

Development of Stowage and Control Systems for an  
Automated Traffic Cone Placement and Retrieval Machine

BY

PETER KUANJEN TSENG

B.S. (University of California, Davis) 1994.

THESIS

Submitted in partial satisfaction of the requirements for the degree of

Master of Science

in

Engineering

in the

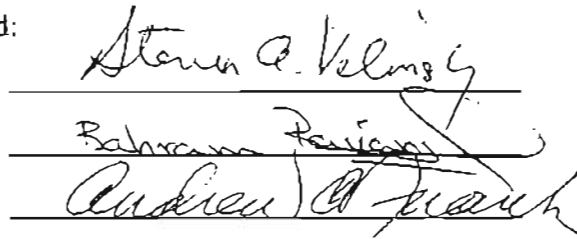
OFFICE OF GRADUATE STUDIES

of the

UNIVERSITY OF CALIFORNIA

DAVIS

Approved:



Committee in Charge

1996

## Acknowledgments

I would like to thank Professor Steve Velinsky at the University of California at Davis for giving me the opportunity to work on this project. His guidance and abundant assistance were invaluable.

I would like to give special thanks to Wil White for his helpful insights and for sharing his expertise. Our long discussions about engineering and life in general will never be forgotten.

I would also like to thank Professors Bahram Ravani and Andrew Frank for their time and consideration. Without their assistance and helpful recommendations, none of this would be possible.

I especially want to thank my parents, Chien and Ying, for their strong support and my brother, Steve, for always giving me a place to rest and relax.

## Table of Contents

ACKNOWLEDGMENTS	ii
LIST OF FIGURES	v
LIST OF TABLES	vii
ABSTRACT OF THESIS	viii
<b>CHAPTER 1 INTRODUCTION</b>	<b>1</b>
1.1 Literature Search	3
1.2 Caltrans Traffic Cones	7
1.3 Current Caltrans Methods	9
1.4 Evaluation of Existing Methods	15
1.5 Problem Description and Objectives	17
<b>CHAPTER 2 SPECIFICATIONS OF THE ACM</b>	<b>18</b>
2.1 Functional Specifications	18
2.2 General Descriptions of the Automated Cone Machine	21
2.3 General Descriptions of the ACM Operational Procedures	27
<b>CHAPTER 3 CONCEPTUAL DESIGN AND DEVELOPMENT OF THE AUTOMATED CONE STOWAGE SYSTEM</b>	<b>37</b>
3.1 Introduction	37
3.2 Important Criterion for the Evaluation of Concepts	37
3.3 The Automated Cone Stowage System	42
3.4 Other Trade-Off Concepts	47
3.5 Evaluation of Conceptual Designs	51
<b>CHAPTER 4 COORDINATED CONTROL UNIT</b>	<b>54</b>
4.1 General Description	54
4.2 Controller Hardware and Software	54
4.3 Development of the ACM Control Code	59

4.4 The Control Scheme	62
<b>CHAPTER 5 CONCLUSIONS AND RECOMMENDATIONS</b>	65
5.1 Conclusions	65
5.2 Recommendations	65
<b>REFERENCES</b>	68
<b>APPENDIX A DETAILED DRAWINGS</b>	69
<b>APPENDIX B FIRST PHASE PSEUDO CODE</b>	113
<b>APPENDIX C SECOND PHASE PSEUDO CODE</b>	136
<b>APPENDIX D CONTROL SCHEME FLOW CHART</b>	144

## List of Figures

Figure 1.1 Traffic Cone Retriever	4
Figure 1.2 The Baliseur Cone Picker	6
Figure 1.3 Cone Wheel Dispenser and Collector	7
Figure 1.4 Lane Closure Configuration	11
Figure 1.5 Cone Body Vehicle	12
Figure 1.6 Cone Body with Crew Workers	13
Figure 1.7 Cone Body with Crew Workers	14
Figure 2.1 The Automated Cone Machine	21
Figure 2.2 The Primary Funnel Configuration	22
Figure 2.3 The Secondary Funnel Configuration	22
Figure 2.4 The Integrated Dispensing and Retrieval Configuration	24
Figure 2.5 The Lateral Conveyor System	25
Figure 2.6 The Automated Cone Stowage System	26
Figure 2.7 Configuration A	28
Figure 2.8 Configuration B	29
Figure 2.9 Desired Orientation of Traffic Cone for Retrieval	31
Figure 2.10a Free Gate Option for Cones Between 0 and 180 Degrees	32
Figure 2.10b Free Gate Allows Cone to Pass Underneath	32
Figure 2.11 Rigid Gate Option for Cones Between 180 and 360 Degrees	33
Figure 2.12 Locked Gate Causes Traffic Cone to Straighten	34
Figure 2.13 Locked Gate Stands Traffic Cone	34
Figure 2.14 Retrieval of Standing Cones	36
Figure 3.1 Longitudinal Conveyor Assembly	38
Figure 3.2 Top View of the Available Space in the LCS	39
Figure 3.3 Top View of the Location of the Stowage System	40

Figure 3.4 Allocated Space for the Traffic Cone Stowage System	41
Figure 3.5 Top View of the Automated Cone Stowage System	43
Figure 3.6 Gripper Mechanisms on the ACSS	44
Figure 3.7 Rotational Motion Caused by the Linkage System	45
Figure 3.8 The Rotating Stowage Assembly	48
Figure 3.9 The Swivel Stowage Unit	49
Figure 3.10 The Rotating Swivel System in Retrieval Mode	51
Figure 4.1 Zworld Little Giant Miniature Controller	56
Figure 4.2 Zworld Keypad Display Module	57
Figure 4.3 Zworld Relay6 Expansion Board	58
Figure 4.4 Zworld IOE-DGL96 Expansion Board	58

## List of Tables

Table 1.1 Physical Properties of Traffic Cones	9
Table 3.1 Trade-Off Table for Conceptual Designs	53
Table 4.1 Zworld Input Designations	60
Table 4.2 Zworld Output Designations	60

Peter Tseng  
March 1996  
Engineering

Development of Stowage and Control Systems for an  
Automated Traffic Cone Placement and Retrieval Machine

ABSTRACT

This thesis discusses the conceptual design of the Automated Cone Machine (ACM) that is currently under development at the University of California, Davis. 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 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 cone stowage system and the framework of the operating control system. The stowage system is modular and plays an integral part in deploying cones and in preparing cones for storage. The design process that includes the generation of conceptual ideas and the methods for final concept selection is described in considerable detail for the cone stowage system. The control system utilizes a miniature controller to integrate and activate ACM systems in predetermined sequences to effectively perform cone handling operations. A number of preliminary codes and flow charts are used to develop and construct a flexible and logical control scheme for the operation of the ACM.



## 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.

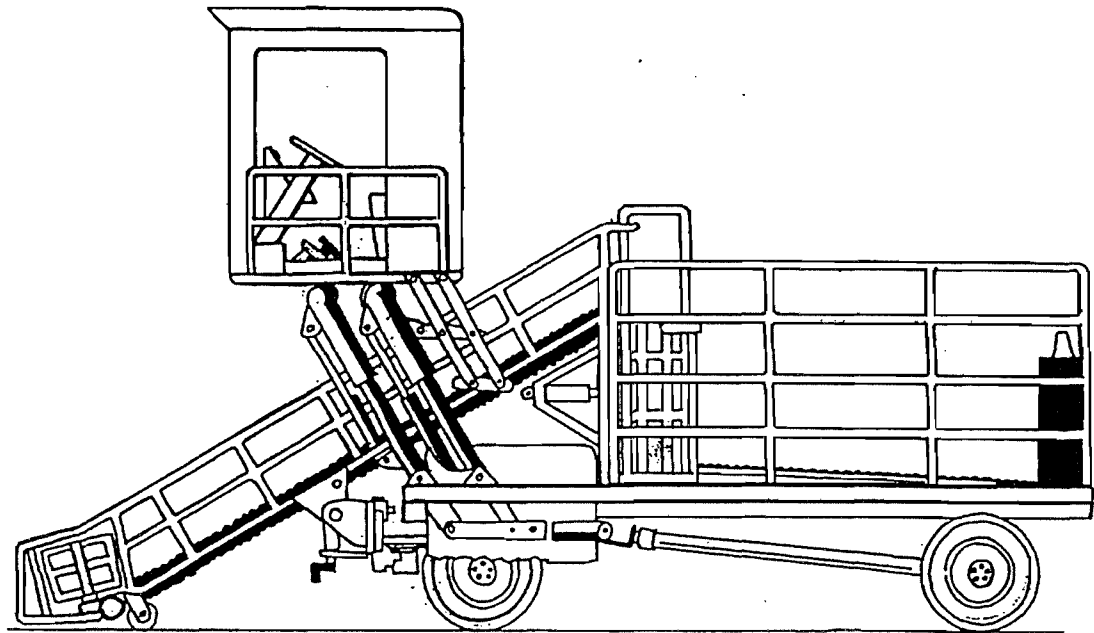
The purpose of this thesis is to develop the Automated Cone Stowage System and the Coordinated Control Unit. The ACSS must actively handle cones from the LCS and from the two stacks of stored cones located on the cone body's main conveyor. A series of sensors will locate the positions of the cones on 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



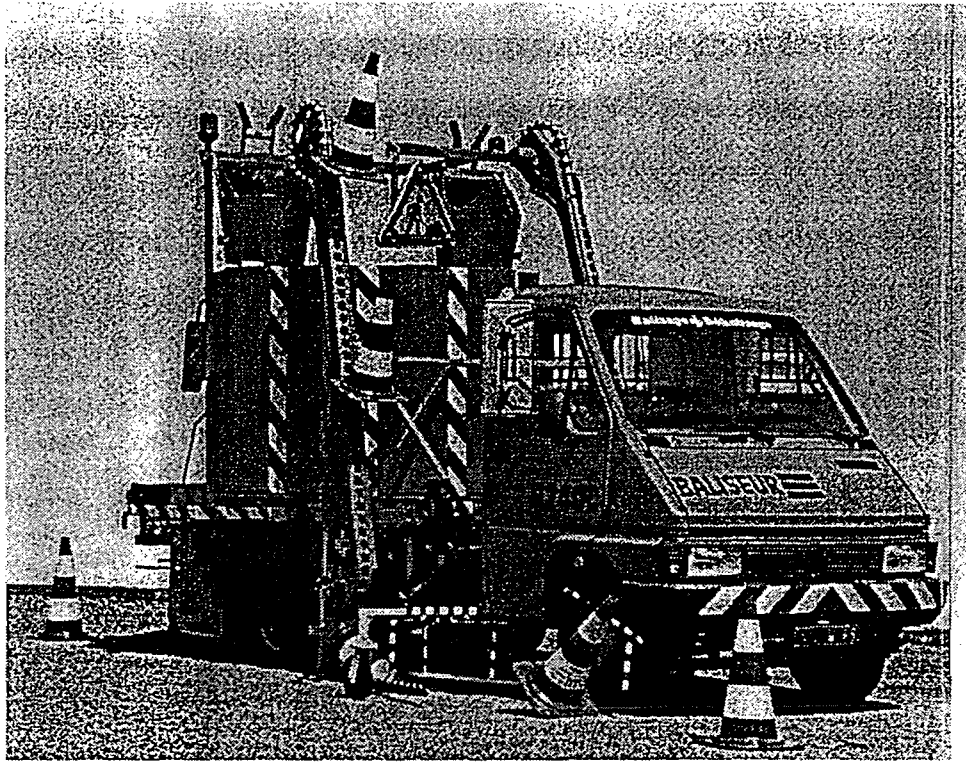
**Figure 1.1** *Traffic Cone Retriever (from Fig. 1 of patent 3750900)*

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.

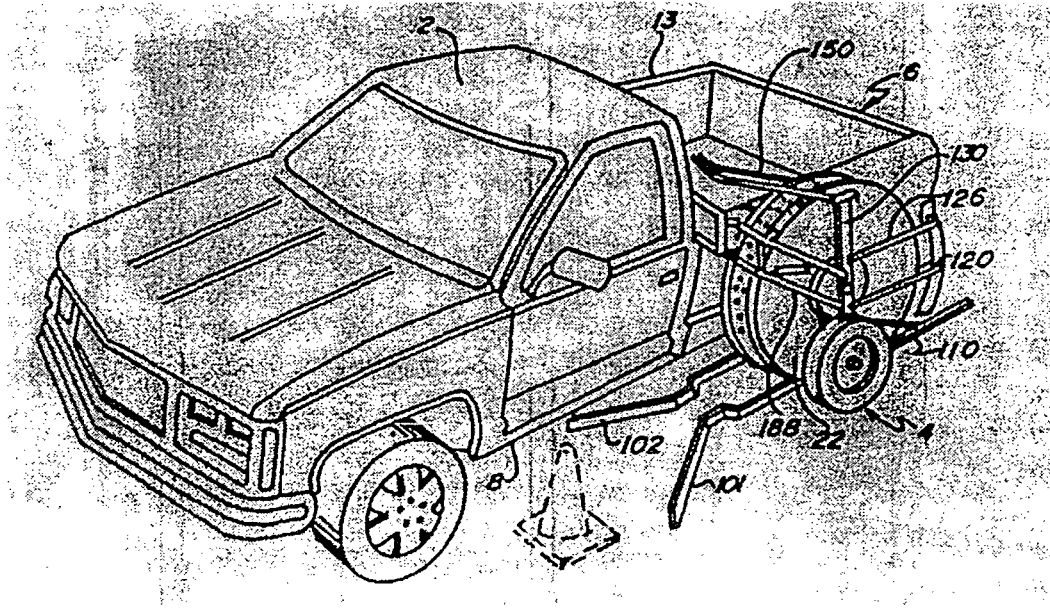
The drop-off mechanisms are located beneath the two most rearward cylinders and can access the cone located at the bottom of their respective storage stacks. Once activated, the bottom cone of one of the stacks falls to the ground where it is surrounded by directive guides. The traffic cone is held for 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 to obtain a wide selection of traffic cones and investigate their physical properties.

The traffic cones chosen by Caltrans have two distinctive parts, the conical section and the base. The thin walled conical section is colored with high visibility orange while

the significantly thicker and heavier square base section is gray. Small extensions are located on the bottom of the bases and serve to elevate the traffic cone approximately 19 mm (0.75 in) off the road surface. The cones are hollow which allow them to be stacked for easy storage and transportation.

The traffic cones are molded out of polyvinyl chloride (PVC) plastic. The behavioral properties of the PVC material change 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 serve little problems during manual operations, the consideration of these temperature dependent behaviors 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 Reflectoring 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 <sup>2</sup> (lb-in <sup>2</sup> )	Z-axis Moment of Inertia kg-m <sup>2</sup> (lb-in <sup>2</sup> )
A&B Reflectoring 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 Reflectoring 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

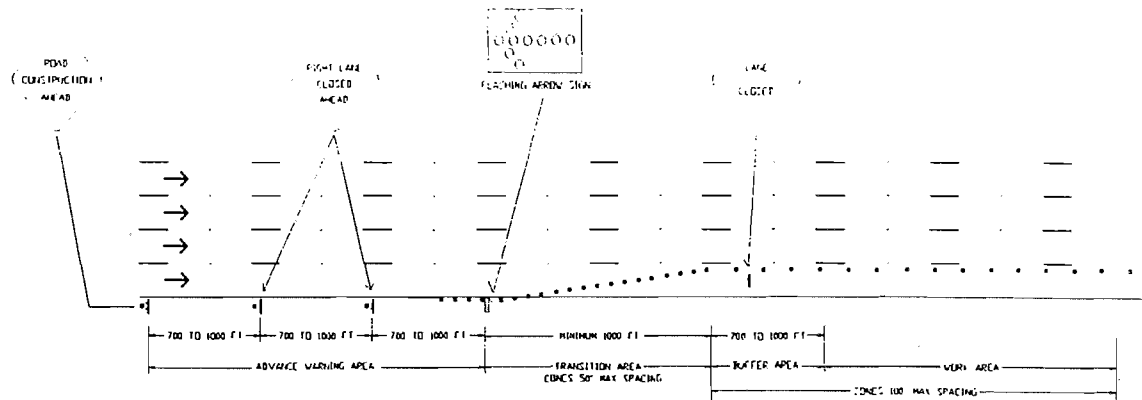
#### 1.3.1 Lane Closure Configuration

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.

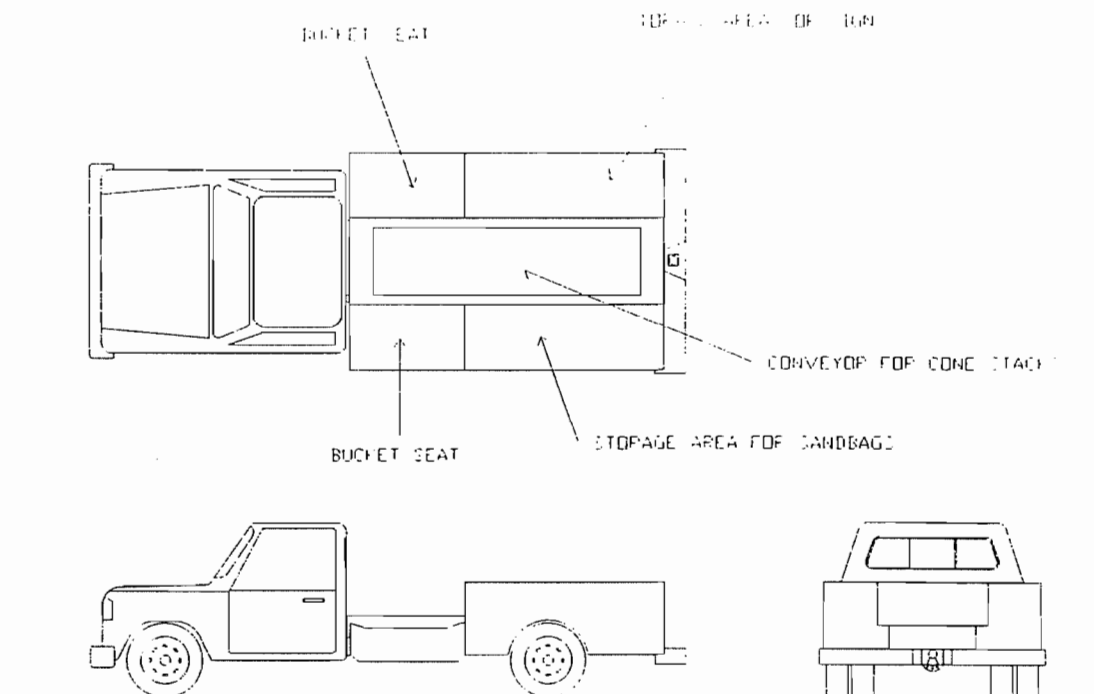
The Buffer and Work Area begins at the end of the taper and runs parallel with the highway lanes. The traffic cones are placed approximately 30 m (100 ft) apart and 0.3 to 0.6 m (1 to 2 ft) from the edge of the lane. This space prevents cones from being struck by oncoming traffic and from being toppled 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 Buufer 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 serves to drive 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.

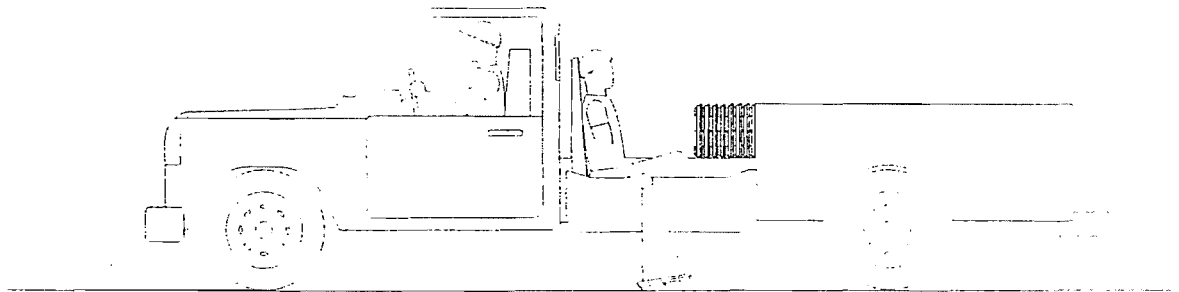


**Figure 1.5** *Cone body vehicle*

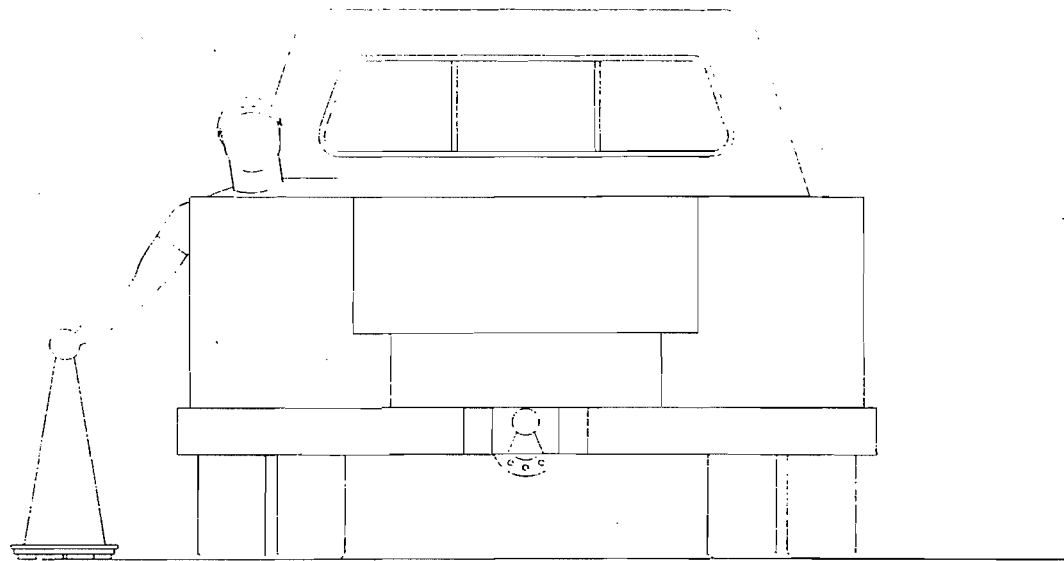
During a cone drop off operation, the cone body vehicle and the shadow vehicle are driven forward at approximately 16 km/hr (10 mph). The cone handler in the cone body's bucket seat faces backwards and accesses the stored stack of cones by using the foot activated buttons to feed the stowage conveyor 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 than 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 thesis 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  $\pm 15$  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.

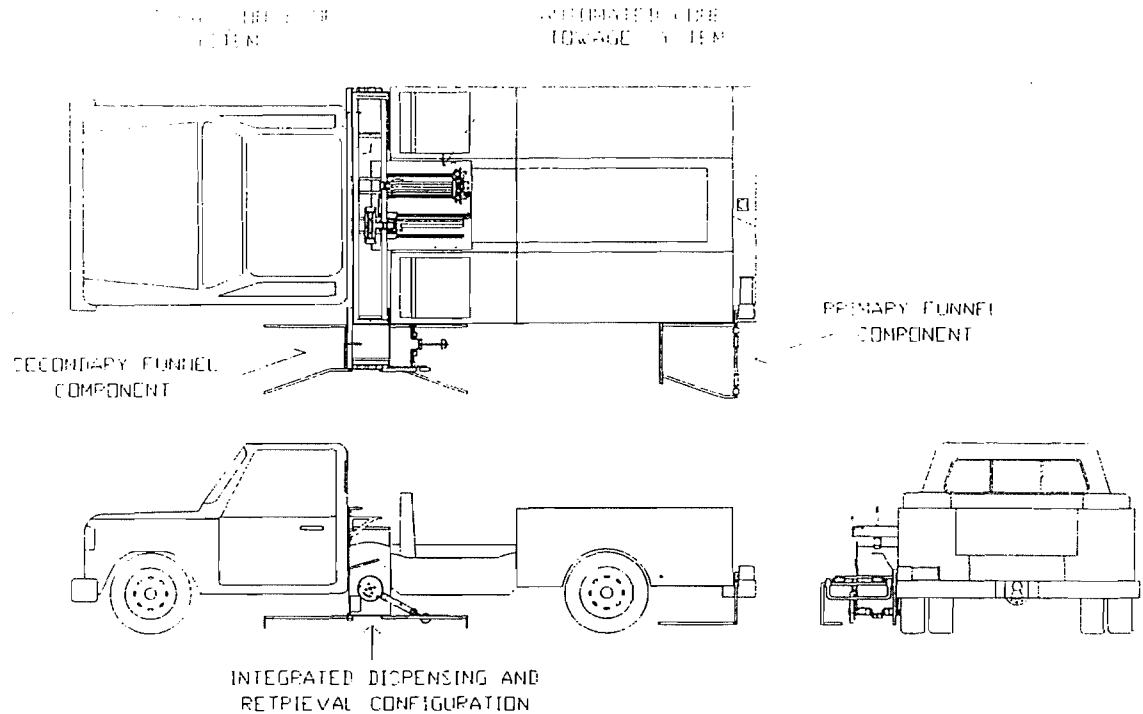
### **2.1.5 Traffic Cones**

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.



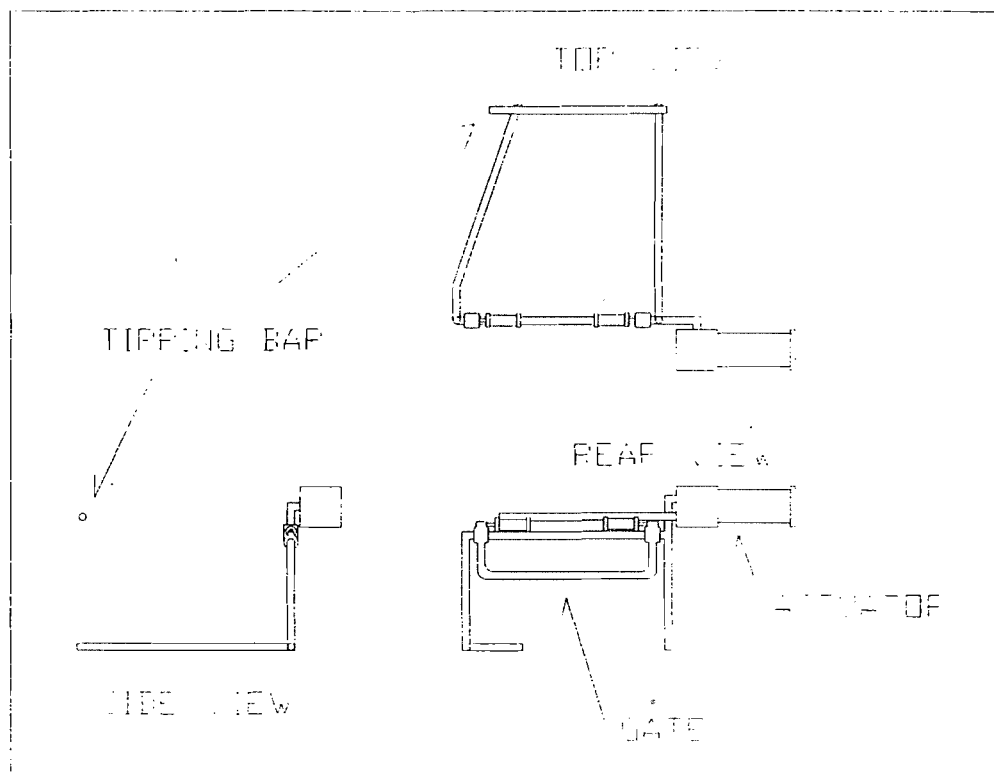
**Figure 2.1** *The Automated Cone Machine*

## 2.2 General Description of the Automated Cone Machine

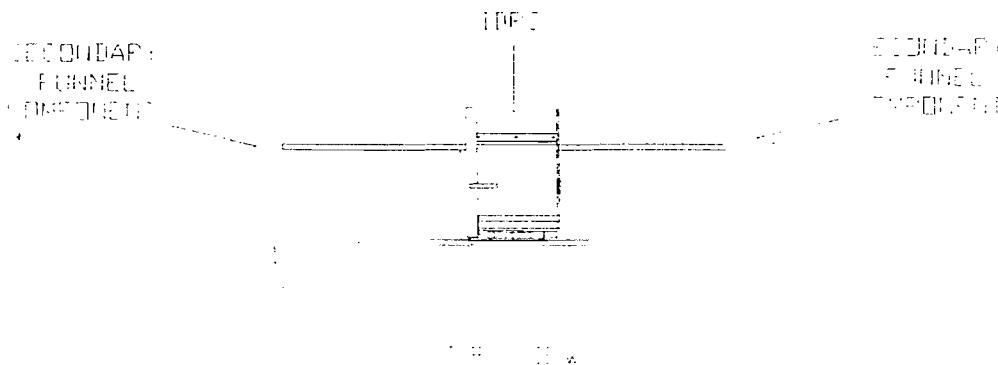
### 2.2.1 The Funnel System

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.



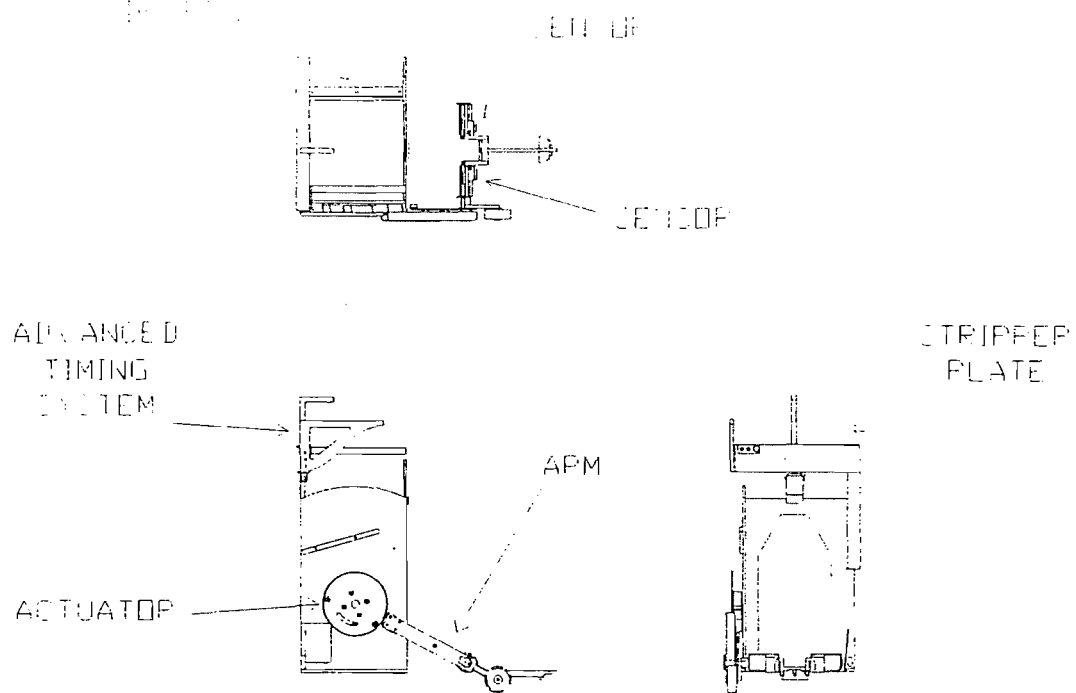
**Figure 2.2** *The Primary Funnel Component of the Funnel System*



**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*

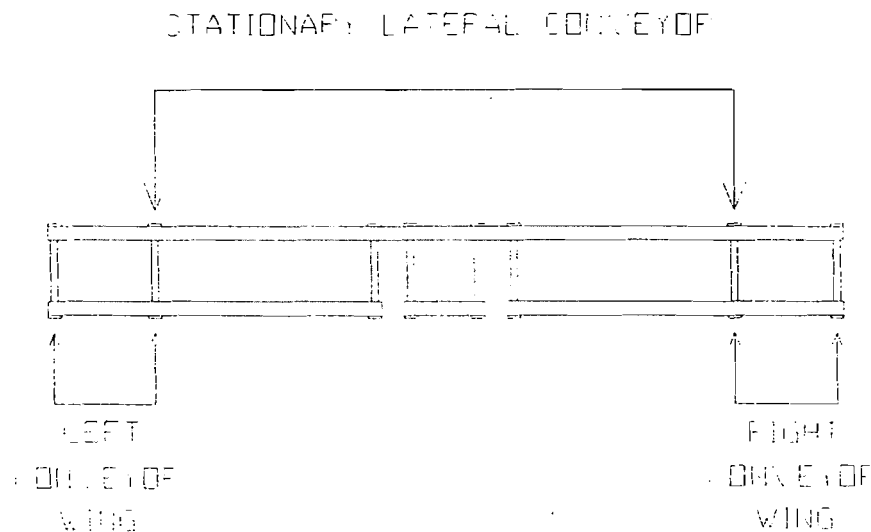
### 2.2.3 The Lateral Conveyor System

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.

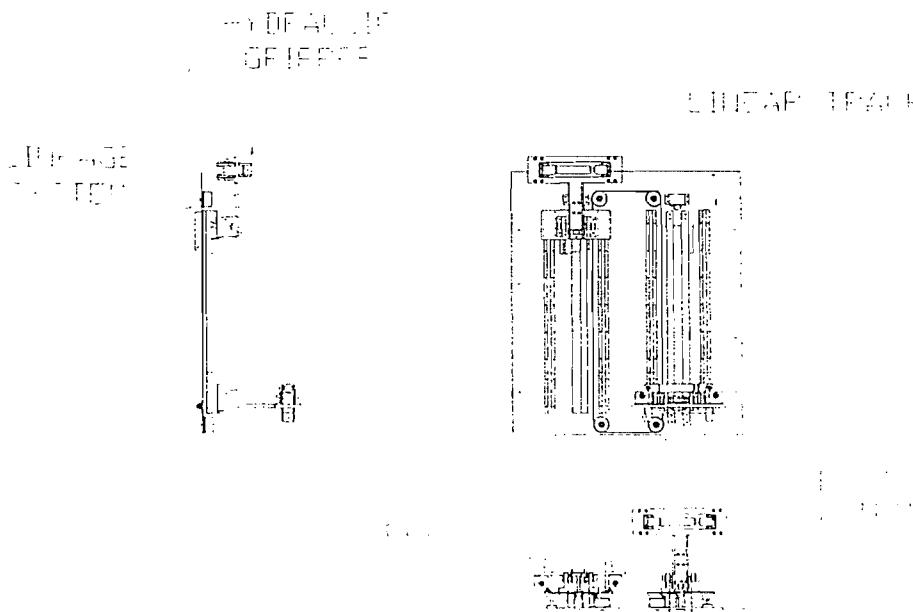


Figure 2.6 *The Automated Cone Stowage System*

### **2.2.5 The Coordinated Control Unit**

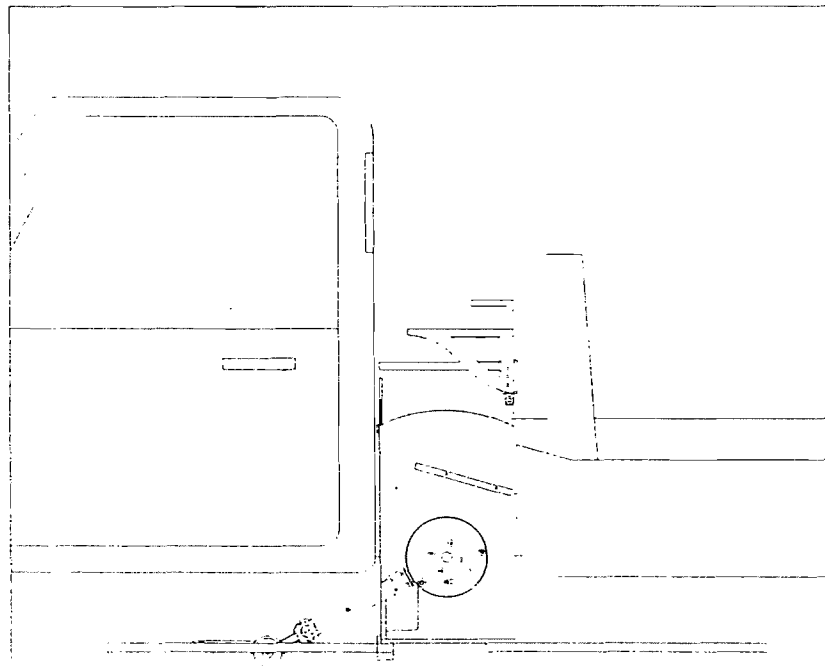
The Coordinated Control Unit (CCU) is responsible for integrating all of the described systems to efficiently manipulate traffic cones during retrieval and deployment operations. By processing the signals produced by the various sensors and switches, the CCU can locate the position of the cone and prepare 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**

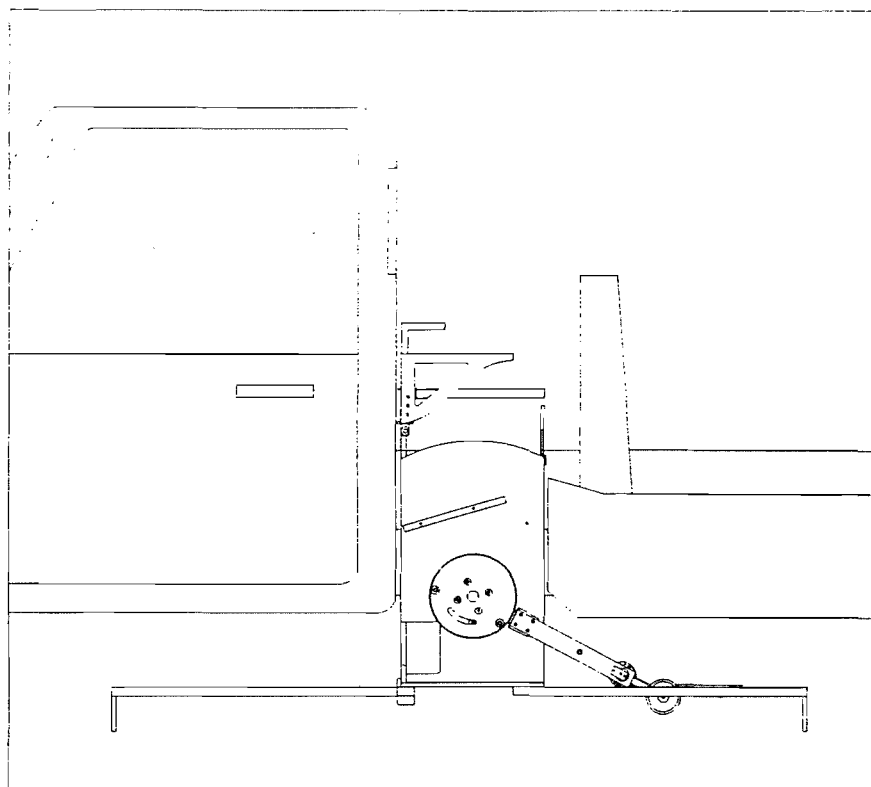
### **2.3.1 Preoperational Setup**

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.

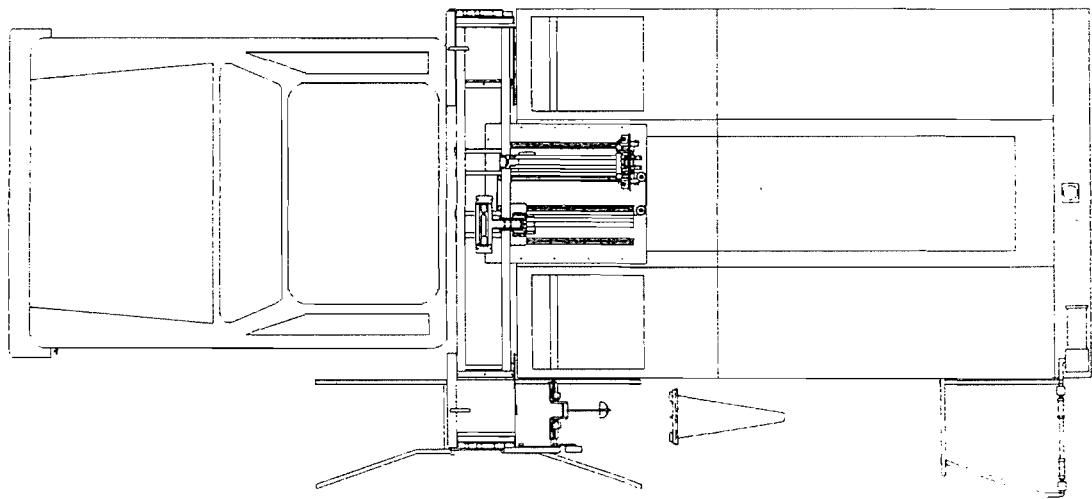
### **2.3.3 Lane Maintenance**

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

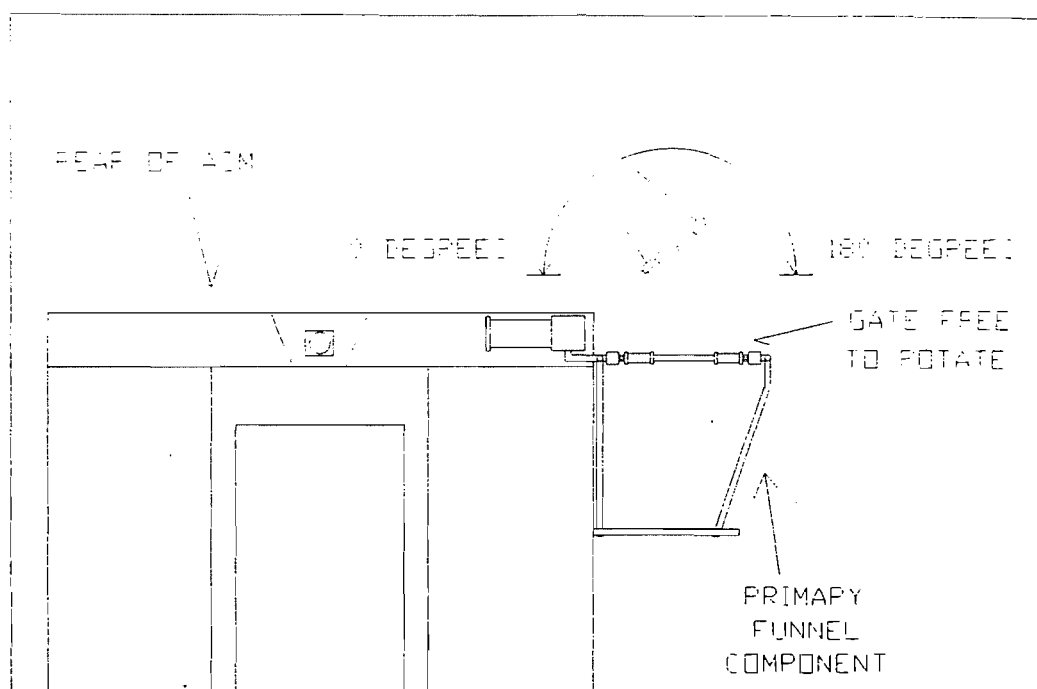
closed lane or at a site located off the highway. The driver would also deploy the IDRC and activate the LS and ACSS.

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.

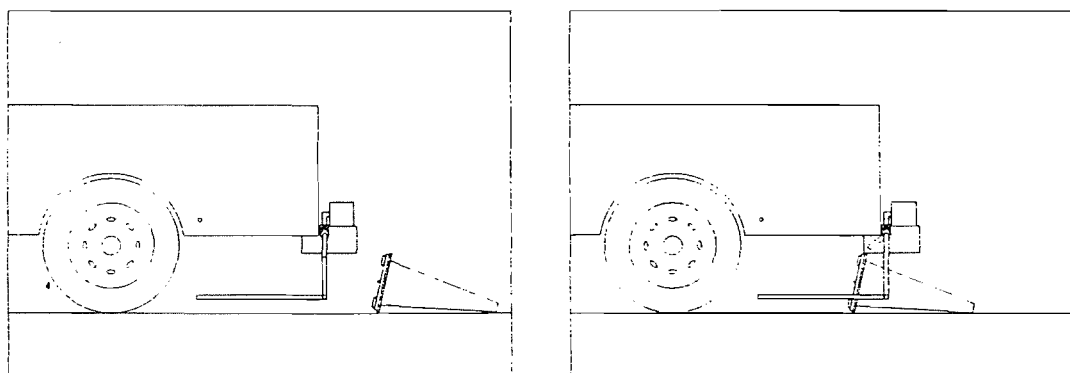
In the first case, the ACM would be maneuvered to the fallen cone and the driver must then evaluate the orientation of the traffic cone. The desired orientation for effective pick up is to have the cone facing the vehicle base first as shown in Figure 2.9. If the cone is not oriented correctly, the driver 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*

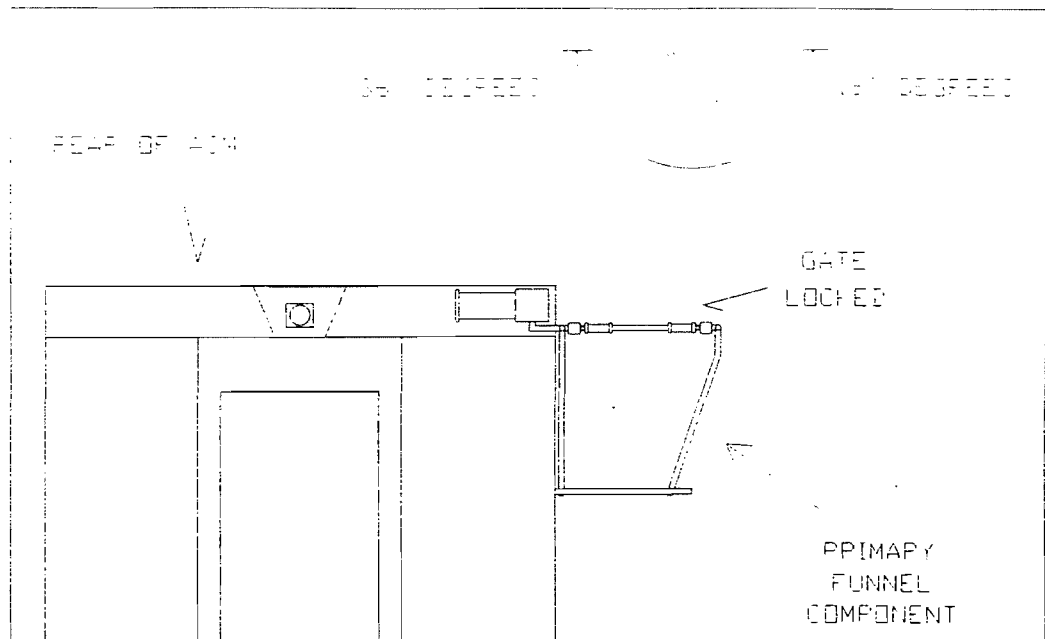


**Figure 2.10a** *Free gate option for cones situated between 0 and 180 degrees*



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

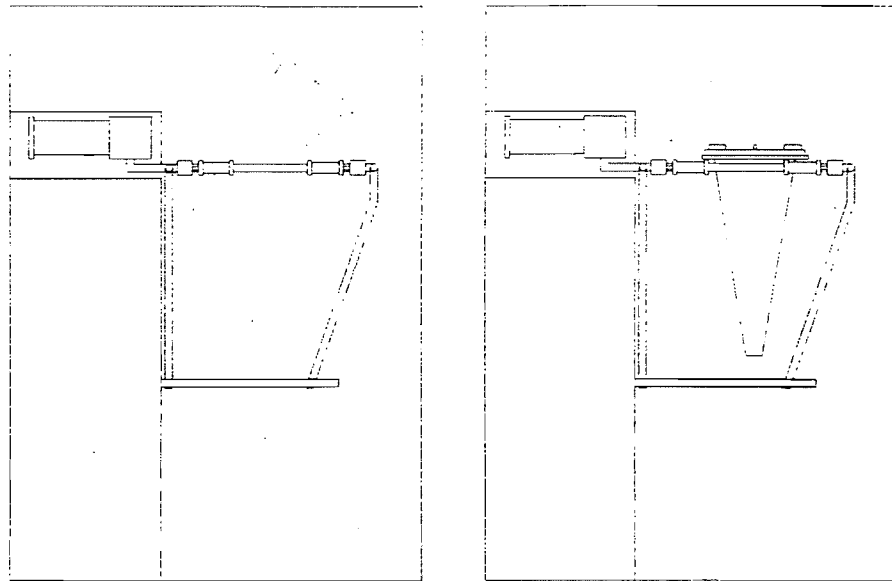




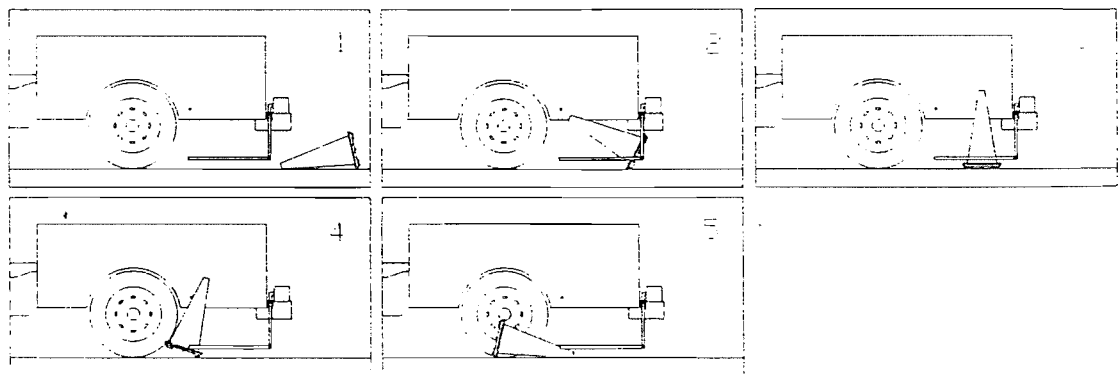
**Figure 2.11** *Rigid gate option for cones situated between 180 and 360 degrees*

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*

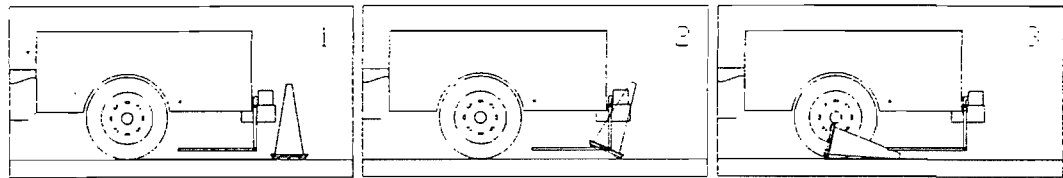
When the cone has been significantly displaced from its initial position, it is up to the driver of the ACM to evaluate the situation. If the cone has been knocked further into the lane closure, the ACM is simply driven to retrieve the fallen cone and to the site where it initially stood so that a substitute 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 CONCEPTUAL DESIGN AND DEVELOPMENT OF THE AUTOMATED CONE STOWAGE SYSTEM**

### **3.1 Introduction**

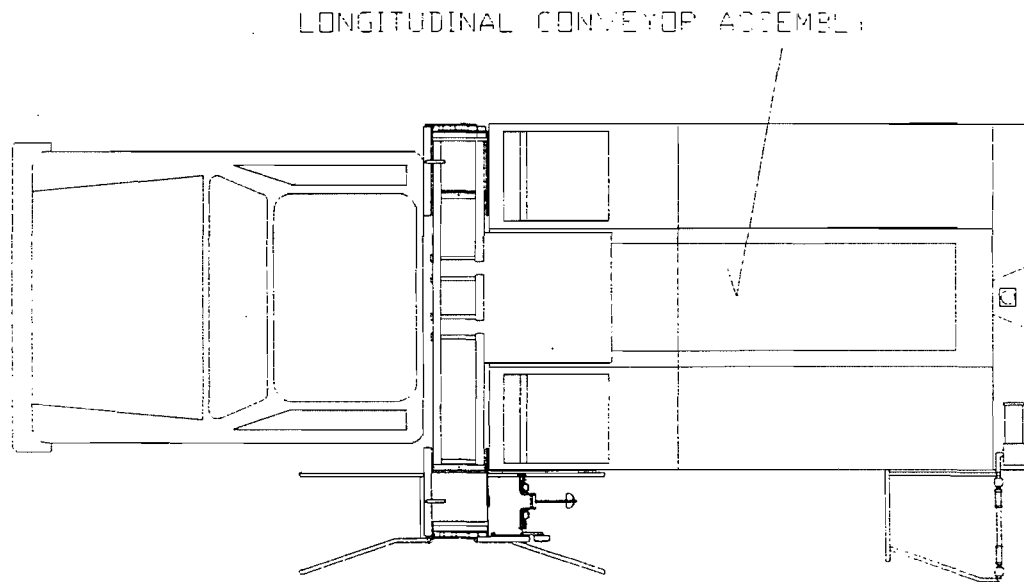
The stowage system for the Automated Cone Machine (ACM) was designed by utilizing a three step process involving brainstorming sessions, conceptual development, and evaluation of designs. Several iterations of these steps were necessary to identify all feasible methods of transporting traffic cones between 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.

### **3.2 Important Criterion for the Evaluation of Concepts**

#### **3.2.1 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 3.1, 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.

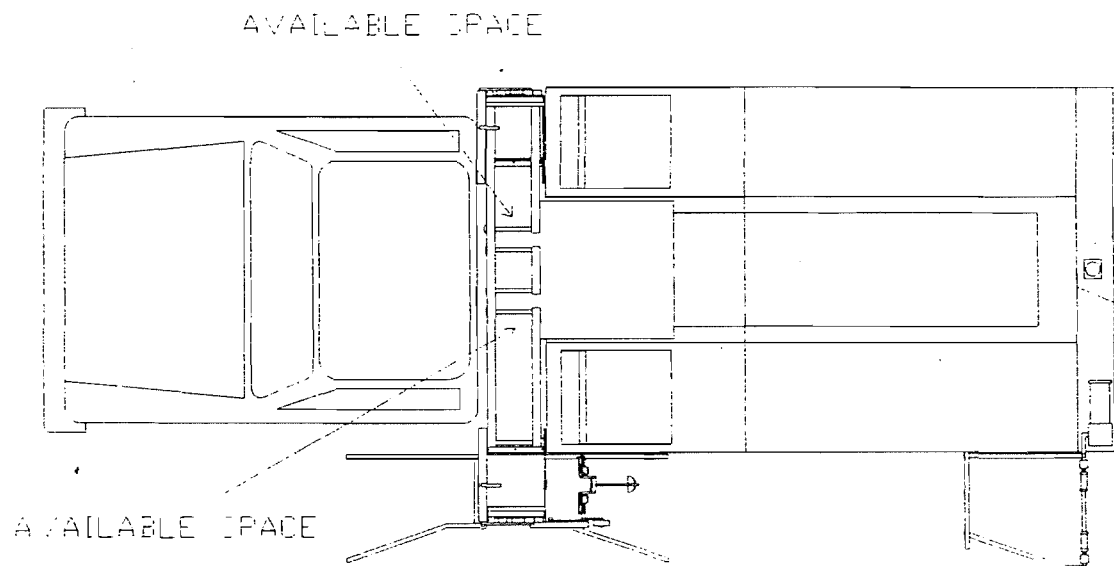


**Figure 3.1** *Longitudinal conveyor assembly*

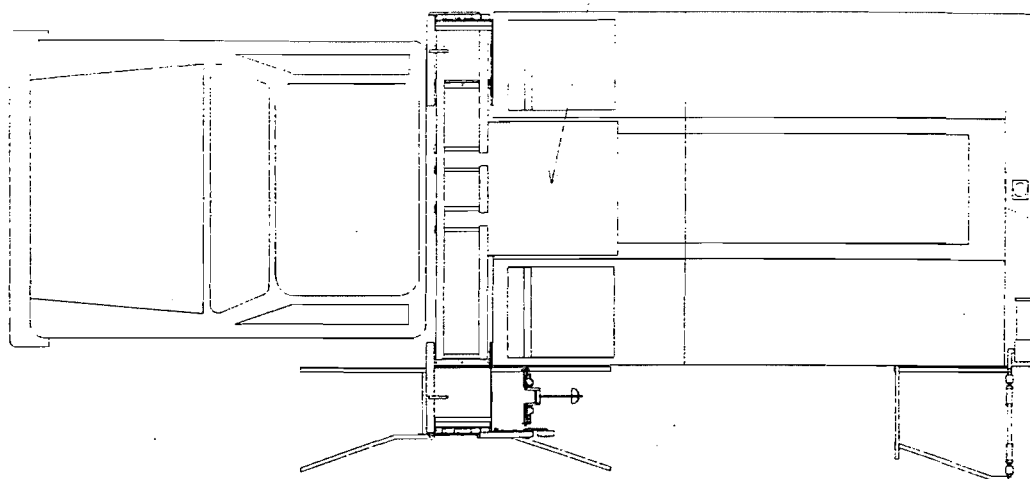
### 3.2.2 Compliance with Spatial Requirements

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 3.2. 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 3.3 shows the allowable space located in the LCS and the interface between the stowage system and the two adjoining systems.



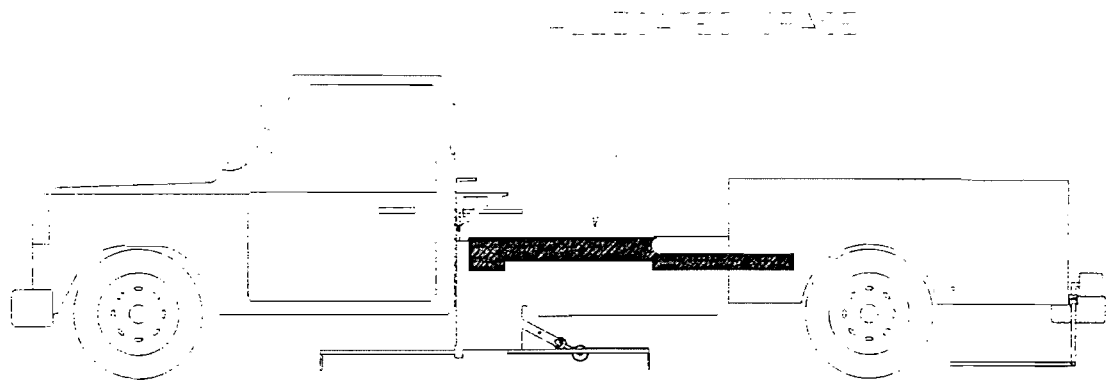
**Figure 3.2** *Top view of the available space in the LCS*



**Figure 3.3** *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 3.4 shows a side view of the location for the stowage system.





**Figure 3.4** *Side View of the allocated space for the traffic cone stowage system*

### 3.2.3 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

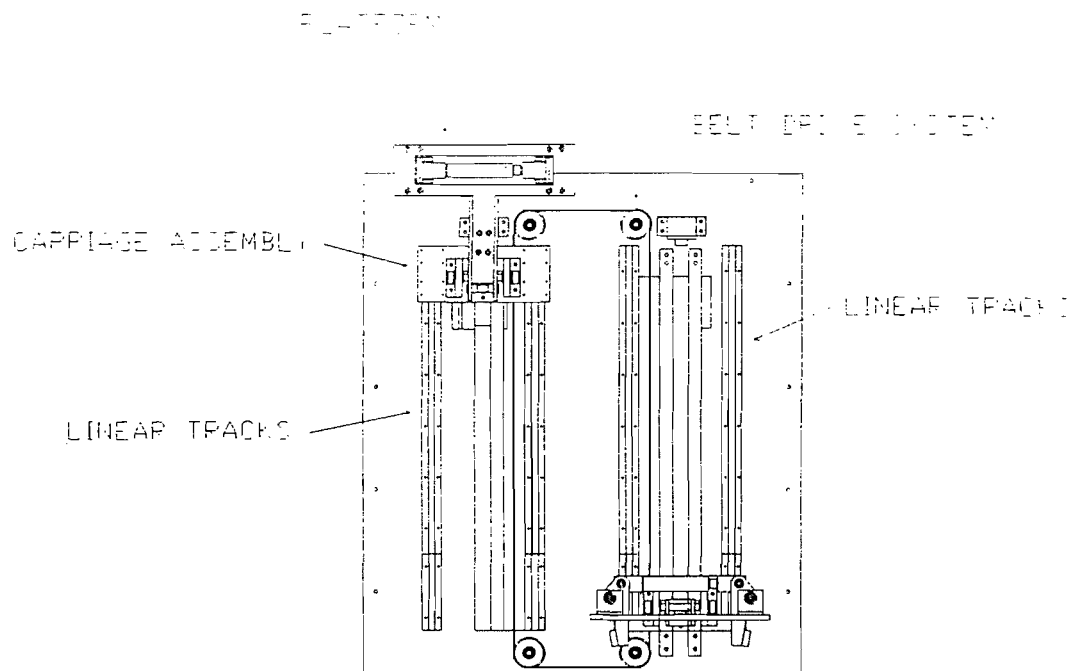
grasping the cone base would be far more reliable than gripping the conical section during stowage.

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.

### **3.3 The Automated Cone Stowage System**

#### **3.3.1 General Description**

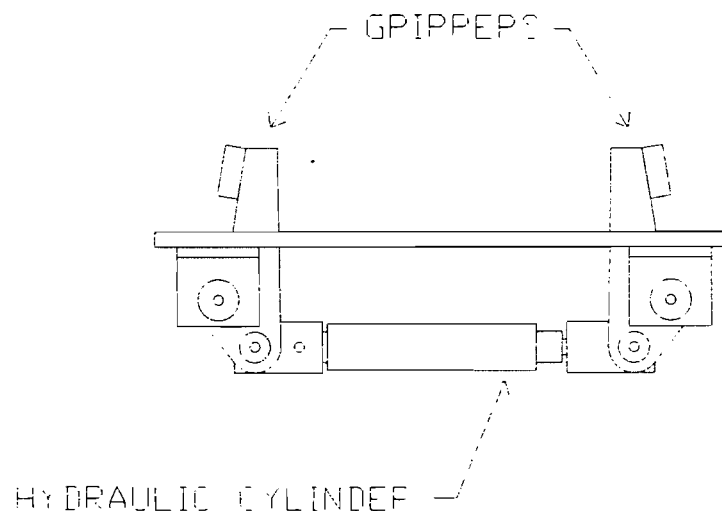
The Automated Cone Stowage System (ACSS) is a very compact design that transports traffic cones between the Lateral Conveyor System (LCS) and the longitudinal conveyor assembly while adhering to all required specifications and spatial limitations. The ACSS is also fully compatible with the moving mechanisms 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 3.5.



**Figure 3.5** *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.

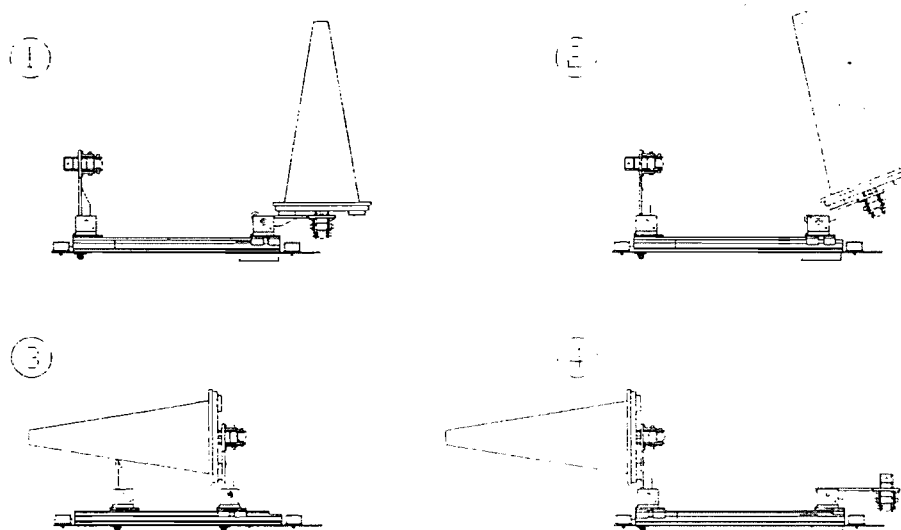
The ACSS utilizes the approach of grabbing and holding traffic cones from below the cone bases. A T-shaped platform is attached to both of the carriage assemblies and serves to extend into the adjoining systems. A small hydraulic cylinder and a pair of rotating grippers are mounted beneath each platform as shown in Figure 3.6. 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 3.6** *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 3.7, 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 3.7** *Rotational motion caused by the linkage system*

### 3.3.2 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

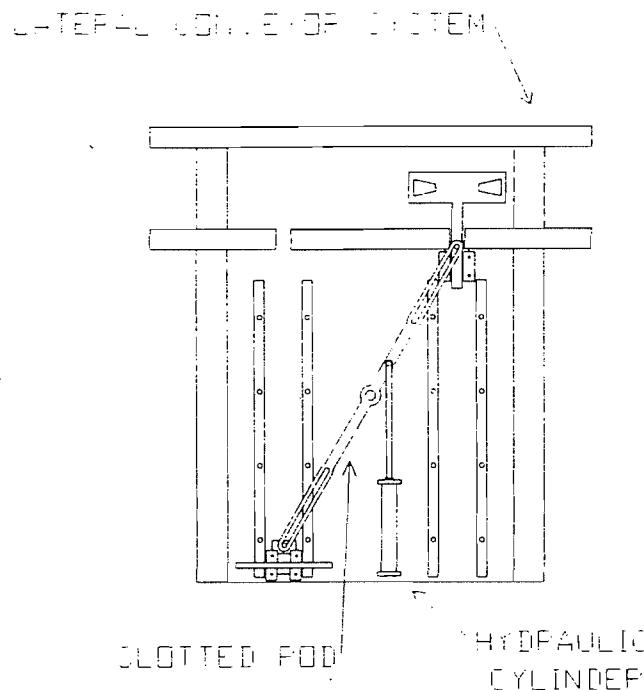
group on the longitudinal conveyor, it is possible to identify open spaces at the front end of the stored stacks of cones. If the sensors identify an empty space in the either left or right stack only, the respective carriage assembly will be moved to the LCS. When the sensors identify end spaces in 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.

### **3.4 Other Trade-Off Concepts**

#### **3.4.1 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 3.8. 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 3.8** *The Rotating Stowage Assembly*

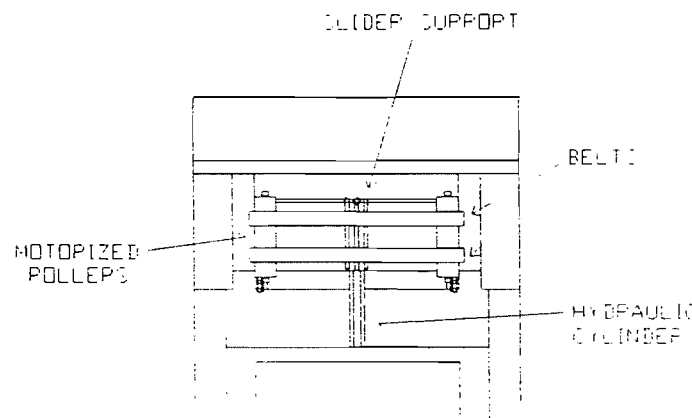
During the deployment and the retrieval of traffic cones, the RSA operates in a similar fashion as the ACSS. When operating in retrieval mode, the RSA sends one of the two carriage assemblies to the LCS depending on which stack has an open space. The cones are stopped in one of two positions on the LCS 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.

### 3.4.2 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 3.9, simply uses the conveyor assembly itself to rotate and to transport two cones at a time.

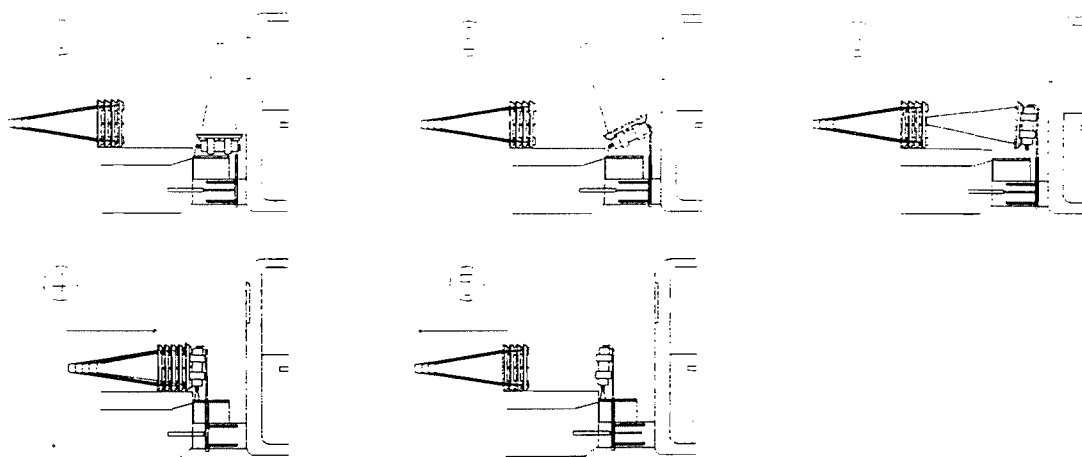


**Figure 3.9** *The Swivel Stowage Unit*

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



**Figure 3.10** *The Rotating Swivel System in retrieval mode*

### 3.5 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 3.1, 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 physical 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 3.1 Trade-off Table for Conceptual Designs

DESIGN CONSIDERATION	Factor	Concept 1 ACSS	Concept 2 RSA	Concept 3 SSU
<b>1. MANDATORY CAPABILITIES</b>				
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
<b>2. SYSTEM CONSIDERATIONS</b>				
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
<b>3. GENERAL DESIGN CONSIDERATIONS</b>				
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 4 COORDINATED CONTROL UNIT**

### **4.1 General Description**

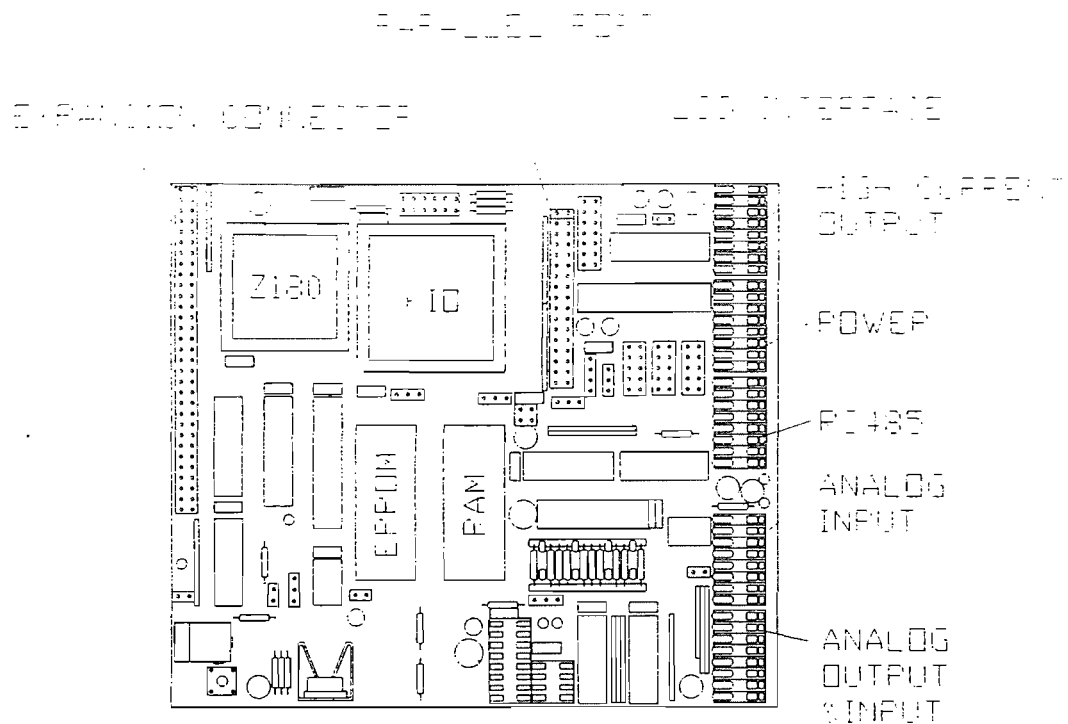
The Coordinated Control Unit (CCU) integrates and controls the various systems of the Automated Cone Machine (ACM) to effectively perform the retrieval and deployment of traffic cones on the highway. The CCU allows the driver to activate the Funnel System (FS), the Integrated Dispensing and Retrieval 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.

### **4.2 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.

#### 4.2.1 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 4.1. 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.

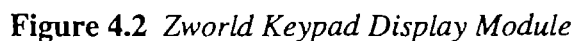


**Figure 4.1** *Zworld Little Giant miniature controller*

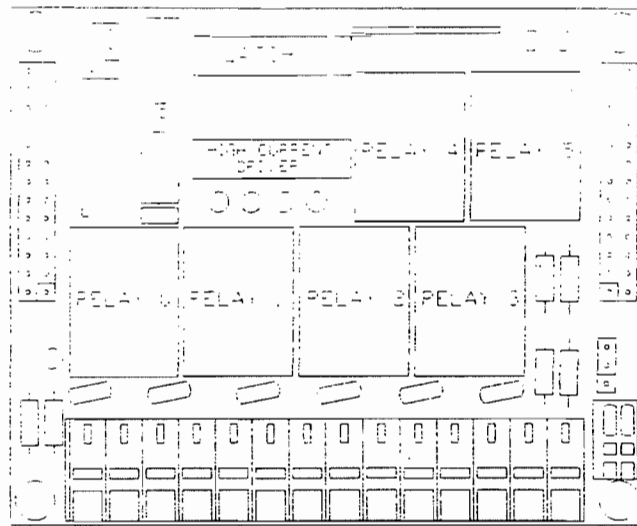
#### 4.2.2 The Zworld Keyboard Display Module

The Zworld Keyboard Display Module (KDM) 4x40 provides a means of user interface for the control system. As shown in Figure 4.2, 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.

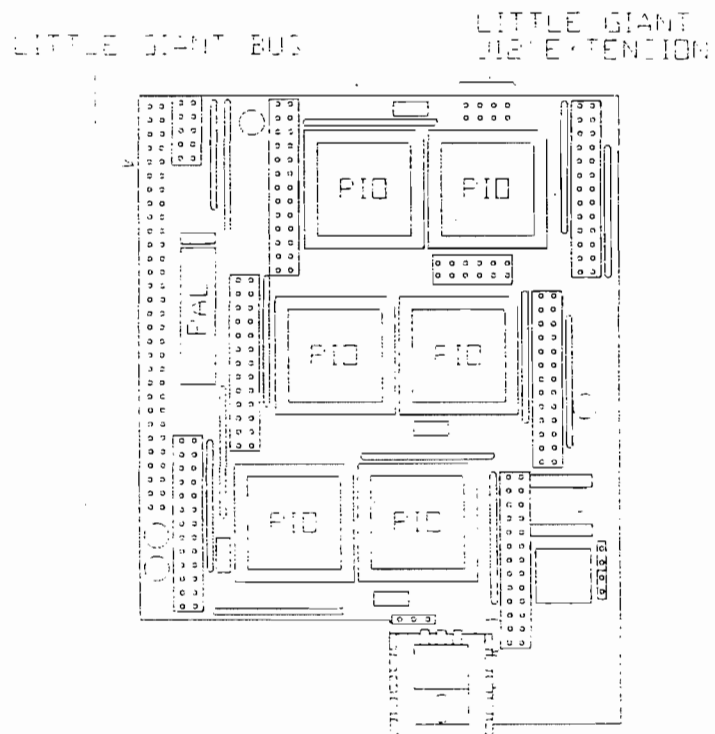




The Zworld Expansion Boards provide simple ways to extend the capabilities of the core Zworld system. The Relay6 Boards, shown in Figure 4.3, measure 89 x 72 mm (2.2 x 2.8 in) and contain six high powered relays that are individually controllable. They feature linkable ports, maximum switching voltage of 24 VDC at 10 amps, and LED status indicators. The IOE-DGL96, shown in Figure 4.4, 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 4.3** *Zworld Relay6 Expansion Board*



**Figure 4.4** *Zworld IOE-DGL96 Expansion Board*

### **4.3 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.

#### **4.3.1 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 4.1 and Table 4.2 respectively.

**Table 4.1** *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 4.2** *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

#### 4.3.2 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 4.3.

**Table 4.3** *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.

#### **4.3.3 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.

#### **4.3.4 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.

#### **4.4 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. The control scheme for the various operations are shown in a flow chart located in Appendix 4. 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 5 CONCLUSIONS AND RECOMMENDATIONS

### 5.1 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 4 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.

### 5.2 Recommendations

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 leading 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 translational 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.

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

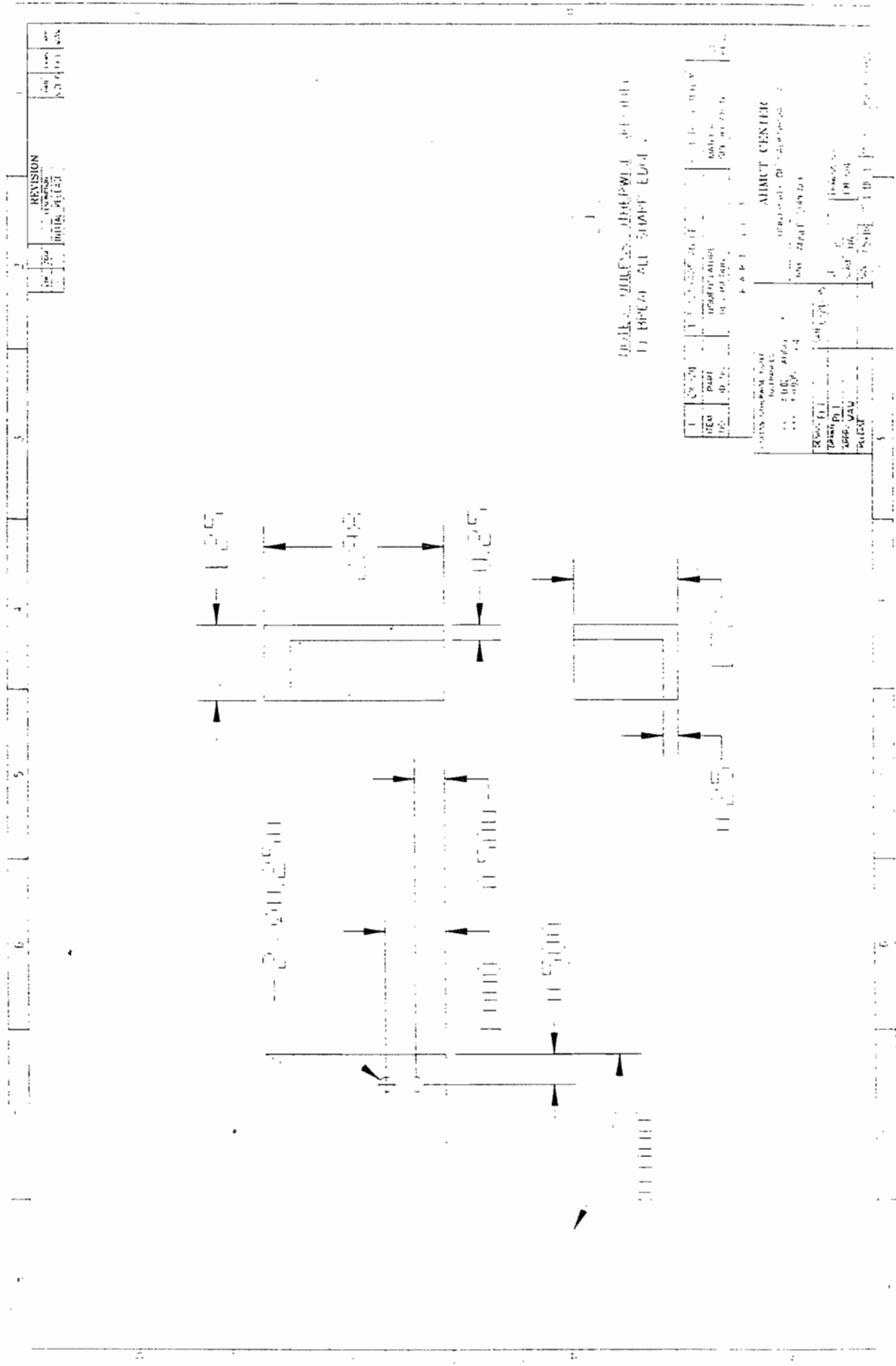
Meriam, J. L., Kraige, L. G., 1987, Engineering Mechanics, DYNAMICS, John Wiley & Sons, NY

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

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

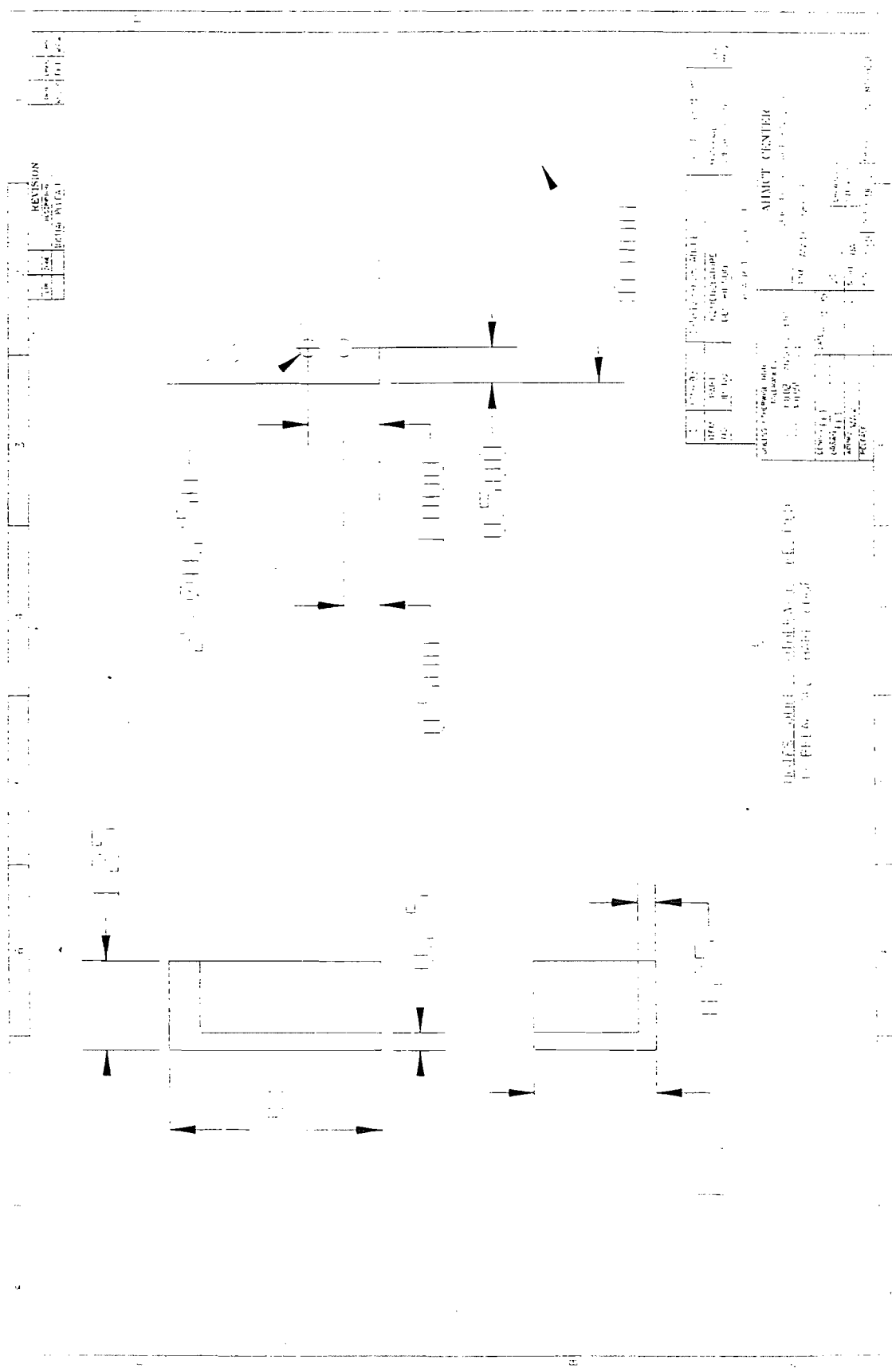
## APPENDIX A

## Detailed Drawings



## APPENDIX A

## Detailed Drawings



The drawing is a vertical section of a building, showing structural elements and floor levels. Key features include:

- Structural Elements:** A central vertical column, horizontal beams, and a roof structure. Dimensions are indicated with arrows and numbers.
- Floor Levels:** Indicated by horizontal lines with labels such as "FLOOR 1", "FLOOR 2", and "FLOOR 3".
- Revisions:** A table in the upper right corner lists revisions made to the drawing.
- Notes:** A block of text in the lower right corner provides additional information about the drawing.

NO.	DATE	REVISION
1	10/10/11	1.00
2	10/10/11	1.00
3	10/10/11	1.00
4	10/10/11	1.00
5	10/10/11	1.00
6	10/10/11	1.00
7	10/10/11	1.00
8	10/10/11	1.00
9	10/10/11	1.00
10	10/10/11	1.00

Notes:

1. All dimensions are in feet and inches.
2. All materials are to be as specified in the schedule.
3. All work is to be in accordance with the latest edition of the building code.
4. All work is to be in accordance with the latest edition of the mechanical code.
5. All work is to be in accordance with the latest edition of the electrical code.
6. All work is to be in accordance with the latest edition of the plumbing code.
7. All work is to be in accordance with the latest edition of the fire code.
8. All work is to be in accordance with the latest edition of the safety code.
9. All work is to be in accordance with the latest edition of the health code.
10. All work is to be in accordance with the latest edition of the environmental code.





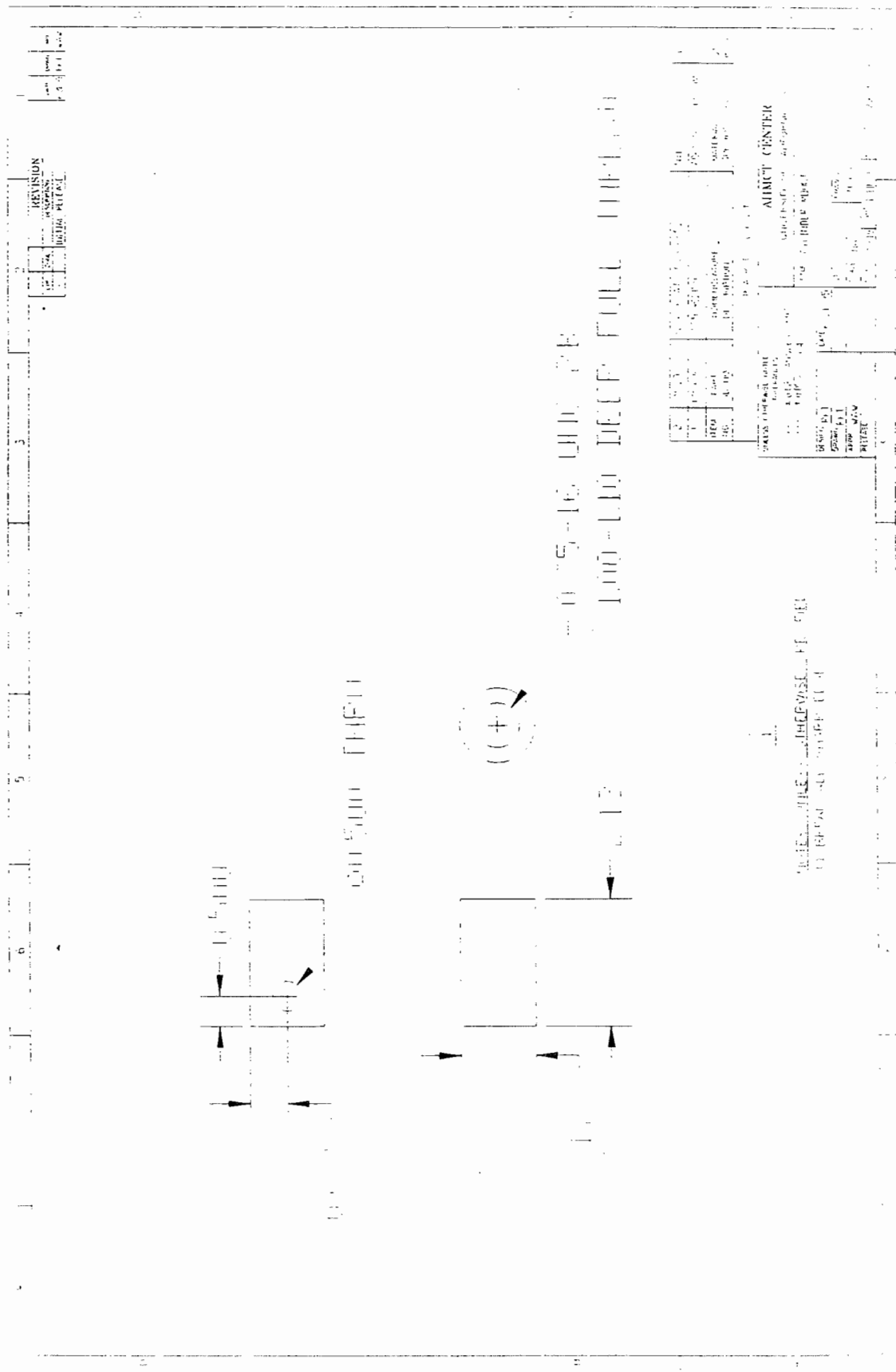
APPENDIX A

Detailed Drawings



# APPENDIX A

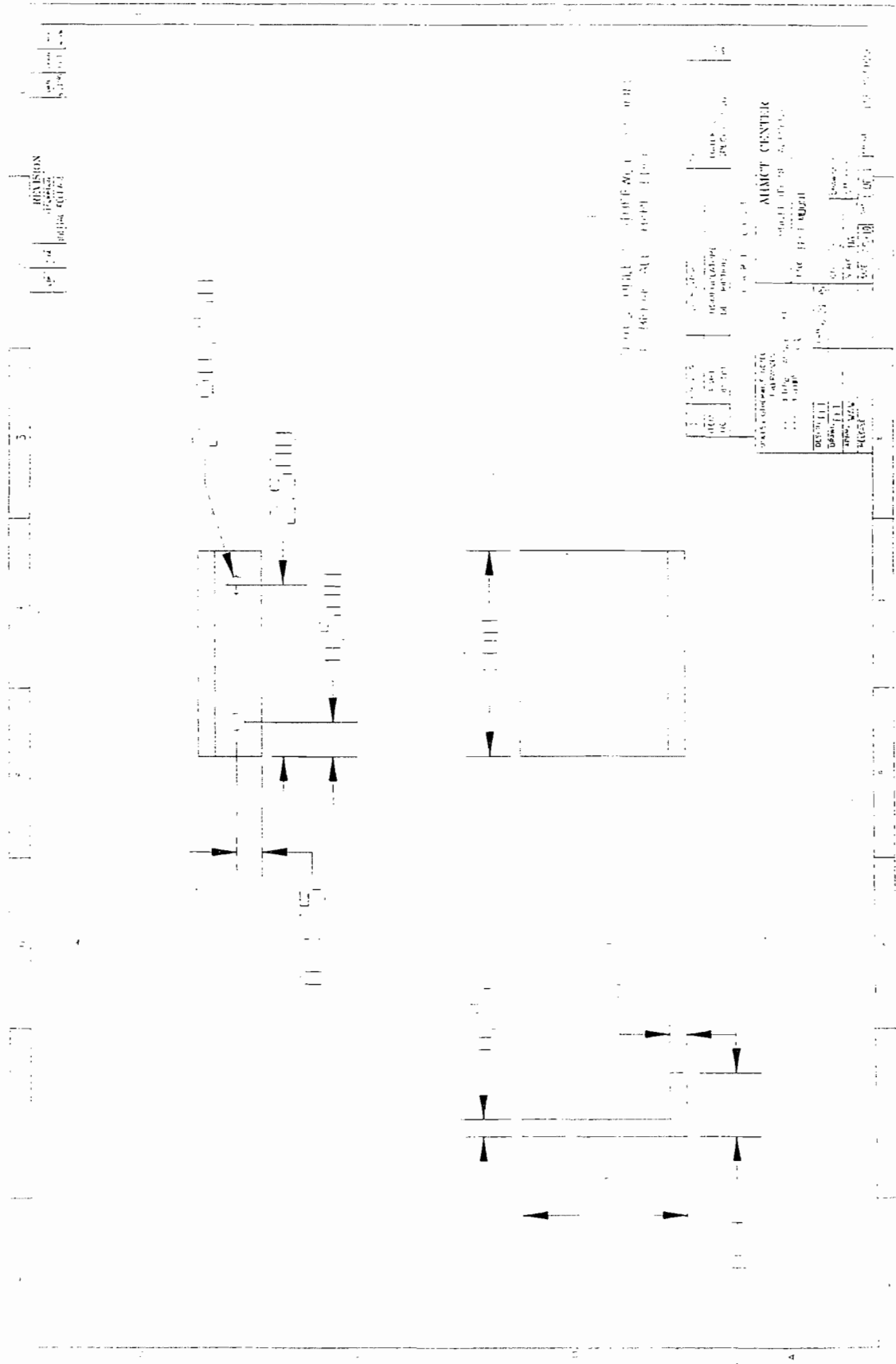
## Detailed Drawings





# APPENDIX A

## Detailed Drawings

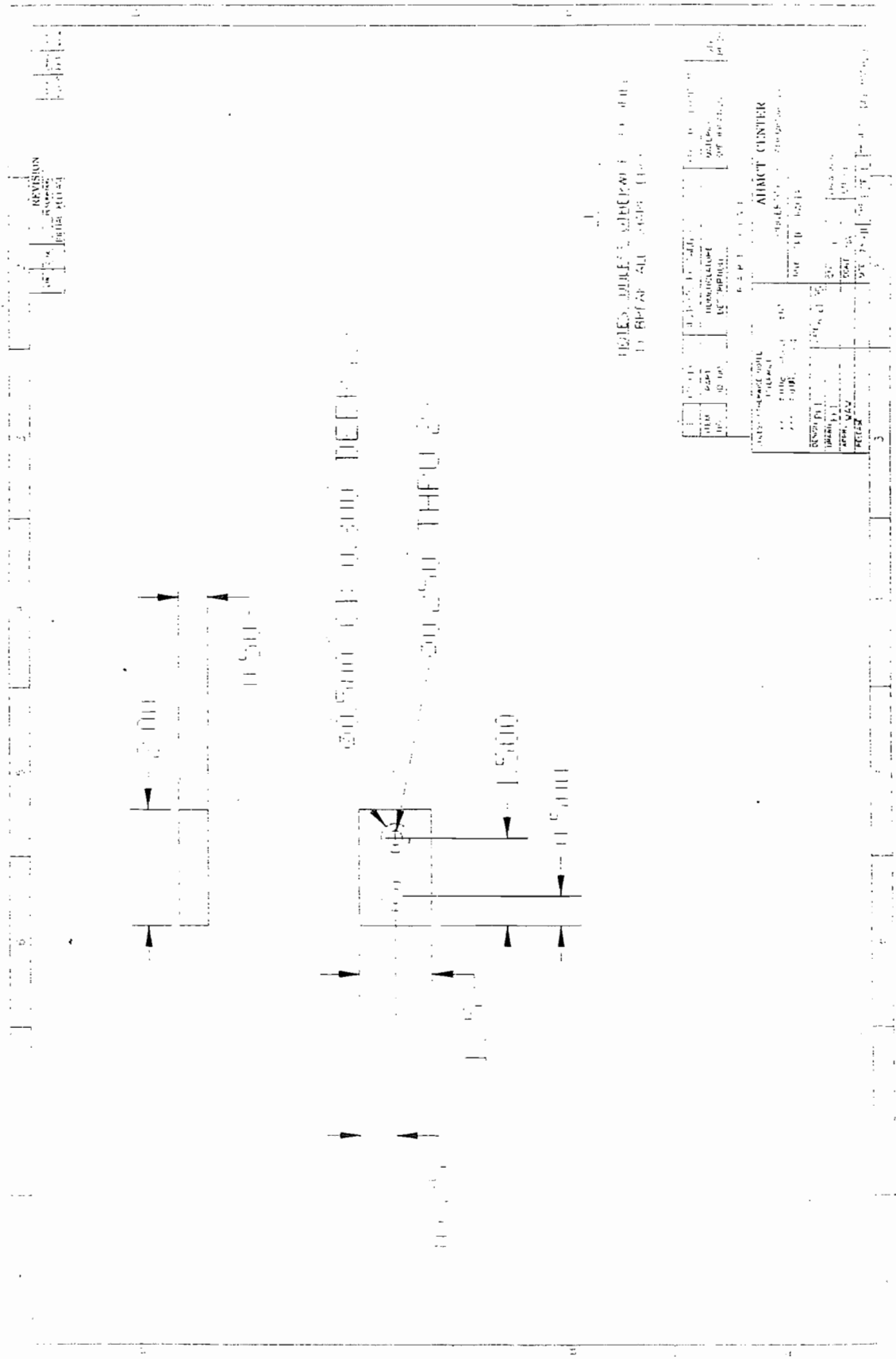


### Detailed Drawings



## APPENDIX A

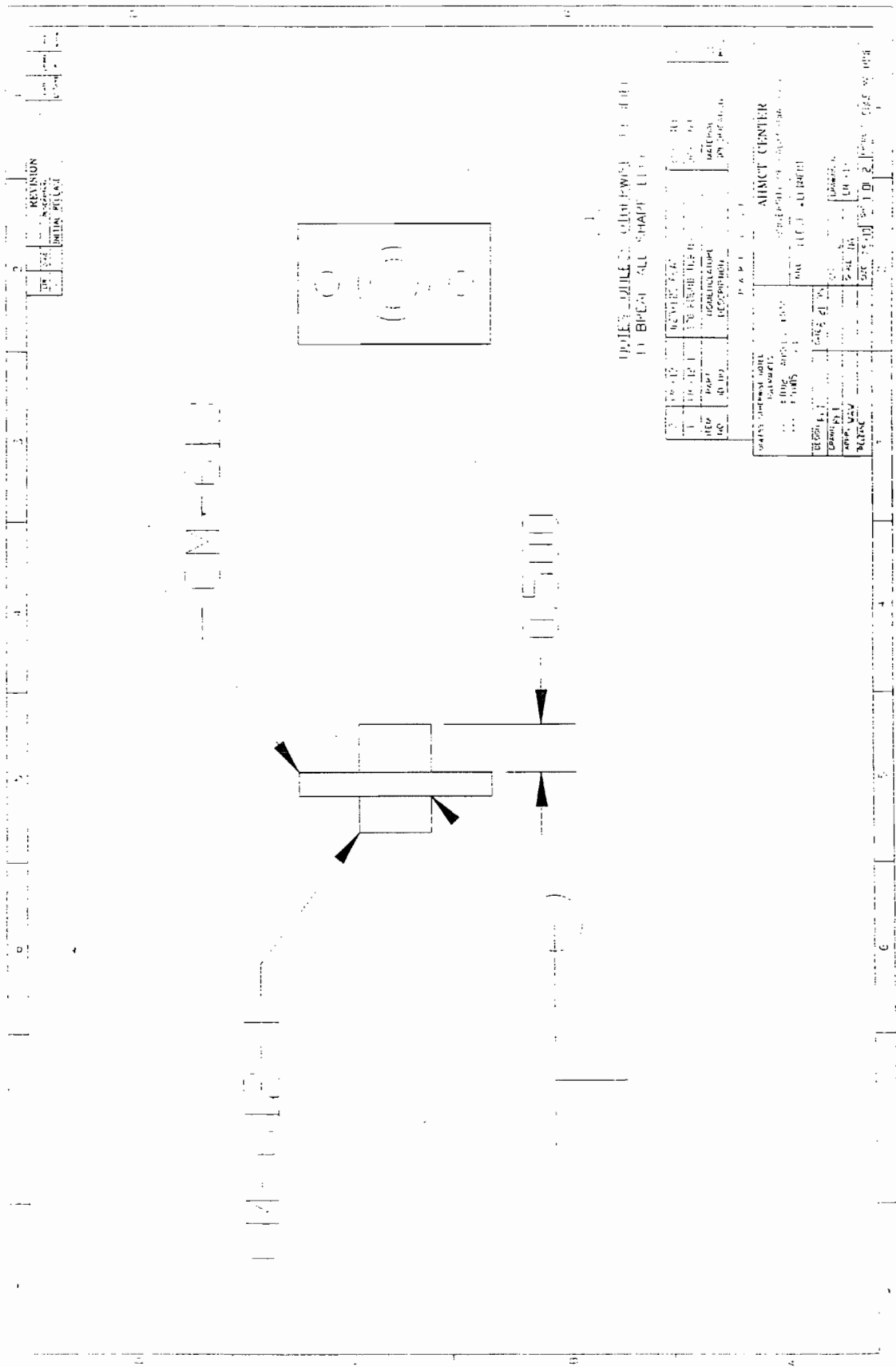
### Detailed Drawings





## APPENDIX A

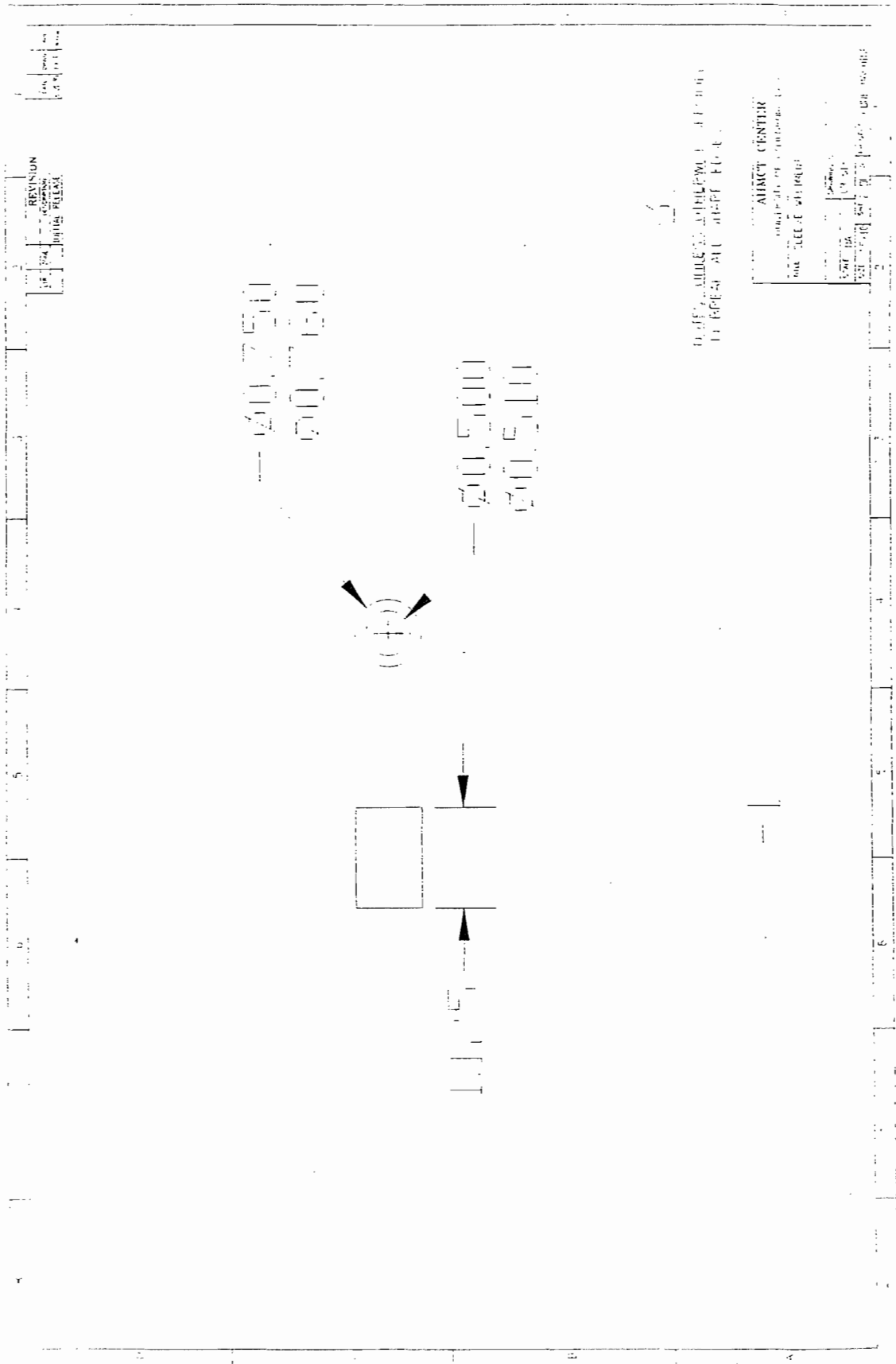
## Detailed Drawings





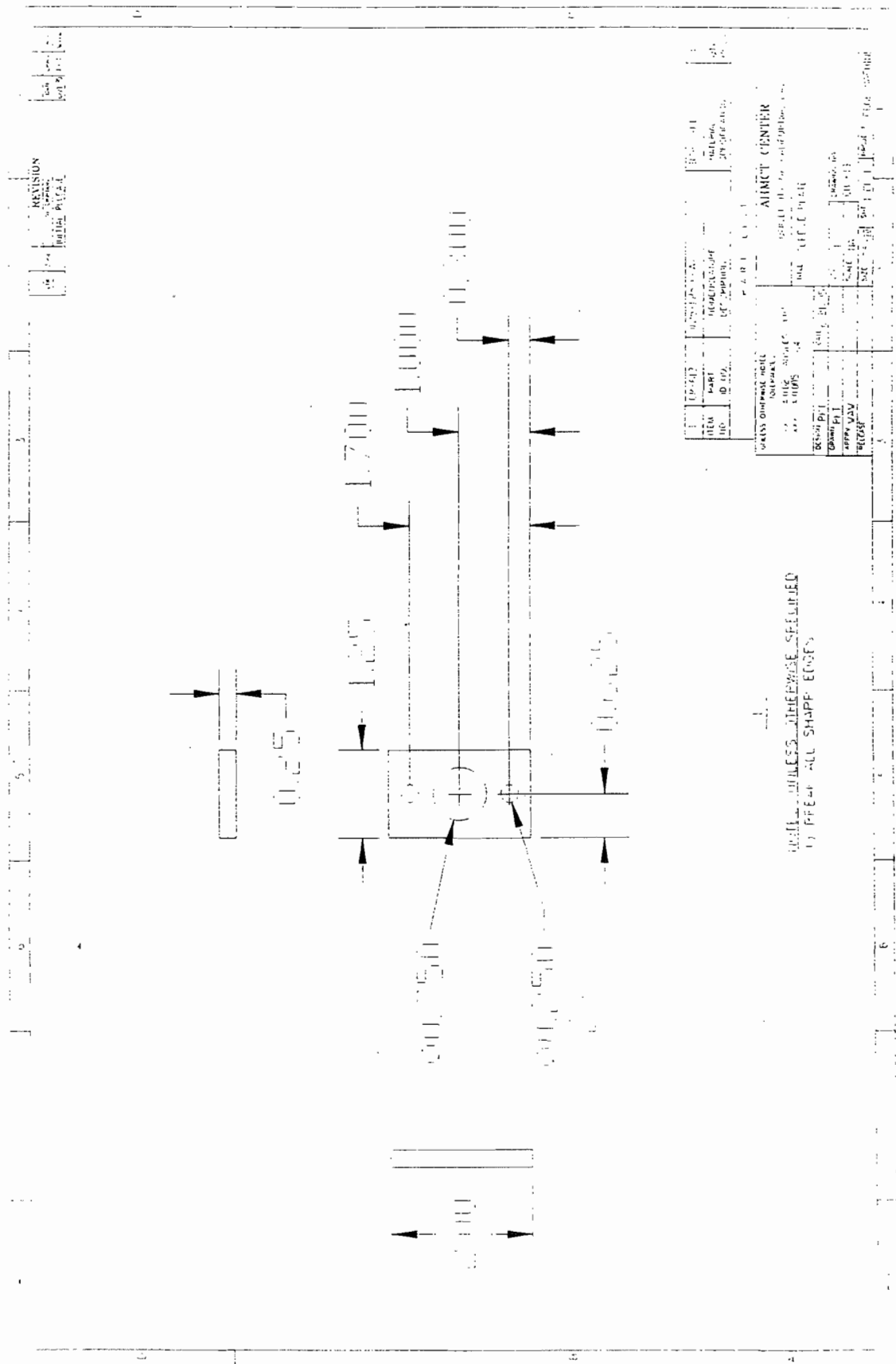
# APPENDIX A

## Detailed Drawings



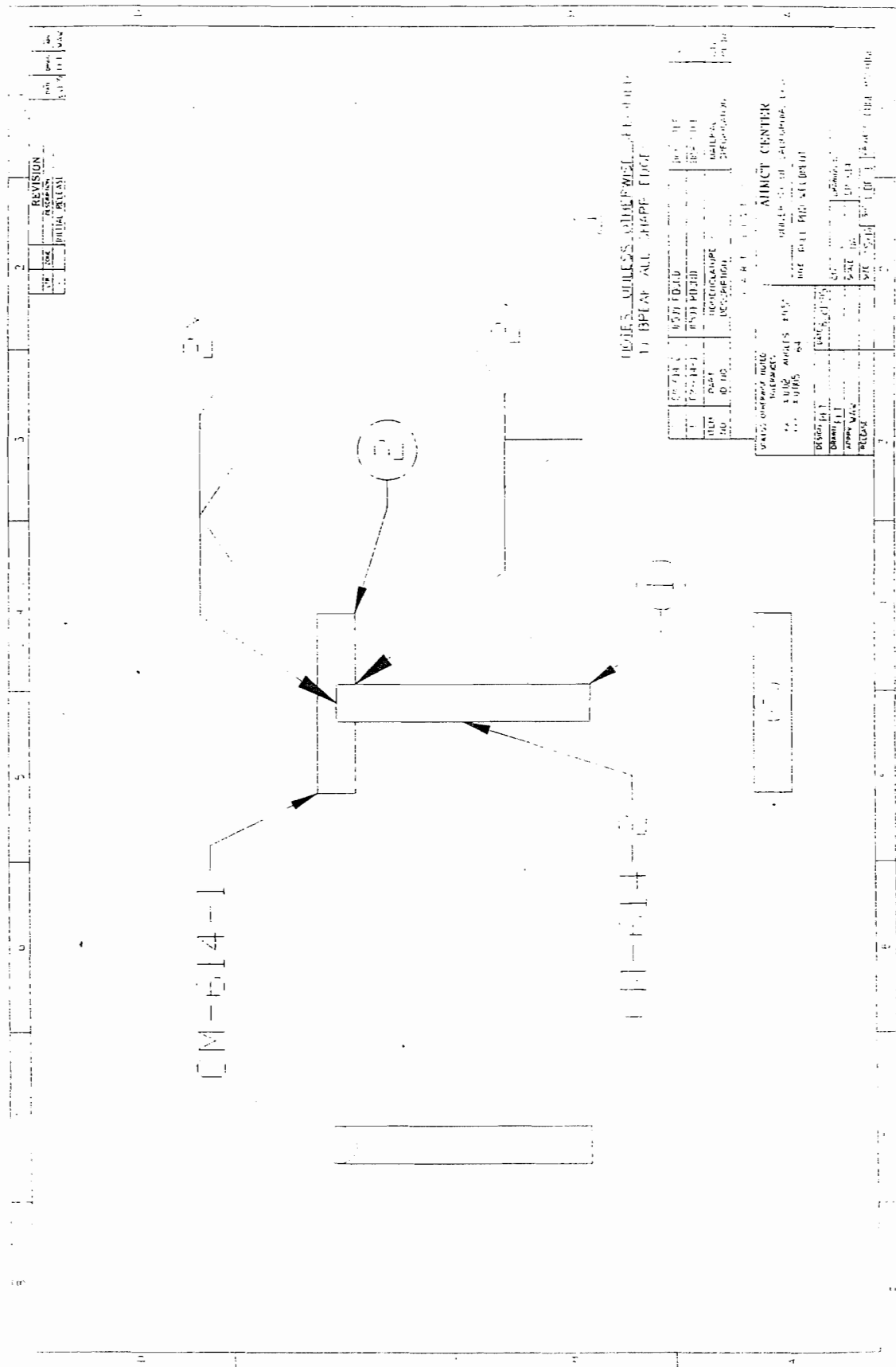
## APPENDIX A

## Detailed Drawings

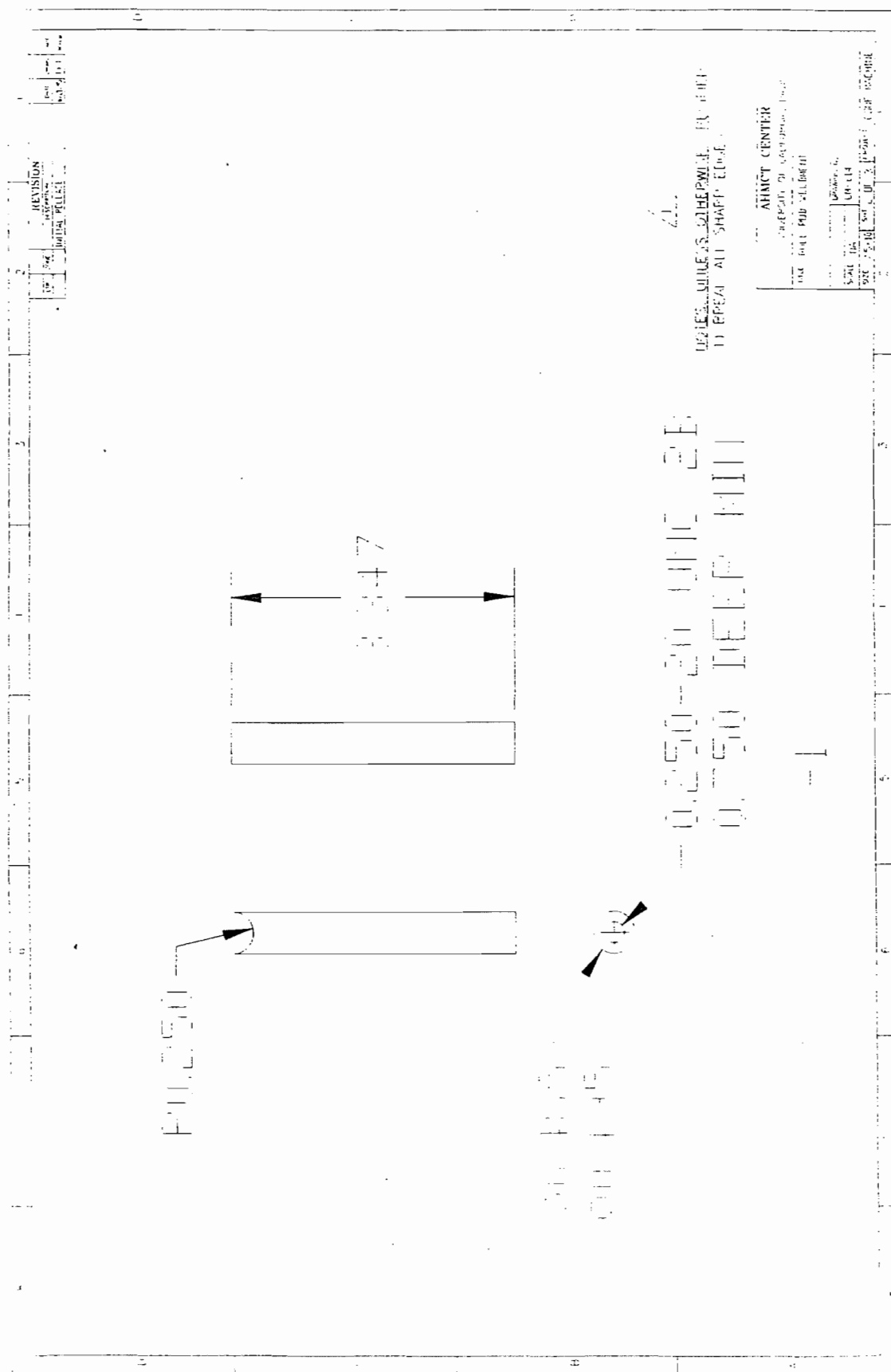


## APPENDIX A

## Detailed Drawings



### Detailed Drawings



### Detailed Drawings

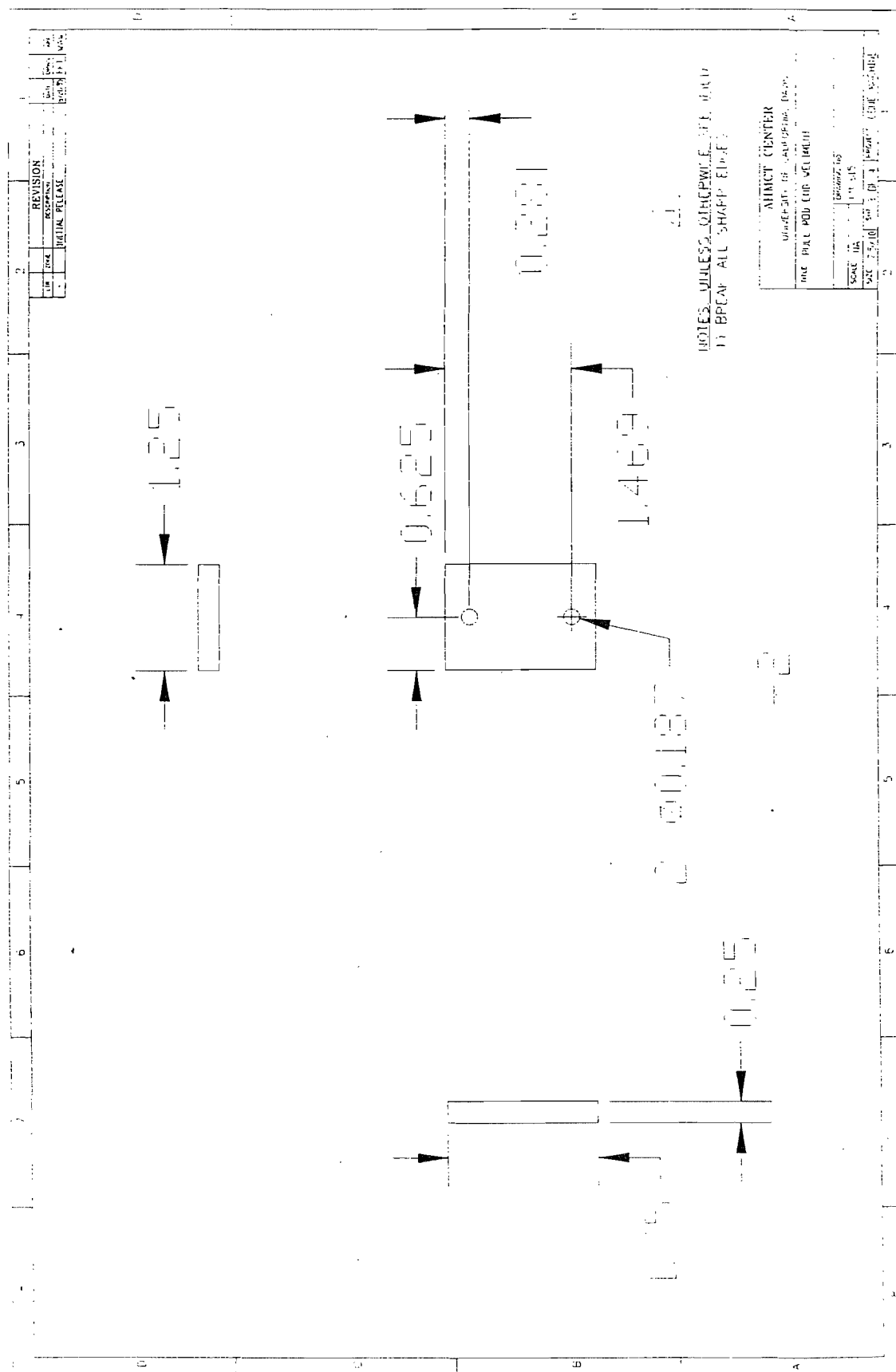






## APPENDIX A

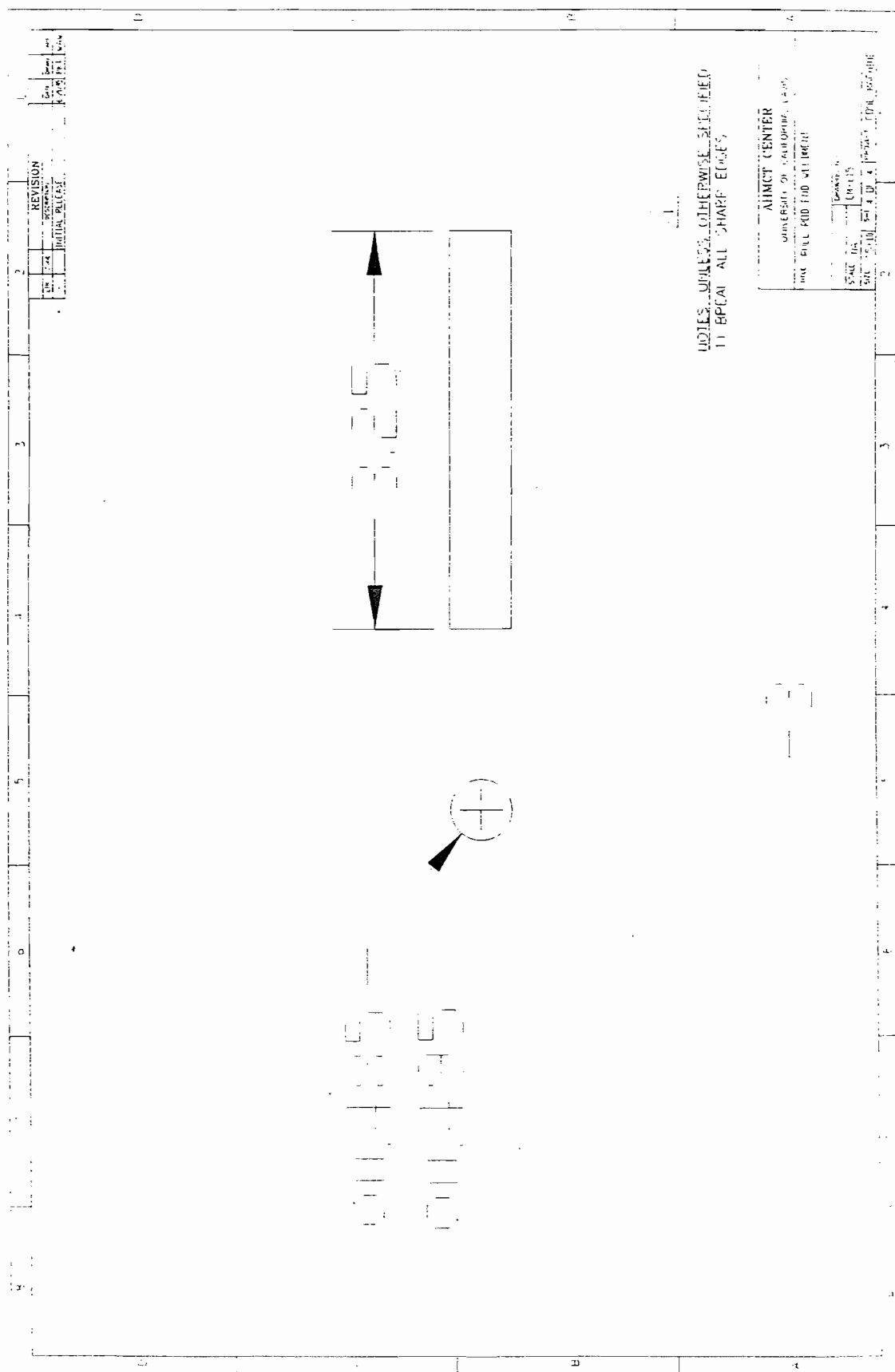
## Detailed Drawings





## APPENDIX A

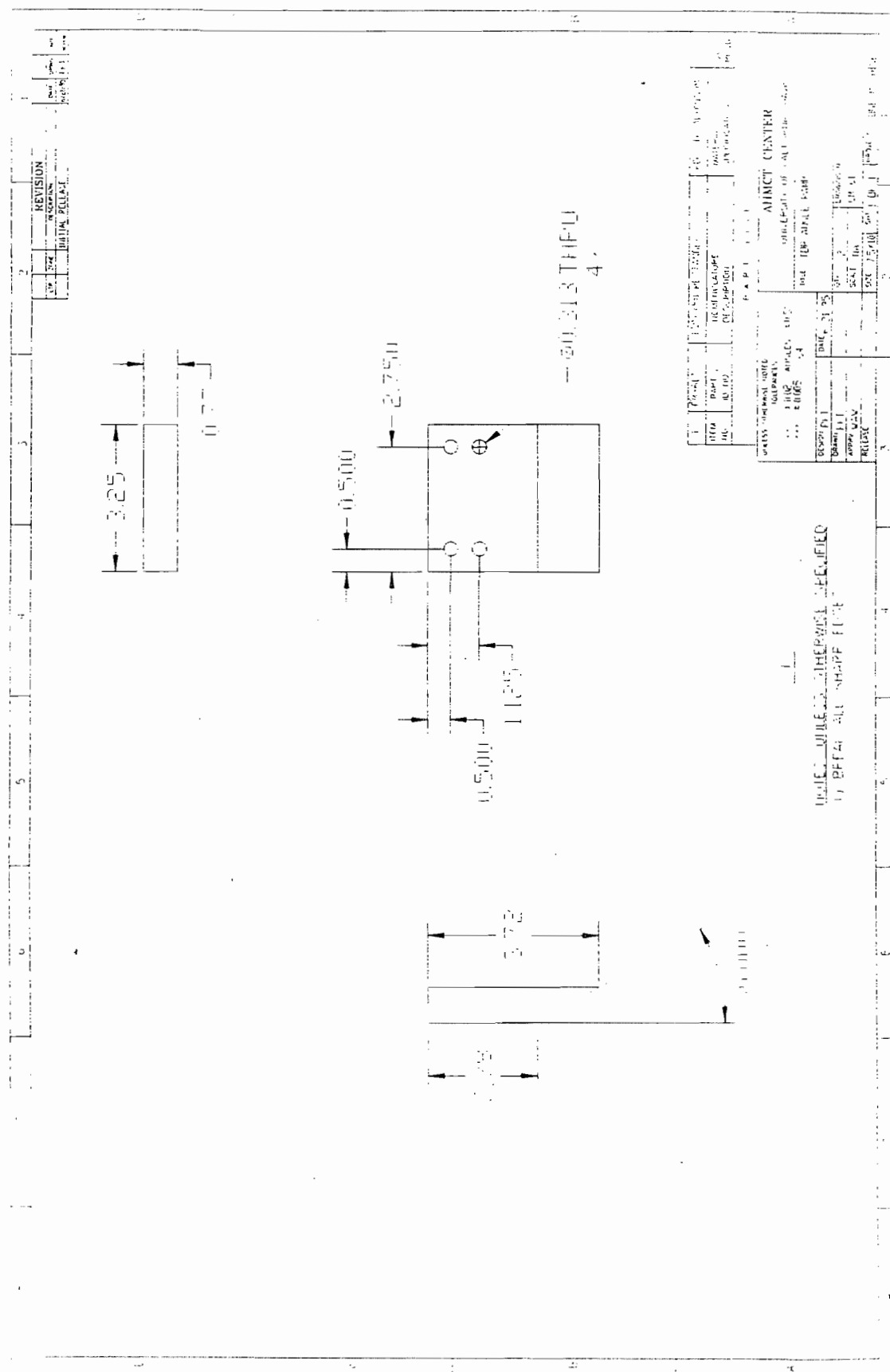
## Detailed Drawings





## APPENDIX A

## Detailed Drawings

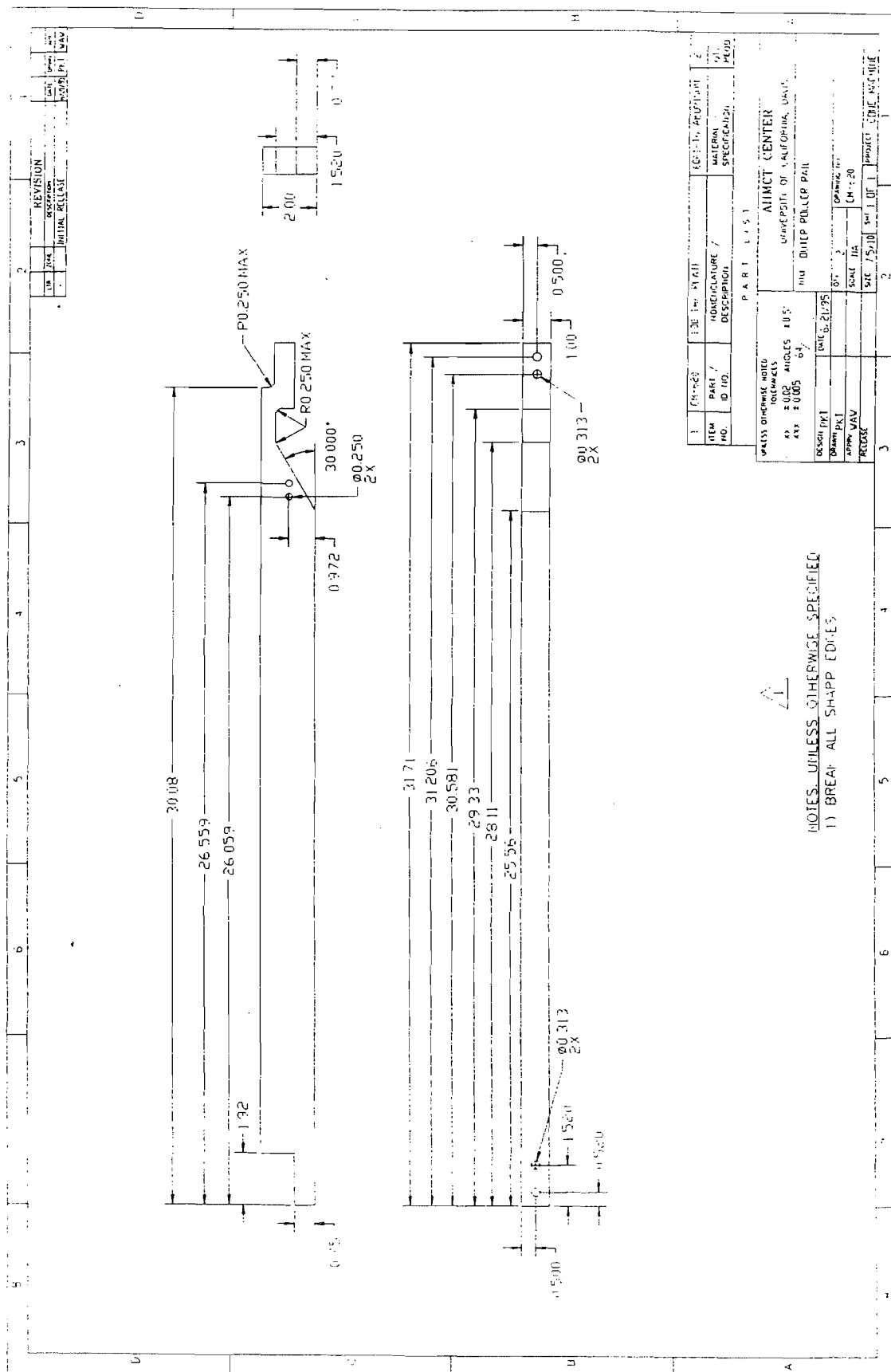






## APPENDIX A

### Detailed Drawings



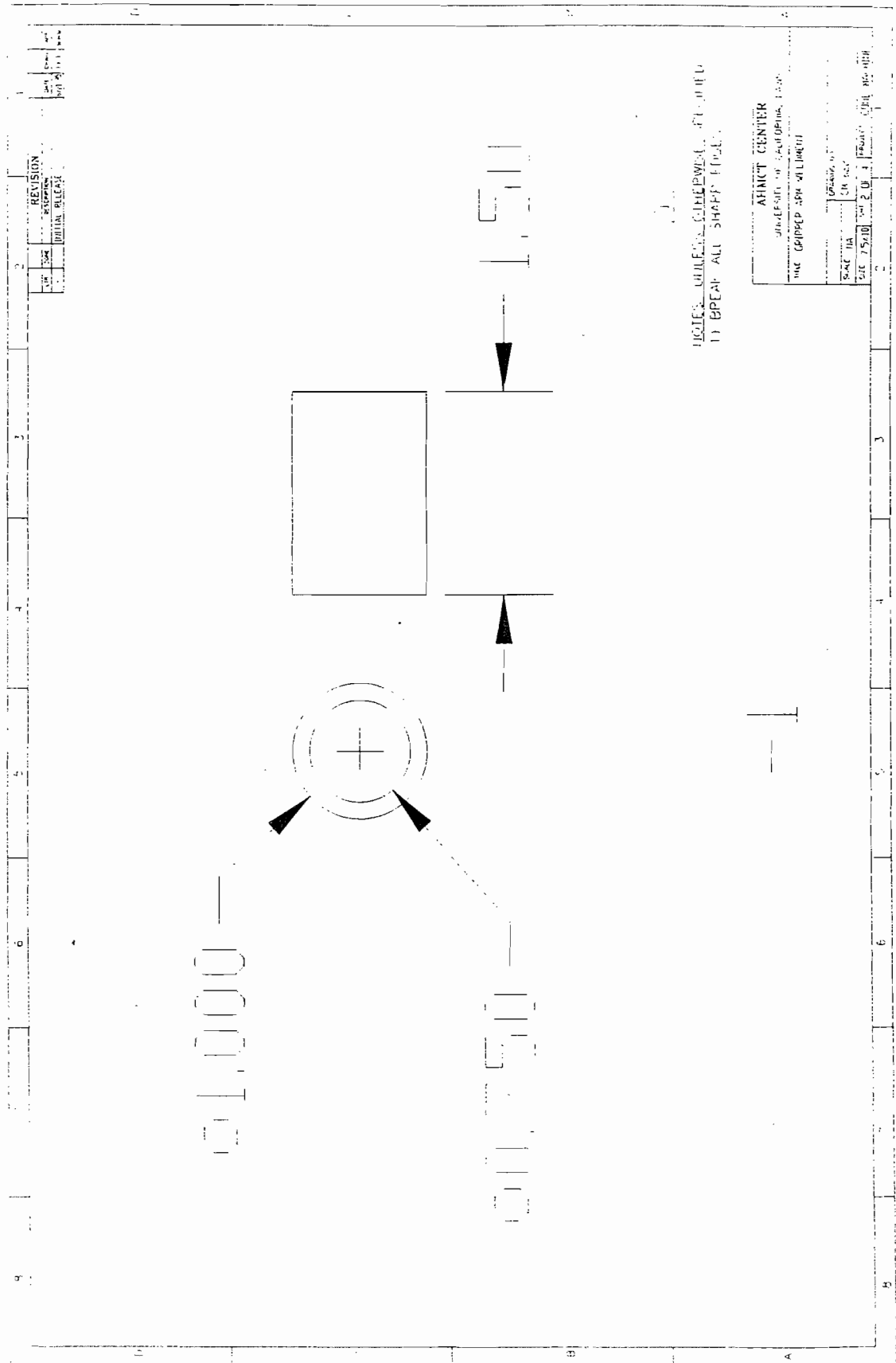






# APPENDIX A

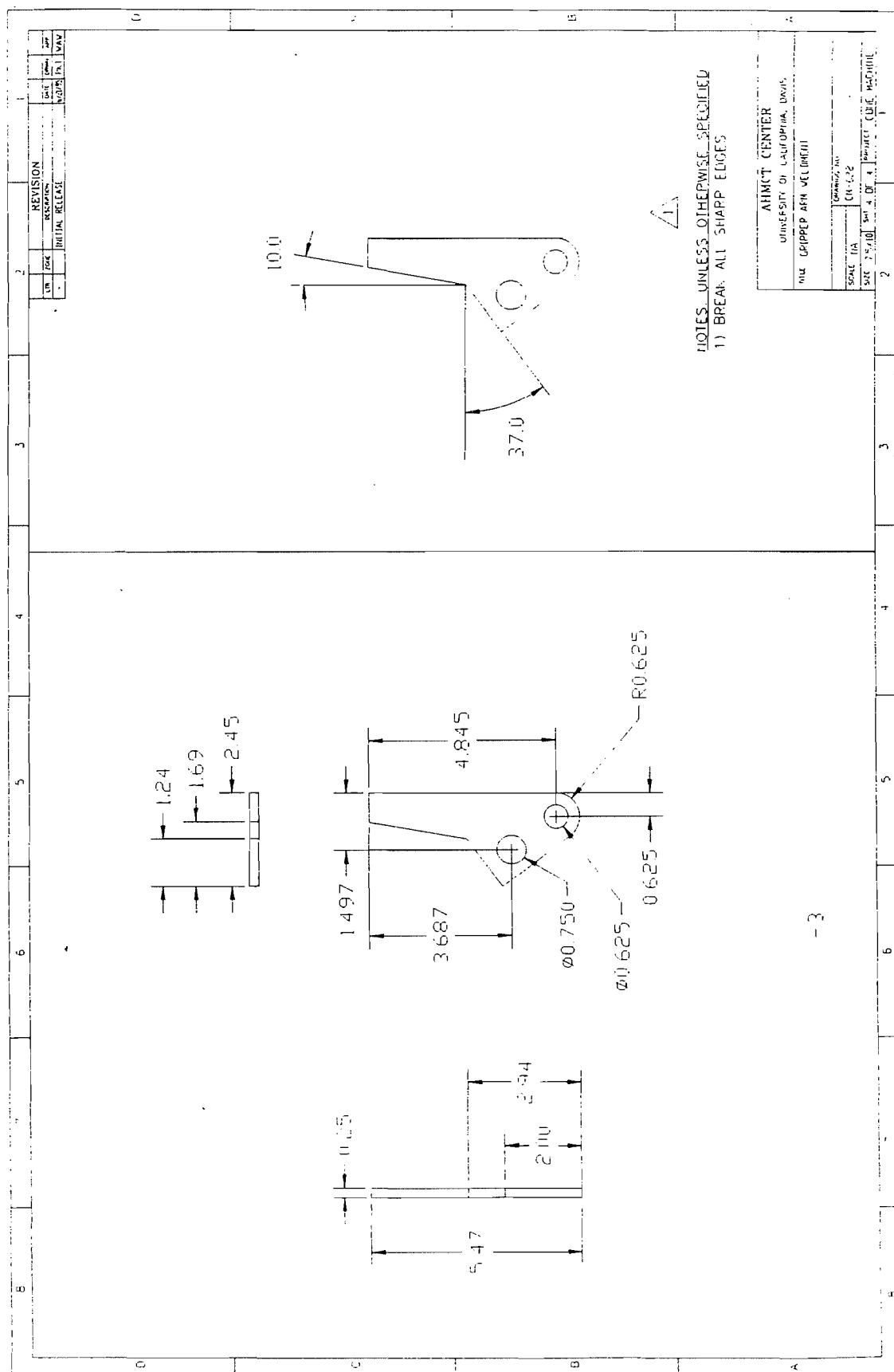
## Detailed Drawings





## APPENDIX A

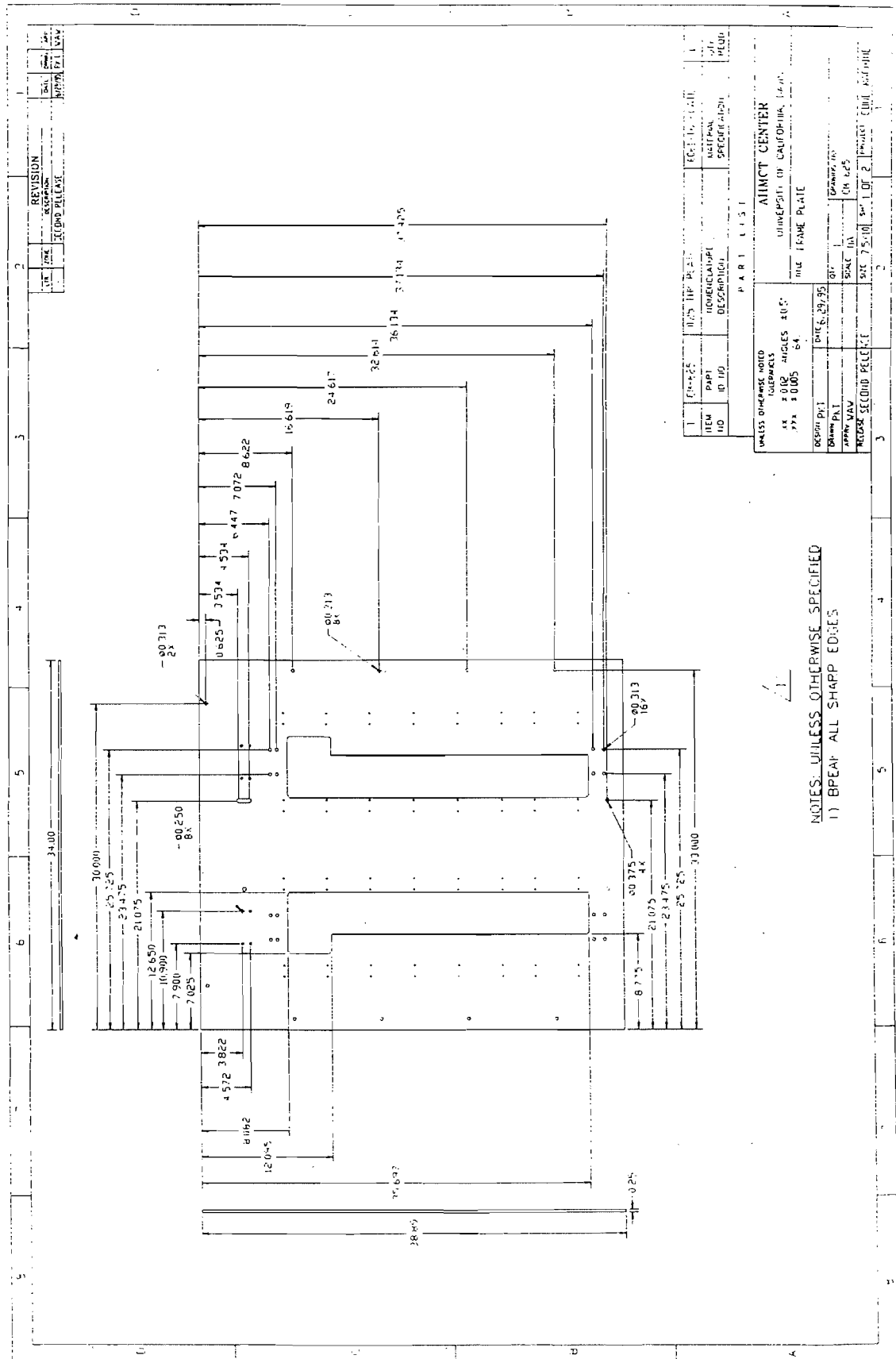
### Detailed Drawings





## APPENDIX A

## Detailed Drawings





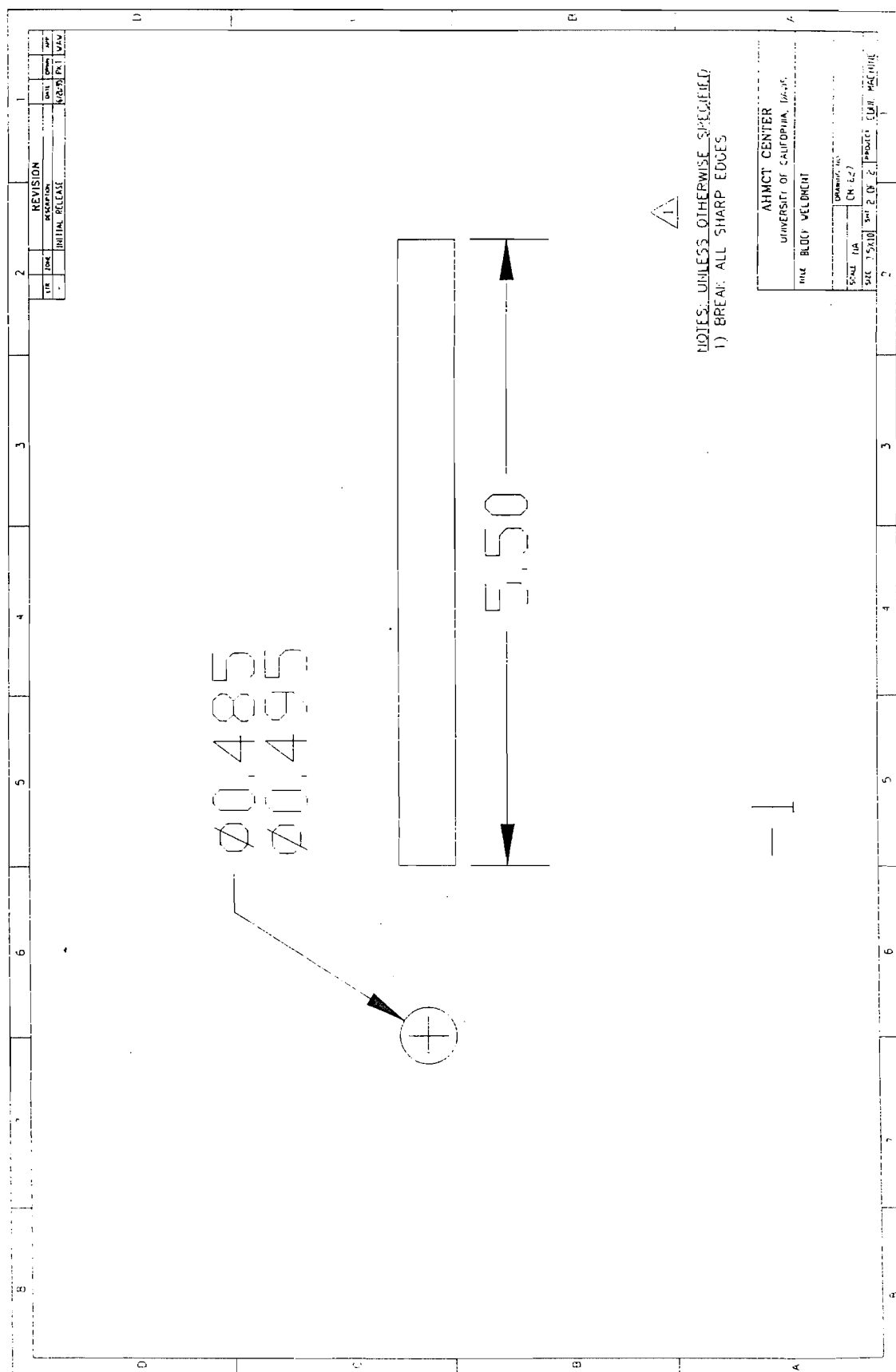






## APPENDIX A

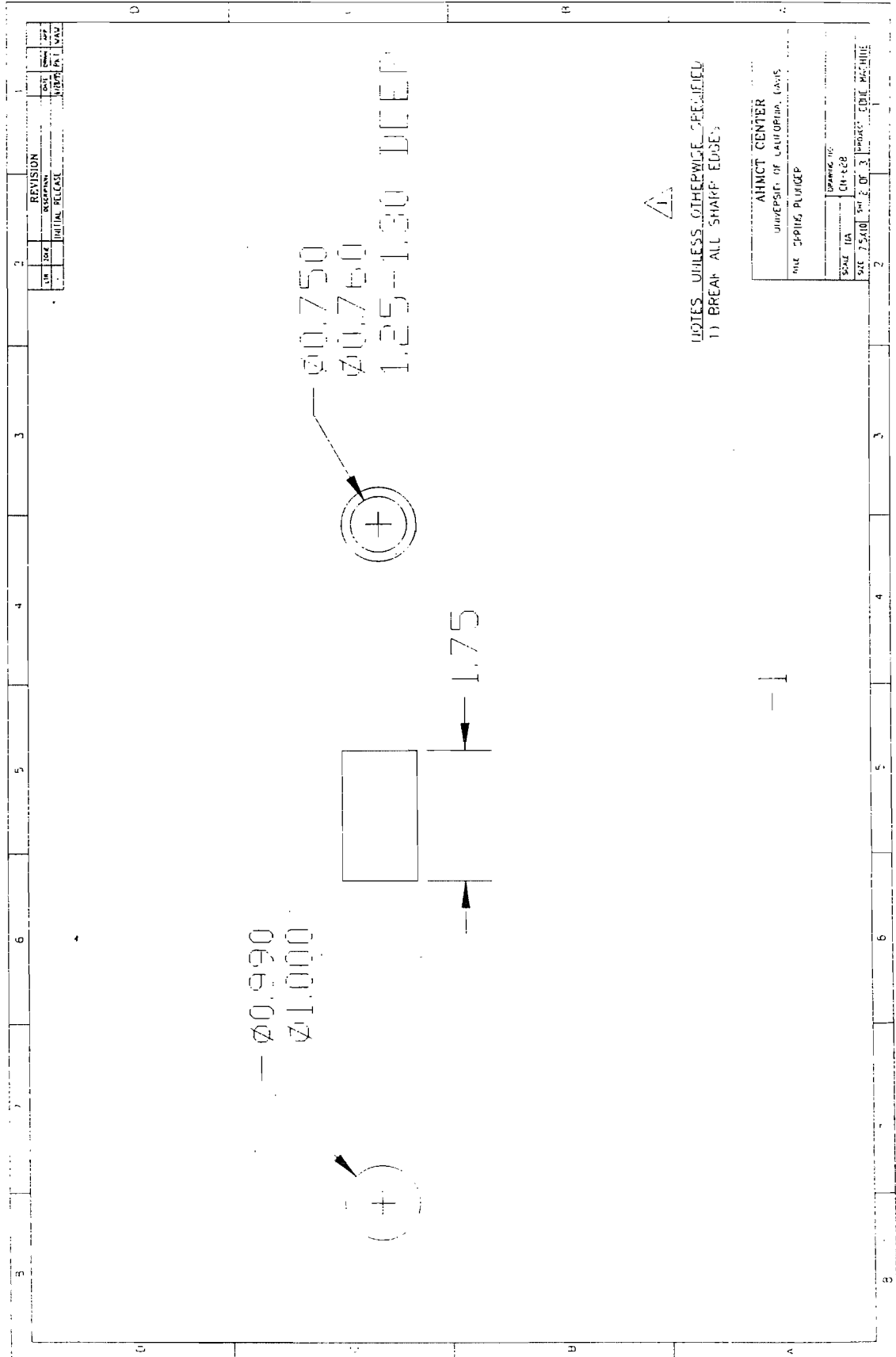
## Detailed Drawings





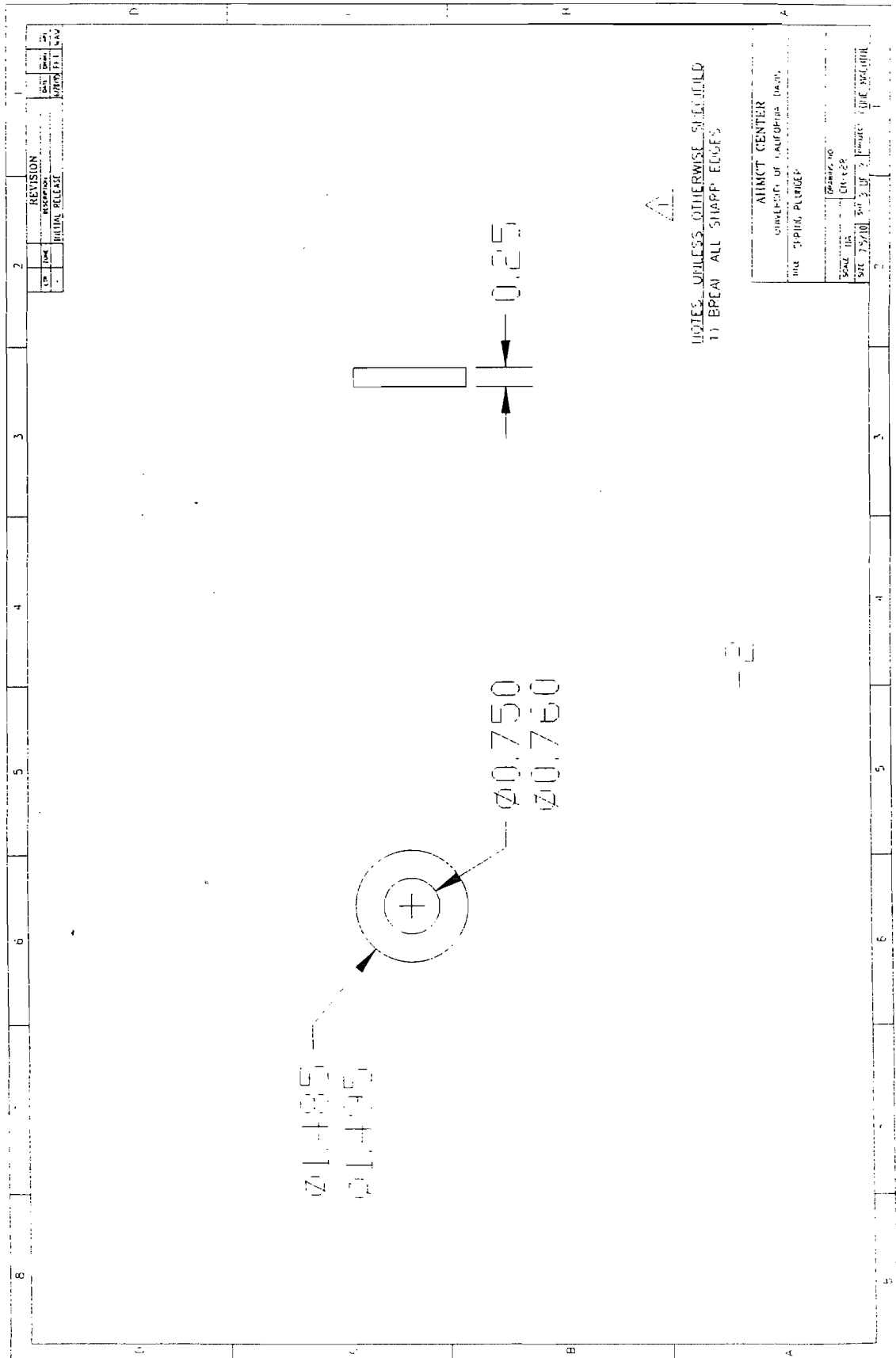
# APPENDIX A

## Detailed Drawings



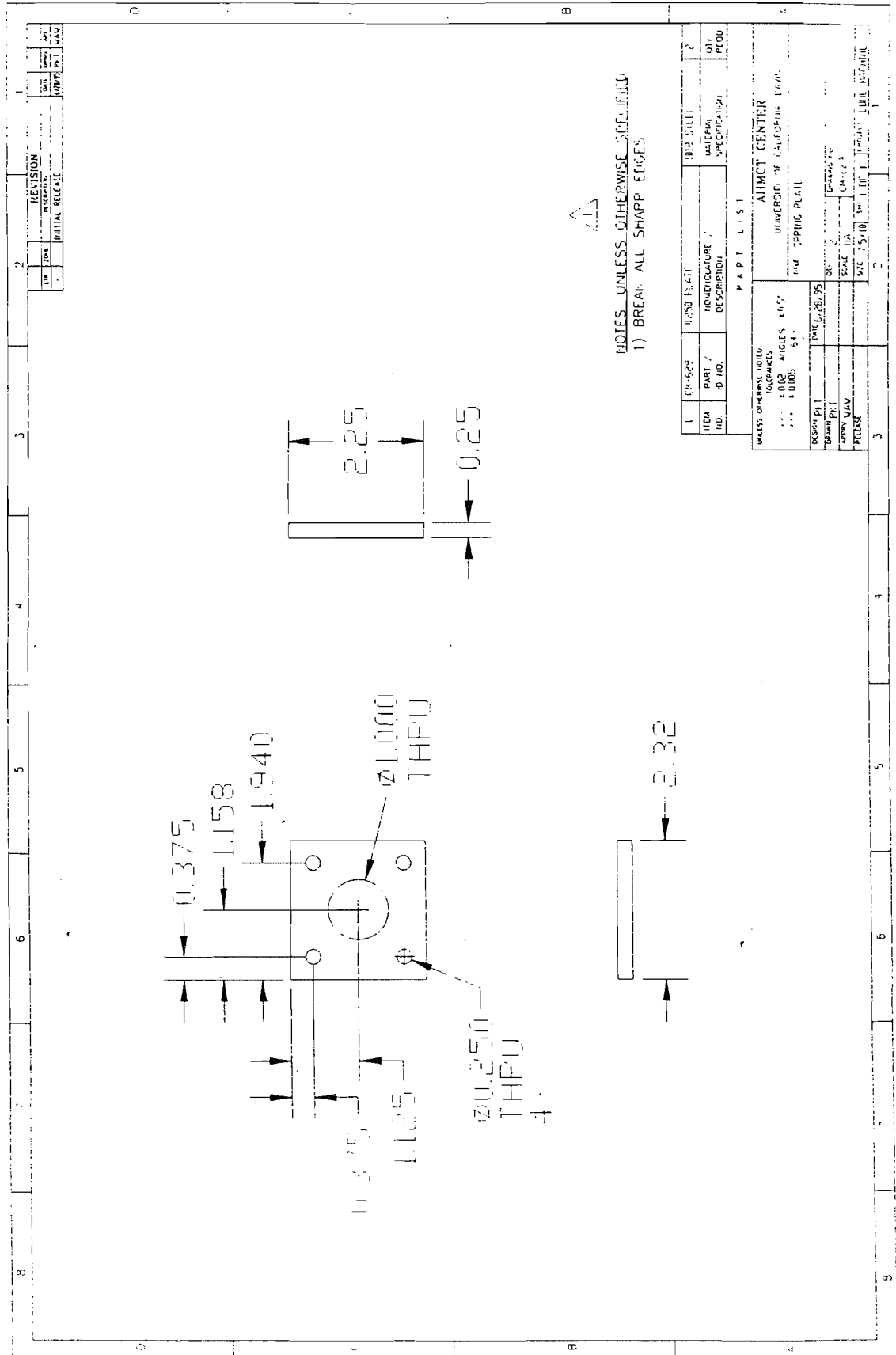
# APPENDIX A

## Detailed Drawings



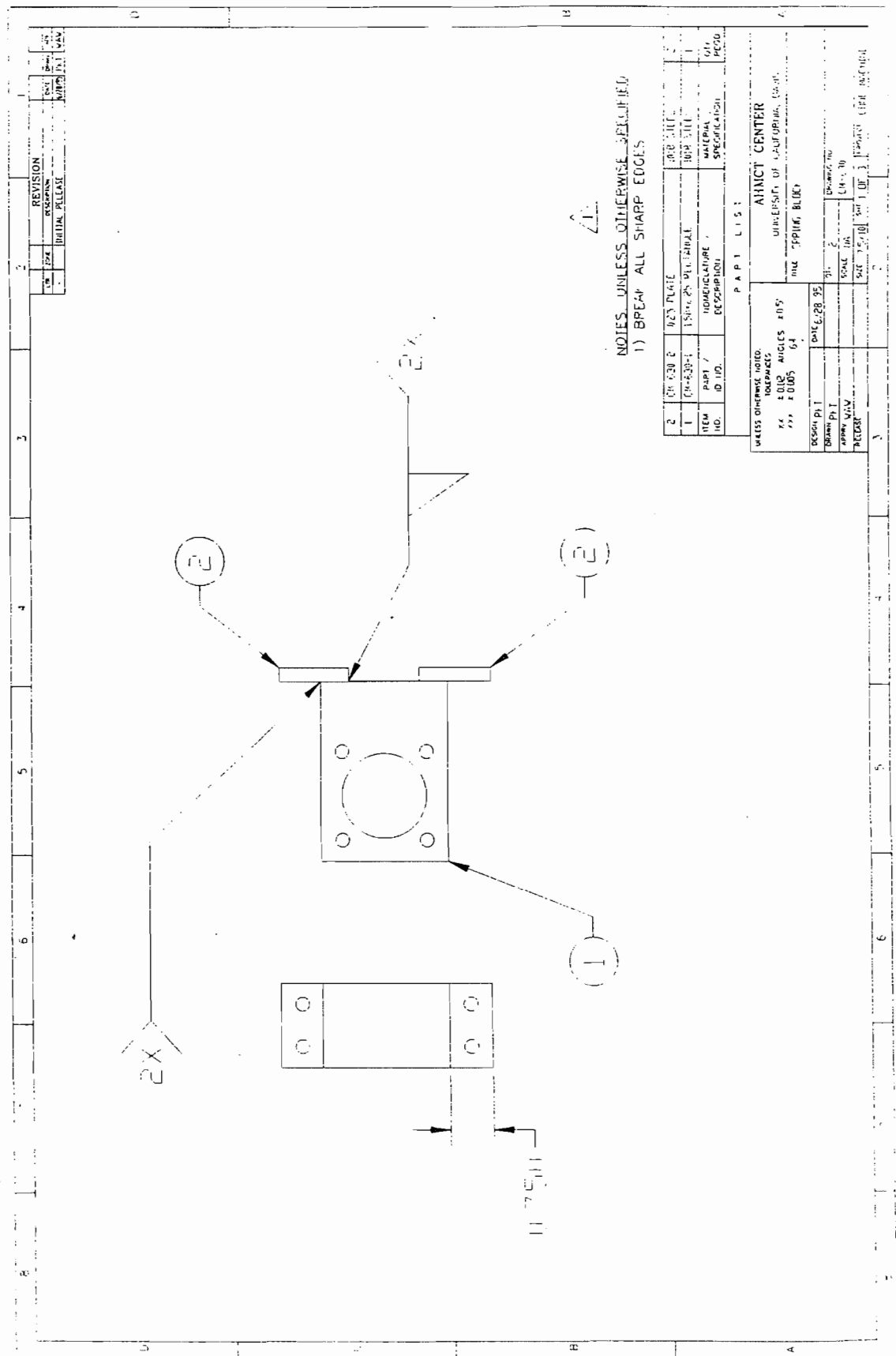
# APPENDIX A

## Detailed Drawings



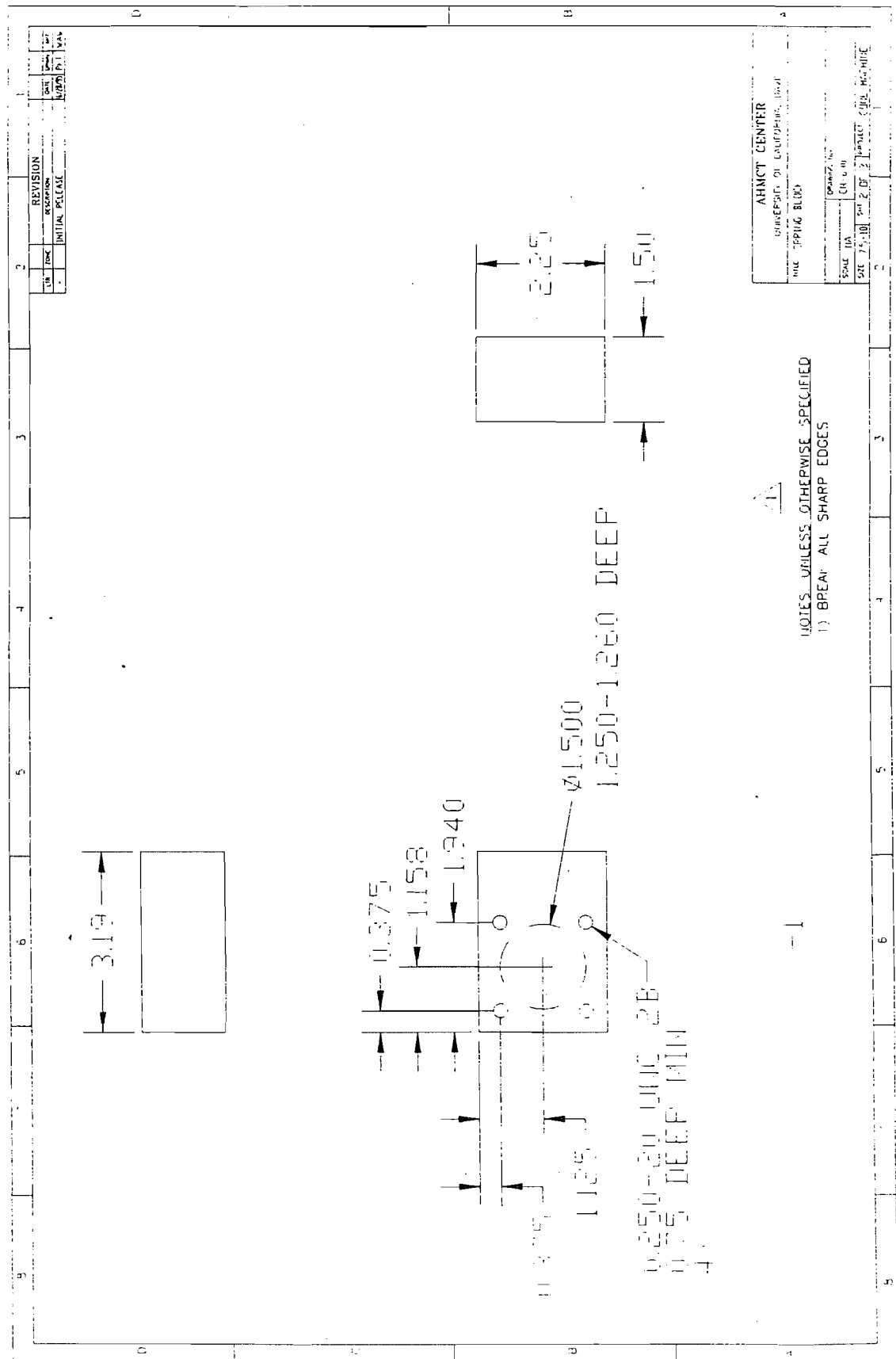
## APPENDIX A

## Detailed Drawings



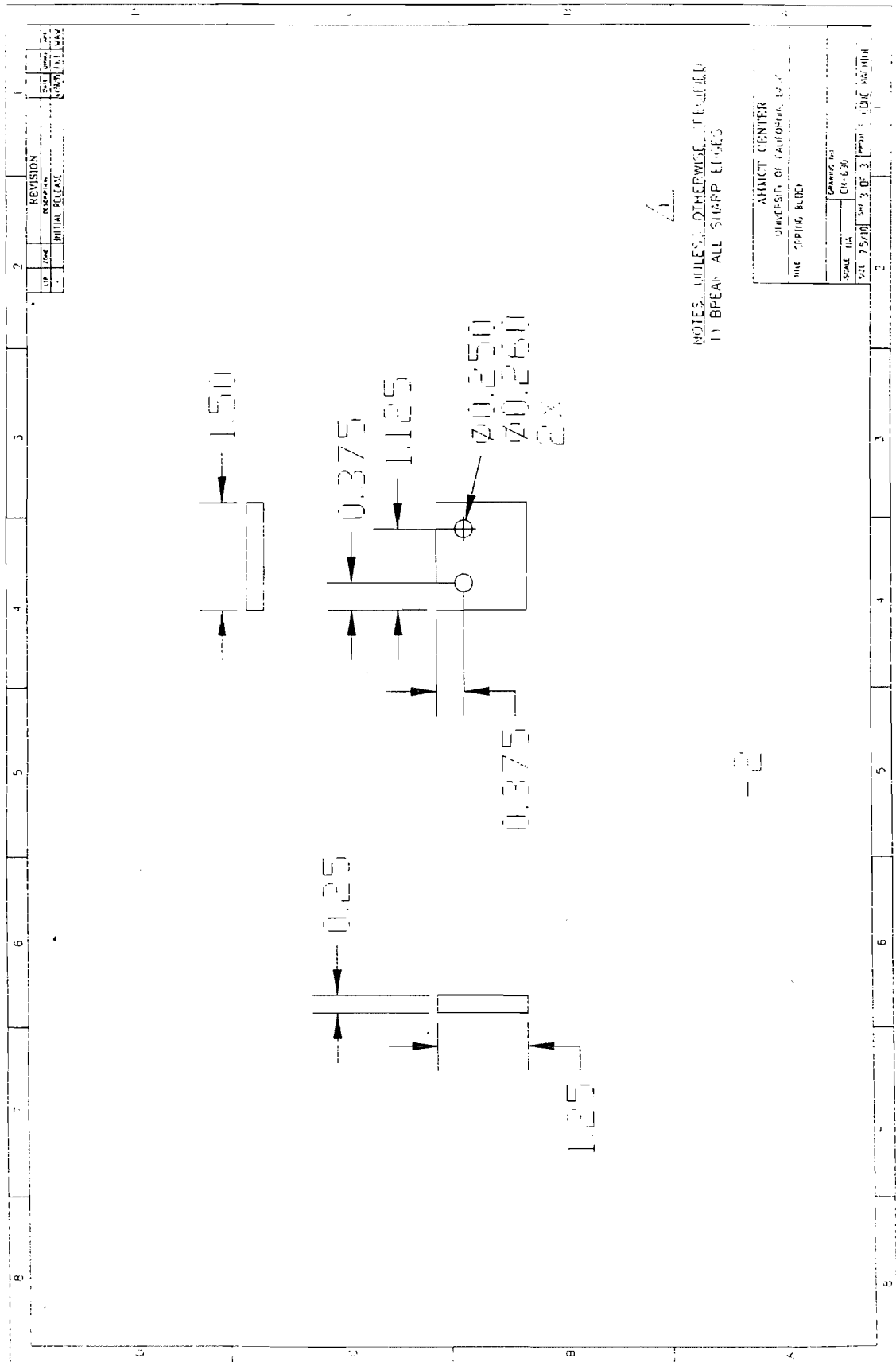
## APPENDIX A

## Detailed Drawings



# APPENDIX A

## Detailed Drawings





## APPENDIX B

### 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

## APPENDIX B

### First Phase Pseudo Code

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:

## APPENDIX B

### First Phase Pseudo Code

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:

## APPENDIX B

### First Phase Pseudo Code

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

## APPENDIX B

### First Phase Pseudo Code

#### 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

## APPENDIX B

### First Phase Pseudo Code

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:

## APPENDIX B

### First Phase Pseudo Code

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

## APPENDIX B

### First Phase Pseudo Code

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



## APPENDIX B

### First Phase Pseudo Code

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

## APPENDIX B

### First Phase Pseudo Code

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

## APPENDIX B

### First Phase Pseudo Code

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:

## APPENDIX B

### First Phase Pseudo Code

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

## APPENDIX B

### First Phase Pseudo Code

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

## APPENDIX B

### First Phase Pseudo Code

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

## APPENDIX B

### First Phase Pseudo Code

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

## APPENDIX B

### First Phase Pseudo Code

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



## APPENDIX B

### First Phase Pseudo Code

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:

## APPENDIX B

### First Phase Pseudo Code

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

## APPENDIX B

### First Phase Pseudo Code

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

## APPENDIX B

### First Phase Pseudo Code

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

## APPENDIX B

### First Phase Pseudo Code

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

## APPENDIX B

### First Phase Pseudo Code

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

## APPENDIX B

### First Phase Pseudo Code

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 C

## 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 input c)
    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)
{

```



## APPENDIX C

## Second Phase Pseudo Code

```

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 deployleftpickup
{
    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 deployrightpickup
{
    while right down limit switch = off do
        deploy right box
    while right arm down switch = off do

```

## APPENDIX C

## Second Phase Pseudo Code

```

        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

```

## APPENDIX C

## Second Phase Pseudo Code

```

    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

```

## APPENDIX C

## Second Phase Pseudo Code

```

    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
}

```

## APPENDIX C

## Second Phase Pseudo Code

```

    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

```

## APPENDIX C

## Second Phase Pseudo Code

```

        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

```

## APPENDIX C

## Second Phase Pseudo Code

```
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
}
```