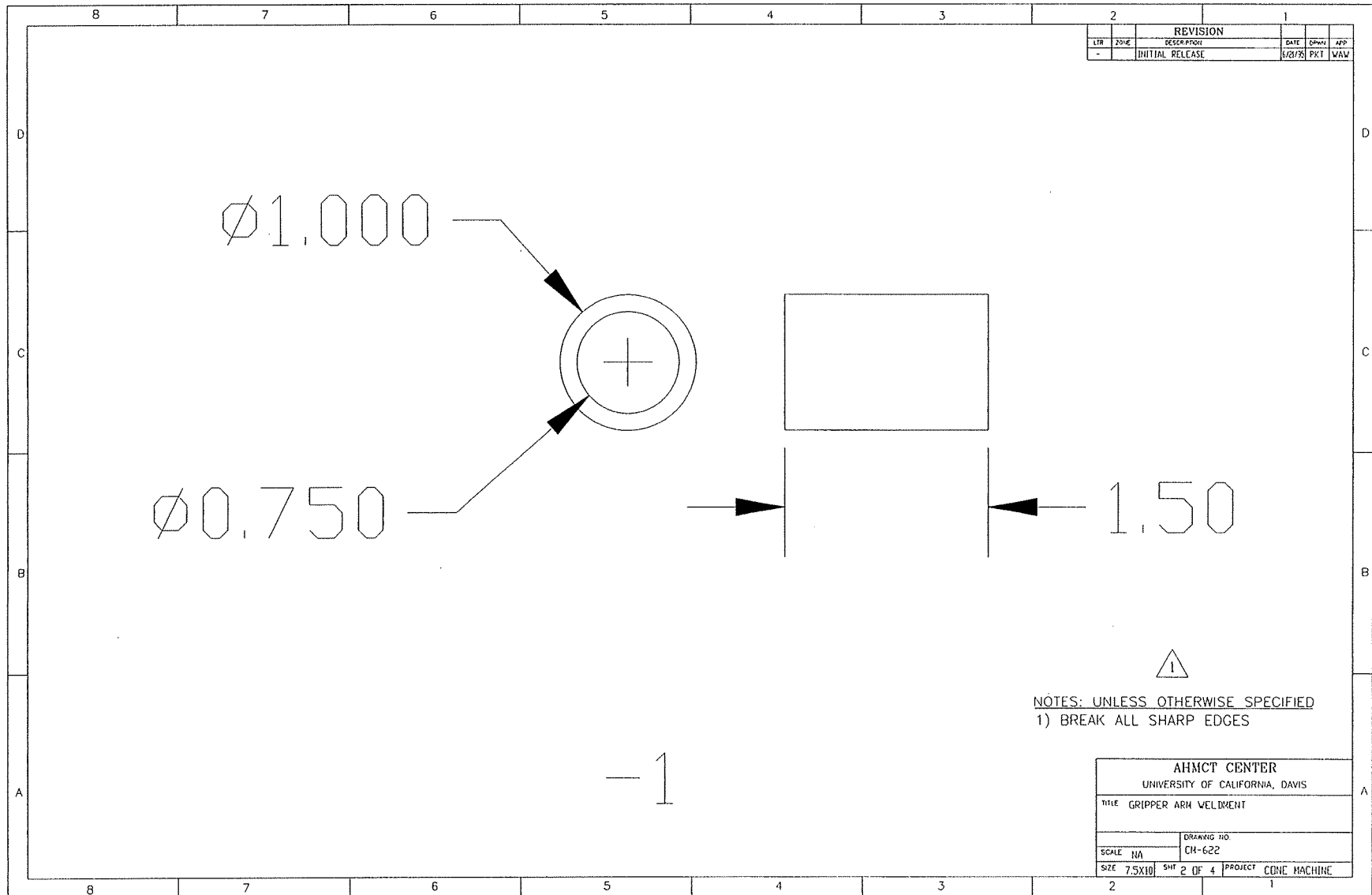


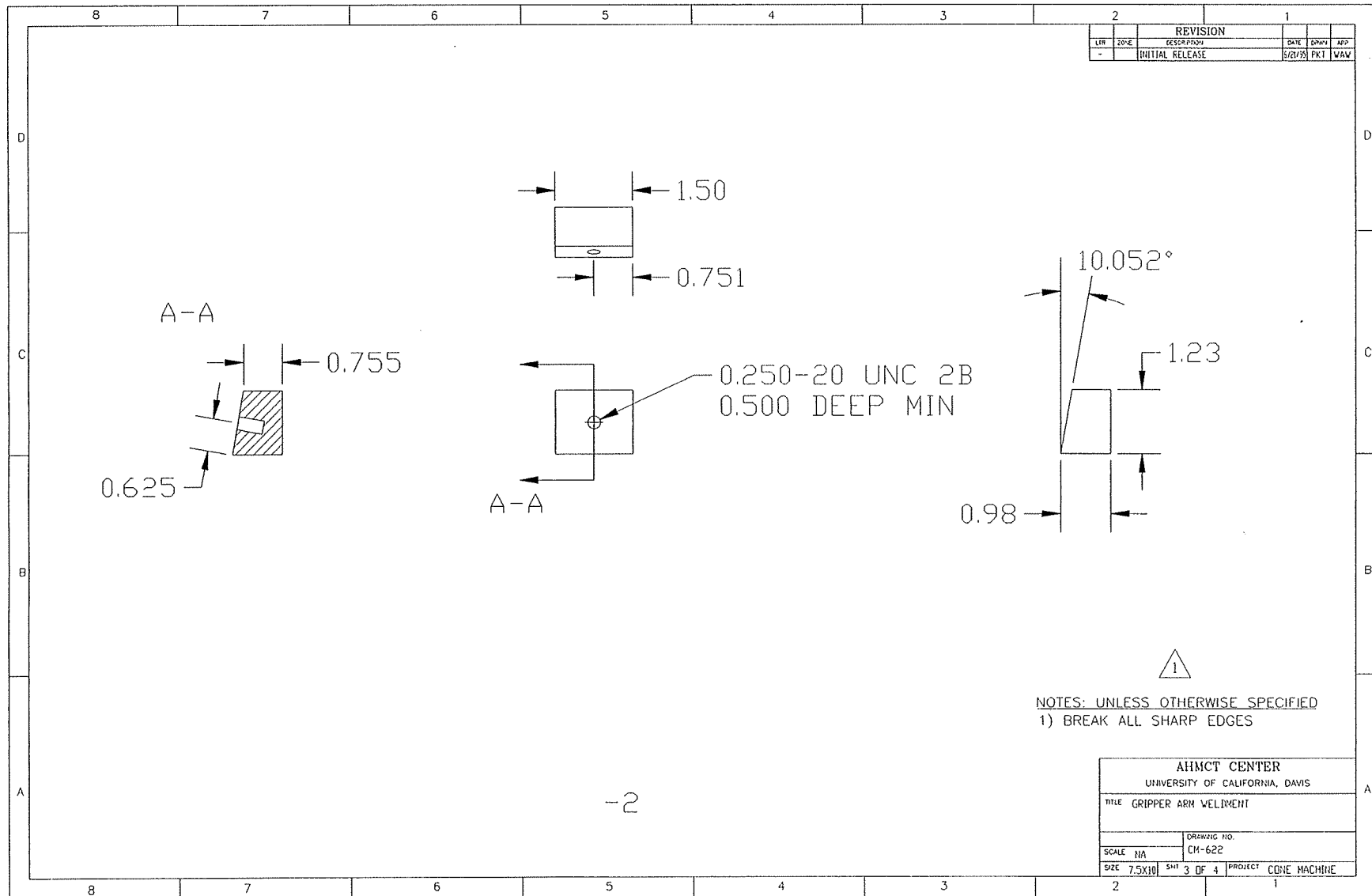


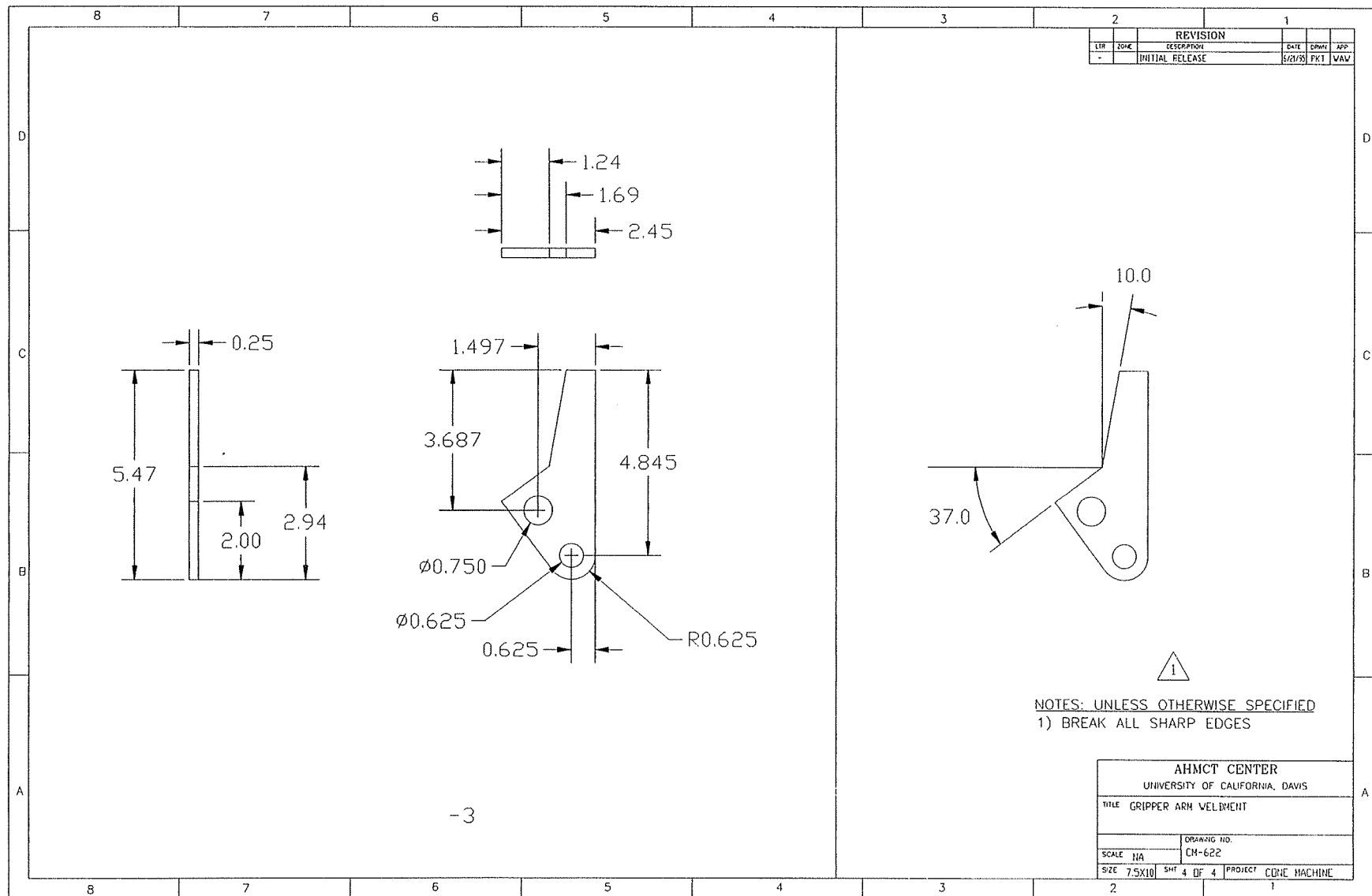


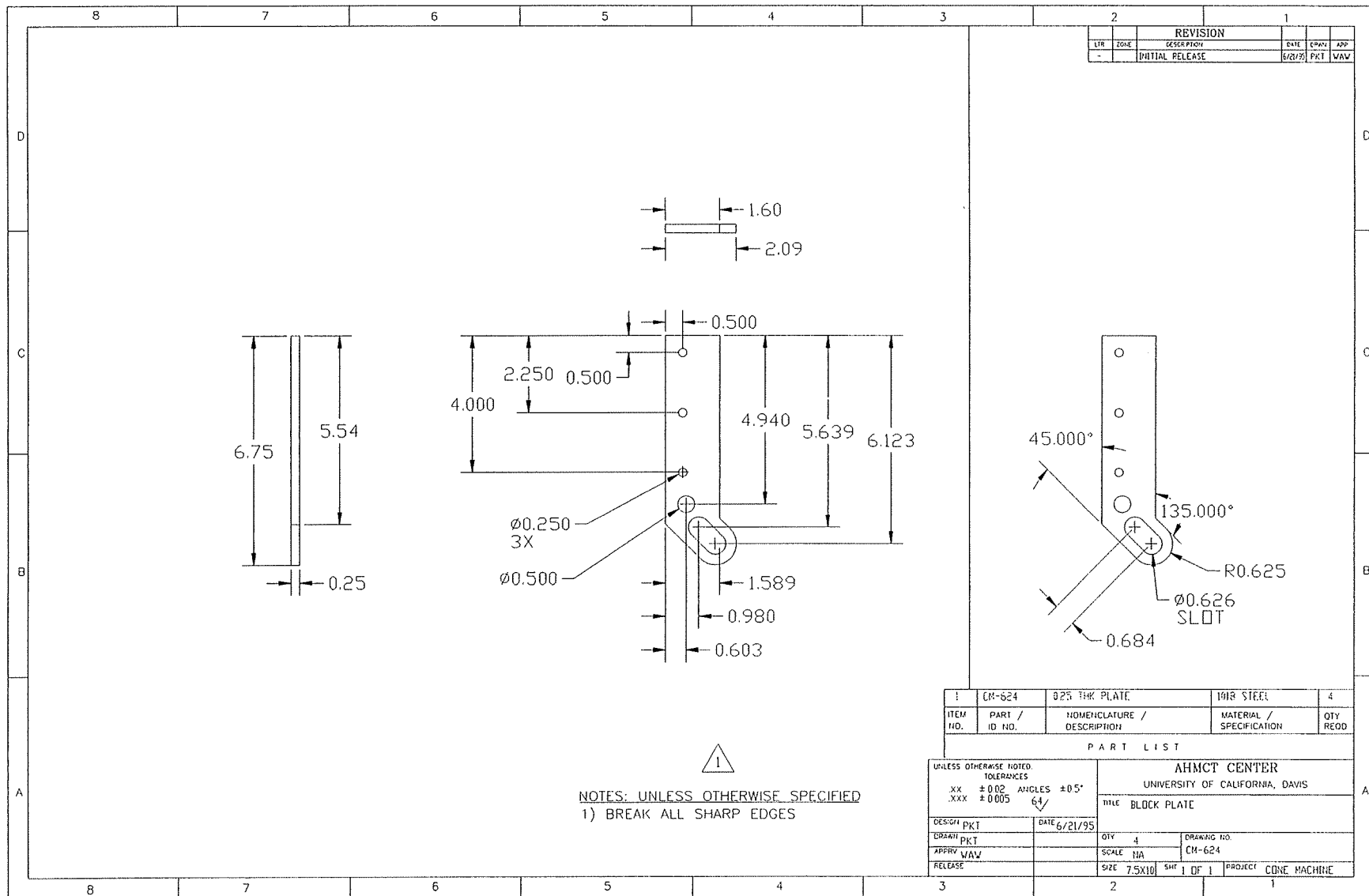


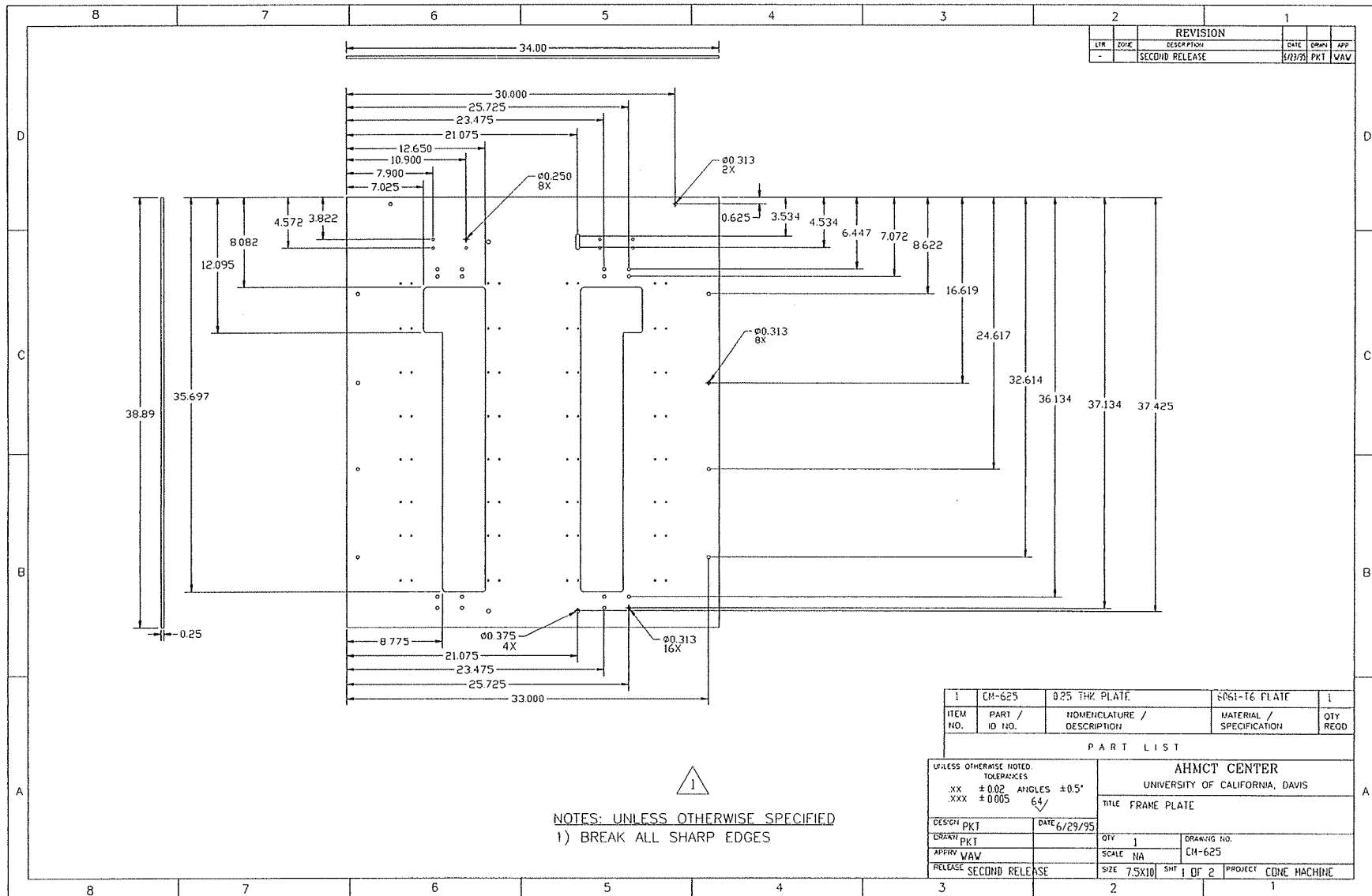


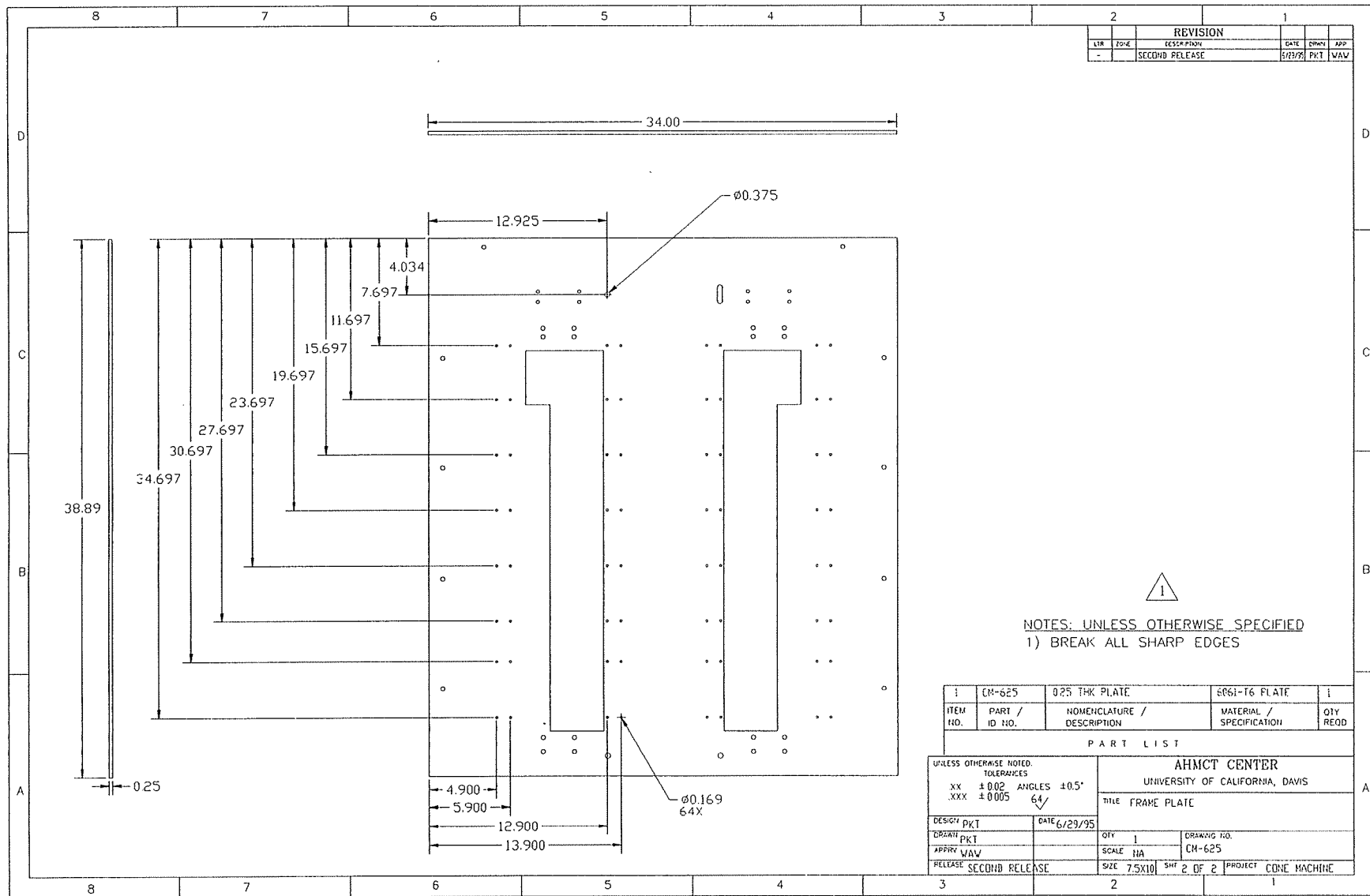


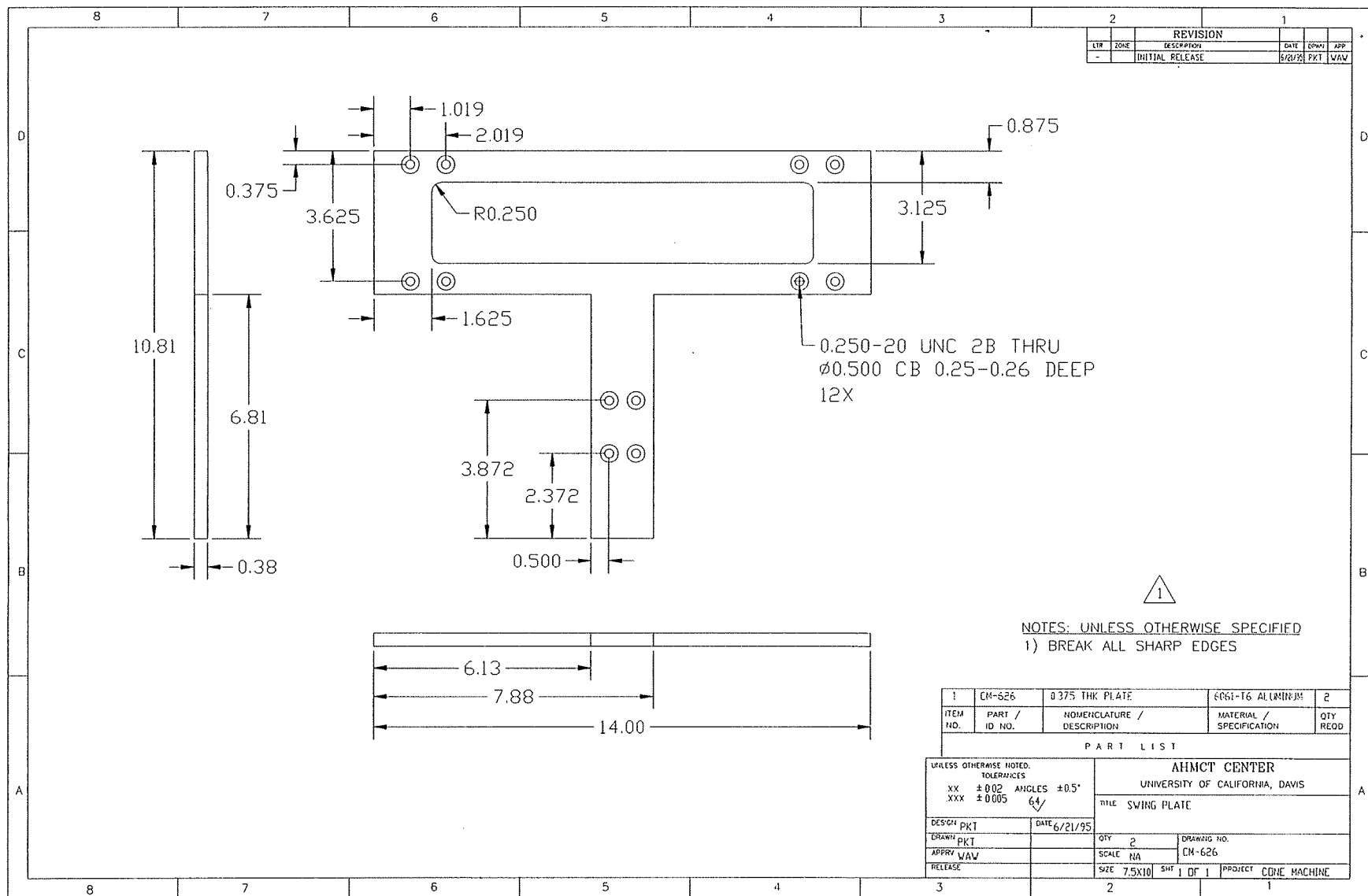


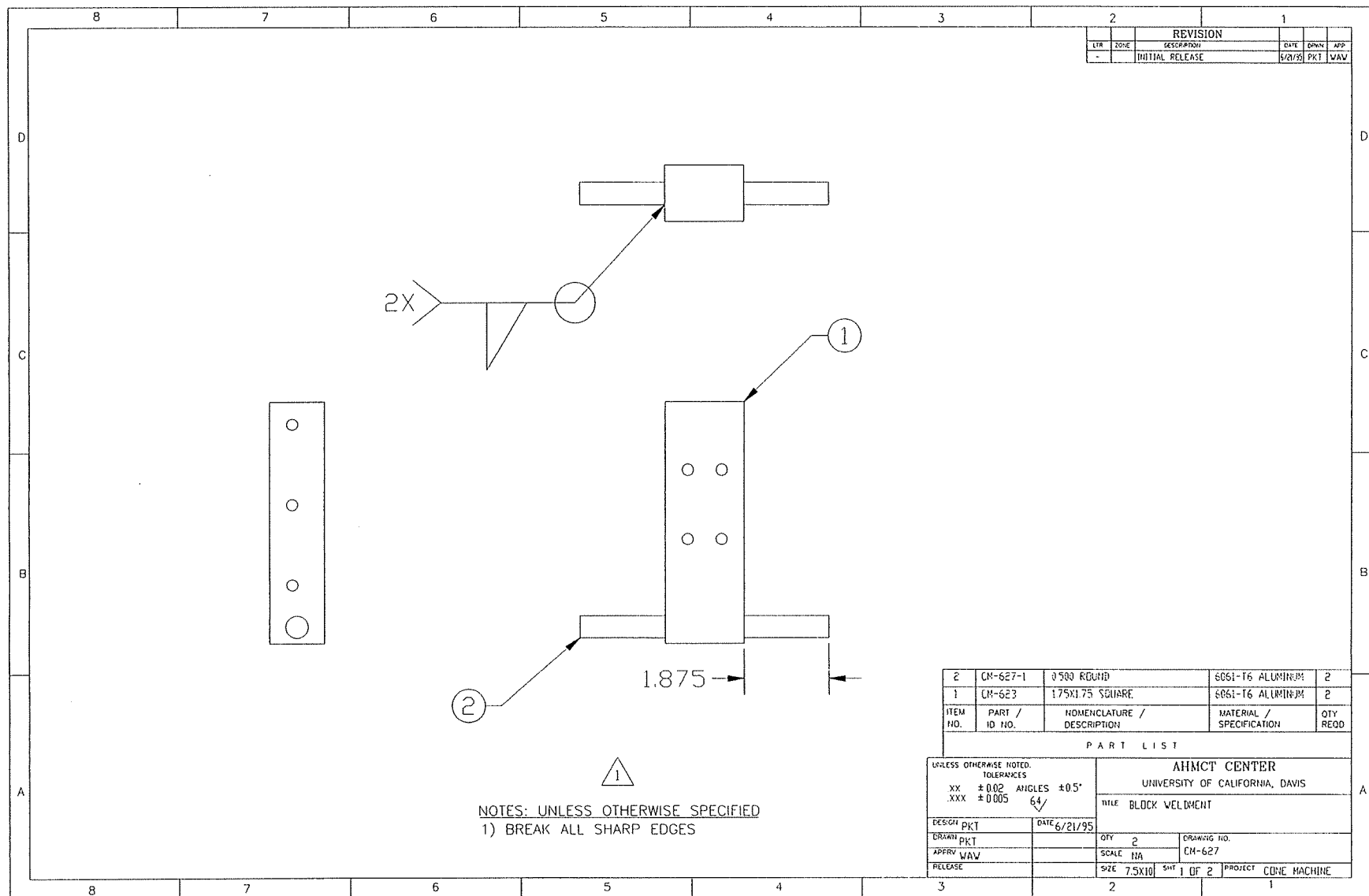


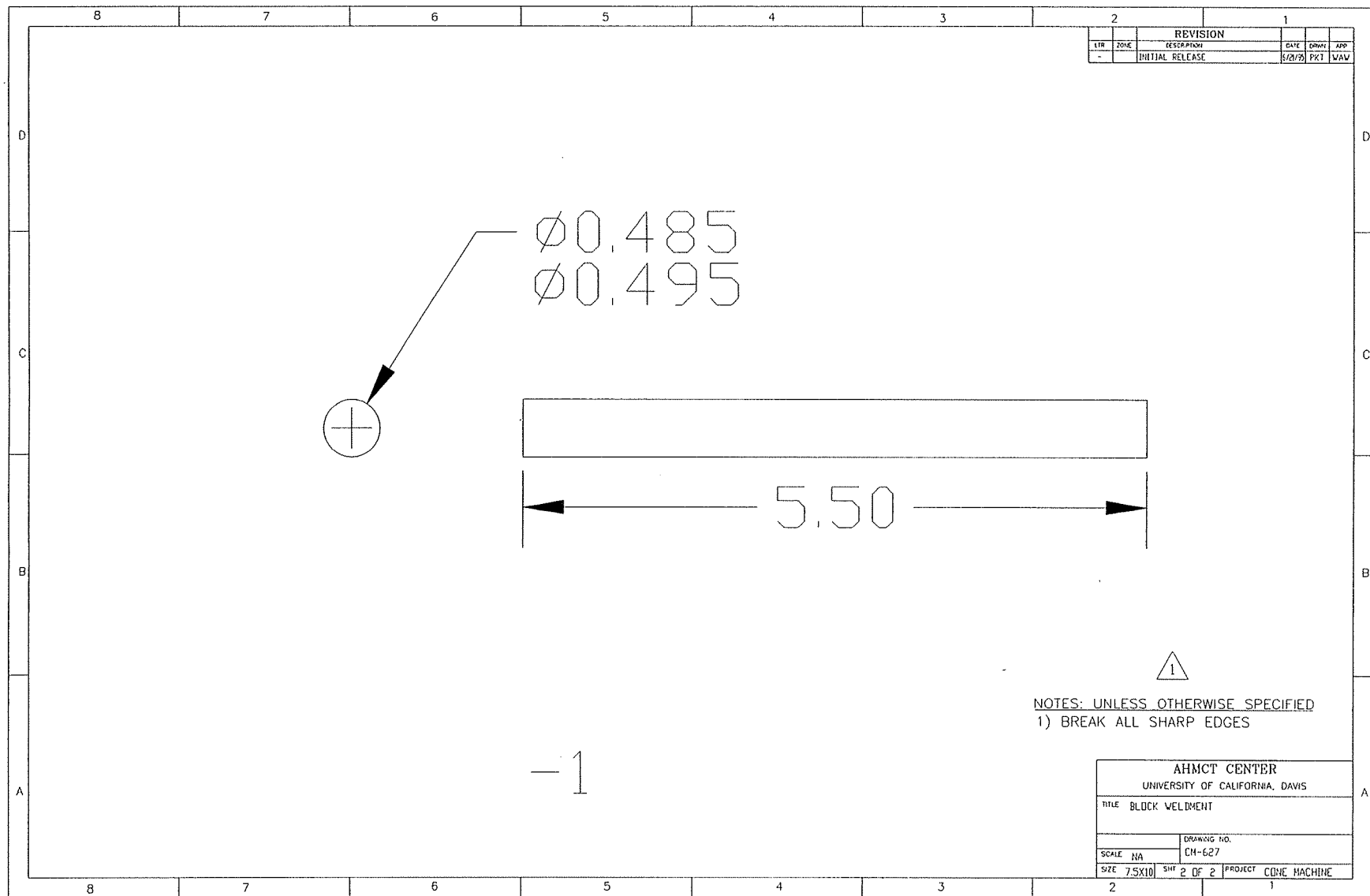


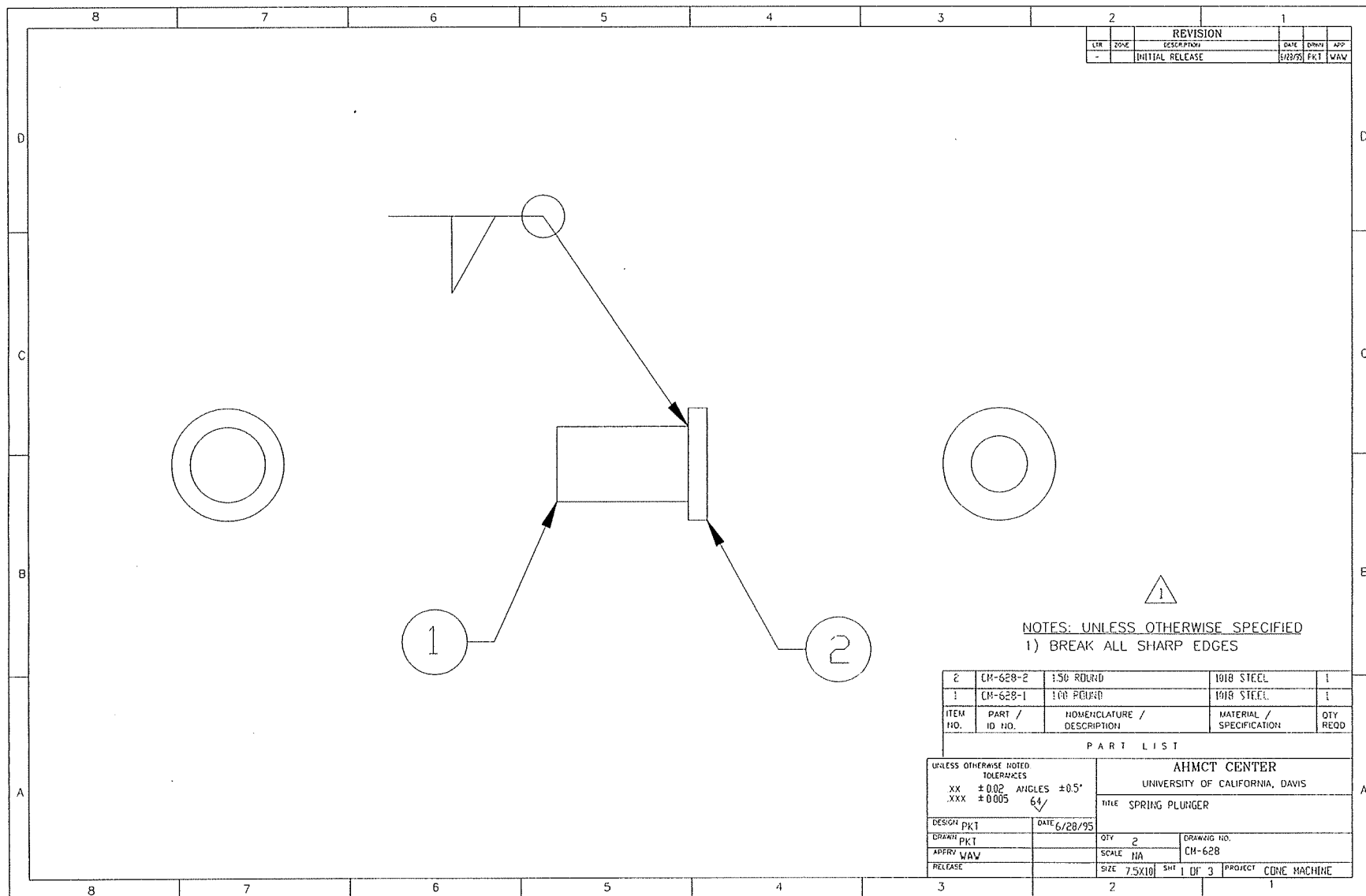


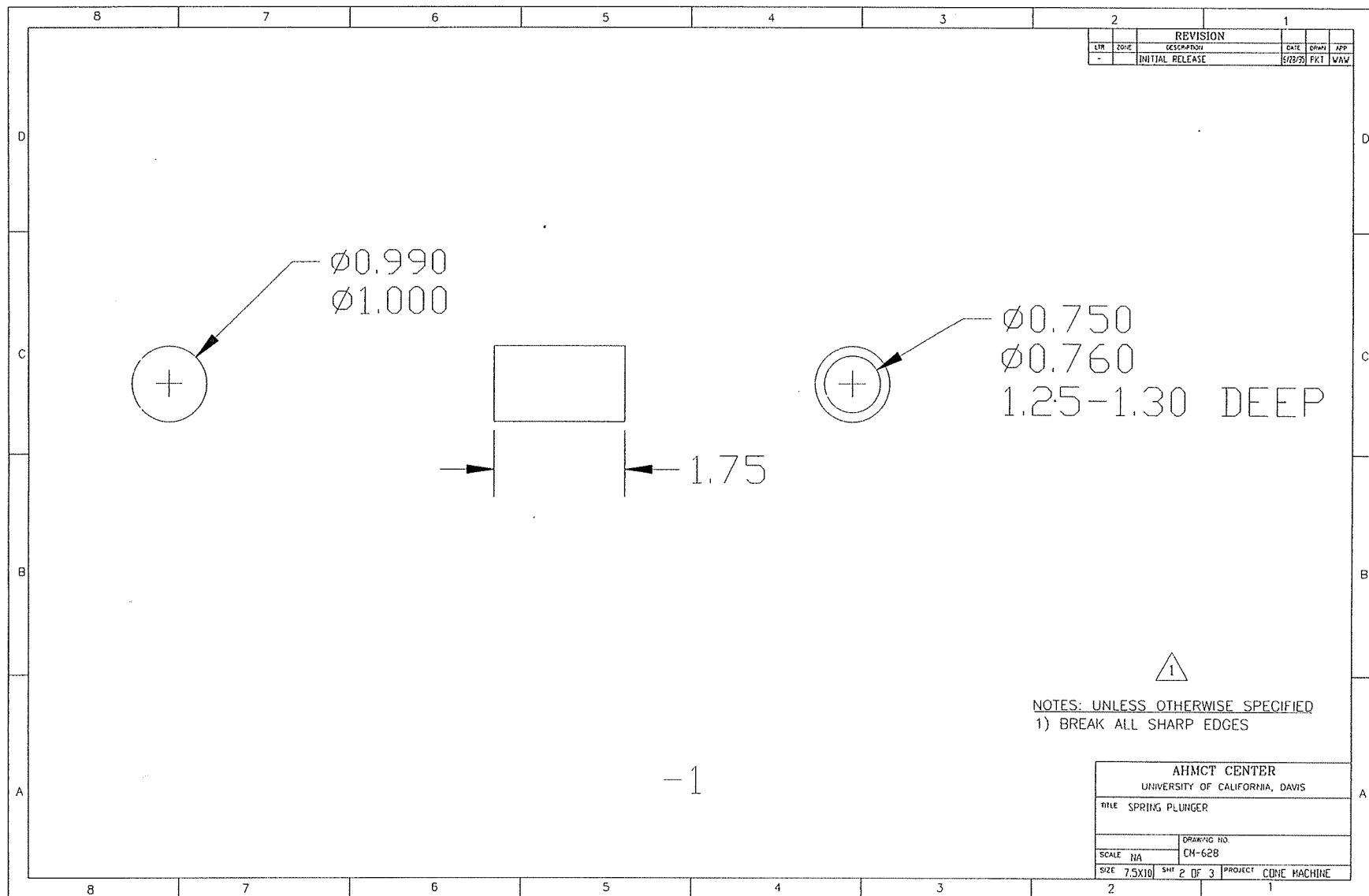


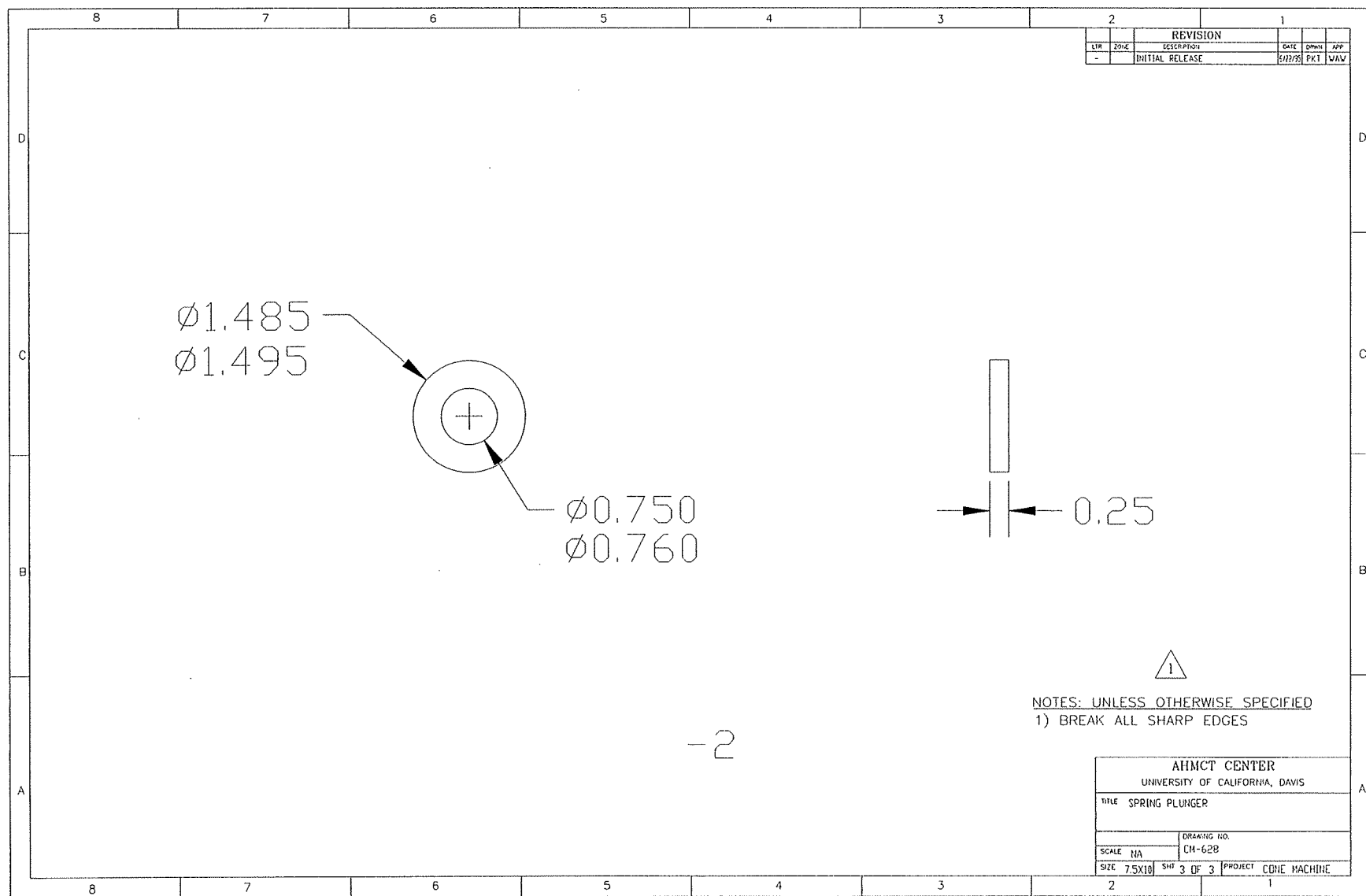


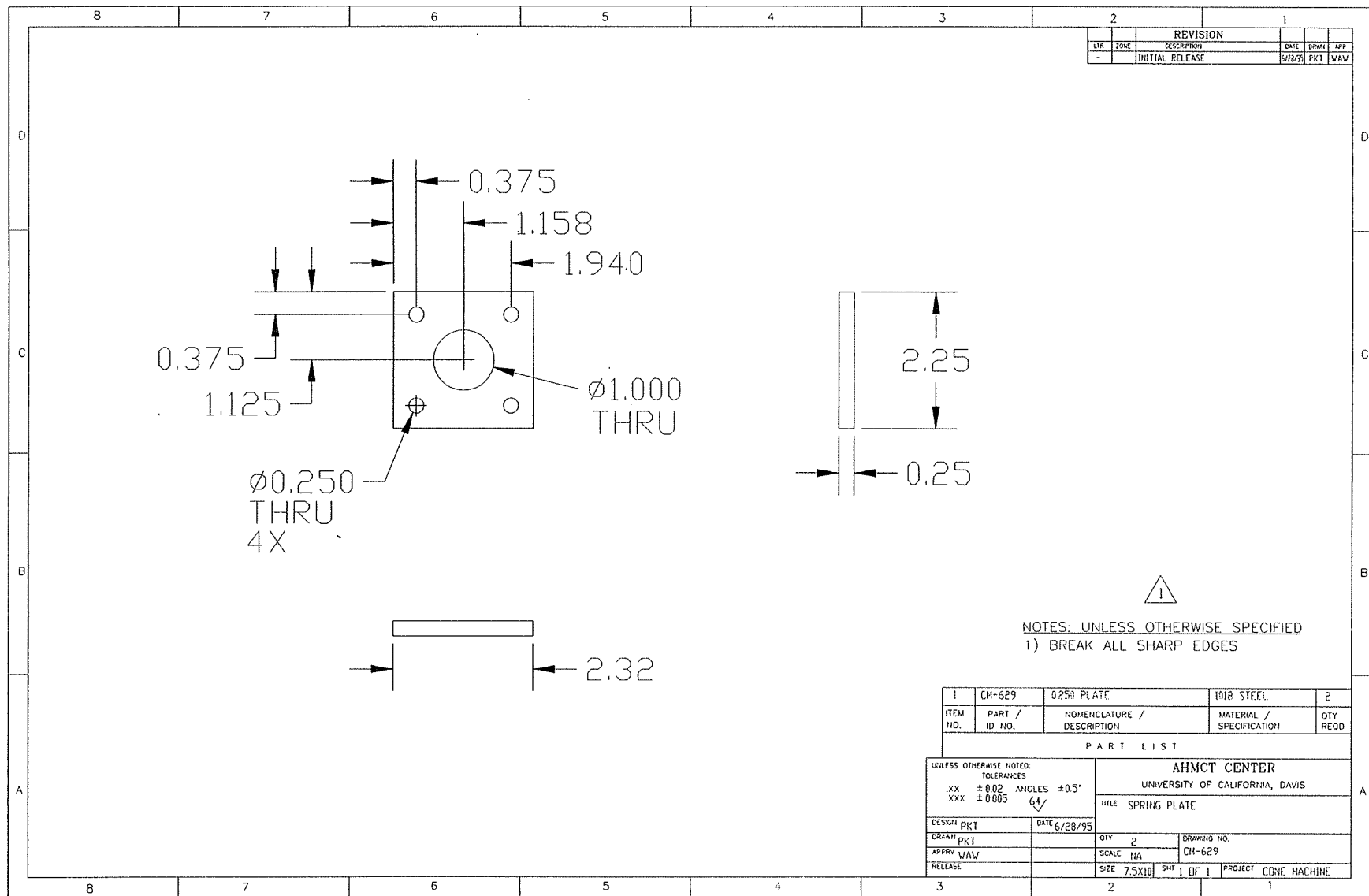


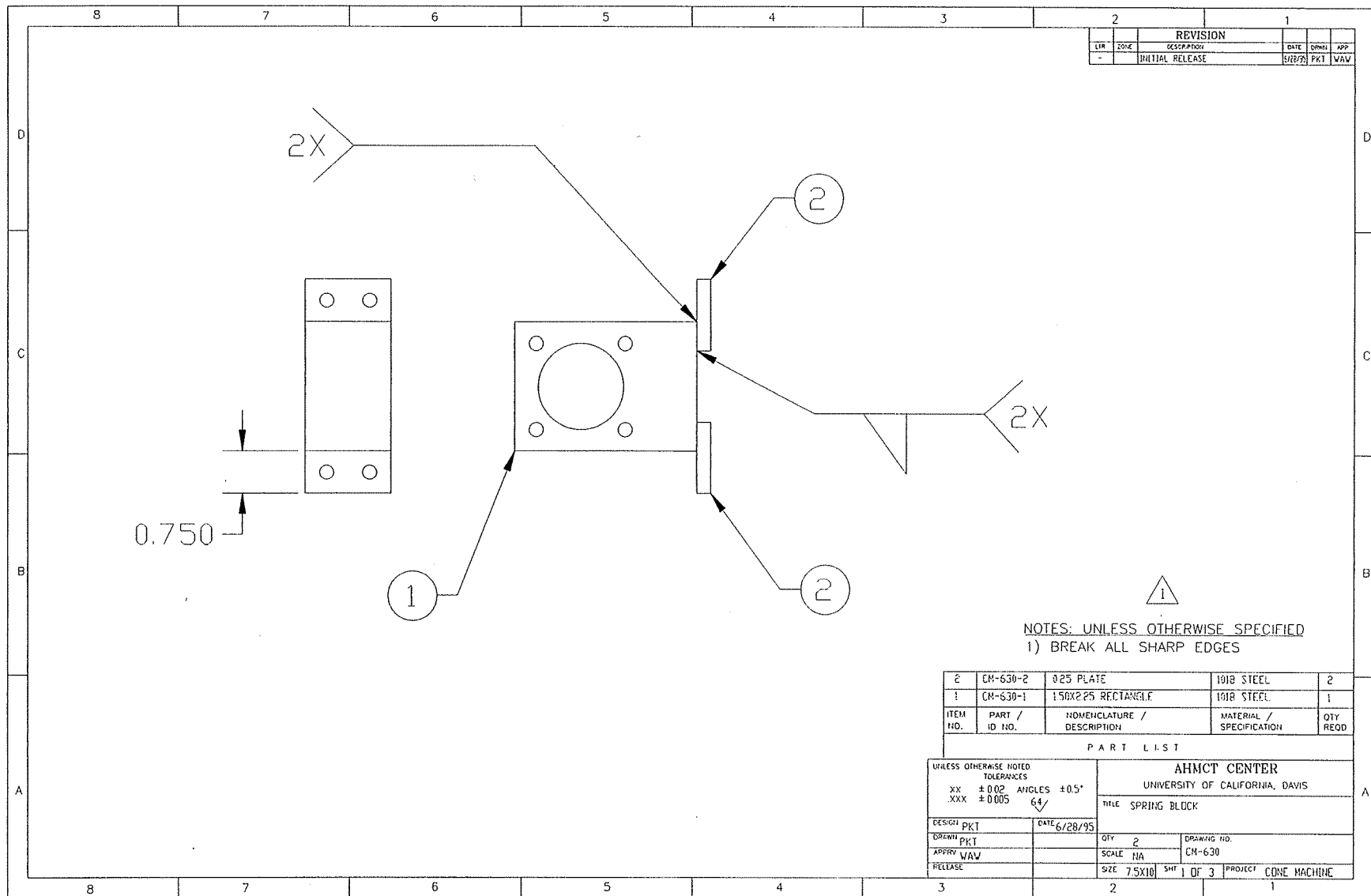


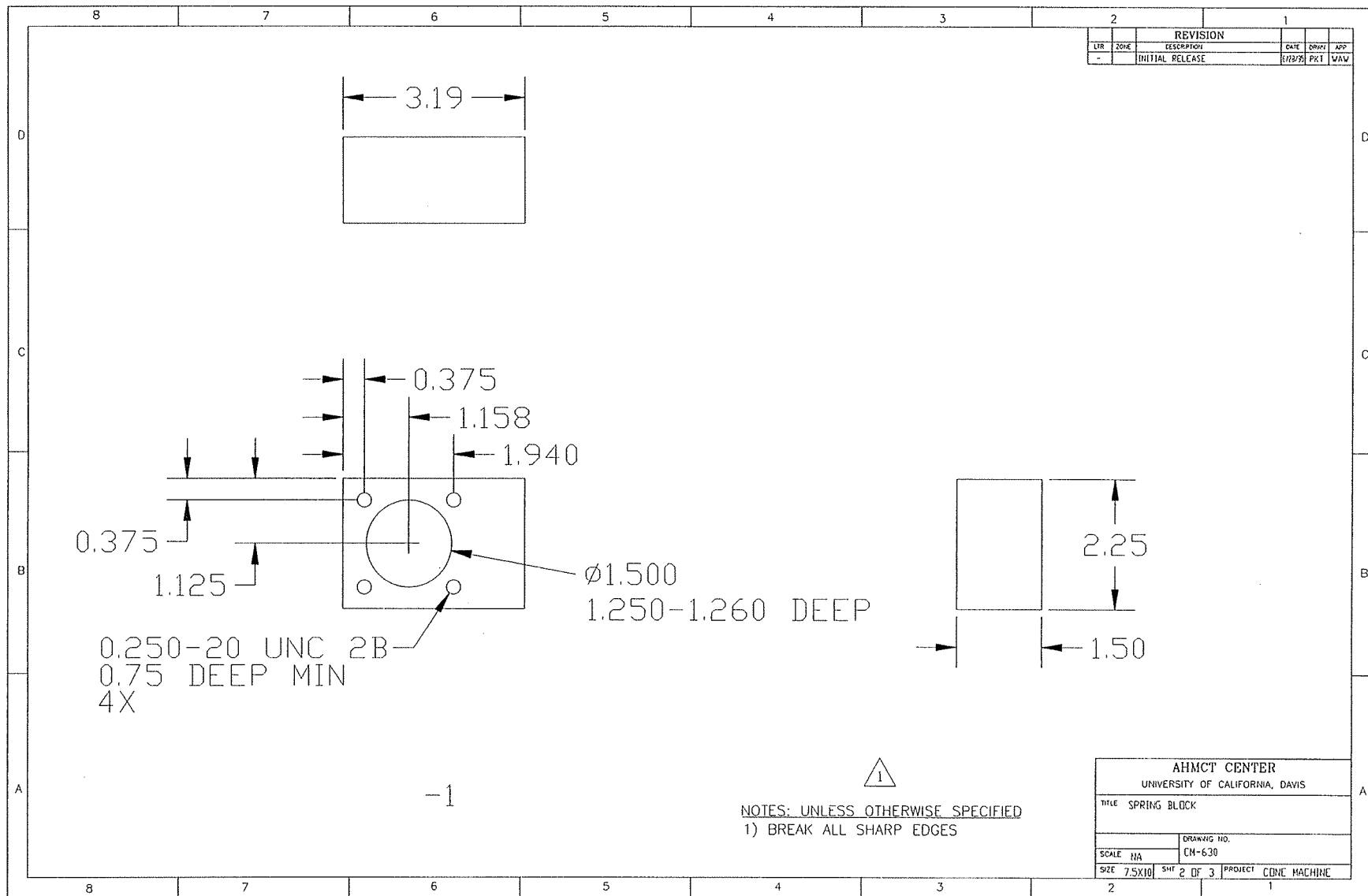


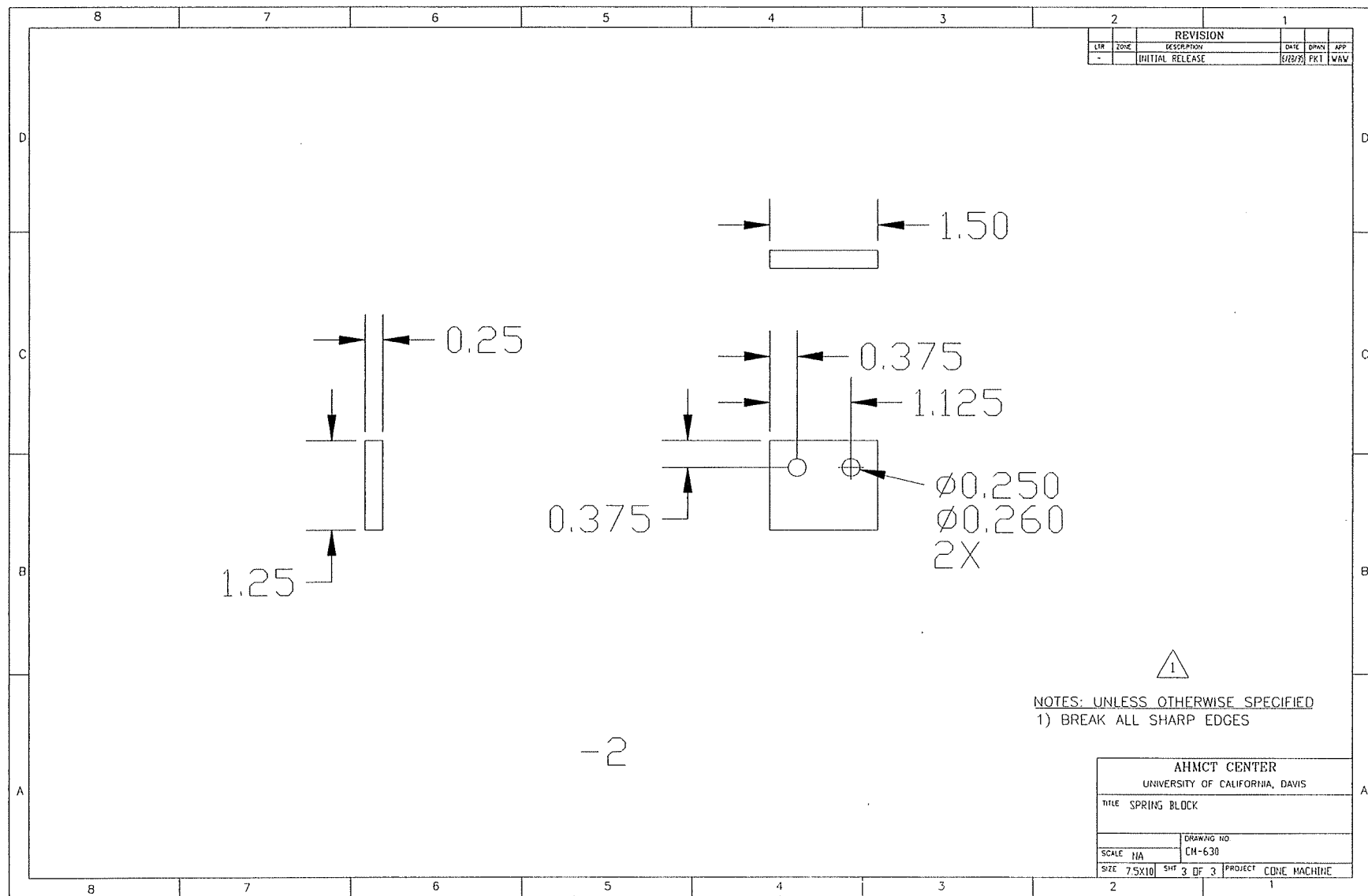












APPENDIX D FIRST PHASE PSEUDO CODE

Operation Scenarios

1. Left Side Retrieval w/ Cone Tip First
2. Left Side Retrieval w/ Cone Standing or Base First
3. Right Side Retrieval w/ Cone Tip First
4. Right Side Retrieval w/ Cone Standing or Base First
5. Left Side Placement Single Cone
6. Right Side Placement Single Cone
7. Left Side Placement Series w/ 25 Foot Spacing
8. Left Side Placement Series w/ 50 Foot Spacing
9. Left Side Placement Series w/ 100 Foot Spacing
10. Right Side Placement Series w/ 25 Foot Spacing
11. Right Side Placement Series w/ 50 Foot Spacing
12. Right Side Placement Series w/ 100 Foot Spacing
13. Stow

1. Left Side Retrieval w/ Cone Tip First

Deployment Procedure:

Output #16 Left Box Down stop when Input #8 Left Down Limit Switch active

Output #7 Left Arm Downward

Output #11 Tip Bar Deployed

Output #20 Funnel Gate Rigid

Output #2 Lateral Conveyor On Left to Right

Prestack Ready (Stowage) Procedure:

If Input #5 Backward Left Stack Sensor active and Input #6 Backward Right Stack Sensor active then Output #15 Advance Stack Backward and stop when either Input #5 Backward Left Stack Sensor or Input #6 Backward Right Stack Sensor are inactive

Stack Ready (Stowage) Procedure:

If Input #5 Backward Left Stack Sensor inactive, Input #6 Backward Right Stack Sensor active, and Input #2 Right Stowage Sensor active then Output #10 (default) Left Gripper Closed, Output #5 Left Gripper Up/ Right Gripper Down, and Output #13 (default) Middle Gate Closed

If Input #5 Backward Left Stack Sensor inactive, Input #6 Backward Right Stack Sensor active, and Input #1 Left Stowage Sensor active then Output #10 (default) Left Gripper Closed and Output #13 (default) Middle Gate Closed

If Input #6 Backward Right Stack Sensor inactive, Input #5 Backward Left Stack Sensor active, and Input #2 Right Stowage Sensor active then Output #1 (default) Right Gripper Closed and Output #13 Middle Gate Open

If Input #6 Backward Right Stack Sensor inactive, Input #5 Backward Left Stack Sensor active, and Input #1 Left Stowage Sensor active then Output #1 (default) Right Gripper Closed, Output #4 Right Gripper Up/ Left Gripper Down, and Output #13 Middle Gate Open

If Input #5 Backward Left Stack Sensor inactive, Input #6 Backward Right Stack Sensor inactive, and Input #1 Left Stowage Sensor active then Output #10 (default) Left Gripper Closed and Output #13 (default) Middle Gate Closed

If Input #5 Backward Left Stack Sensor inactive, Input #6 Backward Right Stack Sensor inactive, and Input #2 Right Stowage Sensor active then Output #1 (default) Right Gripper Closed and Output #13 (default) Middle Gate Closed

Pickup Procedure:

If Input #11 Left Arm Switch #1 active and Input #12 Left Arm Switch #2 active then Output #6 Left Arm Upward

Arm Ready Procedure:

If Input #17 Left Platform Switch active then Output #7 Left Arm Downward

Stowage Procedure:

If Input #23 Middle Gate Leftside Switch #1 active and Input #24 Middle Gate Leftside Switch #2 active then Output #10 Left Gripper Open, Output #4 Right Gripper Up/ Left Gripper Down, and Output #10 (default) Left Gripper Close

If Input #21 Right Gate Switch #1 active and Input #22 Right Gate Switch #2 active then Output #1 Right Gripper Open, Output #5 Left Gripper Up/ Right Gripper Down, and Output #1 (default) Right Gripper Closed

2. Left Side Retrieval w/ Cone Standing or Base First

Deployment Procedure:

Output #16 Left Box Down stop when Input #8 Left Down Limit Switch active

Output #7 Left Arm Downward

Output #11 (default) Tip Bar Deployed

Output #20 Funnel Gate Free

Output #2 Lateral Conveyor On Left to Right

Prestack Ready (Stowage) Procedure:

If Input #5 Backward Left Stack Sensor active and Input #6 Backward Right Stack Sensor active then Output #15 Advance Stack Backward and stop when either Input #5 Backward Left Stack Sensor or Input #6 Backward Right Stack Sensor are inactive

Stack Ready (Stowage) Procedure:

If Input #5 Backward Left Stack Sensor inactive, Input #6 Backward Right Stack Sensor active, and Input #2 Right Stowage Sensor active then Output #10 (default) Left Gripper Closed, Output #5 Left Gripper Up/ Right Gripper Down, and Output #13 (default) Middle Gate Closed

If Input #5 Backward Left Stack Sensor inactive, Input #6 Backward Right Stack Sensor active, and Input #1 Left Stowage Sensor active then Output #10 (default) Left Gripper Closed and Output #13 (default) Middle Gate Closed

If Input #6 Backward Right Stack Sensor inactive, Input #5 Backward Left Stack Sensor active, and Input #2 Right Stowage Sensor active then Output #1 (default) Right Gripper Closed and Output #13 Middle Gate Open

If Input #6 Backward Right Stack Sensor inactive, Input #5 Backward Left Stack Sensor active, and Input #1 Left Stowage Sensor active then Output #1 (default) Right Gripper Closed, Output #4 Right Gripper Up/ Left Gripper Down, and Output #13 Middle Gate Open

If Input #5 Backward Left Stack Sensor inactive, Input #6 Backward Right Stack Sensor inactive, and Input #1 Left Stowage Sensor active then Output #10 (default) Left Gripper Closed and Output #13 (default) Middle Gate Closed

If Input #5 Backward Left Stack Sensor inactive, Input #6 Backward Right Stack Sensor inactive, and Input #2 Right Stowage Sensor active then Output #1 (default) Right Gripper Closed and Output #13 (default) Middle Gate Closed

Pickup Procedure:

If Input #11 Left Arm Switch #1 active and Input #12 Left Arm Switch #2 active then Output #6 Left Arm Upward

Arm Ready Procedure:

If Input #17 Left Platform Switch active then Output #7 Left Arm Downward

Stowage Procedure:

If Input #23 Middle Gate Leftside Switch #1 active and Input #24 Middle Gate Leftside Switch #2 active then Output #10 Left Gripper Open, Output #4 Right Gripper Up/ Left Gripper Down, and Output #10 (default) Left Gripper Close

If Input #21 Right Gate Switch #1 active and Input #22 Right Gate Switch #2 active then Output #1 Right Gripper Open, Output #5 Left Gripper Up/ Right Gripper Down, and Output #1 (default) Right Gripper Closed

3. Right Side Retrieval w/ Cone Tip First

Deployment Procedure:

Output #18 Right Box Down stop when Input #10 Right Down Limit Switch active

Output #9 Right Arm Downward

Output #11 (default) Tip Bar Deployed

Output #20 (default) Funnel Gate Rigid

Output #3 Lateral Conveyor On Right to Left

Prestack Ready (Stowage) Procedure:

If Input #5 Backward Left Stack Sensor active and Input #6 Backward Right Stack Sensor active then Output #15 Advance Stack Backward and stop when either Input #5 Backward Left Stack Sensor or Input #6 Backward Right Stack Sensor are inactive

Stack Ready (Stowage) Procedure:

If Input #5 Backward Left Stack Sensor inactive, Input #6 Backward Right Stack Sensor active, and Input #2 Right Stowage Sensor active then Output #10 (default) Left Gripper Closed, Output #5 Left Gripper Up/ Right Gripper Down, and Output #13 (default) Middle Gate Closed

If Input #5 Backward Left Stack Sensor inactive, Input #6 Backward Right Stack Sensor active, and Input #1 Left Stowage Sensor active then Output #10 (default) Left Gripper Closed and Output #13 (default) Middle Gate Closed

If Input #6 Backward Right Stack Sensor inactive, Input #5 Backward Left Stack Sensor active, and Input #2 Right Stowage Sensor active then Output #1 (default) Right Gripper Closed and Output #13 Middle Gate Open

If Input #6 Backward Right Stack Sensor inactive, Input #5 Backward Left Stack Sensor active, and Input #1 Left Stowage Sensor active then Output #1 (default) Right Gripper Closed, Output #4 Right Gripper Up/ Left Gripper Down, and Output #13 Middle Gate Open

If Input #5 Backward Left Stack Sensor inactive, Input #6 Backward Right Stack Sensor inactive, and Input #1 Left Stowage Sensor active then Output #10 (default) Left Gripper Closed and Output #13 (default) Middle Gate Closed

If Input #5 Backward Left Stack Sensor inactive, Input #6 Backward Right Stack Sensor inactive, and Input #2 Right Stowage Sensor active then Output #1 (default) Right Gripper Closed and Output #13 (default) Middle Gate Closed

Pickup Procedure:

If Input #13 Right Arm Switch #1 active and Input #14 Right Arm Switch #2 active then Output #8 Right Arm Upward

Arm Ready Procedure:

If Input #18 Right Platform Switch active then Output #9 Right Arm Downward

Stowage Procedure:

If Input #25 Middle Gate Rightside Switch #1 active and Input #26 Middle Gate Rightside Switch #2 active then Output #1 Right Gripper Open, Output #5 Left Gripper Up/ Right Gripper Down, and Output #1 (default) Right Gripper Close

If Input #19 Left Gate Switch #1 active and Input #20 Left Gate Switch #2 active then Output #10 Left Gripper Open, Output #4 Right Gripper Up/ Left Gripper Down, and Output #10 (default) Left Gripper Closed

4. Right Side Retrieval w/ Cone Standing or Base First

Deployment Procedure:

Output #18 Right Box Down stop when Input #10 Right Down Limit Switch active

Output #9 Right Arm Downward

Output #11 (default) Tip Bar Deployed

Output #20 Funnel Gate Free

Output #3 Lateral Conveyor On Right to Left

Prestack Ready (Stowage) Procedure:

If Input #5 Backward Left Stack Sensor active and Input #6 Backward Right Stack Sensor active then Output #15 Advance Stack Backward and stop when either Input #5 Backward Left Stack Sensor or Input #6 Backward Right Stack Sensor are inactive

Stack Ready (Stowage) Procedure:

If Input #5 Backward Left Stack Sensor inactive, Input #6 Backward Right Stack Sensor active, and Input #2 Right Stowage Sensor active then Output #10 (default) Left Gripper Closed, Output #5 Left Gripper Up/ Right Gripper Down, and Output #13 (default) Middle Gate Closed

If Input #5 Backward Left Stack Sensor inactive, Input #6 Backward Right Stack Sensor active, and Input #1 Left Stowage Sensor active then Output #10 (default) Left Gripper Closed and Output #13 (default) Middle Gate Closed

If Input #6 Backward Right Stack Sensor inactive, Input #5 Backward Left Stack Sensor active, and Input #2 Right Stowage Sensor active then Output #1 (default) Right Gripper Closed and Output #13 Middle Gate Open

If Input #6 Backward Right Stack Sensor inactive, Input #5 Backward Left Stack Sensor active, and Input #1 Left Stowage Sensor active then Output #1 (default) Right Gripper Closed, Output #4 Right Gripper Up/ Left Gripper Down, and Output #13 Middle Gate Open

If Input #5 Backward Left Stack Sensor inactive, Input #6 Backward Right Stack Sensor inactive, and Input #1 Left Stowage Sensor active then Output #10 (default) Left Gripper Closed and Output #13 (default) Middle Gate Closed

If Input #5 Backward Left Stack Sensor inactive, Input #6 Backward Right Stack Sensor inactive, and Input #2 Right Stowage Sensor active then Output #1 (default) Right Gripper Closed and Output #13 (default) Middle Gate Closed

Pickup Procedure:

If Input #13 Right Arm Switch #1 active and Input #14 Right Arm Switch #2 active then Output #8 Right Arm Upward

Arm Ready Procedure:

If Input #18 Right Platform Switch active then Output #9 Right Arm Downward

Stowage Procedure:

If Input #25 Middle Gate Rightside Switch #1 active and Input #26 Middle Gate Rightside Switch #2 active then Output #1 Right Gripper Open, Output #5 Left Gripper Up/ Right Gripper Down, and Output #1 (default) Right Gripper Close

If Input #19 Left Gate Switch #1 active and Input #20 Left Gate Switch #2 active then Output #10 Left Gripper Open, Output #4 Right Gripper Up/ Left Gripper Down, and Output #10 (default) Left Gripper Closed

5. Left Side Placement Single Cone

Deployment Procedure:

Output #16 Left Box Down stop when Input #8 Left Down Limit Switch active

Output #6 Left Arm Upward

Output #3 Lateral Conveyor On Right to Left

Output #13 Middle Gate Open

Prestack Ready (Placement) Procedure:

If Input #3 Forward Left Stack Sensor inactive and Input #4 Forward Right Stack Sensor inactive then Output #14 Advance Stack Forward and stop when Input #3 Forward Left Stack Sensor active and Input #4 Forward Right Stack Sensor active

Stack Ready (Placement) Procedure:

If Input #3 Forward Left Stack Sensor inactive, Input #4 Forward Right Stack Sensor active, and Input #2 Right Stowage Sensor active then Output #1 (default) Right Gripper Closed and Output #5 Left Gripper Up/ Right Gripper Closed

If Input #3 Forward Left Stack Sensor inactive, Input #4 Forward Right Stack Sensor active, and Input #1 Left Stowage Sensor active then Output #1 (default) Right Gripper Closed

If Input #4 Forward Right Stack Sensor inactive, Input #3 Forward Left Stack Sensor active, and Input #2 Right Stowage Sensor active then Output #10 (default) Left Gripper Closed

If Input #4 Forward Right Stack Sensor inactive, Input #3 Forward Left Stack Sensor active, and Input #1 Left Stowage Sensor active then Output #10 (default) Left Gripper Closed and Output #4 Right Gripper Up/ Left Gripper Down

If Input #3 Forward Left Stack Sensor active, Input #4 Forward Right Stack Sensor active, and Input #1 Left Stowage Sensor active then Output #1 (default) Right Gripper Closed

If Input #3 Forward Left Stack Sensor active, Input #4 Forward Right Stack Sensor active, and Input #2 Right Stowage Sensor active then Output #10 (default) Left Gripper Closed

Drop Ready Procedure:

If Input #2 Right Stowage Sensor active then Output #10 Left Gripper Open and Output #5 Left Gripper Up/ Right Gripper Down

If Input #1 Left Stowage Sensor active then Output #1 Right Gripper Open and Output #4 Right Gripper Up/ Left Gripper Down

Drop-off Procedure:

If Input #2 Right Stowage Sensor active then Output #1 (default) Right Gripper Closed

If Input #1 Left Stowage Sensor active then Output #10 (default) Left Gripper Closed

6. Right Side Placement Single Cone

Deployment Procedure:

Output #18 Right Box Down stop when Input #1 Right Down Limit Switch active

Output #8 Right Arm Upward

Output #2 Lateral Conveyor On Left to Right

Output #13 Middle Gate Open

Prestack Ready (Placement) Procedure:

If Input #3 Forward Left Stack Sensor inactive and Input #4 Forward Right Stack Sensor inactive then Output #14 Advance Stack Forward and stop when Input #3 Forward Left Stack Sensor active and Input #4 Forward Right Stack Sensor active

Stack Ready (Placement) Procedure:

If Input #3 Forward Left Stack Sensor inactive, Input #4 Forward Right Stack Sensor active, and Input #2 Right Stowage Sensor active then Output #1 (default) Right Gripper Closed and Output #5 Left Gripper Up/ Right Gripper Closed

If Input #3 Forward Left Stack Sensor inactive, Input #4 Forward Right Stack Sensor active, and Input #1 Left Stowage Sensor active then Output #1 (default) Right Gripper Closed

If Input #4 Forward Right Stack Sensor inactive, Input #3 Forward Left Stack Sensor active, and Input #2 Right Stowage Sensor active then Output #10 (default) Left Gripper Closed

If Input #4 Forward Right Stack Sensor inactive, Input #3 Forward Left Stack Sensor active, and Input #1 Left Stowage Sensor active then Output #10 (default) Left Gripper Closed and Output #4 Right Gripper Up/ Left Gripper Down

If Input #3 Forward Left Stack Sensor active, Input #4 Forward Right Stack Sensor active, and Input #1 Left Stowage Sensor active then Output #1 (default) Right Gripper Closed

If Input #3 Forward Left Stack Sensor active, Input #4 Forward Right Stack Sensor active, and Input #2 Right Stowage Sensor active then Output #10 (default) Left Gripper Closed

Drop Ready Procedure:

If Input #2 Right Stowage Sensor active then Output #10 Left Gripper Open and Output #5 Left Gripper Up/ Right Gripper Down

If Input #1 Left Stowage Sensor active then Output #1 Right Gripper Open and Output #4 Right Gripper Up/ Left Gripper Down

Drop-off Procedure:

If Input #2 Right Stowage Sensor active then Output #1 (default) Right Gripper Closed

If Input #1 Left Stowage Sensor active then Output #10 (default) Left Gripper Closed

7. Left Side Placement Series w/ 25 Foot Spacing

Deployment Procedure:

Output #16 Left Box Down stop when Input #8 Left Down Limit Switch active

Output #6 Left Arm Upward

Output #3 Lateral Conveyor On Right to Left

Output #13 Middle Gate Open

Set Counter Activate Every 25 feet

Prestack Ready (Placement) Procedure:

If Input #3 Forward Left Stack Sensor inactive and Input #4 Forward Right Stack Sensor inactive then Output #14 Advance Stack Forward and stop when Input #3 Forward Left Stack Sensor active or Input #4 Forward Right Stack Sensor active

Stack Ready (Placement) Procedure:

If Input #3 Forward Left Stack Sensor inactive, Input #4 Forward Right Stack Sensor active, and Input #2 Right Stowage Sensor active then Output #1 (default) Right Gripper Closed and Output #5 Left Gripper Up/ Right Gripper Closed

If Input #3 Forward Left Stack Sensor inactive, Input #4 Forward Right Stack Sensor active, and Input #1 Left Stowage Sensor active then Output #1 (default) Right Gripper Closed

If Input #4 Forward Right Stack Sensor inactive, Input #3 Forward Left Stack Sensor active, and Input #2 Right Stowage Sensor active then Output #10 (default) Left Gripper Closed

If Input #3 Forward Left Stack Sensor active, Input #4 Forward Right Stack Sensor inactive, and Input #1 Left Stowage Sensor active then Output #10 Left Gripper Closed (default) and Output #4 Right Gripper Up/ Left Gripper Down

If Input #3 Forward Left Stack Sensor active, Input #4 Forward Right Stack Sensor active, and Input #1 Left Stowage Sensor active then Output #1 (default) Right Gripper Closed

If Input #3 Forward Left Stack Sensor active, Input #4 Forward Right Stack Sensor active, and Input #2 Right Stowage Sensor active then Output #10 (default) Left Gripper Closed

Position Cone Procedure:

If Input #2 Right Stowage Sensor active then Output #10 Left Gripper Open and Output #5 Left Gripper Up/ Right Gripper Down

If Input #1 Left Stowage Sensor active then Output #1 Right Gripper Open and Output #4 Right Gripper Up/ Left Gripper Down

Drop-off Procedure:

Activate every 25 feet

If Input #2 Right Stowage Sensor active then Output #1 (default) Right Gripper Closed

If Input #1 Left Stowage Sensor active then Output #10 (default) Left Gripper Closed

8. Left Side Placement Series w/ 50 Foot Spacing

Deployment Procedure:

Output #16 Left Box Down stop when Input #8 Left Down Limit Switch active

Output #6 Left Arm Upward

Output #3 Lateral Conveyor On Right to Left

Output #13 Middle Gate Open

Set Counter Activate Every 50 feet

Prestack Ready (Placement) Procedure:

If Input #3 Forward Left Stack Sensor inactive and Input #4 Forward Right Stack Sensor inactive then Output #14 Advance Stack Forward and stop when Input #3 Forward Left Stack Sensor active or Input #4 Forward Right Stack Sensor active

Stack Ready (Placement) Procedure:

If Input #3 Forward Left Stack Sensor inactive, Input #4 Forward Right Stack Sensor active, and Input #2 Right Stowage Sensor active then Output #1 (default) Right Gripper Closed and Output #5 Left Gripper Up/ Right Gripper Down

If Input #3 Forward Left Stack Sensor inactive, Input #4 Forward Right Stack Sensor active, and Input #1 Left Stowage Sensor active then Output #1 (default) Right Gripper Closed

If Input #3 Forward Left Stack Sensor active, Input #4 Forward Right Stack Sensor inactive, and Input #2 Right Stowage Sensor active then Output #10 (default) Left Gripper Closed

If Input #3 Forward Left Stack Sensor active, Input #4 Forward Right Stack Sensor inactive, and Input #1 Left Stowage Sensor active then Output #10 (default) Left Gripper Closed and Output #4 Right Gripper Up/ Left Gripper Down

If Input #3 Forward Left Stack Sensor active, Input #4 Forward Right Stack Sensor active, and Input #1 Left Stowage Sensor active then Output #1 (default) Right Gripper Closed

If Input #3 Forward Left Stack Sensor active, Input #4 Forward Right Stack Sensor active, and Input #2 Right Stowage Sensor active then Output #10 (default) Left Gripper Closed

Position Cone Procedure:

If Input #2 Right Stowage Sensor active then Output #10 Left Gripper Open and Output #5 Left Gripper Up/ Right Gripper Down

If Input #1 Left Stowage Sensor active then Output #1 Right Gripper Open and Output #4 Right Gripper Up/ Left Gripper Down

Drop-off Procedure:

Activate every 50 feet

If Input #2 Right Stowage Sensor active then Output #1 (default) Right Gripper Closed

If Input #1 Left Stowage Sensor active then Output #10 (default) Left Gripper Closed

9. Left Side Placement Series w/ 100 Foot Spacing

Deployment Procedure:

Output #16 Left Box Down stop when Input #8 Left Down Limit Switch active

Output #6 Left Arm Upward

Output #3 Lateral Conveyor On Right to Left

Output #13 Middle Gate Open

Set Counter Activate Every 100 feet

Prestack Ready (Placement) Procedure:

If Input #3 Forward Left Stack Sensor inactive and Input #4 Forward Right Stack Sensor inactive then Output #14 Advance Stack Forward and stop when Input #3 Forward Left Stack Sensor active or Input #4 Forward Right Stack Sensor active

Stack Ready (Placement) Procedure:

If Input #3 Forward Left Stack Sensor inactive, Input #4 Forward Right Stack Sensor active, and Input #2 Right Stowage Sensor active then Output #1 (default) Right Gripper Closed and Output #5 Left Gripper Up/ Right Gripper Closed

If Input #3 Forward Left Stack Sensor inactive, Input #4 Forward Right Stack Sensor active, and Input #1 Left Stowage Sensor active then Output #1 (default) Right Gripper Closed

If Input #4 Forward Right Stack Sensor inactive, Input #3 Forward Left Stack Sensor active, and Input #2 Right Stowage Sensor active then Output #10 (default) Left Gripper Closed

If Input #3 Forward Left Stack Sensor active, Input #4 Forward Right Stack Sensor inactive, and Input #1 Left Stowage Sensor active then Output #10 (default) Left Gripper Closed and Output #4 Right Gripper Up/ Left Gripper Down

If Input #3 Forward Left Stack Sensor active, Input #4 Forward Right Stack Sensor active, and Input #1 Left Stowage Sensor active then Output #1 (default) Right Gripper Closed

If Input #3 Forward Left Stack Sensor active, Input #4 Forward Right Stack Sensor active, and Input #2 Right Stowage Sensor active then Output #10 (default) Left Gripper Closed

Position Cone Procedure:

If Input #2 Right Stowage Sensor active then Output #10 Left Gripper Open and Output #5 Left Gripper Up/ Right Gripper Down

If Input #1 Left Stowage Sensor active then Output #1 Right Gripper Open and Output #4 Right Gripper Up/ Left Gripper Down

Drop-off Procedure:

Activate every 100 feet

If Input #2 Right Stowage Sensor active then Output #1 (default) Right Gripper Closed

If Input #1 Left Stowage Sensor active then Output #10 (default) Left Gripper Closed

10. Right Side Placement Series w/ 25 Foot Spacing

Deployment Procedure:

Output #18 Right Box Down stop when Input #8 Right Down Limit Switch active

Output #8 Right Arm Upward

Output #2 Lateral Conveyor On Left to Right

Output #13 Middle Gate Open

Set Counter Activate Every 25 feet

Prestack Ready (Placement) Procedure:

If Input #3 Forward Left Stack Sensor inactive and Input #4 Forward Right Stack Sensor inactive then Output #14 Advance Stack Forward and stop when Input #3 Forward Left Stack Sensor active or Input #4 Forward Right Stack Sensor active

Stack Ready (Placement) Procedure:

If Input #3 Forward Left Stack Sensor inactive, Input #4 Forward Right Stack Sensor active, and Input #2 Right Stowage Sensor active then Output #1 (default) Right Gripper Closed and Output #5 Left Gripper Up/ Right Gripper Closed

If Input #3 Forward Left Stack Sensor inactive, Input #4 Forward Right Stack Sensor active, and Input #1 Left Stowage Sensor active then Output #1 (default) Right Gripper Closed

If Input #4 Forward Right Stack Sensor inactive, Input #3 Forward Left Stack Sensor active, and Input #2 Right Stowage Sensor active then Output #10 (default) Left Gripper Closed

If Input #3 Forward Left Stack Sensor active, Input #4 Forward Right Stack Sensor inactive, and Input #1 Left Stowage Sensor active then Output #10 (default) Left Gripper Closed and Output #4 Right Gripper Up/ Left Gripper Down

If Input #3 Forward Left Stack Sensor active, Input #4 Forward Right Stack Sensor active, and Input #1 Left Stowage Sensor active then Output #1 (default) Right Gripper Closed

If Input #3 Forward Left Stack Sensor active, Input #4 Forward Right Stack Sensor active, and Input #2 Right Stowage Sensor active then Output #10 (default) Left Gripper Closed

Position Cone Procedure:

If Input #2 Right Stowage Sensor active then Output #10 Left Gripper Open and Output #5 Left Gripper Up/ Right Gripper Down

If Input #1 Left Stowage Sensor active then Output #1 Right Gripper Open and Output #4 Right Gripper Up/ Left Gripper Down

Drop-off Procedure:

Activate every 25 feet

If Input #2 Right Stowage Sensor active then Output #1 (default) Right Gripper Closed

If Input #1 Left Stowage Sensor active then Output #10 (default) Left Gripper Closed

11. Right Side Placement Series w/ 50 Foot Spacing

Deployment Procedure:

Output #18 Right Box Down stop when Input #8 Right Down Limit Switch active

Output #8 Right Arm Upward

Output #2 Lateral Conveyor On Left to Right

Output #13 Middle Gate Open

Set Counter Activate Every 50 feet

Prestack Ready (Placement) Procedure:

If Input #3 Forward Left Stack Sensor inactive and Input #4 Forward Right Stack Sensor inactive then Output #14 Advance Stack Forward and stop when Input #3 Forward Left Stack Sensor active or Input #4 Forward Right Stack Sensor active

Stack Ready (Placement) Procedure:

If Input #3 Forward Left Stack Sensor inactive, Input #4 Forward Right Stack Sensor active, and Input #2 Right Stowage Sensor active then Output #1 (default) Right Gripper Closed and Output #5 Left Gripper Up/ Right Gripper Closed

If Input #3 Forward Left Stack Sensor inactive, Input #4 Forward Right Stack Sensor active, and Input #1 Left Stowage Sensor active then Output #1 (default) Right Gripper Closed

If Input #4 Forward Right Stack Sensor inactive, Input #3 Forward Left Stack Sensor active, and Input #2 Right Stowage Sensor active then Output #10 (default) Left Gripper Closed

If Input #3 Forward Left Stack Sensor active, Input #4 Forward Right Stack Sensor inactive, and Input #1 Left Stowage Sensor active then Output #10 (default) Left Gripper Closed and Output #4 Right Gripper Up/ Left Gripper Down

If Input #3 Forward Left Stack Sensor active, Input #4 Forward Right Stack Sensor active, and Input #1 Left Stowage Sensor active then Output #1 (default) Right Gripper Closed

If Input #3 Forward Left Stack Sensor active, Input #4 Forward Right Stack Sensor active, and Input #2 Right Stowage Sensor active then Output #10 (default) Left Gripper Closed

Position Cone Procedure:

If Input #2 Right Stowage Sensor active then Output #10 Left Gripper Open and Output #4 Left Gripper Up/ Right Gripper Down

If Input #1 Left Stowage Sensor active then Output #1 Right Gripper Open and Output #5 Right Gripper Up/ Left Gripper Down

Drop-off Procedure:

Activate every 50 feet

If Input #2 Right Stowage Sensor active then Output #1 (default) Right Gripper Closed

If Input #1 Left Stowage Sensor active then Output #10 (default) Left Gripper Closed

12. Right Side Placement Series w/ 100 Foot Spacing

Deployment Procedure:

Output #18 Right Box Down stop when Input #8 Right Down Limit Switch active

Output #8 Right Arm Upward

Output #2 Lateral Conveyor On Left to Right

Output #13 Middle Gate Open

Set Counter Activate Every 100 feet

Prestack Ready (Placement) Procedure:

If Input #3 Forward Left Stack Sensor inactive and Input #4 Forward Right Stack Sensor inactive then Output #14 Advance Stack Forward and stop when Input #3 Forward Left Stack Sensor active or Input #4 Forward Right Stack Sensor active

Stack Ready (Placement) Procedure:

If Input #3 Forward Left Stack Sensor inactive, Input #4 Forward Right Stack Sensor active, and Input #2 Right Stowage Sensor active then Output #1 (default) Right Gripper Closed and Output #5 Left Gripper Up/ Right Gripper Closed

If Input #3 Forward Left Stack Sensor inactive, Input #4 Forward Right Stack Sensor active, and Input #1 Left Stowage Sensor active then Output #1 (default) Right Gripper Closed

If Input #4 Forward Right Stack Sensor inactive, Input #3 Forward Left Stack Sensor active, and Input #2 Right Stowage Sensor active then Output #10 (default) Left Gripper Closed

If Input #3 Forward Left Stack Sensor active, Input #4 Forward Right Stack Sensor inactive, and Input #1 Left Stowage Sensor active then Output #10 (default) Left Gripper Closed and Output #4 Right Gripper Up/ Left Gripper Down

If Input #3 Forward Left Stack Sensor active, Input #4 Forward Right Stack Sensor active, and Input #1 Left Stowage Sensor active then Output #1 (default) Right Gripper Closed

If Input #3 Forward Left Stack Sensor active, Input #4 Forward Right Stack Sensor active, and Input #2 Right Stowage Sensor active then Output #10 (default) Left Gripper Closed

Position Cone Procedure:

If Input #2 Right Stowage Sensor active then Output #10 Left Gripper Open and Output #5 Left Gripper Up/ Right Gripper Down

If Input #1 Left Stowage Sensor active then Output #1 Right Gripper Open and Output #4 Right Gripper Up/ Left Gripper Down

Drop-off Procedure:

Activate every 100 feet

If Input #2 Right Stowage Sensor active then Output #1 (default) Right Gripper Closed

If Input #1 Left Stowage Sensor active then Output #10 (default) Left Gripper Closed

13. Stow

If Input # Left Arm Down Switch is active then

If Input # Left Arm Down Switch is active then Output #6 Left Arm Upward and stop when Input #15 Left Arm Stow Switch is active

If Input # Left Arm Up Switch is active then Output #7 Left Arm Downward and stop when Input #15 Left Arm Stow Switch is active

Output #17 Left Box Up

Output #12 (default) Tip Bars Retracted

If Input # Right Arm Down Switch is active then

If Input # Right Arm Down Switch is active then Output #8 Right Arm Upward and stop when Input #16 Right Arm Stow Switch is active

If Input # Right Arm Up Switch is active then Output #9 Right Arm Downward and stop when Input #16 Right Arm Stow Switch is active

Output #19 Right Box Up

Output #12 (default) Tip Bars Retracted

APPENDIX E SECOND PHASE PSEUDO CODE

```

main
{
do while power is on
    read driver input a
    read driver input b
    read driver input c
    if driver input a = leftside then goto function leftside (send driver input b and driver
    inputc)
    if driver input a = rightside then goto function rightside (send driver
    input b and driver input c)
}

```

```

function leftside (driver input a, driver input b)
{

```

```

    if driver input b = dropoff then
        case if driver input c = 25 then goto function leftdrop (send dist=25)
        case if driver input c = 50 then goto function leftdrop (send dist=50)
        case if driver input c = 100 then goto function leftdrop (send dist=100)
        case if driver input c=single then goto function leftsingledrop
    if driver input b = pickup then
        function deployleftpickup
        function prestack store
        function stack store
        case if driver input c = standing/base first then goto function
        stand/basefirst
        case if driver input c = tip first then goto function tipfirst
    while stow=off do
        read left arm switch #1
        read left arm switch #2
        if left arm switch #1=on and left arm switch #2=on then
            move left arm upward
            while left platform switch=off do
                read left platform switch
            move left arm downward
        function left stowage
}

```

```

function rightside (driver input a, driver input b)
{

```

```

    if driver input b = dropoff then
        case if driver input c = 25 then goto function rightdrop (send dist=25)
        case if driver input c = 50 then goto function rightdrop (send dist=50)
        case if driver input c = 100 then goto function rightdrop (send dist=100)
}

```

```

        case if driver input c=single then goto function rightsingledrop
if driver input b = pickup then
    function deployrightpickup
    function prestack store
    function stack store
    case if driver input c = standing/base first then goto function
stand/basefirst
    case if driver input c = tip first then goto function tipfirst
    while stow=off do
        read right arm switch #1
        read right arm switch #2
        if right arm switch #1=on and right arm switch #2 then
            move right arm upward
            while right platform switch=off do
                read right platform switch
                move right arm downward
            function right stowage
    }

function deploy left pickup
{
    while left down limit switch = off do
        deploy left box
    while left arm down switch = off do
        left arm down
    deploy left tip bars
    lateral conveyor on left to right
    return
}

function deploy right pickup
{
    while right down limit switch = off do
        deploy right box
    while right arm down switch = off do
        right arm down
    deploy right tip bars
    lateral conveyor on right to left
    return
}

function tipfirst
{

```

```

        funnel gate rigid
        return
    }

function stand/basefirst
{
    funnel gate free
    return
}

function prestack store
{
    read backward left stack sensor
    read backward right stack sensor
    while (backward left stack sensor=on and backward right stack sensor=on) do
        advance stack backward
    }

function stack store
{
    read backward left stack sensor
    read backward right stack sensor
    read right stowage sensor
    read left stowage sensor
    case backward left stack sensor=off and backward right stack
    sensor=on
        function close left gripper
        function close middle gate
        if right stowage sensor =on then
            function left gripper up/ right gripper down
        case backward right stack sensor=off and backward left stack
        sensor=on
            function close right gripper
            function open middle gate
            if left stowage sensor=on then
                function right gripper up/ left gripper down
        case backward left stack sensor=off and backward right stack
        sensor=off
            if left stowage sensor=on then
                function close left gripper
                function close middle gate
            else
                function close right gripper

```



```

        function open middle gate
    return
}

function left stowage
{
    do while
        read middle gate left side switch #1
        read middle gate left side switch #2
        read right gate switch #1
        read right gate switch #2
        if middle gate left side switch #1=on and middle gate left side
switch #2=on
            function open left gripper
            function right gripper up/ left gripper down
            function close left gripper
        if right gate switch #1=on and right gate switch #2=on
            function open right gripper
            function left gripper up/ right gripper down
            function close right gripper
    }

function right stowage
{
    do while
        read middle gate right side switch #1
        read middle gate right side switch #2
        read left gate switch #1
        read left gate switch #2
        if middle gate right side switch #1=on and middle right side gate
switch #2=on
            function open right gripper
            function left gripper up/ right gripper down
            function close right gripper
        if left gate switch #1=on and left gate switch #2=on
            function open left gripper
            function right gripper up/ left gripper down
            function close left gripper
    }

function leftsingledrop
{
    function deployleftdrop

```

```

        function prestack drop
        function stack drop
        function dropoff
    }

function rightsingledrop
{
    function deployrightdrop
    function prestackdrop
    function stack drop
    function dropoff
}

function deployleftdrop
{
    while left down limit switch=off do
        deploy left box
    while left up switch =off do
        left arm up
    lateral conveyor on right to left
    function open middle gate
}

function deployrightdrop
{
    while right down limit switch=off do
        deploy right box
    while right up switch =off do
        right arm up
    lateral conveyor on left to right
}

function prestack drop
{
    read forward left stack sensor
    read forward right stack sensor
    while (forward left stack sensor=off and forward right stack sensor=off) do
        advance stack forward
}

function stack drop
{
    read forward left stack sensor

```

```

read forward right stack sensor
read right stowage sensor
read left stowage sensor
case forward left stack sensor=off and forward right stack sensor=on
    function close right gripper
    if right stowage sensor=on then
        function left gripper up/ right gripper down
case forward right stack sensor=off and forward left stack sensor=on
    function close left gripper
    if left stowage sensor=on then
        function right gripper up/ left gripper down
case forward left stack sensor=on and forward right stack sensor=on
    if left stowage sensor=on then
        function close right gripper
    else
        function close left gripper
}

```

```

function dropoff
{
    read right stowage sensor
    read left stowage sensor
    if right stowage sensor=on
        function open left gripper
        function left gripper up/ right gripper down
    if left stowage sensor=on
        function open right gripper
        function right gripper up/ left gripper down
    while do
        read driver input d
        if driver input d=stow then
            function stow
        if driver input d= drop then
            if right stowage sensor=on then
                function close left gripper
            else
                function close right gripper
}

```

```

function left drop (dist)
{
    function deployleftdrop
    function prestackdrop
}

```

```

    function stackdrop
    function distcounter (dist)
}

function right drop (dist)
{
    function deployrightdrop
    function prestackdrop
    function stackdrop
    function discountner (dist)
}

function distcounter (dist)
{
    while do
        read distance
        if remainder of distance/dist = 0 then
            read right stowage sensor
            read left stowage sensor
            if right stowage sensor=on
                function open left gripper
                function left gripper up/ right gripper down
                function close left gripper
            if left stowage sensor=on
                function open right gripper
                function right gripper up/ left gripper down
                function close right gripper
        }

function open left gripper
{
    hydraulics open left gripper
}

function open right gripper
{
    hydraulics open right gripper
}

function close left gripper
{
    hydraulics close left gripper
}

```

```
function close right gripper
{
    hydraulics close right gripper
}
```