

Design and Testing of Retrieval Arm and Secondary Funnel Operations for an  
Automated Traffic Cone Machine

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BY

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THESIS

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ABSTRACT

This thesis describes the research and development of an automated cone placement and retrieval machine being done at the University of California, Davis. More specifically it discusses the transition of a Test Bed Automated Cone Machine into a potentially widely used Prototype Automated Cone Machine. The thesis emphasizes the development, design, and testing of automatic systems for cone retrieval and guidance processes.

The PACM is specifically designed for the California Department of Transportation (Caltrans) and conforms with their current cone placement and retrieval operation specifications. The use of the PACM will dramatically increase the safety of cone workers and reduce the amount of time needed for lane closure operations. This will be a drastic improvement over the Caltrans' current cone operations which manually place the cones on and retrieve the cones from the road from either a bucket seat in a specialized cone truck bed or the back of a truck's tailgate. The workers will also no longer be subjected to repetitive stress injuries. To further facilitate the introduction and use of the PACM, it is designed around the Caltrans original cone body truck which can still be utilized for manual cone placement and retrieval operations.

## CHAPTER ONE: INTRODUCTION

Today's impacted highway system needs constant and continued maintenance in order to facilitate the high traffic density traveling at a high rate of speed. In 1993 California motorists drove a total of 428 billion km (266 billion miles), and in this same year \$340 million was spent by the California Department of Transportation (Caltrans) for maintenance (Slater, 1993 Highway Statistics). The traffic density is expected to continue to increase in the future and agencies such as Caltrans are researching ways to maximize utilization of the current infrastructure. Some solutions include high occupant vehicles, high speed platoon vehicles, and autonomous driven vehicles. In order to realize any of these solutions the maintenance efficiency and safety must also increase. The routine maintenance of pavement overlays and ordinary repair must be done in a safe and efficient manner. With increased traffic densities the danger to maintenance workers increases proportionally. The California highway worker is likely to get injured during routine maintenance work since the maintenance work usually must be done directly along the travel lane of high speed vehicles. Therefore, it is imperative that ways be found to increase lane delineation efficiency while reducing the high risk exposure of the worker on the highway.

Typically two methods of delineation are used. One method, a more permanent delineation, is accomplished by placing concrete K-rail (Jersey) barriers along the lane to separate the workers from the traffic. This method is time consuming and requires heavy duty equipment to move and place the barrier rails. The second method, a quicker temporary measure, is achieved by placing traffic safety cones, evenly spaced, along the edge of the lane closure. This method is commonly used since traffic cones are easily transported and relatively quickly retrieved and dispatched, thus limiting the lane closure time. Caltrans has already developed a specialized truck to aid in the task of cone dispensing and retrieval. This truck does provide some limited protection for the workers

who handle the cones, but, a considerable amount of physical effort is required. Also, the workers are still exposed to the high speed traffic in the adjacent lane and its accompanying debris stirred up by this traffic. This combination is still undesirable and causes unnecessary harm to the worker from the exertion of handling the cones and/or from the adjacent traffic.

The Advanced Highway Maintenance and Construction Technology (AHMCT) Center, at the University of California, Davis (UC Davis), has previously been established to address the safety of the Caltrans' workers. The focus of the AHMCT Center includes the workers' unnecessary physical exertion and exposure to dangerous conditions such as high speed traffic. The principal solution to these problems is to replace any repetitive task with automated machinery.

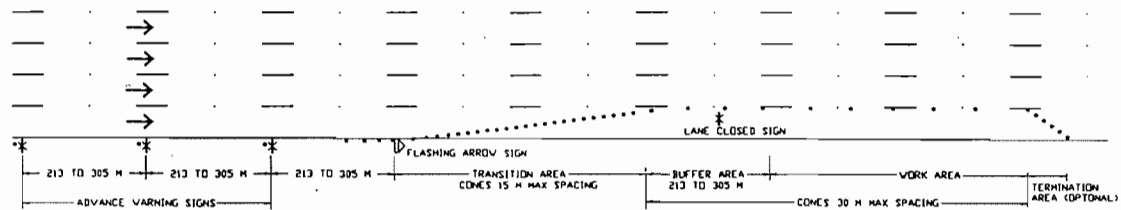
A current project of the AHMCT Center is the development of the Automated Cone Machine. This machinery is developed to address the shortcomings of the present traffic cone dispensing and retrieving methods. The physical functioning of the Automated Cone Machine is meant to correspond directly with Caltrans' operating specifications and procedures. These specifications will be discussed in the next section. The functioning of previously developed cone machines by other manufacturers will also be discussed. The initial efforts of the AHMCT center resulted in a Test Bed Automated Cone Machine (TBACM). The current focus of the center is the transition from the TBACM into the first generation Prototype Automated Cone Machine (PACM), which will be discussed in detail, especially the design of the retrieval arm and secondary funnel, which is the main focus of this thesis.

## **1.1 Caltrans Operations and Existing Procedures**

### **1.1.1 Lane Closure Procedures**

For almost all road maintenance performed, a lane closure is first required to allow delineation of the work area and provide the maintenance crew some safety and

separation from traffic. Most types of road work done is of short duration and uses a typical highway cone as a separation barrier. The typical placement of these cones is done in conformance with Chapter 5 the 1990 Caltrans “Manual of Traffic Control”, and is shown graphically in Figure 1.1.



**Figure 1.1** *Typical Cone Placement Configuration*

The procedure calls for an Advanced Warning Area, to allow for driver reaction and provide time for lane correction. The Advance Warning Area is created by the erection of four warning signs prior to commencement of a traffic cone barrier placement. These signs are placed from a minimum of 213m and up to 305m (700 to 1000ft) apart. The first three signs, made of cloth material with a metal frame, warn the public of road construction and specifies which lane(s) are closed. The wind-porous cloth-type signs collapse to ease transport and deployment, while they allow any wind to blow through the sign area to prevent the signs from blowing over. The procedure calls for a single cone to be placed next to the base of each of these three signs. The fourth specified sign is a flashing sign which flashes an arrow to indicate the merge direction. This sign is preceded by the placement of four traffic cones placed at 15m (50ft) intervals.

The Transition Area is created by the placement of cones, spaced at a maximum of 15m (50ft) apart, in a taper configuration to slowly close the lane. It starts at the flashing sign and stops when the far edge of the closed lane(s) to be closed is reached. The total allowable minimum length of the transition is 305m (1000ft) per lane closed.

Furthermore, if more than one lane is closed, additional flashing arrow signs are required for each additional lane closed.

After the Transition Area and prior to the Work Area a Buffer Area is created. This is an additional safety area where no work is to be performed and allows a vehicle to safely come to a complete stop, prior to entering the Work Area, in case of an unintentional or emergency closed lane entrance. This Transition Area is a minimum of 213m to a maximum of 305m (700 to 1000ft) long, and is created by cones spaced at a maximum of 30m (100ft) apart.

The extension of the buffer area creates the actual Work Area, and is started with the placement of a "Lane Closed" sign. Obviously, this area is specifically set up for the road work to be performed. For the entire length of the delineated Work Area the cones are also spaced a maximum of 30m (100ft) apart. Additional "Lane Closed" signs are required in the work area at 610m (2000ft) intervals.

Finally an optional Termination Area could be created, which consists of a small tapered area at the end of the Work Area. If used, this section of the lane closure will aid redirection of traffic flow back into the previously closed lane. The cones in this section are placed at a maximum spacing of 15m (50ft).

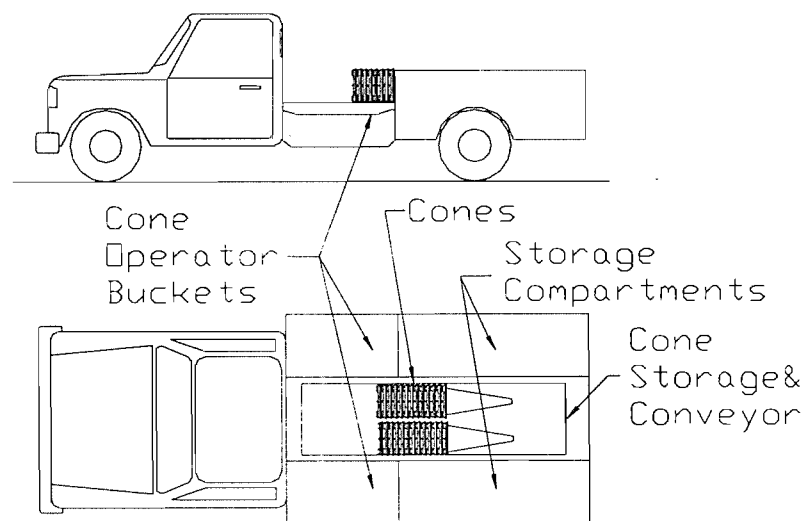
### **1.1.2 Typical Cone Truck**

Caltrans has developed its own specialized vehicle for almost all types of cone placement operation. This vehicle is based on a domestic one-ton pickup truck and usually has a single rear axle with dual wheels on each side. One current model used, a GMC Model 3500HD, has a gross vehicle rating of 6804 kg (15000 lbs), a wheel base of 4.11 m (162 in) and a total length of approximately 6.27 m (247 in).

The truck bed is replaced with a cone body bed which is custom built. This bed was designed by the Office of Equipment at Caltrans; the eleven pages of drawings are dated 3/9/81 and referenced by the number E2-D071-07. This cone body consists of the

main cone storage and conveyer, two seating areas which each contain a reversible bucket seat, and additional storage compartment adjacent to the conveyer belt. The current cost of a cone body retrofit is in the range of \$8,000 to \$11,000, depending on the quantity manufactured. This cone truck with a cone bed is illustrated in Figure 1.2.

The seating areas are outfitted with reversible seats which are used by the cone operator who orients these seats to facilitate the most convenient cone operation. These seating areas are directly behind the cab, are purposely designed close to the ground to aid the cone operator in his duties, and have reinforced steel side wall to provide him with the some protection in case of any mishaps. Each bucket seat only provides the cone operator with a single lap belt.



**Figure 1.2** *Truck Modified for Cone Operations*

The cone storage and conveyer has a capacity of 80 cones in two side by side rows of 40 cones in the longitudinal direction. A payload of 80 cones is typically enough to

close a lane for a length of 1.8km (1.1mi). The conveyer brings the stacks of cones forward to and backward away from the cone operator and is controlled by the cone operator's foot switches.

The storage compartments allow convenient storage of the required road signs, and miscellaneous equipment such as tools and sandbags. If an extra long lane closure is required, additional cones could also be stored in these storage compartments.

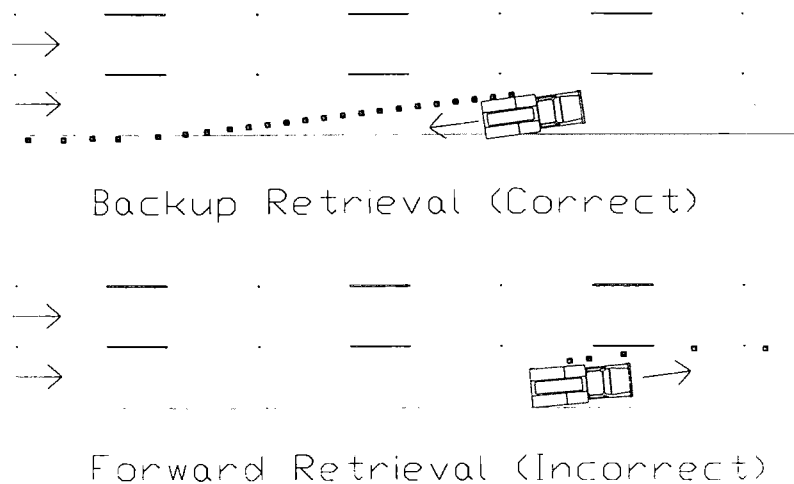
### **1.1.3 Cone Dispatch and Retrieval Operations**

There are two main operations of the cone truck. One is the dispatch of the cones to create the lane closure and delineation. The other main task is the retrieval of the cones after the completion of the road work while operation within the closed lane work area. Both dispatch and retrieval operation require two workers. One worker, the driver, is always positioned in the cab and drives the truck, communicates via two way radio with other crew members, and monitors the surrounding traffic. The second worker, the cone operator, is positioned in a bucket seat of the cone body. The cone operator manually handles the cones during both dispatch and retrieval, and uses the foot switches to operate the conveyor.

During the dispatch the driver drives forward, along with the flow of traffic inside the lane to be closed, with the truck's edge adjacent to the edge of the lane to be delineated. The cone operator sits in the appropriate bucket seat so that s/he is located at the edge of the lane closure and faces forward. The cone operator picks up each cone from the conveyor and physically sets it on the road directly adjacent to the bucket seat area's edge. The cones are placed at a specified separation distance as per the Caltrans Traffic Manual. The spacing of the bott dots usually assists the cone operator in judging this distance, since bott dots are typically placed at more accurately prescribed distances. The speed of this dispatch operation is usually limited by the cone operator's ability to

keep up with cone handling and to prevent the cone from toppling over immediately after placement on the road.

The retrieval must always be done in reverse order of cone dispatch. This order prevents the danger of vehicles entering the closed lane area after the transition area cones have been picked up. The retrieval is typically done while backing up inside the closed lane area, as illustrated in Figure 1.3. This way the cone truck still faces the direction of traffic. This is much safer as it does not confuse drivers with an oncoming vehicle facing their direction, and it eliminates the need for turning the cone truck around in frequently tight right-of-way areas. While retrieving the cones the cone truck driver again drives immediately next to the delineated lane edge. The cone operator usually sits facing the cones to be retrieved. The cone operator reaches out and manually pick up each cone and place it back on the conveyor. Again, the cone operator uses the foot switches to control the conveyor's back and forth motion.



**Figure 1.3** *Typical Cone Retrieval Direction*



The signs are picked up last, after all the cones have been retrieved. Since the retrieval vehicle still faces the direction of traffic, the driver is easily able to merge back into traffic during the departure from the maintenance site.

While operating, the cone truck is almost always shadowed by a shadow vehicle, especially during heavy traffic conditions. This vehicle is used and designed to provide protection to the cone truck in case a stray vehicle enters the delineated closed lane. This shadow vehicle is equipped with a large energy-absorbing crash attenuator which is usually mounted near its rear bumper. This shadow vehicle is strategically positioned between the cone truck and the direction of traffic toward the cone truck, thus creating a physical protection barrier.

#### **1.1.4 Inherent Shortcomings of Cone Procedure**

The dispatch and retrieval methods currently used offer limited protection to the cone operator. The cone bed's bucket seat area reinforcement does provide some very limited protection to the cone operator, and the bucket seat has a seat belt to retain the cone operator in the truck in case of an impact. Although this is an improvement over sitting on the tail gate of a pickup truck, it still allows significant exposure to other dangers.

On a typical freeway, both cone workers are exposed to a large speed differential between their cone truck and the passing traffic. Their only physical protection is the use of the shadow vehicle which is still limited to the longitudinal traffic flow direction only. The side of the cone truck is constantly exposed to the high-speed passing vehicles. This exposure poses the largest danger to the cone operator. His upper torso is unprotected from any road debris kicked up by passing vehicles. Any vehicles traveling close to the lane closure can impact a traffic cone which would then become a dangerous flying object. Even more threatening is the possibility of injury to the cone operator's extended arm into the edge of the travel lane. Besides the immediate dangers due to the location of

cone placement, cone operators must constantly exert themselves during the repetitive motion of cone operation which often leads to injury.

## **1.2 Caltrans Traffic Cones**

Experience has shown that no entity exists that handles cone specification and that numerous different traffic cones exist. These range from conical cones in various sizes to those that have an octagon base and a slender orange tube protruding out of this base. Even when a conical traffic cone is specified by height, cones vary in the slope angle of the conical section, total weight and width of the base. When a large operation has different cones, there are difficulties in stacking, handling, and standardization of the procedure. Therefore, Caltrans saw a need to have traffic cone specifications. They chose to standardize using the heavier 4.5 kg (10 lbs) cone that is 71 cm (28 in) tall. These cones are molded from Poly-Vinyl Chloride (PVC) plastic, and are made up of two basic parts, a base and a conical section. The base is the heaviest part, thus keeping the center of gravity low, and is made of dark gray PVC. The conical section is thin walled and the outer shell is colored a highly visible orange. Since the specified cone is heavier than most cones, this size resists being blown over in windy conditions or by wind caused by a close-passing vehicle. Testing of these cones have shown that the center of gravity is approximately 11.5 cm (4.5 in) from the bottom of the base.

The material properties of these PVC cones vary. The change in properties due to temperature should be considered since the state of California encounters a wide variety of temperatures, ranging from desert heat to sub-zero high altitude winter conditions. The cones become extremely pliable when hot to the point where they can collapse with a small amount of normal force, and they become brittle and rigid when cold. The cones' properties also vary due to different levels of service endured. Some have asphalt and tar coated surfaces while others have twists, indentations and abrasion from being impacted or run over by highway traffic. Also, new cones are still coated with a mold release

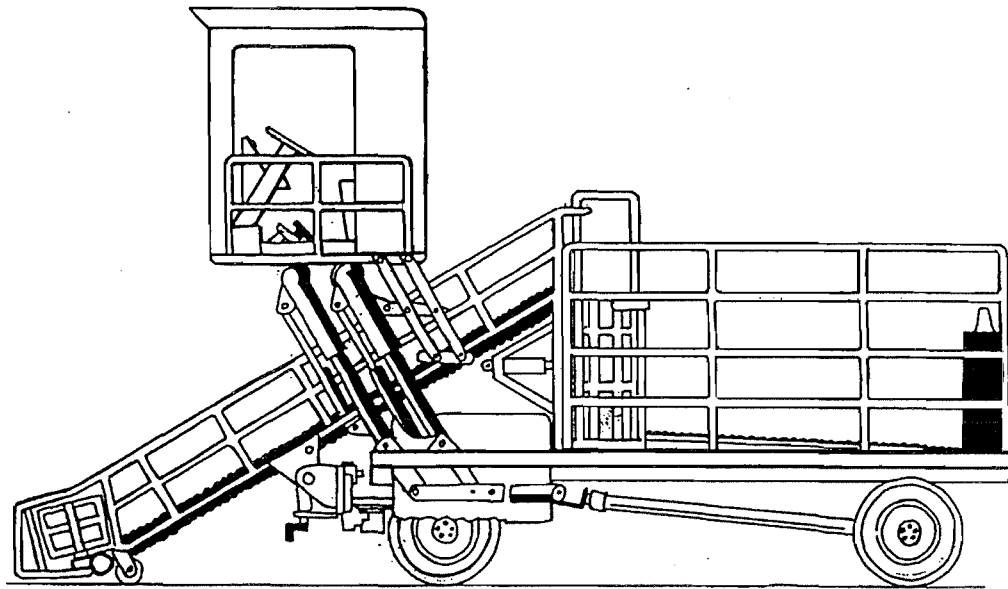
compound used in manufacturing which makes the new cones extremely slippery until this compound is worn off. Typically these properties and cone conditions present no problem for manual operations but the variation in the cones certainly needs to be considered for any kind of automated system.

### **1.3 Existing Automated Cone Machines**

Prior to the development of the Test Bed Automated Cone Machine (TBACM) the AHMCT center researched and investigated the existence of any other machines created for the retrieval and placement of traffic cones (Tseng et al, 1996). Three mechanisms were found that could handle cone operations. These mechanisms are the Traffic Cone Retriever, the French Baliseur, and the Canadian Cone Wheel Dispenser and Collector. Of these three machines only two, the Baliseur and the Cone Wheel, are commercially available. Further patent research conducted during the design of the PACM revealed an additional patent covering the updates to the Cone Wheel.

#### **1.3.1 Traffic Cone Retriever**

The Traffic Cone Retriever, shown in Figure 1.4, was the first automated cone machine to receive a patent, number 3,750,900, issued in 1973. This machine is rather large and is described operating with a forward speed at up to 56 km/hr (35 mph) into a standing cone in order to retrieve it. After the initial contact, the cone enters into the revolving paddles which force the cone onto a conveyor that brings the cone standing up towards the rear of the vehicle. The cone is then stacked vertically in the storage area. This area holds up to 2000 traffic cones.



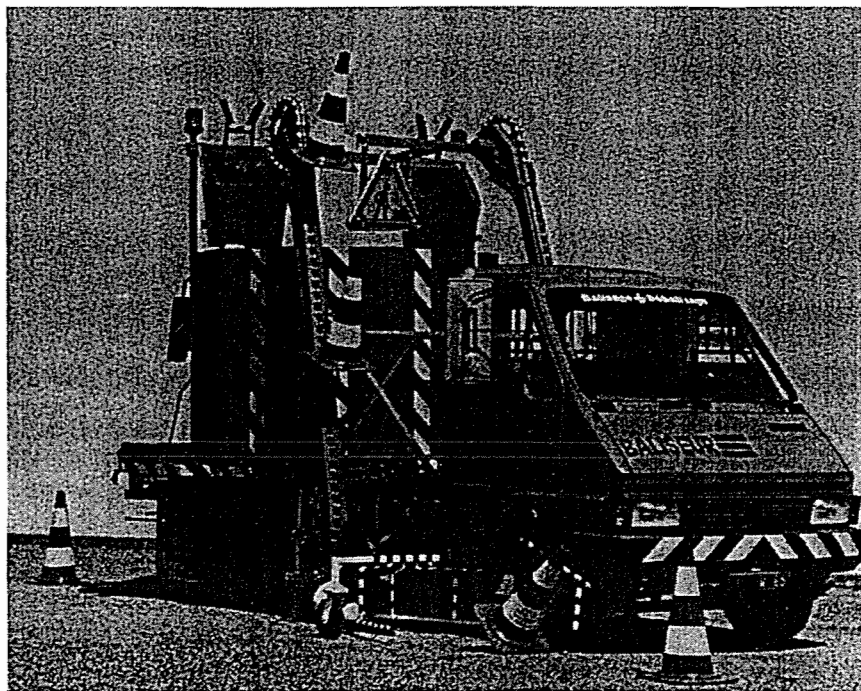
**Figure 1.4** *Traffic Cone Retriever (Fig. 1 of patent #3,750,900)*

The problem with the traffic Cone Retriever is its inability to dispense cones. Furthermore, it seems rather bulky and large and is most likely unable to drive to the maintenance site using public roads since it fails today's vehicle safety standards. Other issues never addressed with this device is the retrieval of cones that are knocked over and pointing various directions. This system was therefore found unsuitable for the Caltrans cone operations.

### **1.3.2 The Baliseur Cone Picker**

This Baliseur Cone Picker, made by the French company SEP in 1986, is shown in Figure 1.5 and holds U.S. patent number 4,597,706. This machine is described as retrieving all cones, standing up or tipped over, at a speed of 18 km/h (11 mph). Just prior to retrieval, the cones are tipped and oriented so that the bottom of the cone faces the retriever. They are then guided up using a chain link conveyor with a guiding mechanism that inserts into the bottom opening of the cone. Once the cones reach the top of the conveyor they are stored in one of the 10 revolving vertical cylinders, which can

hold 24 cones each. In the dispatch operation, each cone is dispensed from the bottom of these cylinders and is then stabilized and guided to its desired lateral position on the road by flexible bristles.



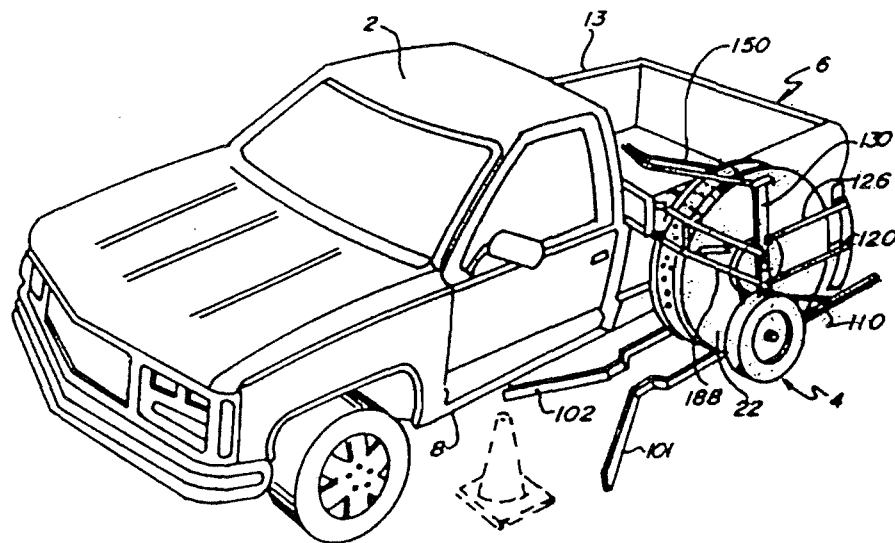
**Figure 1.5** *Baliseur Cone Machine (from SEP brochure)*

This truck is also rather bulky, but the biggest drawback is its requirement for its very own strictly specified cones. Modifying this truck to accept the standard Caltrans cones or adapting the existing Caltrans cone truck with this system was found unfeasible and cost prohibitive by SEP. An even bigger problem is the system's inability to retrieve cones while traveling in reverse as is often done by Caltrans cone crews.

### **1.3.3 Cone Wheel**

The original Cone Wheel Dispenser and Collector designed and manufactured by the ADDCO company, shown in Figure 1.6, was issued the U.S. patent number 5,054,648, in October of 1991. This wheel is claimed to be capable of retrieving and

dispatching cones at speeds up to 40 km/h (25 mph). However, this operation is not fully automated and still requires a cone operator in the truck bed. To retrieve a cone, the driver maneuvers the truck so that the cone wheels rolls over the cone, which will cause the conical section of the cone to become wedged and lodged between two disks. These two disks together make up the large cone wheel of approximately 1.2m (4 ft) in diameter and will turn proportionally to the forward speed of the truck. The wedged cone is brought up to the top during the rotation of the cone wheel. At the top the cone is stripped of the wheel by a metal bar and left for the cone operator to manually handle and store. The cone dispatch operation is similar but in opposite sequence of the retrieval. The cone operator will manually set a cone upside down in the top of the wheel. As the wheel rotates the cone is firmly placed upon the road surface and then stripped loose of the wheel by a metal bar.



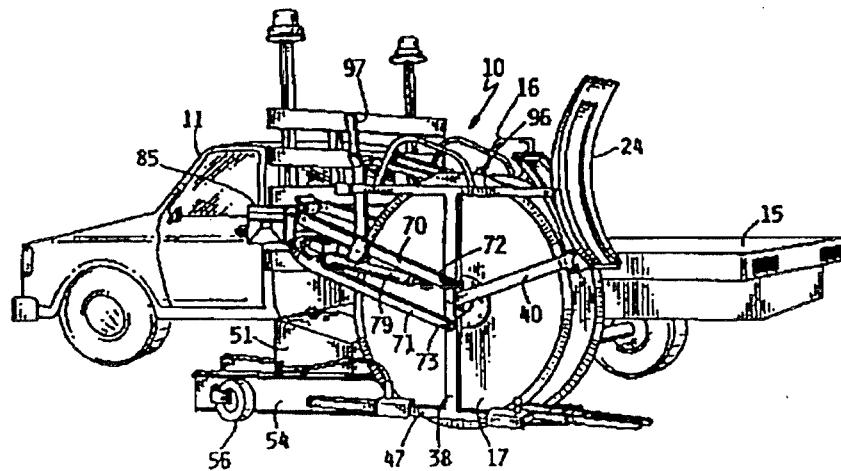
**Figure 1.6** *Cone Wheel (Fig. 1 of patent #5,054,648)*

Although this system is used in several states and other countries it still has certain significant shortcomings. One problem with this system is the setup of the cone wheel. The entire wheel is stored in the truck bed during transport to the maintenance site and requires significant manual force to deploy the wheel to the side of the truck. The operational shortcomings are its inability to retrieve cones while traveling in reverse, or cones that are tipped over with the point facing away from the cone wheel.

The updated patent on the Cone Wheel, number 5,213,464 issued in 1993, discusses changes in operation and covers some of the above described shortcomings. The updated Cone Wheel shown in Figure 1.7 has a slightly slower operational speed of 32 Km/h (20 mph). The main difference in operation is the way in which the cones are grabbed, in that the newer version will squeeze the base of the cones between the two disks of the wheel rather than the conical section. This new retrieval operation causes significant bending and deflection of the cone base during the squeeze time in the wheel. The inside of the wheel disks have scoop-shaped guides to engage and confine the cone being squeezed. The cone is lifted upwards during the wheel's rotation. During this upward rotation the squeeze on the base is loosened to allow the cone to rotate so that the tip of the cone points down. Similar to the old model, the cones arriving at the top are stripped from the wheel by a stripper bar and are left to be manually handled and stored. The cone dispatch operation with the updated version of the Cone Wheel is very similar. The only significant change is the addition of a loading magazine at the top to aid the cone operator with the loading of cones into the wheel.

One significant overall change is the addition of hydraulic cylinders which can either lower the wheel from the truck bed at the beginning of work or lift the wheel onto the truck bed at the conclusion of work, thus eliminating the high amount of physical work previously required. The redesigned wheel also facilitates cone retrieval in the reverse direction after the entire wheel has been completely disconnected and remounted in reverse. If wheel mounting brackets are installed on both sides of the truck the wheel

is versatile enough to allow mounting on either side. These combinations allow for cone operation on both sides of the truck and in either forward or reverse direction, but require a significant amount of changeover. The only unclear aspect of this newer version is whether the cones are always properly oriented for retrieval by the cone guides or need manual intervention when the cone is tipped over and pointing toward the cone wheel.



**Figure 1.7** *Cone Wheel II (Fig. 1 from patent #5,213,464)*

Although significant improvements were made to the Cone Wheel it still has several undesirable characteristics. First, a cone operator is still required in the truck bed, and s/he is left open to the associated dangers. The change from cone dispatch to retrieval or visa-versa requires manual changes. The cone stabilizers need to be installed or removed, and the scoops-shaped guides on the inside of the wheel disks need to be tilted up or down. Also, in order to operate the truck in the reverse direction the whole wheel assembly needs to be disconnected and remounted in reverse. This apparatus also causes undue stress to the cone base during the retrieval operation and could wear out the



cones prematurely. Manual intervention probably still needed when the cone is tipped over and pointing toward the cone wheel.

Overall, the Cone Wheel operation hardly seems an improvement over the current Caltrans' method that uses a cone truck. The cone operator is still outside the confines and safety of the truck cab and has to manually handle the cones. During the setup of the wheel, usually done directly adjacent to traffic, the cone workers are outside the truck.

## **1.4 Design Process**

The approach to the design of the Prototype Automated Cone Machine (PACM) must be done in a methodical way in order to ensure success of the entire project. All the experience gained from prior endeavors or other similar products features must be considered, and in this case all the lessons learned from the Test Bed Automated Cone Machine (TBACM) must be incorporated into the design process. Since the PACM is a team project the machine as a whole must be divided into individual subsystems. This allows for individual subsystem concept development, evaluation and testing. Through careful team work, and constant monitoring of how one subsystem affects the other, these subsystems are integrated into the machine as a whole.

Prior to beginning any project, the functional specification and requirements must be generated. Then, any ideas or concepts generated are visualized and judged individually, based on their merit and feasibility using a systematic approach. This approach uses a trade-off table which considers all the desired qualities, features and detrimental attributes. Each of these is then rated on the same scale and given an importance or weighting factor as a multiplier. The total score is then added up to provide a total point value for each concept. This process clearly reveals the superior concept without any personal preconceptions or prejudices, but the entire process might require several iterations. Once the overall best concept is selected the entire product must be subdivided into subsystems to allow multi-level engineering and team work.

Careful selection of the subsystems will provide easier subsystem integration and interfacing with the rest of the machine. Once the subsystems are established the entire process of concept generation and the systematic rating must be repeated to again reveal the superior subsystem concept.

Once the subsystem concepts are decided, the next step of detailing the design can begin. This is by far the most time consuming, detailed and intricate task. Not only must care be taken that each subsystem meets its required functions but it must also interface correctly with other subsystems and the machine as a whole. Then, all the correct materials must be chosen based on durability, strength, corrosion resistance, wear, density, and machinability. The geometric dimensions of each part must be determined and analyzed for stresses and failure. It is often an iterative process to come up with the correct part that is resistant or immune to failure and made from the correct material. The interaction between the parts must also be analyzed. The wear, frictional interactions, tolerances and clearances or fits between mating parts must be correct to allow for proper assembly and operation. Once all the decisions for each part has been made, they must be communicated to the fabricator or machinist through a detailed drawing so that fabrication can commence.

After the fabrication of each part the subsystems are assembled to create the machine, and allow testing to begin. Through testing, all the concepts are either proven or rendered inoperable and weaknesses are exposed for future enhancements. During the testing phase, the engineer can observe the entire machine interacting and functioning. This leads to much insight into the product design and points to the improvements and refinements to be made. Often these changes can be incorporated into the working machine, but in some cases they lead to the next generation of the prototype.

## 1.5 Overall Purpose, Objectives and Requirements

Obviously there is a need for automated cone devices, as several companies such as SEP and ADDCO have developed automated cone machinery. However, none of these devices are adequate to replace the current Caltrans cone truck, nor are they compatible with Caltrans' methods of road delineation by the use of cones. Still the Caltrans method of manually handling the cones, and the cone operator's vulnerable position in the buckets needs to be improved for increased safety. The cone operators receive injuries from repetitive stress and risk even more serious injury since they are so close to the high speed traffic while using the standard Caltrans cone truck.

To remedy the safety situation, the AHMCT Center at the University of California, Davis has developed an automated cone machine compatible with all Caltrans methods and specifications. Previously, the TBACM was built to develop working concepts and prove feasibility. Much knowledge was gained from this endeavor. To further develop the project the first prototype is currently being designed and manufactured by the AHMCT Center to be introduced into Caltrans' fleet of equipment as a working machine. This PACM will be introduced into the fleet to receive more detailed feedback from the maintenance workers who will use the PACM on a daily basis, prior to mass introduction and production of PACM's. Numerous Caltrans workers were consulted throughout the development of the PACM to ensure and enhance the overall success of the end product.

The PACM has to fit and comply with numerous specifications and constraints. First of all, the PACM must make no compromise of the current operation, standards, or dispatch and retrieval rates. The PACM has to conform to all the typical design criteria such as durability, low maintenance, operation safety, and monetary considerations. Furthermore it must comply with all of the more project-specific criteria. The safety enhancements must preclude the need for any cone operator to be in the truck bed or bucket seat area, and the need for any physical work or intervention during normal

operation. As a result all the cone workers will be located only in the safety of the truck cab. The PACM might only require one person to drive and operate the control panel. Consideration must be given to the level of technical expertise of the workers who operate the PACM's control panel. Therefore, the control panel must be user friendly by being simple to use and easy to understand. The PACM must use the standard Caltrans cone currently in use to prevent a retrofit or replacement of the existing cone stock and make introduction of the PACM as easy as possible. The machine must operate and not jam or malfunction with cones that are previously used and worn, or with new cones that are slippery due to the coating of mold release compound.

The PACM should not sacrifice the current eighty-cone payload quantity. If the eighty-cone payload is somewhat diminished it may be remedied by a future enhancement to the PACM that incorporates a double stacking mechanism to increase the maximum cone quantity. The standard cone truck should be seen as a starting point for the PACM to allow for easy retrofitting of any existing cone trucks in the fleet into an PACM which would also keep the cost down. This will also prevent the need for specialized trucks and facilitate the multipurpose use of the PACM as is currently often done with the cone trucks by maintenance crews.

Any on the job site mechanism setup required by the PACM retrofit must be automated to keep any worker from having to leave the safety of the truck cab prior to using the PACM. These same mechanisms must also be automatically retracted at the conclusion of the cone retrieval. This will allow for easy and safe transport to and from the maintenance site and safe operation at the site.

No manual labor should be required if a system failure occurs. In this case, the PACM should be useable with the old standard manual procedure without significant interference from any equipment installed for automation. Thus the conveyer belt must still be operable with the foot switches located in the bucket seat area. The buckets seat must also be installed, empty, and reversible.

The PACM should be able to dispense cones from either side of the truck while driving forward. It must retrieve cones while traveling forward and backward and from either side of the truck without any manual changeover. The PACM must also be able to retrieve any cone that has been knocked over, and pointing in any direction, again without manual intervention. The PACM should have no preclusion from operating in varied weather conditions, and must not fail due to temperature variations or wet conditions.

This PACM developed, which meets or exceeds the operation criteria discussed above, results in a multipurpose cone machine. Not only will it suit the Caltrans operation well, it will conform to most cone operations used in other municipalities and states as well as other countries.

The purpose of this thesis is to document the development of the PACM with emphasis on the development, design, manufacture and testing of the Retrieval Arm and Secondary Funnel, all of which encompass my personal contributions to the AHMCT center's efforts.

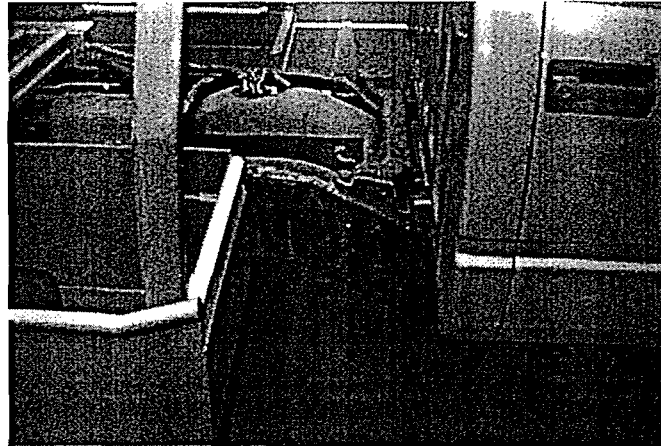
Chapter 2 will present the PACM as a whole by discussing all the subsystems that make up the PACM. This will provide an understanding of the machine as a whole prior to the detailed discussion on the Retrieval Arm and Secondary Funnel. The testing of the TBACM's Retrieval Arm and Secondary Funnel is presented in chapter 3. The new design and other improvements to these systems will be presented in chapter 4. Chapter 5 will present the testing of the PACM Retrieval Arm and Secondary Funnel. The thesis will conclude with some final conclusions and recommendations in chapter 6.

## CHAPTER TWO: PROTOTYPE AUTOMATED CONE MACHINE

The development of the TBACM is discussed in detail in Tseng et al, 1996, and will not be discussed in this chapter. This TBACM has shown me the nature of cone behavior and provided much valuable insight for the prototype machine. Major subsystem differences between the TBACM and the PACM will be elucidated.

The topic of this chapter is to describe the PACM and its subsystems. This is done so that an understanding of the machine as a whole is established prior to detailed discussion of the development and design of the retrieval arm and Secondary Funnel Systems.

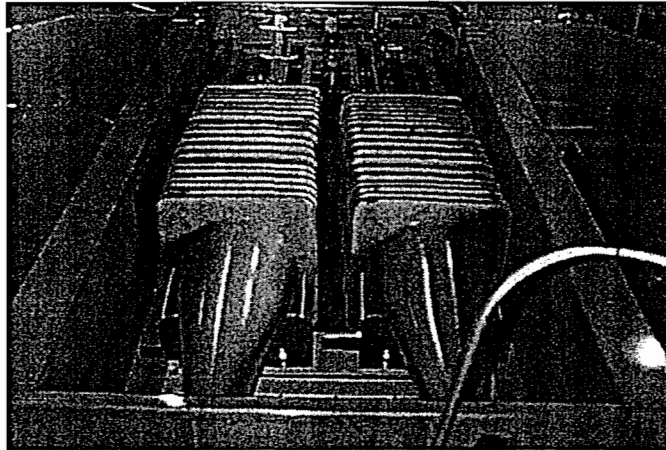
The PACM is based on a standard domestic one-ton truck whose truck bed has been replaced by a cone body bed, which comprises the typical standard Caltrans cone truck. In order to facilitate the automated machinery the cone bed was moved back from the cab 43 cm (17 in), as shown in Figure 2.1. The PACM has nine equally important subsystems which work together to make up the PACM as a whole. These subsystems are presented in the order encountered by a cone traveling the path from the conveyor storage to the road. Then, the additional subsystems encountered only during the retrieval from the road are presented, and the chapter concludes with the Automated Control and Power Systems.



**Figure 2.1** *Cone Truck with Rearward Moved Cone Body*

## **2.1 Main Conveyor Belt System**

The standard Caltrans cone body bed is equipped with a longitudinal conveyor belt which is the main component and the starting point of the Main Conveyor Belt System (MCBS). In the event of an automated equipment failure, manual operation would be needed, and the MCBS is therefore kept as simple and as close to the standard manual configuration as possible. The main parts and operation of the conveyor belt were maintained and only modified slightly for the PACM. This method maximizes conveyor cone storage, and minimizes design time and costs. As in the manual operation, the PACM stores the cones in two adjacent stacks, in the longitudinal direction, on top of the conveyor belt. Four main modifications or equipment additions were done to the conveyor belts. First, the overall length of the belt was shortened by 86 cm (34 in) in order to allow the necessary room for a cone to be turned from an upright standing position to the horizontal storage position or vice versa. The three additions are the Cone Support Fixture (CSF), Infrared Sensor Mounts (ISMs), and the Lateral Cone Guides (LCGs). The original shortened cone body conveyor belt, along with the three mounted modifications comprise the MCBS, which is shown in Figure 2.2.



**Figure 2.2** *Main Conveyor Belt System*

The CSF is mounted on top of the belt and is shown in Figure 2.3. The purpose of the CSF is to keep all the cones lined up in the longitudinal direction and keep the cone bottom base plane perpendicular to the belt surface. These tasks are accomplished by holding the very first cone in each stack in the correct alignment. This alignment is required for proper interfacing with the Stowage System which removes the cones during the dispatch mode, and then, replaces the cones in the stacks during the retrieval mode. The operation of the Stowage System will ensure that each subsequent stored cone is firmly and correctly placed into the previous cone which will continue the correct alignment of the cone stacks with the aid of the CSF.



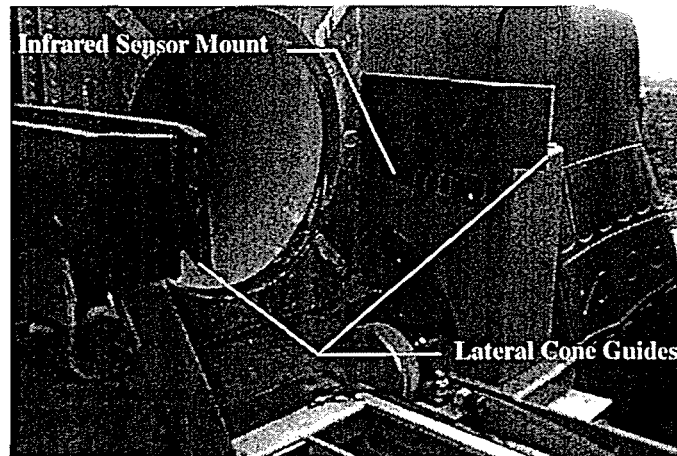
**Figure 2.3** *Cone Support Fixture*



Both of the ISMs are located near the front and next to the MCBS belt, and driver side ISM shown in Figure 2.4. The purpose of the ISM is to monitor the position of the last cone of each stack and transmit this position to the control system. The cone stacks have two basic positions. One position is when the cone stacks are moved one cone base thickness away from the MCBS front edge to allow receiving room for a cone to be stored, as is done in the retrieval mode. The other position places the cone stacks at the very edge of the MCBS so that the Stowage System can remove the last cone in a stack during the cone dispatch mode.

Since the cone stacks are both on the same belt, each operation mode must use each stack alternatively to keep the stacks of equal length or at most offset by one cone. The two infrared sensors mounted in each ISM monitor the two distinct cone stack positions by transmitting two beams across their corresponding planes. Each infrared plane corresponds to a cone stack position. Basically, if a cone is present in the infrared plane the beam will not be reflected by the reflector across from the infrared transmitter and receiver sensor. Of course, if no cone is present the beam will be reflected and is detected by the receiver of the sensor. The automated controls will use the sensor's signal differently in each mode of operation.

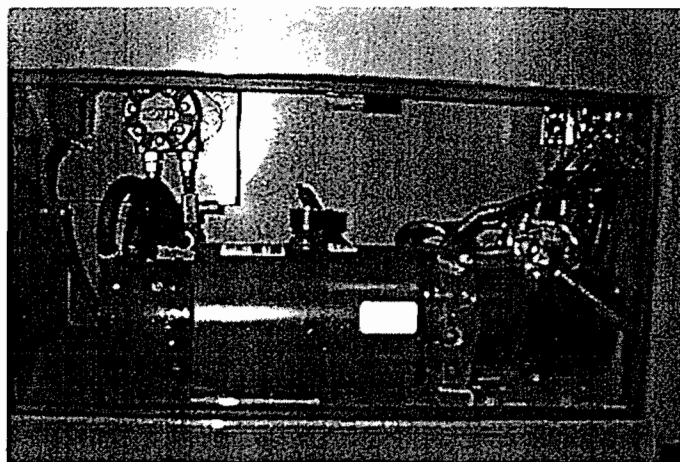
In the dispatch mode it moves the belt with cone stacks forward until the instant the infrared beam of the forward cone stack position plane is interrupted by the cone stack. During the retrieval mode the belt is moved backwards until the moment the infrared beam of the cone stack receiving position plane is reflected after the departure of the last cone in the stack. Since each set of infrared sensors monitors each stack independently, the control system is able to discern the stack in which to place or remove a cone. Again, the ISM System is required for proper interfacing with the Stowage System which can place or remove cones only from the correct position on the belt.



**Figure 2.4** *Infrared Sensor Mounts and Lateral Cone Guides*

The LCG keeps the cones in the correct lateral position on the MCBS, again to facilitate proper interfacing with the Stowage System. These guides are composed of black Ultra High Molecular Weight (UHMW) Polyethylene molded to guide the cone to the proper lateral position and are mounted near the center line of the cone as shown in Figure 2.4.

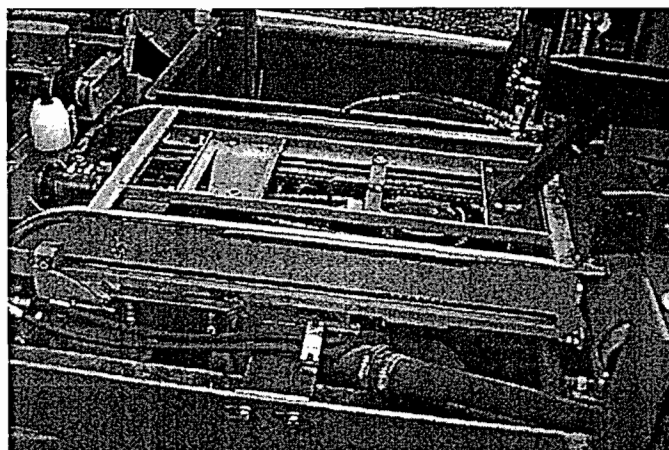
The main conveyor belt comes equipped with its own power system and is shown in Figure 2.5. This system uses a 12 Volt, Direct Current (DC) motor that is directly coupled to a hydraulic power unit with an attached switching manifold. This manifold controls the flow direction of the pressurized hydraulic fluid to the rotary motor. This motor in turn rotates the rear roller of the conveyor belt in the rotation direction dependent on the fluid flow direction. Each rotation direction corresponds to either forward or backward motion of the main belt. The whole system uses a 1.9 l (0.5 gal) fluid tank. Since the overall load on the system was not increased, no improvements to the system were required. This original power system is intentionally left intact to allow the standard foot-switched belts operation in case an automated system failure occurs.



**Figure 2.5** *Main Conveyor Belt Power System*

## 2.2 Stowage System

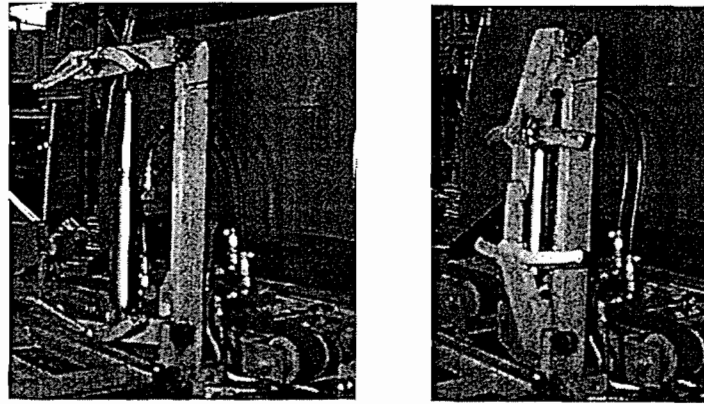
Centrally located between the two cone operator buckets is the Stowage System which is shown in Figure 2.6. The main purpose of the Stowage System is to provide a cone transport link between the Lateral Conveyor Belts and the MCBS. This requires the Stowage System to rotate a cone 90° since the cone is in an upright position on the lateral conveyor belt and is stored in a horizontal position on the MCBS.



**Figure 2.6** *Stowage System*

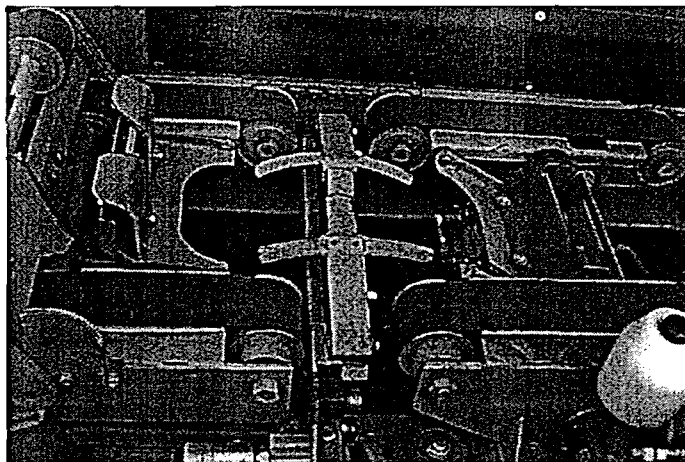
During any cone transport by the Stowage System the cone is firmly grabbed on the inside of the conical section with a set of expanding grippers. These grippers are

pivot-mounted on an arm and linked by a double acting low pressure hydraulic cylinder. This cylinder's action opens and closes the grippers as is shown in Figure 2.7.



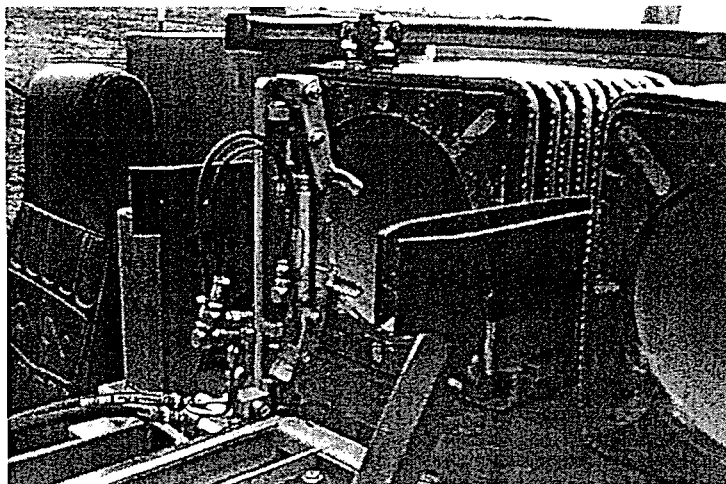
**Figure 2.7** *Open and Closed Grippers*

A circular bend angle iron section of the gripper serves as a high friction contact on the inside of the cone's conical section. This whole gripper arm assembly is again pivoted on a roller assembly. This roller assembly moves along a V notched track to facilitate movement between the MCBS to the lateral conveyor belt. Mounted on top of this V track is a contoured surface which controls the pivot motion of the gripper arm assembly. This surface forces the gripper arm assembly to fold to a horizontal position at the lateral conveyor belt and forces it to a vertical position at the MCBS. When the gripper arm assembly is at the lateral conveyor belt, it is located below the lateral conveyor belts surface so that the cone can be moved over the top of the grippers as shown in Figure 2.8. At this point, the grippers can either grip the cone from underneath as during the retrieval mode or release a cone that has just been placed on the lateral conveyor belt as during the dispatch mode.



**Figure 2.8** *Gripper Arm Assembly at Lateral Conveyor Belt*

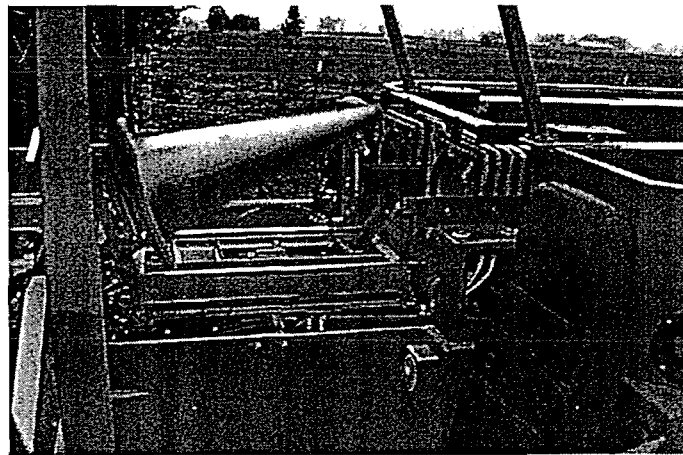
At the other end of the track, the gripper arm assembly is vertical at the bottom of the cone stack on the MCBS as shown in Figure 2.9. The gripper arm assembly at this location can again either grip a cone to be dispatched or release a cone that has been placed in the stack.



**Figure 2.9** *Gripper Assembly at MCBS*

Since there are two different stacks of cones on the MCBS, a gripper arm assembly with its track was manufactured for each stack. As previously described the cone stack must be accessed alternately which is performed by the Stowage System. The Stowage System was cleverly designed so that this alternating accessing motion is accomplished with the power of a single hydraulic vane motor. The gripper arm

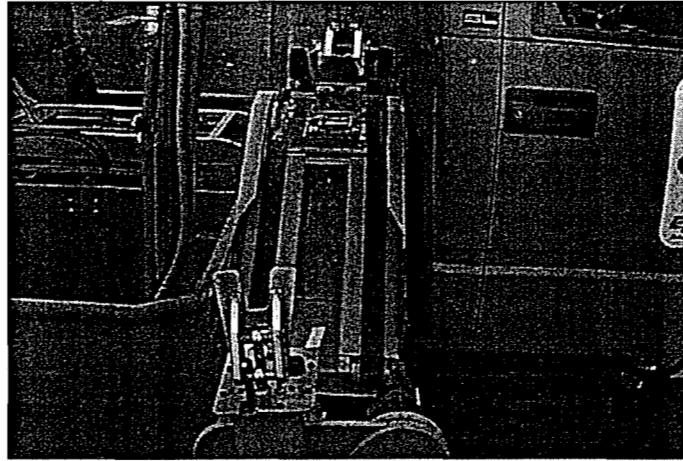
assemblies are linked via a single chain so that when one arm is at the Lateral Conveyor Belt the other is located at the MCBS. To exchange the gripper arm positions, the hydraulic fluid flow to the vane motor is reversed and the grippers will be moved to the other end of their track. This combination of components allows for efficient and convenient cone operation between the Lateral Conveyor Belt and the MCBS. The main difference in the PACM Stowage System is the gripper orientation. The new gripper are in the vertical plane which increases the gripper's moment arm with respect to the cone resulting in a better overall hold on the cone. A cone moving on the Stowage System and in transition from upright to horizontal position is shown in Figure 2.10.



**Figure 2.10** *Stowage System in Operation*

### **2.3 Lateral Conveyor Belt**

The gap created by moving the Cone Body backward (as previously shown in Figure 2.1) is occupied by the Lateral Conveyor Belt (LCB) System. This system spans the entire width of the truck and is responsible for the lateral motion of cones. The LCB interfaces with the Stowage System in the middle of its length and terminates at the Drop Boxes on both ends. This is shown in Figure 2.11.



**Figure 2.11** *Lateral Belt System*

The LCB is comprised of a total of ten notched groove belts, each 5 cm (2 in) in width. The belts are spaced so that they will contact the frontal and rear edges, usually the feet, of a cone placed on the system. The frontal and rear tracks always move at the same rate and each equally support the weight of the cone. Any cone moving on the LCB is guided on both sides with guides. The frontal guide spans the entire length of the LCB, while the rear guide is interrupted at strategic places to allow for interfacing with the Stowage System.

At the Stowage System interface the belts are interrupted to allow the stowage grippers room to move to their horizontal position below the surface of the LCB. These interruptions leave gaps in the belt and create a discontinuity in the carrying of the cone while moving laterally over these gaps. These gaps are designed so that the cone remains stable at all times during any lateral movement.

The LCB operates in both modes of cone operation. During the dispatch mode, the cone is placed on the belts by the Stowage System. After the Stowage System gripper releases the cone, the LCB then laterally moves the cone to a desired Drop Box, depending on which drop off side is requested by the operator. During the retrieval mode, the cone is slid, by the Retrieval Arm, onto the LCB which has its belts in motion to receive the moving cone, and the cone is transported and then positioned on top of one

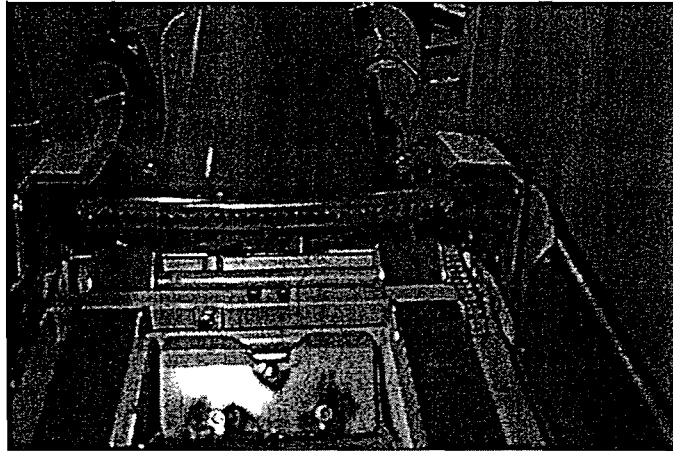
of the two gripper arm assemblies of the Stowage System. To gauge the correct position of the cone over the gripper, the LCB has gates with switches which are activated by the impact of the cone's lateral motion. The instant this switch is activated, the motion of the lateral belt is stopped by the Automated Control System. In case of any delay, the gates also serve as a physical stop for the cone to ensure that an overshoot of correct cone position does not occur. These gates are required to be able to retract from or protrude above the top surface of the LCB. This requirement allows a cone to transverse the LCB as needed in a dispatch; the cone is only stopped during the retrieval mode. Since alternate cone stacks are used during the retrieval mode, alternate gates will be employed to position the cone over alternating gripper assemblies.

Also part of the LCB are the two Wing Actuators, positioned at each end of the LCB. The Wing Actuators are lifted up or positioned down, again depending on the operating mode. It should be noted that the PACM Wing Actuators' function is drastically changed from that on the TBACM. During the cone dispatch mode the Wing Actuators are inclined down at a  $30^\circ$  angle. This will bring the cone as close to the ground as possible just prior to being positioned into a Drop Box. This low cone position is desirable since the cone controllability increases when it is dispatched closer to the ground. In the retrieval mode, the Wing Actuator is raised from the dispatch position and placed at a  $14^\circ$  angle. This higher position is required by the Retrieval Arm to ensure correct placement of a retrieved cone onto the LCB. A small hydraulic cylinder positions the Wing Actuators and receives its position command from the Automated Control System.

Sometimes a cone transversing on the LCB is subjected to other acceleration forces due to the motion of the truck. The cones are especially vulnerable during their motion on the inclined Wing Actuators. Therefore, the cone guides on the Wing Actuators section of the LCB are folded over to create extra guidance and prevent the



cone from toppling over. The correct cone position on the LCB and the fold over guides are shown in Figure 2.12.



**Figure 2.12** *Cone Positioned on Wing Actuator*

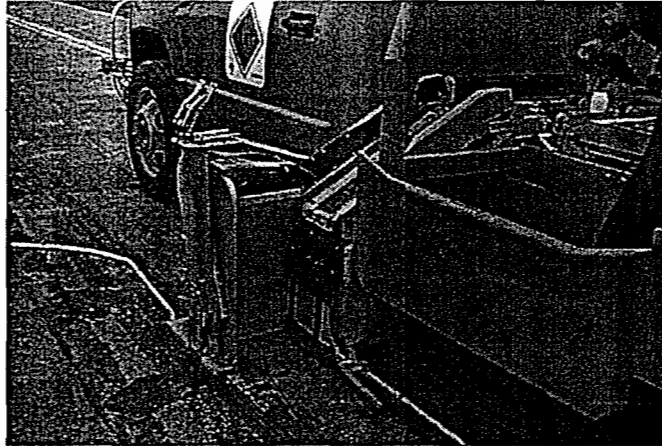
The LCB is powered by a single hydraulic rotary motor which rotates one main shaft of the LCB. Since all the belts are notched and roll over matching notched pulleys, with the front and rear pulleys connected by shafts, the entire set of ten LSB belts rotates in synch and at the same speed. In the case that no inter shaft belt connection can be made, a small plastic chain will connect the shafts. The direction of the LSB is controlled by the hydraulic fluid flow direction to the rotary motor. The speed of a transversing cone on the LSB is set at approximately 0.6 m/s (2.0 ft/s). This lateral speed is close to the stable operating limit which was determined by testing the cone's stability at higher speeds.

## 2.4 Drop Boxes

Located at both ends of the LCB is a Drop Box System (DBS), which is shown in Figure 2.13. The DBS only operates during the cone dispatch mode, and also serves as a mounting base for other subsystems such as the Retrieval Arm and Secondary Funnel System. The basic DBS operation is to receive the cone from the LCB and to allow the

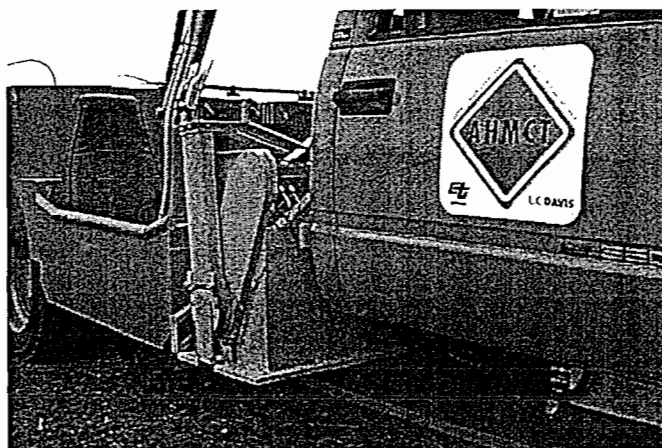
cone to drop 55.9 cm (22.0 in) of the LCB edge down to the ground. In order to position the cone upright when received in the inclined position from the LCB and during the free fall, a holding mechanism was added. This holding mechanism embraces the conical section of the cone, 30.5 cm (12.0 in) above the base, with nylon bristles. The bristles allow the cone to slide down vertically while providing circumferential force around the conical cone section, thus ensuring that upright cone position is maintained during the drop.

A dropped cone often becomes unstable since it is dropped from a significant height to the road surface, which has a significant speed differential with respect to the cone truck. If a dropped cone is not stabilized it will likely topple and be incorrectly dispatched. To stabilize the cone, flaps were added inside the drop box. These flaps are forced open by the dropping cone and they then snap over the base to provide the stabilizing guides. These guides are then continued rearward with the direction of the departing cone to provide continued stabilization. The Drop Box with the holding mechanism and stabilizing flaps and guides is shown in Figure 2.13. The total effect of all these mechanisms and guides is a cone that is forced to stay upright after the dispatch. The guides are molded from UHMW Polyethylene which is resistant to impacts caused by the abnormalities encountered in the road. Once the cone leaves the stabilizing guides of the DBS, it has completed its journey from the MCBS to the road.



**Figure 2.13** *Drop Box System (Left Side)*

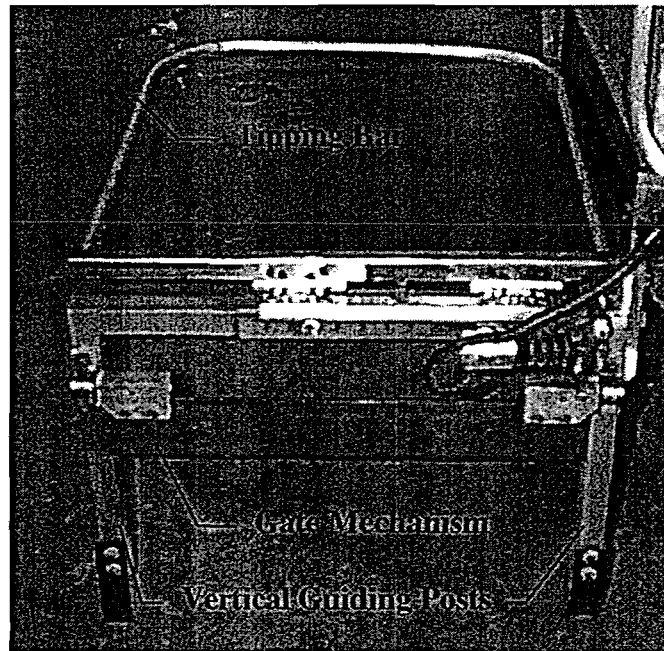
When not in use, the DBS is automatically stowed by retracting the DBS inside the confinement of the PACM body as shown in Figure 2.14. The retraction of the box includes all the attached subsystem components. Each DBS is mounted on two V tracks mounted at a  $27.5^\circ$  angle with respect to the horizontal. The rear track is mounted to the cone body while the front track is cantilevered from the truck's frame. This incline angle of the mounting track allows the DBS to be lower 25.4 cm (10.0 in) and moved out laterally 49.0 cm (19.3 in) from the stowed position. The motion of the DBS originates from a ball and screw shaft powered by a 106 W (1/7 Horse Power) DC Motor. The motion and position of the DBS is controlled by the Automated Control System.



**Figure 2.14** *Stowed Drop Box System (Right Side)*

## 2.5 Primary Funnel System

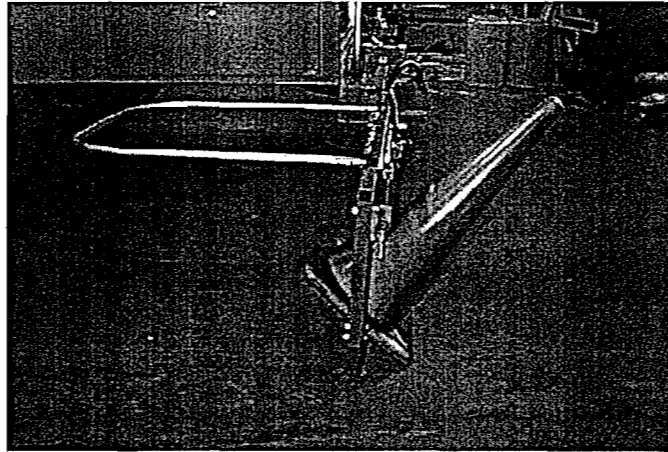
The Primary Funnel System (PFS) is only used during the retrieval mode of operation and is the first subsystem encountered by a cone being retrieved from the road. The main purpose of the PFS is to reorient the cones so that the bottoms will face the Secondary Funnel within an acceptable angular range in the horizontal plane. The PACM has a PFS mounted on all four corners of the truck. The four systems are necessary for cone retrieval from either side of the PACM and while driving forward or in reverse. Each PFS is comprised of three main components, the Gate Mechanism, the Vertical Guides, and a Tipping Bar. The Gate Mechanism is a metal plate that is able to freely rotate along its longitudinal top edge and has locking device that can keep it rigidly in the vertical position. This locking device is activated by pushing a button on the truck cab. The Vertical Guides consist of two downwards pointing metal tubes. The Vertical Guides will rotate any cone, in the horizontal plane, that does not have its longitudinal axis coinciding with that of the truck. The Tipping Bar is only required in certain instances which will be explained and clarified below. The right rear PFS and its main components are shown and labeled in Figure 2.15.



**Figure 2.15** *Primary Funnel System*

The PFS must accept any cone orientation, including cones that have been tipped over and pointing in any direction. The PFS can encounter three basic categories of cone positions during its operation. The first category is a cone that is properly standing upright. The second is a cone that was knocked over and has its tip generally pointing away from the truck. And lastly, the third type of cone position includes cones that are knocked over and have their tips generally facing toward the truck.

The first type of cone position is the easiest cone position to handle, as well as the most common encountered. The Gate Mechanism of the PFS will simply knock the cone over during the truck motion toward the stationary cone which will result in a cone correctly positioned for retrieval. This operation is shown in Figure 2.16.



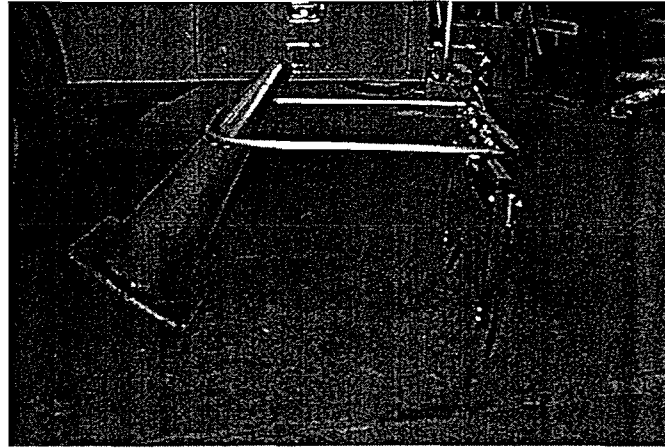
**Figure 2.16** *Standard Primary Funnel System Operation*

Cones that are already knocked over and have their tip pointing away from the truck are simply passed through the PFS. The freely rotating Gate Mechanism will be rotated over the base of the cone by their contact, but the cone's orientation will not be affected. The Vertical Guiding Post will contact the cone's conical section if its longitudinal axis does coincide with that of the truck. The result of this contact is rotation of the cone in the horizontal plane so that the cone's bottom ends up facing the secondary funnel within an angular range that is acceptable to the Secondary Funnel. The driver of the PACM must carefully watch the position of the PFS relative to the cone so that the PFS properly passes over the cone and its rotation in the horizontal plane is facilitated.

Cones that are knocked over and have their tips facing toward the truck require the most attention. The best way to handle cones in this orientation is to rotate the cones 180° in the vertical plane. In order to accomplish this task the Gate Mechanism must be manually locked by the driver in its the vertical position, and the tip of the cone must be first to enter the PFS.

As the PFS is passed over the cone, the locked Gate Mechanism will contact the base of the cone and rotate it 90° to its upright position. Since the cone is brought to its upright position as the PFS passes over it, the tip of the cone will always be positioned

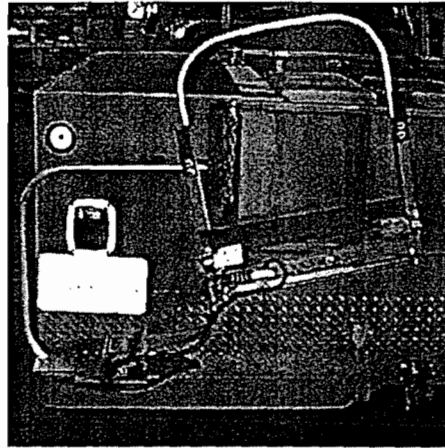
inside the confines of the tipping bar. As the truck continues to move past the stationary cone the tipping bar will contact the cone's conical section and knock it over to the properly oriented position. The Tipping Bar operation is shown in Figure 2.17.



**Figure 2.17** *Tipping Bar Operation*

For the PFS to function properly, the driver is required to learn and experience the basic PFS operation prior to using the PACM on the open road. The PFS on the PACM is modular so that the width of the system can be adjusted for the driver's preference and level of expertise in positioning the PFS over the cone while driving. The variation in the PFS width can also be adjusted to facilitate PACM operation in narrow quarters or lanes which are often encountered on bridges. This modular feature is an improvement to the system used on the TBACM.

Since the PFS is only used during the retrieval mode, the PACM must be able to retract the PFS when not in use, and deploy it when needed for retrieval. This function is accomplished by activating the hydraulic vane motor to which each of the PFSs is mounted. The Tipping Bar was designed so that it can fold down during the PFS retraction, and it automatically folds to the open position when the PFS is deployed. Figure 2.18 shows a retracted PFS.



**Figure 2.18** *Retracted Primary Funnel System*

## **2.6 Secondary Funnel System**

One of the subsystems attached to each Drop Box is the Secondary Funnel (SF) System which only operates during the retrieval mode. The SF SYSTEM receives the cones from the PFS and does the final cone positioning required for the proper interfacing with the Retrieval Arm. The SF SYSTEM retraction on the PACM is fully automatic, as opposed to the manual system on the TBCM. This system's operation, design and testing is described in extensive detail in Chapters 4 and 5.

## **2.7 Retrieval Arm**

The second subsystem mounted to each Drop Box is the Retrieval Arm (RA) which also operates only during the retrieval mode. This system receives the cones from the SF SYSTEM and slides them onto the LCB. The RA has been completely redesigned and is radically different from the retrieval system used on the TBACM. Again, this system's operation, design and testing is described in extensive detail in Chapters 4 and 5.



## 2.8 Automated Control System

The Automated Control System is made up of many sensors, actuators, solenoids, and a Little Giant C-Programmable Miniature Controller. This controller is based on a 16 bit Z180 microprocessor and is mounted in a metal enclosure located behind the seat in the truck cab. Sensors are incorporated throughout the subsystems. Besides the infrared sensors on the MCBS and the gate switches on the LCB that were previously described, sensors exist on other subsystems. The LCB has a sensor on each Wing Actuator to indicate if a cone has been dropped off into the Drop Box, and the RAs have sensors to indicate if a cone has arrived and is ready for retrieval. Each RA System also has a potentiometer that determines the position of the arm.

The C program algorithm, running in the driver selected operation mode, uses all the input signals to determine the correct output signals and timing. While in automated mode, all the cylinders, solenoids, fluid valves, DC electric motors, and the MCBS power system are controlled by the output signals from the controller. In all, the control system controls the operation and timing of six hydraulic cylinders, one rotary motor, seven hydraulic vane motors, and three DC motors, one of which in turn operates the MCBS hydraulics. Since previously there were problems experienced with the solenoid-induced voltage spikes, diode suppression was used in all the control signals.

The desired operating mode is communicated by the operator in the truck cab to the controller using a touch-pad interface panel. This panel is mounted just below the dashboard in the center of the truck cab.

Allowing for safe operation and emergency situations, panic stop buttons were incorporated into the PACM. One button is present in each cone operator bucket in the cone bed as well as one conveniently located in the truck cab.

## 2.9 Power Systems

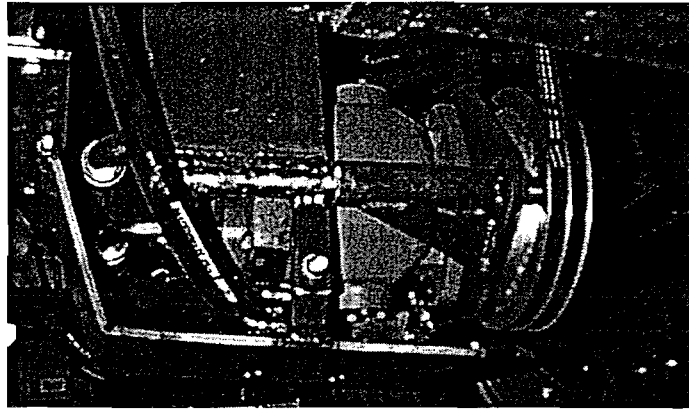
Two sources of power are utilized by the PACM. Some systems require electrical power while most motion system require pressurized hydraulic fluid to power their systems.

Electrical power is provided by the truck's standard electrical system which is comprised of a 12 Volt DC battery and an alternator driven by the truck's engine. The subsystems that require electrical power include the MCBS motor, the Drop Box System position motor, and the control system with all its associated switches and solenoids. Miscellaneous systems such as the sign board mounted on top of the PACM also require electricity. Before finalizing the PACM project the electrical power system might require additional components or retrofitting to ensure that the electrical systems are always supplied with enough amperage and voltage levels above their thresholds.

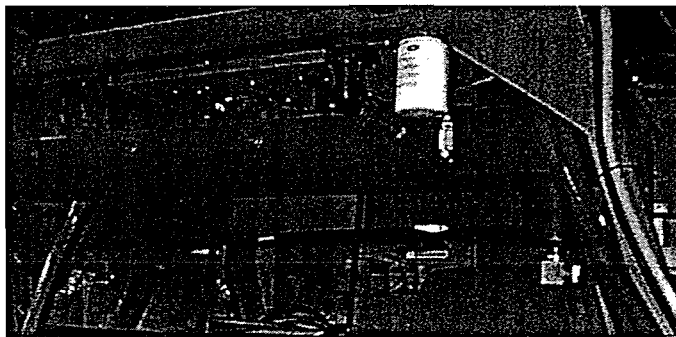
The Hydraulic power system is comprised of a variable displacement rotary piston pump, a 10 gallon fluid reservoir, and four cylinders, one rotary motor and seven vane motors. The pump, mounted near the front of the truck engine, is driven by the engine's crank shaft via a pulley and two belts. The mounted hydraulic pump is shown in Figure 2.19. A variable volume pump was chosen because of the unique operational circumstances of the PACM. The PACM at times has several hydraulic actuators operating at one time, requiring a large fluid volume per minute. At other times, the PACM can encounter periods with no hydraulic activity. The variable displacement pump will not continuously pump fluid past the bypass valve during idle hydraulic periods, while it can keep up with the fluid flow requirements that the PACM requires. This also prevents any unnecessary heat build up from idly pumping fluid.

The fluid tank is mounted below the truck's sign board and above the rear of the truck cab. This location was chosen to prevent any heat build up in the fluid and to allow for easier cooling. To allow for fluid cooling during hot weather operation or other

strenuous conditions, a heat exchanger with cooling fan was also mounted below the sign board. The fluid reservoir and heat exchanger with cooling fan are shown in Figure 2.20.



**Figure 2.19** *Hydraulic Pump*



**Figure 2.20** *Hydraulic Fluid Reservoir and Heat Exchanger*

## **2.10 Summary**

In this Chapter the basic operation of the PACM has been provided by a description of each subsystem. The journey of cones from the MCBS to the road and back is now achievable by using the totally automated PACM. The following chapter will discuss the testing of the Retrieval Arm and Secondary Funnel of the TBACM. The weaknesses and improvements needed in each of these systems will be outlined.

## **CHAPTER THREE: TESTING OF TEST BED AUTOMATED CONE MACHINE**

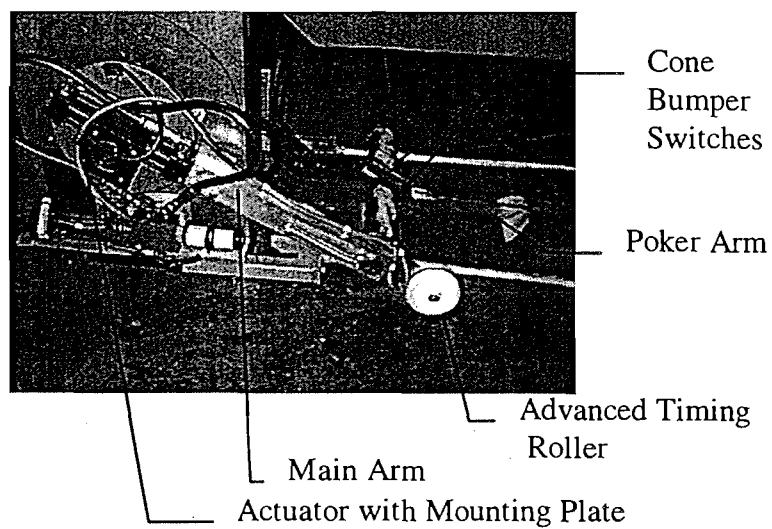
The focus of this chapter is the testing of the Test Bed Automated Cone Machine (TBACM's) Retrieval Arm and Secondary Funnel Subsystems. Before the Prototype Automated Cone Machine PACM generation, all subsystems must be thoroughly tested. This testing must be done prior to committing the current design for the PACM or considering a redesign of a subsystem for the PACM.

The TBACM's Retrieval Arm (RA) and Secondary Funnel (SF) Subsystems were tested to learn the cone behavior during the handling of cones by these subsystems and any shortcomings of the two systems. The testing of these subsystems was done simultaneously since they interface so closely during the retrieval process, but the results are provided separately and discussed in their respective sections. Testing was performed both on the road while operating in fully automated mode and during manual operation in a laboratory setting to control the environmental effects.

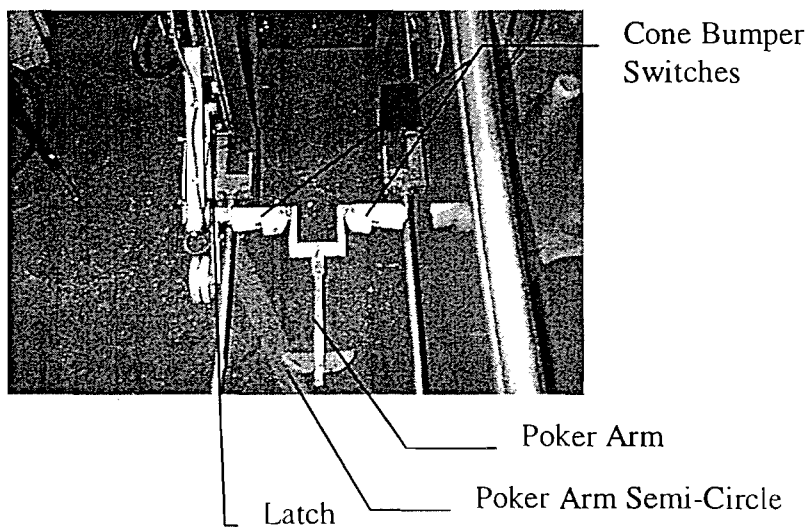
### **3.1 TBACM Retrieval Arm System**

The TBACM RA System is shown in Figures 3.1, 3.2 and 3.3 so that its main components are clear to the reader without the need to refer to Tseng et al, 1996. A very brief description of the TBACM RA System is given following these Figures. For further detail or discussion please refer to the above referenced research report.

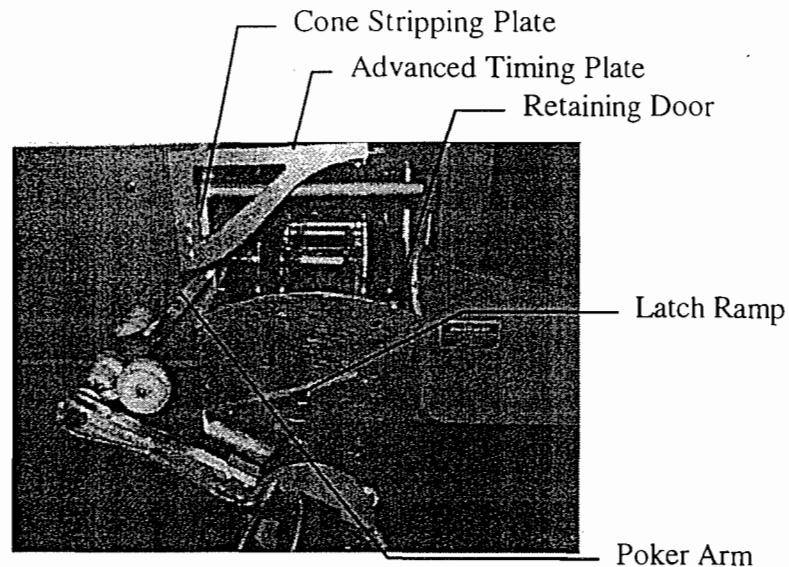
The TBACM RA System is composed of several basic components which are shown and labeled in Figure 3.1, 3.2, and 3.3. These components will be referenced throughout this chapter.



**Figure 3.1** *Retrieval Arm System Side View*



**Figure 3.2** *Retrieval Arm System Top View*



**Figure 3.3** *Retrieval Arm System in Retracted Position*

The TBACM RA System performs a series of simple operations. While the arm is in the down position, the cone's open bottom is guided onto the poker arm by the Secondary Funnel. The impact of a cone against the two Cone Bumper Switches activates them. Once both switches are continuously activated, the rack and pinion Actuator rotates the arm upwards with the cone being lifted up on the poker arm. As the main arm approaches the vertical position, the Latch contacts the Latch Ramp, unlocking the poker arm assembly and allowing its rotation around its pin connection at the main arm. At the same time the Advanced Timing Roller will contact the Advanced Timing Plate, which will control the rotation of the poker arm assembly. As the main arm and the poker arm assembly continues to rotate, the cone base will come into contact with the Cone Stripping Plate, at which point the poker arm is retracted out of the cone. Immediately after the poker arm is retracted out of the cone, it is left to fall freely onto the Lateral Conveyor Belt (LCB) System. The RA at this point is positioned in the retracted position as shown in Figure 3.3.

The TBACM RA System is able to retrieve cones in the forward direction in the same way as described above. This retrieval direction requires the symmetrical

components to be remounted in their mirror mounting positions. These components include the Latch Ramp, Advanced Timing Plate, Actuator Mounting Plate, poker arm Assembly, Cone Stripper Plate, and Retaining Door. Testing in the forward retrieving mode was not done with the TBACM.

### **3.1.1 Testing of the Retrieval Arm System**

The RA System was fine tuned and had its guides positioned correctly prior to all testing. Also, maintenance or lubrication required, especially on the Cone Bumper Switches, was meticulously performed prior to each testing session. These tasks were performed to ensure the best possible operation of the subsystems.

Most testing was video taped to enable a frame by frame analysis of failure occurrences if necessary. This facilitated the correct identification of the individual failures and the failure categories. The video taping of the TBACM during the faster vehicle motion attained during fully automated operation was accomplished by using a custom made video camera mounting frame attached to the side of the Cone Body. This mounting frame allowed the video camera to be positioned closely and correctly above any subsystem for optimal viewing.

The testing of the RA System consisted of two basic operations. One was the operation of the subsystem in the laboratory in manual operation mode. This method eliminated most of the environmental conditions and any interface errors with the other subsystems. The other test method consisted of fully automated functioning on a section of a public roadway. This testing method tested the subsystem's interface with other subsystems and the effect of varying environmental conditions. These conditions include road crown and cross slope, irregularities in the pavement, varying operational speed, and varying weather conditions. A total of 52 retrieval attempts were performed in the laboratory setting and 118 retrieval attempts were performed, in numerous different testing sessions, during the open road tests.

### 3.1.2 Results of Retrieval Arm System Testing

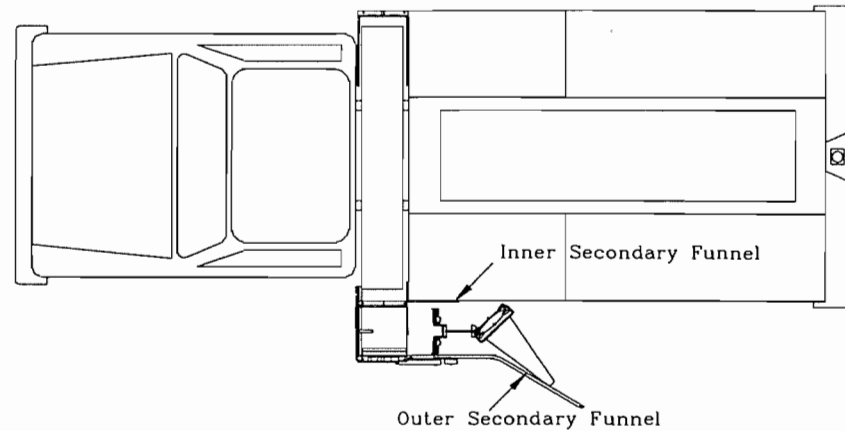
Seven basic failure modes were identified during the testing of the TBACM RA System, which are described and explained below.

1. The first failure mode occurs when a cone rotates about its central axis, on the poker arm. The Cone is still lifted upward on the poker arm but when it makes contact with the Stripper Plate, the rotated cone base is tilted beneath the Stripper Plate. This action prevents the poker arm from fully retracting out of the cone resulting in a jammed Retrieval Arm, which requires manual intervention.
2. Since the Cone Bumper Switches' activation directions are not aligned along a horizontal plane, additional friction is encountered during activation. As a result, any built-up road grime on the inner Bumper Switch surfaces will prevent the switches from properly activating, unless the Cone Bumper Switches are fully and persistently lubricated. This failure causes an increase in retrieval time if they are finally activated by the cone that slides along the road's surface. If the Cone Bumper Switches fail to activate at all, manual intervention is required.
3. Since the Cone that was just stripped off the poker arms falls freely onto the Lateral Conveyor Belt, it encounters a large degree of free-fall freedom. This free-fall freedom often results in cones being improperly positioned on the LSB immediately after landing. This problem varies in degree of severity since often the motion on the LCB will correct the cone position; its motion moves the cone and forces it between the LCB guides. This process often results in a retrieval delay. At other times manual intervention is required to free the cone, which is often necessary for a cone that lands with an edge of its base resting on the outer edge lip of the Drop Box.



4. The basis of this failure mode lies in the cycle time required by the RA System. This failure occurs when the RA is not back in receiving position when the next cone for retrieval arrives. This failure mode is a combination of the time delay from the large degree of rotation required by the RA, delay in Cone Bumper Switch activation, and the delay resulting from improperly landed cones (as described in mode 3).
5. The fifth failure mode is a result of improper interfacing with the Retaining Door. A cone that has slightly shifted its position on the poker arm Assembly will often come in contact with the Retaining Door which will shift the cone further out of position. Another improper interface with the Retaining Door occurs when the stripped free-falling cone is incorrectly guided onto the LCB by the Retaining Door. This failure mode usually results in the need for manual intervention.
6. In failure mode 6 the cone simply falls off the poker arm. During the time between the Cone Bumper Switches' activation and the initiation of the upward motion of the RA, the cone can bounce around against the Cone Bumper Switches as a result of the abrasion of the cone base edge rubbing against the road. When the RA starts its upward motion while the cone is not seated against the Cone Bumper Switches, the cone will slide and fall off the poker arm. Sometimes the driver can reposition the truck to reattempt the retrieval, but often the driver must manually move the cone to either retrieve it by hand or reposition the cone to allow automated retrieval.
7. The last retrieval failure mode occurs when the cone is passed to the RA System from the Secondary Funnel (SF) with the cone axis parallel to the outer bend of the SF. This results in a cone with its base wedged between the poker arm tip and the poker arm Semi-circle, as is illustrated in Figure 3.4. If

this failure mode occurs the driver of the TBACM can move the truck momentarily forward to clear up the wedged base, and reattempt the retrieval.



**Figure 3.4** *Cone Wedged on Poker Arm (Failure Mode 7)*

The results of 118 retrieval attempts during full automation are summarized by the percentage of each failure mode occurrence in Table 3.1.

Fully Automated Road Testing (118 Attempts)		
Failure Mode	Failure Description	Failure Percentage
1	Cone Rotated on Poker Arm	0.85%
2	Cone Bumper Switches not Activated	2.54%
3	Improperly Positioned Cone on LCB	5.08%
4	Retrieval Cycle Time too Slow	0.85%
5	Retaining Door Interference	0.00%
6	Cone Slid or Fallen off Poker Arm	1.69%
7	Cone Wedged on Poker Arm	7.63%

**Table 3.1** *Fully Automated Retrieval Road Testing Results*

The fully automated road testing had a total failure rate of 18.64%, leaving only a 81.36% successful retrieval rate. This may seem to be a very low success rate, but when analyzed, a clearer situation is elucidated.

The Cone Bumper Switches are high maintenance items and require constant lubrication. Since this was previously known, they were always meticulously lubricated prior to any testing. As a result, the percentages for failure mode 2 are artificially low, although it is still a serious problem with the RA System. However, the mode 2 failure could be illuminated if the Cone Bumper Switches were continuously and fully lubricated. Another better possibility would be to introduce lower frictional surfaces to the whole switch assembly and contact surfaces. These surfaces should be lubricated and then be shielded by a cover or boot to prevent the introduction of road grime and dirt.

Failure mode 3 could also be significantly reduced or eliminated if more guides were provided to the free-falling cone. This is, however, a packaging challenge since limited room is available.

Failure mode 7 should really be considered a Secondary Funnel System failure, and can be remedied by either lengthening the Secondary Funnel or by shortening the poker arm. However, if the poker arm were shortened, the failure mode 6 would increase. Therefore, the best remedy for the mode 7 failure is to lengthen the SF System, and is therefore left for discussion in the SF System testing section.

If the failure modes 2, 3, and 7 were resolved with the suggestions provided, the failure mode 4 occurrence would most likely be reduced or possibly be eliminated. If the modes 2, 3, 4, and 7 were eliminated, then the successful retrieval rate would increase to 97.46%. This is a much better success rate but depends on the success of the suggested solutions, and is still subject to new failures arising or other failures becoming more prevalent. The remaining 2.54% failure could prove to be very difficult or impossible to eliminate, and a success rate approaching 100% is strongly desired to provide the maximum protection to the cone workers.

Table 3.2 shows the failure occurrences for 52 retrieval attempts during laboratory testing.

Laboratory Testing (52 Attempts)		
Failure Mode	Failure Description	Failure Percentage
1	Cone Rotated on Poker Arm	0.00%
2	Cone Bumper Switches not Activated	N.A.
3	Improperly Positioned Cone on LCB	11.54%
4	Retrieval Cycle Time too Slow	N.A.
5	Retaining Door Interference	3.85%
6	Cone Slid or Fallen off Poker Arm	1.92%
7	Cone Wedged on Poker Arm	N.A.

**Table 3.2** *Laboratory Retrieval Testing Results*

Several failure modes are simply not applicable to or present in the laboratory retrieval testing. The mode 1 failure did not occur since the surface in the laboratory is constant and has no cross slope. Also the dynamic motion of a moving truck, which sometimes induces the cone to roll on the poker arm, was not present in the stationary lab setting. Failure modes 4 and 7 were not present since the cones were manually fed to the RA System and not evenly spaced on the road as in the road testing.

The failure mode 3 was more prevalent during the laboratory testing since the self-correcting effects of the LCB were not in action. The difference between the failure mode 3 occurrences during the two testing types provides the total percentage of improper landing positions corrected by the LCB, which is 6.46%. The solution of additional guides for this failure described above should still eliminate this higher

laboratory failure percentage, although the higher failure rate will never be encountered during normal operation since the LCB System will always be in operation.

The fact that the failure mode 5 did not occur in the road testing but only on the laboratory, is somewhat of an anomaly. The only difference that could account for the discrepancy is the dynamics of the moving truck. The additional guides that would be needed to correct mode 3 failures could also prevent most of the mode 5 failures.

Mode 6 failure occurrence rates are very similar between the two testing types. The slightly lower percentage in the road testing setting could be the result of the dynamics of the truck motion. In road testing the truck is typically moving toward the cone so that when a cone does lose contact with the poker arm assembly, even while rotating upwards, the truck's motion brings them back together.

Mode 7 failure was not seen in the laboratory testing since the cross slope of the laboratory ground surface is very low and constant. In order to test the effect of cross slope the cones were manually rotated to simulate the effect of road cross slope. Although the cross slope effect was artificially induced, a cone roll on the poker arm of over 3° (5% slope) consistently caused jams at the stripper plate. Therefore, if the TBACM's operating plane and the retrieval plane slopes differ by more than 5% a problem will occur.

### **3.1.3 Improvements Needed and Shortcomings of TBACM Retrieval Arm System**

From the testing results it can be clearly seen that improvements to the RA System are needed. Besides the improvements already listed above, other corrections must also be made. During the testing, the poker arm Semi-circle came loose several times, and better mounting or fasteners must be utilized. Also, if the solutions for the Cone Bumper Switches are applied, it should be done in such a way that the switches are waterproof.

In general the RA System is not aesthetically pleasing; it has too many components and guides, and lacks overall robustness. The system is very sensitive to modifications or impacts and requires quite a bit of constant fine tuning. The safety of the system could also be questioned, especially the pointy poker arm. When a RA is in the retracted position, it prevents the cone operator from opening the truck door, which would be a serious hazard in an emergency situation. During non-operation, the RA System shifts its resting position to one of numerous undesirable locations, several of which could either interfere with manual cone dispatch operation or prevent the cone truck cab door(s) from opening. If the desired retrieval direction is frequently changed it is prohibited by the extent of changeover required by the RA System. Even when a retrieval direction change is mounted, the components must once again be fine tuned to provide the best operation. When the RA System encounters road cross slopes of over 5% it has no way of correcting and successfully retrieving the cones. The retrieval rate is also limited with this system.

One of the system's major shortcomings is its lack of control over the cone in motion on the RA or during the free-fall onto the LCB. If the TBACM were to be used on a construction site with rough roads, the dynamic motion of the truck would definitely influence the cone behavior during retrieval and result in retrieval failures.

After the testing of the RA System and reviewing its shortcomings it was determined that considering other RA Subsystem options would be beneficial. The process of developing concepts and designing a new RA System will be presented in the next chapter.

### **3.2 TBACM Secondary Funnel System**

The TBACM SF System is a simple system, whose only function is to guide the cone to the RA System, but which is still an integral part of the cone retrieval process. Any SF System used is designed and tuned to the RA system's requirements. The

functioning of the SF System also depends on the correct interfacing with the Primary Funnel System. If the cone is correctly passed from the Primary Funnel System, the SF System receives the cone between its outer and inner funnel and simply guides it to the RA System.

The testing of the SF System was done simultaneously with the RA System testing. Laboratory testing is not applicable to the SF System since there is no truck motion relative to a stationary cone. Therefore, only the automated road testing performed was considered for analyzing the SF System function and failures. The layout of the TBACM SF System is illustrated in Figure 3.4.

### **3.2.1 Testing of Secondary Funnel System**

The SF System was tested during the 118 retrieval attempts made during numerous different testing sessions. These are the same video taped 118 retrieval attempts used for the RA System testing.

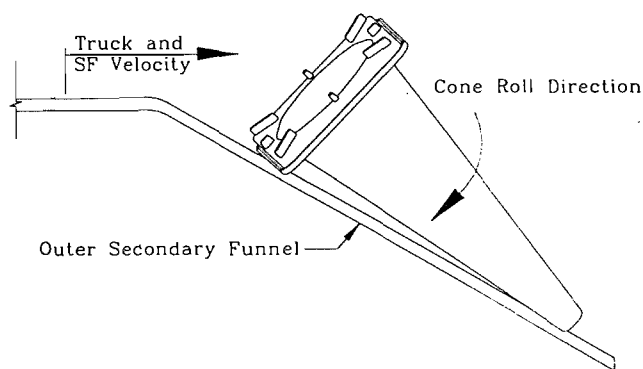
Since the SF System is a relatively simple system only a few failure modes exist. One retrieval failure that could occur is driver error, which would not be considered a SF System failure. This type of error occurs if the driver of the truck takes sharp erratic turns during the retrieval and rotates the truck away from the cone resulting in its arrival at the SF outside the normal passage lane boundary of a cone traveling to the SF from the Primary Funnel. This retrieval failure is dependent on only the driver's skill and experience level with the TBACM and was not encountered during the 118 retrieval attempts.

### **3.2.2 Results of Secondary Funnel System Testing**

There were only two basic failure modes identified during the SF System testing. The first failure mode is the same as failure mode 7 described as part of RA System testing. In the above discussion of the RA System testing, this failure was assigned to the

SF System. To recapitulate, this failure occurs when the cone is passed to the RA System from the Secondary Funnel with the cone's central axis parallel to the outer bend of the SF. When this occurs the cone wedges its base between the poker arm tip and the poker arm Semi-circle. This failure was previously illustrated in Figure 3.4, and occurred in 7.63% of the retrieval attempts.

The second failure mode also occurs when the cones meet the outer bend of the SF, but is only seen during faster retrieval speeds above the critical failure velocity. The failure mode consists of a cone rolling over the top of the outer SF bend. This scenario is the result of the impact of the outer bend SF with the cone below its center of gravity. If the impact velocity of the SF is above critical, it will cause the cone to rotate and roll over the top of the Secondary Funnel. This failure is illustrated in Figure 3.5. Since this failure mode was known prior to the road testing, the operational speed during the testing was kept below the critical velocity to prevent this SF failure.



**Figure 3.5** *Cone Rolling over Secondary Funnel*

### 3.2.3 Improvements Needed and Shortcomings of TBACM Secondary Funnel System

Overall the SF System functions very well. The main improvement needed to prevent retrieval failure is the lengthening of the outer Secondary Funnel. This will prevent the cone from wedging its base between the poker arm tip and the poker arm



Semi-circle. Care must however be taken not to intrude the SF System into the operational space of the Primary Funnel and to prevent the funnel from contacting the rear tires and axle while either deployed or retracted. If faster cone retrieval is desired the critical speed of second failure mode must be raised. In order to increase the critical speed, the outer Secondary Funnel should be raised, effectively lowering the moment arm length that causes the cone to rotate and roll over the outer SF. However, if the SF is raised too much, it will create another problem by allowing the cone tip and conical section to be wedged beneath the SF. If this occurs, stiff nylon bristles could be mounted vertically along the edge of the outer SF bend section. These bristles would then guide the cone tip in the same fashion the tubular section of the lower SF has done in the past.

Further enhancements to the SF System should include a mechanism to automatically deploy and retract the funnels. Also, the funnels should be easily installed and removed.

### **3.3 Summary**

The TBACM RA and SF Systems were thoroughly tested and analyzed. As a result of these tests and the shortcomings described, it was determined that consideration of other RA Subsystem options along with the accompanying SF System would be beneficial. This research, development, and the considerations and design of these subsystems are described in the next chapter.

## **CHAPTER FOUR: CONCEPT DEVELOPMENT AND DESIGN OF THE PACM RETRIEVAL ARM AND SECONDARY FUNNEL**

This chapter focuses on the development and design of the Retrieval Arm (RA) and the Secondary Funnel (SF) Subsystems. There are many factors and considerations that must be contemplated in the design of any subsystem. All these considerations can never be sufficiently explained or discussed in detail in a chapter of any reasonable length. Therefore, only the major design factors will be discussed in this chapter. However, much can be learned by analyzing the categories in the concept trade-off table. These categories will provide insight into some of the minor and more specific considerations desired and/or required. The general design and overall requirements were previously provided in Section 1.5.

The design of the RA subsystem was done first since it is a critical subsystem. Then, the SF was designed to meet its own general requirements and the interfacing requirements with the RA Subsystem. The components of each subsystem were analyzed to ensure that a safety factor of at least two existed for each possible failure mode. The calculations for the final designs are attached as Appendix B.

### **4.1 Retrieval Arm Requirements and Concepts**

After the analysis of the operation of the Test Bed Automated Cone Machine (TBACM) RA subsystem, the Prototype Automated Cone Machine (PACM) RA subsystem main requirements were easily identified. One requirement is that the RA must never trap an occupant inside the truck cab. This will require a sensor that will

provide the location of the arm at all times, and a fail-safe break away mechanism in case of an Automated Control System failure. As requested by the Caltrans workers, the width of the system must be kept to a minimum to facilitate operation in narrow travel lanes which are often encountered on bridge decks. The RA subsystem must function rapidly to prevent any time delays and effectively handle cones at any ambient temperature encountered, as well as cones that are coated with the mold release compound or with road tar, oil, or dirt. The cone should be effectively handled during the entire retrieval process and prevent the cone's rotational or free-fall freedom. The cone sensing switches also require operational improvements and must be sealed to prevent water and road dirt from penetrating, thus preventing a switch failure. It is desired for the RA system to allow bi-directional (forward and backward) retrieval without requiring extensive manual change over. Other desired functionalities include an operational speed of at least 10 mph and the possibility of handling other standard cone configurations with at most a simple retrofit.

The interfacing with the Lateral Conveyor Belts (LCB) must also receive design improvements. The interface must be done without extensive use of guides, which could be adjustment-sensitive. The interface would also be greatly enhanced if the need for an actuated full size drop-off table could be eliminated.

All these requirements lead to a RA system that has some sort of positive grip on the cone during retrieval. This requires an arm with a higher degree of mechanical sophistication which will likely be heavier.

Since much previous testing was performed, the cone behavior was fairly well known and established, and many concepts were generated, discussed and evaluated.

From all these concepts, five main concepts emerged after much consideration, initial calculations, and thought. The many other concepts generated were considered, but did not advance to the last five because they failed the final screening process. The five final concepts are the Telescopic Arm, the Partial Linear Slide Arm, the Telescopic Arm with Table, the Arm with Sliding Table, and the Arm with Pull-in System. All these concepts still operate on the cones that are oriented with the bottom openings facing the RA System. All the concept arms are visualized to rotate about a central point on the Drop Box and will be driven via a sprocket and chain. This allows the rotational actuator to be somewhat remotely mounted and supply the torque to the arm by the chain-driven sprockets. This configuration is preferable to minimize the overall width and facilitate the mounting of a potentiometer to monitor the arm's position.

#### **4.1.1 Telescopic Arm Concept**

The Telescopic Arm concept still has a poker arm that inserts into the bottom opening of the cone. The telescopic section retracts after the arm, with a cone on the poker arm, is rotated up to the vertical position. This action sets the retrieved cone onto the LCB wing drop-off table. The cone is centered on the drop-off table by either grippers, flap contact as the arm retracts, or fingers that spread inside the cone. The chosen mechanism will be activated by and during the retraction of the telescoping arm but is attached to the drop box. This limits the weight of the arm. The poker arm folds out from under the cone by rotating down during the lateral motion of the cone on the LCB. This requires the poker arm to have a rotational degree of freedom with some sort

of passive return spring action. The linear hydraulic actuator is mounted inside the arm assembly.

This concept requires a LCB drop-off table. A linear hydraulic actuator that rotates with the arm is also required, which creates minor hydraulic complications in that it requires rotational hydraulic fittings. Also, the telescoping system is a rather heavy mechanism. Another questionable aspect is whether the folding poker arm would create a problem for the laterally moving cone. The resistance created by the poker arm folding could prevent the cone from moving laterally, and the cone could be misaligned by the poker arm.

#### **4.1.2 Partial Linear Slide Arm Concept**

This concept still has a poker arm and has a partial length linear slide on the retrieval arm. This system has the linear hydraulic actuator mounted on the side of the Drop Box to prevent the complications of rotating the actuator and to reduce the arm's weight. As the arm rotates to the near vertical position, a latch unlocks the telescopic locking mechanism of the arm, and then, the actuator engages with the linear slide when the arm reaches its vertical position. The actuator then retracts the upper section of the arm on which the cone is resting. This retraction action also provides some limited rotation to the upper arm section to assist in the retraction of the poker arm. This retraction action positions the cone onto the LCB drop-off table. The cone is centered on the drop-off table by a mechanism activated by the retraction action. This mechanism could be either a set of grippers, flaps moving as the arm retracts, or a set of fingers that spreads inside the cone. The poker arm is partially retracted by the rotation of the upper

section of the arm, but still folds out from under the cone by the lateral motion of the cone on the LCB.

This concept has a lighter weight arm and no rotating hydraulic actuators. The poker arm still needs to partially fold down and rotate out of the cone. This could still create a problem for the laterally moving cone. Also, this concept still requires a drop-off table.

#### **4.1.3 Telescopic Arm with Table Concept**

This concept is very similar to the Telescopic Arm concept except that it has the LCB wing actuator table attached to the arm. In this concept, the cone on the poker arm and resting against the wing actuator table is rotated up to the vertical position during retrieval. At the vertical position the telescoping arm retracts and causes the actuator table to come into contact with the LCB system. The contact points are friction pulleys which cause the belts on the actuator table to rotate, thus laterally moving the cone. The poker arm folds under the cone by the lateral motion of the cone. The cone is centered by some sort of gripper or otherwise moved inward on the LCB and centered by guides.

The retraction actuator in this concept could be mounted on the side of the Drop Box to limit the weight of the arm which is already weighted down by the wing actuator table attached. This also simplifies the hydraulic connections by leaving them non-rotating. The poker arm could be partially retracted by the telescoping action. This would simplify and limit the folding out of the cone's hollow conical section required by the poker arm. The main disadvantage in this concept, besides from the extra weight, is

wear on the contact pulleys and the possibility of the somewhat fragile actuator table coming in contact with the road surface.

#### **4.1.4 Arm with Sliding Table Concept**

In this concept the arm has a slide table attached. This arm also has a clamping device that engages on the cone's base at the vertical edge. When the arm rotates to the vertical position, the arm releases the clamp and allows the cone to slide onto the LCB. This clamp most likely will be actuated hydraulically, necessitating that a hydraulic cylinder be mounted inside the arm. This actuator probably is single acting and is returned by using springs. This requires only one complicated rotating hydraulic fitting.

Although this concept will have the additional weight of an attached table, the weight could be limited by designing a simple but effective table slide. This concept does not require any poker arm, but requires rotating hydraulics. The major benefit of this concept is that it has a positive grip on the cone during retrieval, and it does not require a drop-off table.

#### **4.1.5 Arm with LCB Pull-in System Concept**

This concept is similar to the Telescopic Arm with Table concept. However, in contrast, this concept does not telescopically retract, and it has a very simple table with no rotating belts attached to limit the arm's weight. The arm with the cone on the poker arm will rotate up to the vertical position. At this location the arm's table height matches the height of the LCB. To move the cone inward off the table onto the LCB, a pull-in device attached to the LCB is activated. This pull-in device inserts some sort of hook into the

open bottom of the cone which then pulls and moves the cone inward with the motion of the lateral belts.

This concept is one of the simplest RA systems, but certainly complicates the LCB system. The poker arm folds under and out of the cone's conical section during the cone's lateral motion of the LCB which could be problematic. The arm itself is relatively light in weight and has no extra hydraulics except for the rotational actuator which all the RA Systems have in common.

## **4.2 Retrieval Arm Concept Selection**

In order to unbiasedly select the superior concept to be further developed, a Trade-off Table, like the one discussed in Section 1.4, was created and used. This table is divided into several sections. The first section lists all the mandatory capabilities that each concept must possess. However, since all of the concepts have passed the previous screening, these criteria have been met. The next section lists the optional capabilities, which shows the concept's flexibility and usefulness. The final section lists all the design considerations. This section includes factors such as durability, safety, complexity and most certainly includes cost.



Considerations	Weighting Factor	Telescopic Arm	Partial Linear Slide Arm	Telescopic Arm with Table	Arm with Sliding Table	Arm with LCB Pull in System
<b>Mandatory Capabilities</b>						
Operate on both left and right sides		yes	yes	yes	yes	yes
Pick up moving forward and backward		yes	yes	yes	yes	yes
Operate up to 10 Mph		yes	yes	yes	yes	yes
Handle the standard Caltrans cones		yes	yes	yes	yes	yes
Install on current drop box		yes	yes	yes	yes	yes
No interference for manual operation		yes	yes	yes	yes	yes
<b>Optional Capabilities</b>						
Complexity of retrieval table/landing	4	2	2	0	5	5
Able to stabilize cone on dispatch	3	0	0	0	3	3
Eject defective cones	2	0	0	0	0	0
Quick conversion for change in direction	3	5	5	5	5	5
Weight and size of arm	4	2	2	2	4	5
Modifications required of other subsystems	3	4	4	4	5	1
<b>Design Considerations</b>						
Width of design	5	4	4	4	5	5
Positive grip on cone	4	2	2	2	5	2
Operate in variable weather conditions	5	4	4	4	5	4
Safety of mechanism	5	3	3	3	3	3
Minimum number of actuators	4	2	2	2	2	5
Safety of traffic	5	4	4	4	4	3
Setup upon arrival	3	5	5	5	5	5
Aesthetics	3	3	2	2	3	3
Estimated cost	3	2	1	3	3	3
Minimum sensors and control	4	2	2	2	5	1
Durability & robustness	5	3	2	3	3	2
Minimum operators view obstructions	2	3	3	2	2	3
Compatible with various cones	3	4	4	3	3	1
Operate in various road conditions	4	3	3	3	3	3
Scrubbing of cone	3	3	3	3	4	3
Compatible with existing stowage mechanism	5	4	4	3	5	1
Totals		246	235	228	314	248

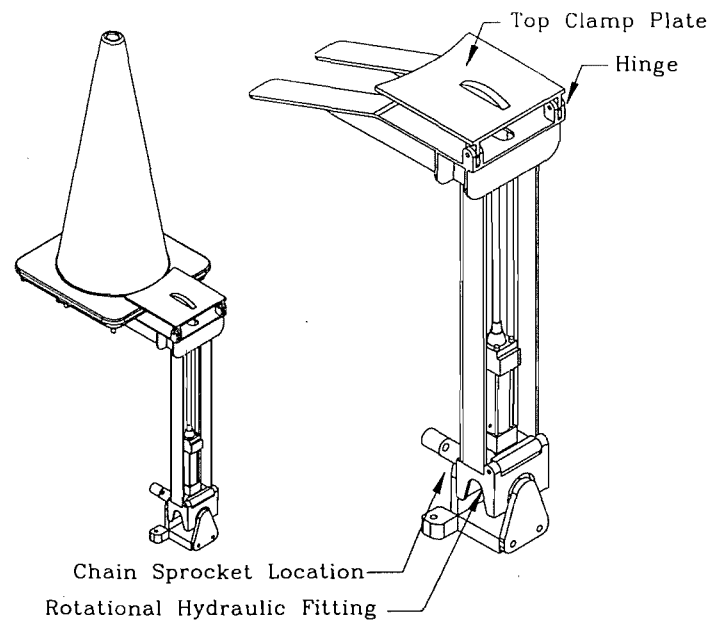
**Table 4.1** Trade-off Table for Retrieval Arm Concepts

The total scores in the trade-off table clearly indicate the Arm with Sliding Table as the superior design to be further developed and tested.

### **4.3 Retrieval Arm Design**

To further develop the Arm with Sliding Table concept, preliminary component and assembly drawings were generated. This allows the effective illustration and communication of the design concept with the other engineers working on the project. The team's input is vital to ensure that the concept conceptually interfaces with the other subsystems. The concept drawing will also allow the fabrication shop personnel to create a test fixture which provides the engineer with a way of quickly testing questionable aspects and quantifying some operational parameters of the concept.

Figure 4.1 shows the first assembly drawings for the Arm with Sliding Table concept. The assembly on the left shows the concept with a cone in the gripper, while the assembly on the right is a larger scale version without the cone. The gripper opens by simply having the hydraulic actuator extend and move the rod, connected to the Top Clamp Plate, up thus forcing the plate to rotate about its two stationary hinge points, to the open position.



**Figure 4.1** *Arm with Sliding Table Concept Assembly Drawings*

The main shaft cover is purposely not shown in the arm assembly drawing to show additional detail. The hydraulic actuator is mounted as low as possible to minimize the moment of inertia of the assembly. Additional space in the bottom rotational area is strategically created to allow room for a rotational hydraulic fitting and a chain sprocket. This concept also has a break away mechanism with the hinge located at the bottom of the arm shaft.

The point of rotation of this arm is determined by the geometry of the component layout. The area on which the cone is clamped needs to be co-planer with the plane of a cone bottom that is lying down ready for its retrieval. The cone clamping area also needs to come in contact with the cone base about the edge's midpoint. Measuring along the arm's length, from the center of the top plate, would pinpoint the arm rotational axis. Determining the total length of the arm is an iterative process which is determined by the

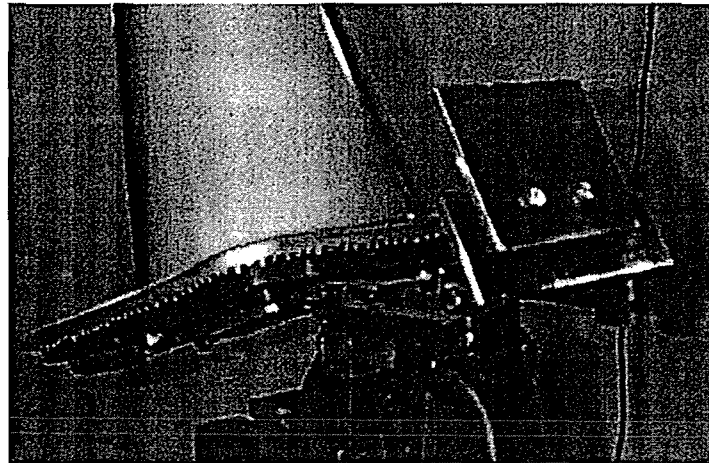
geometry discussed above, the vertical drop distance created by the sliding ramp, and the height of the LCB. The optimum resulting arm length is quite long. This length causes interfacing difficulties with the Secondary Funnels (SF) System since the cone needs to be ready for retrieval much earlier and further away from the Drop Box. This long arm also requires extra torque for upward rotation. A shorter arm creates a LCB interface dilemma as the cone cannot reach the height required to properly slide onto the LCB.

The solution to this dilemma was a modified LCB System. Since the drop height from the LCB onto the ground during a cone dispatch was preferably minimal, the LCB Subsystem engineer designed Wing Actuators. During the cone dispatch these actuators are inclined down at a  $30^\circ$  angle, thus dropping the cone much lower to the ground. These same Wing Actuators can be rotated upwards to meet the desired interfacing height of the RA. This process was previously discussed in Section 2.3 and shown in Figures 2.11 and 2.13. Now that the length of the arm was somewhat more flexible, the final configuration needed some testing to determine the optimum sliding ramp and Wing Actuator angles.

#### **4.3.1 Retrieval Arm Clamp Test Fixture**

In order to determine some preliminary operating parameters for the RA System, a clamp test fixture was built in the laboratory, which is shown in Figure 4.2. The main purpose was to estimate the amount of force required on the cone base to ensure a good positive hold on the cone during retrieval. The force required would dictate the hydraulic clamping cylinder size. Also, the amount of wear and the deflection of the cone base during this applied force needed to be established. The ideal sliding ramp and Wing

Actuator angles needed to be determined and tested. This testing included determining the behavior of a cone traveling the path down the sliding ramp and then up the Wing Actuator. All the tests included wet weather simulation.



**Figure 4.2** *Clamp Testing Fixture*

The clamp test fixture and a bar with a spring scale attached, was used to determine the amount of clamping force at the cone base. It was somewhat arbitrary what the appropriate hold on the cone should be. The initial considerations were based on the maximum initial forces encountered by the cone during fast upward RA rotation. These calculations provided a threshold level to which an additional 50% was added as a safety factor. This force was applied to the center of the cone base perpendicular to the clamped cone base edge. Other tests included just simply pulling on the cone base to see if a good hold was achieved. The minimum clamping force on the cone base deemed appropriate was approximately 900 N (200 lb<sub>f</sub>).

Other tests needed to determine any possible wear and deformation of the cone base. It was easily determined that the cone base was sufficiently resilient to wear from

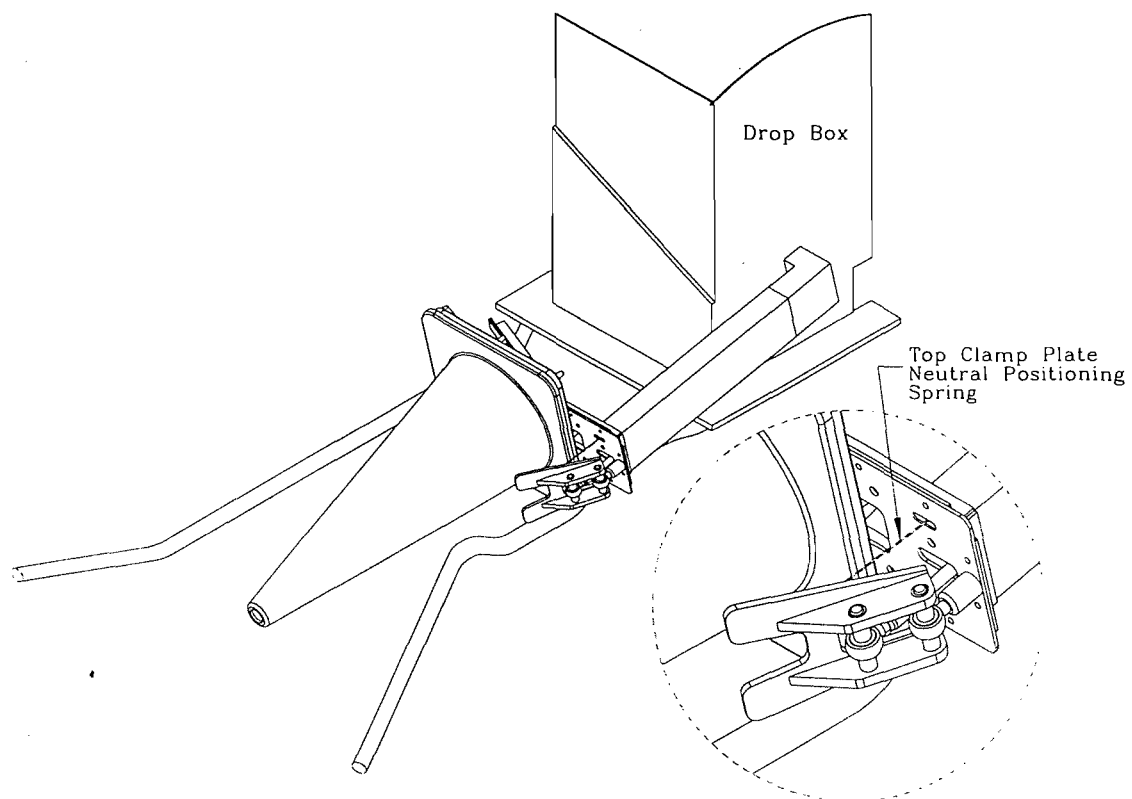
the relatively smooth clamping plate surface, and cone wear would not be a problem with the concept. The deflection of the cone base is a critical issue. If the Top Clamping Plate is hinged at two points and the cone base thickness is uneven, then the cone could be clamped at only one point leaving the cone free to rotate about this point. It was initially thought that the somewhat pliable PVC cone base would easily compress and allow enough deflection to always provide two good clamping points on the cone base. This assumption was quickly discovered to be false, and the clamping plate requires a roll axis degree of freedom to operate and clamp the cone base effectively.

The ramps of the clamp test fixture were utilized to experiment with the angle of the sliding ramp and of the Wing Actuator. The sliding ramps were covered with Teflon sheets to reduce the friction while sliding. The drop-off table on the TBACM was used to simulate the Wing Actuator's moving conveyor belts and to vary the inclination. The belts and sliding ramps were also tested wet to simulate rainy conditions. The tests indicated that the slide ramp angle should be in the range of 10 to 30° and the Wing Actuator inclination should be below 20°. When the sliding ramp angle was set higher than 30°, the cone risked tipping over after the clamp opened. If the Wing Actuator inclination was higher than 20°, the cone to belt friction during wet conditions was not sufficient to move the cone up the inclination.

#### **4.3.2 Retrieval Arm Design Details and Further Testing**

Knowing the design parameters and operation limits allowed the creation of the first set of detail drawings. The detail assembly drawing for this arm is shown in Figure 4.3. The Figure shows a cone, guided by the Secondary Funnel to the arm, that is ready

for retrieval. The arm is shown attached to a conceptual Drop Box. However, the rotational actuator and the chain and sprocket configuration are not shown. Also, the design of the rotational connection of the arm to the Drop Box are also shown. This connection was designed by the engineer who developed the Drop Box Subsystem, and it will include an emergency break away mechanism. The details inside the arm are not shown here, but will be discussed and shown later. The figure also shows a close up of the clamping mechanism.



**Figure 4.3** *Retrieval Arm Detail Drawing*

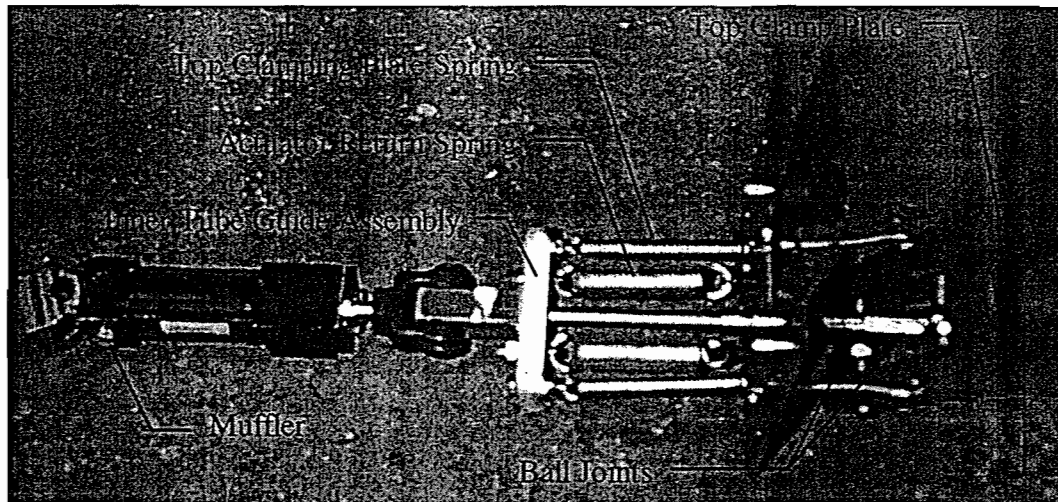
A thin walled rectangular tube was specified for the arm shaft due to its higher torsional rigidity compared to an open channel with a cover. A single acting 2.5 cm (1 inch) diameter hydraulic cylinder was chosen to power the clamping mechanism. This

actuator has a muffler installed in the open port to prevent dirt and moisture from entering the cylinder and to quiet its operation. The Inner Tube Guide Assembly, which guides the motion inside the tube and has spring anchors mounted to the top surface, is mounted on top of the cylinder. The Top Clamp Plate is mounted on two ball joints to provide it with a roll degree of freedom. The Top Clamp Plate maintains a nominal neutral position using two springs which easily deflect during clamping. Since the Top Clamp Plate receives significant bending loads and could be subjected to impact loads, it was designed to be rather stout and its material specified as Stainless Steel. The Stainless Steel clamp is also able to withstand the environmental conditions. The system as a whole is shielded from water and the specified cone sensing switch is water proof and an commercially available item. The arm utilizes only one cone position sensing switch which has a long stainless tap extending into the cone's arrival path during the retrieval.

The final geometry layout specified a 56 cm (22 inch) total arm length, a sliding table inclination of  $20^{\circ}$ , and a  $14^{\circ}$  Wing Actuator inclination. This setup would self-correct the cone rotation due to road cross slope. The correction is achieved when the cone is slid down the sliding ramp and is rotated to the correct alignment by the impact with the Wing Actuator.

This arm was fabricated and assembled on the TBACM for further testing and to determine if any further improvements were required prior to committing this design to the PACM. As the prototype arm was assembled an inner arm shaft assembly picture was taken, which shows details not usually shown in detail drawings, and this is shown and labeled in Figure 4.4.





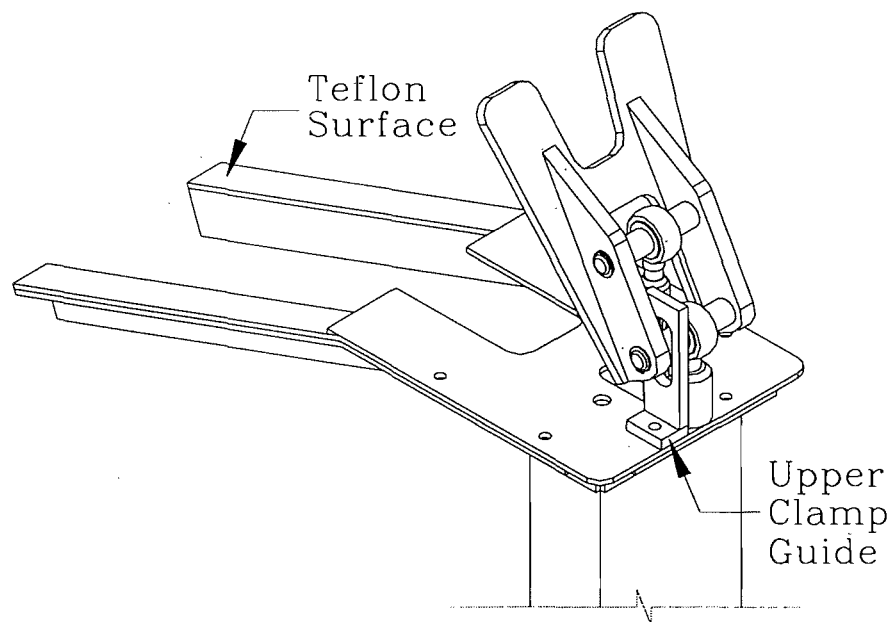
**Figure 4.4** *Retrieval Arm Inner Shaft Assembly*

The prototype arm mounted on the TBACM functioned remarkably well during the laboratory testing. The arm securely held the cone for up to five or six, back and forth, maximum rotational acceleration cycles, a demanding duty cycle never encountered during normal retrieval operations. The only questionable aspect of the design was the Top Clamp Plate neutral positioning springs' durability and functionality. These springs were the only aspect modified in the arm's transition to the final design.

#### **4.3.3 Retrieval Arm Final Design**

The transition to final design was rather quick and simple, and the detail drawings for the final design are contained in Appendix C. Because of thorough testing and careful design, the final arm only needed one final modification. This consisted of removing the Top Clamp Plate springs and designing an Upper Clamp Guide. The guide designed allows the Top Clamp Plate to freely rotate about its roll axis only when the clamp is in the clamping position. However, when the Top Clamp Plate rotates upward, it receives increased roll axis restriction. When the Top Clamp reaches the full open position the

roll axis is restricted, leaving the plate in the neutral position. Figure 4.5 provides a closer look at the clamping mechanism and clearly shows the new Upper Clamp Guide.



**Figure 4.5** *Clamping Mechanism with Upper Clamp Guide*

The final Retrieval Arm design produced a rather unique and fully functional system. It processes all the desired traits needed to effectively retrieve cones from any kind of road surface. This RA System will always have a secure positive grip on the cone except during the moment it slides down the sliding ramp. However, before starting to slide, the cone's full base edge will come into contact with the Wing actuator which provides significant stability. This RA System has no dangerous and bothersome poker arm and is slightly longer than the TBACM RA System's arm. This is another advantage because it allows some additional room to mount cone dispatch stabilizing guides on the bottom of the Drop Box.

#### 4.4 Secondary Funnel System Design and Concepts

Once the Retrieval Arm (RA) was designed, the focus changed to the Secondary Funnel (SF). The function of the SF as a whole is rather simple. It needs to receive the cone from the Primary Funnel System and guide it to the RA System in such a manner that successful retrieval is ensured. The new arm is a little longer but has no poker arm, making it shorter than the previous RA System total length. As a result, the new SF System may get the cone base oriented to the correct retrieval position later and closer to the Drop Box. A longitudinally aligned cone tip orientation is no longer critical since it is not necessary for retrieval with the new RA System. The above differences result in a shorter overall SF System which will ultimately be safer and narrower.

Only a few operational improvements were needed to the previous SF System. One, the new SF is required to automatically retract. The retraction should ideally be powered by the Drop Box System retraction and occur simultaneously. Second, the SF System should be higher to prevent the cone from rolling over the SF System outer funnel bend section. This failure was discussed in Section 3.2 and illustrated in Figure 3.5. However, the outer funnel on the new system cannot be too high since it needs to allow operating room for the Top Clamp Plate of the RA System. The plate in the open position should be above the outer secondary funnel so that it will not hinder the entrance of a cone. One solution to this problem is a dip in the outer funnel at the Top Clamp Plate. The last desired improvement is modular functionality of the outer funnels. This will allow the operator of the PACM to interchange the funnels and most likely always provide spares in the event that a funnel is damaged during maneuvering or operations.

Numerous concepts for the SF System were generated and considered. After much thought, discussion and initial calculations, three final concept emerged. The three final concepts are the Body Pin Retracting, Cable Retracting, and the Folding Retraction. All these concepts still function in the same basic way as the previous SF System; the main difference is the retraction mechanism. The retraction is only needed in the outer funnel, and the inner funnels are securely and permanently attached to the Drop Box.

#### **4.4.1 Body Pin Retracting Concept**

In this concept, the outer funnel has a hinge near the middle of its section just beyond the funnel bend. This hinge has some sort of upward pointing pin mounted on a short moment arm that is connected to the outer bend section. During the Drop Box retraction, the pin comes in contact with the underside of the cone body. The contact point at the cone body is a lubricated horse shoe shaped receiver to help align the contact with the upward pointing pin. As the Drop Box continues to retract, the pin is restricted from moving inward any further. This restriction activates the hinge and effectively turns in and retracts the outer bend section of the outer funnel. This hinge has a stiff torsional spring which normally keeps the outer bend funnel section in the closed - deployed position.

#### **4.4.2 Cable Retracting Concept**

This concept is very similar to the Body Pin Retracting concept just described above and has a similar hinge. The main difference is the way the hinge is activated. This concept does not have a pin on the outer bend section's moment arm. Rather, it has

a cable attached which runs inside the stationary outer funnel section. At the Drop Box, this cable is routed so that it can be connected to the cone truck frame. The cable length is adjusted so that the cable is pulled tight when the Drop Box is fully deployed. The cable can have some spring tension and compliance to keep it from breaking during accidental over extension and to always keep the cable taut. The hinge on the outer funnel section has a stiff torsional spring that automatically opens the hinge and retracts the outer funnel bend section when the cable is not taut.

#### **4.4.3 Folding Retraction Concept**

In this concept the entire outer funnel will be rotated -- retracted inward about a rotation point beneath the Drop Box. The outer funnel will be one continuous section of tube without any hinges. Each funnel is modular and inserts into a rectangular steel tube sleeve section beneath the Drop Box. These sleeve sections each have their own rotation point location beneath the Drop Box. Since they rotate about their own point, these sleeves are connected by slotted connecting links so that if one funnel rotates inward or outward, it will force the same movement on the other funnel. The forward funnel sleeve has the first bar of a three bar linkage attached. The third link is attached to the truck frame. This configuration will force the movement of the forward sleeve section during the Drop Box retraction and deployment. Again, since the sleeve sections are connected, both sleeves retract or deploy simultaneously. This whole retraction mechanism operates whether or not an outer funnel is inserted into a sleeve section.

## 4.5 Secondary Funnel Concept Selection

Once again the concepts must be unbiasedly evaluated by utilizing a Trade-off-Table. This table basically is subdivided the same way as the table in Section 4.2, and the sections again include the Mandatory Capabilities, the Optional Capabilities, and the Design Considerations.

Considerations	Weighting Factor	Body Pin Retracting	Cable Retracting	Folding Retraction
<b>Mandatory Capabilities</b>				
Operate on both left and right sides of truck		yes	yes	yes
Guide cones moving forward and backward		yes	yes	yes
Operate up to 10 Mph		yes	yes	yes
Guide the standard Caltrans cones		yes	yes	yes
Install on PACM Drop Box		yes	yes	yes
Automatically retract with Drop Box motion		yes	yes	yes
No interference with Top Clamp Plate operation		yes	yes	yes
Proper interface with RA System		yes	yes	yes
No interference during manual operation		yes	yes	yes
<b>Optional Capabilities</b>				
Modular outer funnel	3	3	0	5
Eject defective cones	2	0	0	0
Quick conversion for change in direction	3	4	3	5
Ease of disassembly	4	4	3	5
Ease of replacing damaged funnel	4	2	1	5
Weight and size of retraction mechanism	4	4	5	3
Modifications required of other subsystems	3	5	5	5
<b>Design Considerations</b>				
Width of design	5	4	4	4
Operate in variable weather conditions	5	4	4	4
Safety of mechanism	5	3	4	4
Safety of traffic	5	4	4	4
Setup upon arrival	3	5	5	5

Aesthetics	3	2	3	4
Utilization of commercially available parts and stock metal	4	3	4	4
Estimated cost	3	4	4	3
No sensors and control	3	5	5	5
Durability & robustness	5	4	2	5
Dependability of Retraction	5	3	3	5
Compatible with various cones	3	4	4	4
Operate during various road conditions	4	5	5	5
Compatible with existing Primary Funnel	5	5	5	5
	Totals	294	285	331

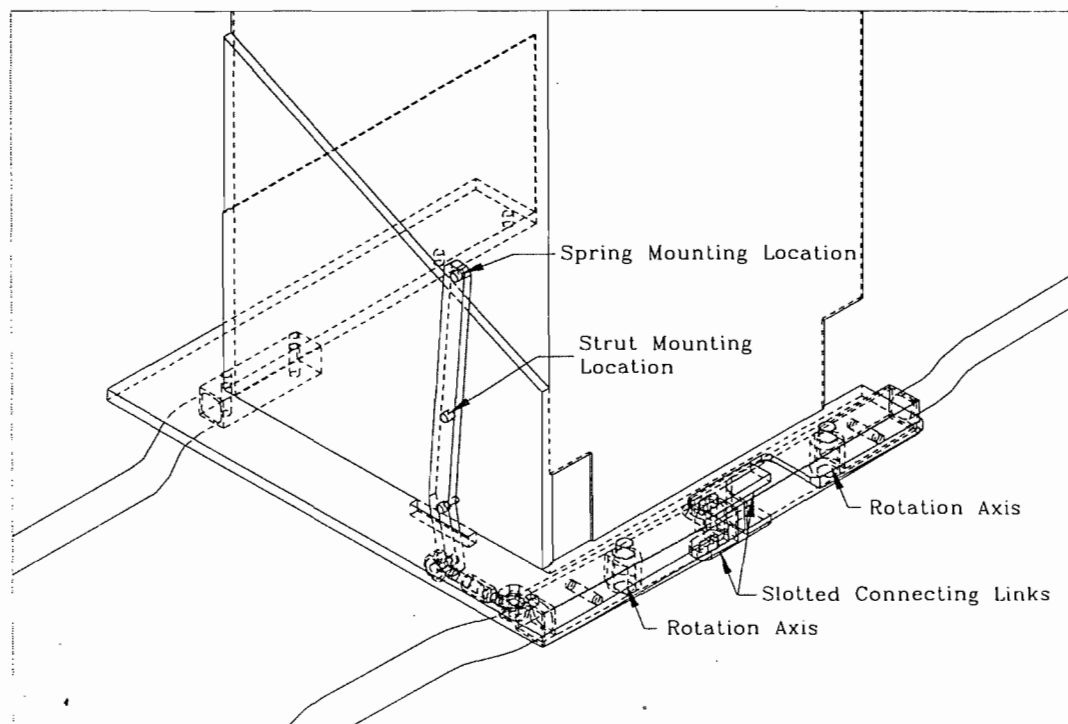
**Table 4.2 Trade-off Table for Secondary Funnel Concepts**

From the total scores in the Trade-off Table it is clear that the Folding Retraction Concept should be further developed and tested.

## 4.6 Secondary Funnel Design

The concept was further developed and detail drawings were generated. The design utilized a maximum amount of commercially available items and standard stock metal configurations. The sleeves are stock 3.8 cm (1.5 inch) rectangular tubing with a 0.32 cm (0.13 inch) wall thickness. The funnel sections are 2.5 cm (1.0 inch) diameter electrical conduit which are pressed into and welded to a 3.2 cm (1.25 inch) rectangular tubing which insert into the sleeve weldments. Since the three bar linkage is orthogonal to each bar respectively, the lower (first) link is comprised of two ball joints to allow some relative angular displacement due to the rotational motion of the sleeve weldment. The two ball joints also allow length to be finely adjusted, since they are connected with male and female threads. The final link that will be connected to the truck frame is a strut

type cylinder that breaches the 55.2 cm (21.7 inch) traveled by the Drop Box. The activation distance required to deploy or retract the sleeves is only a fraction of the Drop Box distance traveled. The outer funnel has a dip at the RA System's Top Clamp Plate location to allow the plate to freely move over the secondary funnel, while still keeping the rest of the funnel high enough to ensure proper functioning. The detail drawings for all the SF components are included in Appendix C. The isometric assembly drawing of the deployed SF System is shown in Figure 4.6.

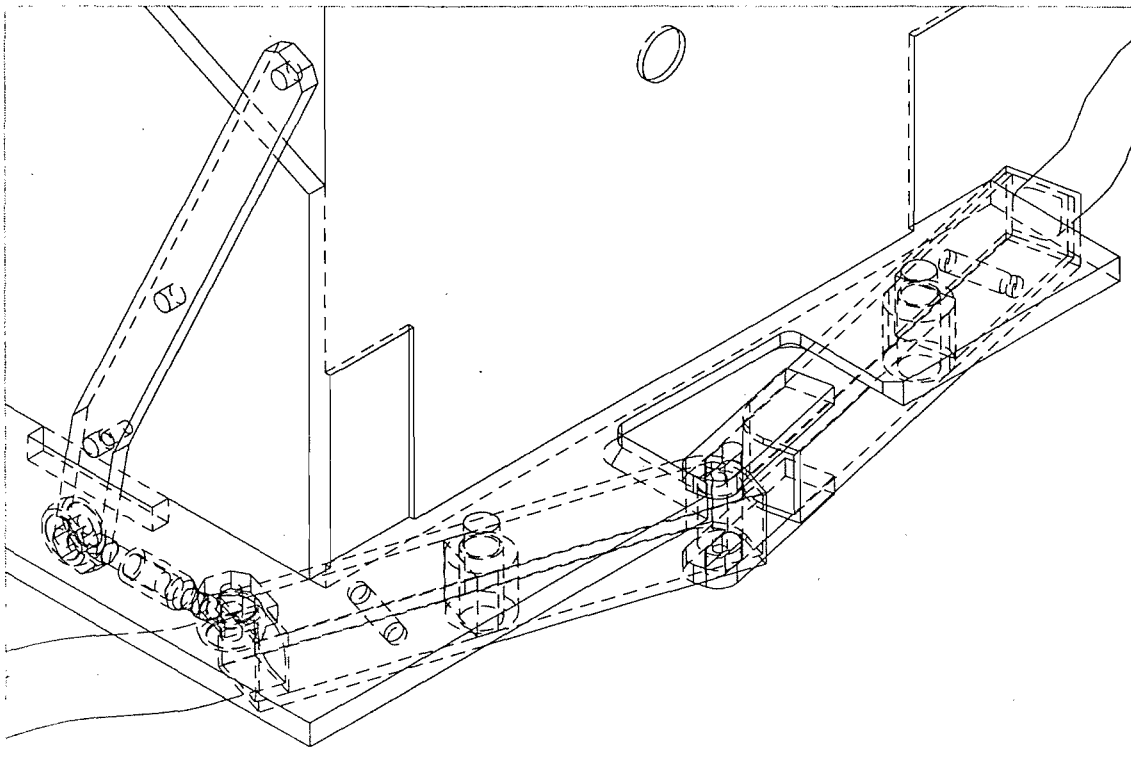


**Figure 4.6** *Deployed Secondary Funnel System*

The two sleeve weldments, into which the funnel sections insert, are held to the Drop Box by 1.91 cm (0.75 inch) diameter Stainless Steel shoulder bolts. The funnel sections are held in the sleeve weldment by a clevis pin. The two sleeve weldments are connected by the slotted connecting links which have shoulder bolts inserted in the slots. None of these fasteners are shown in the assembly drawing. In the deployed position the

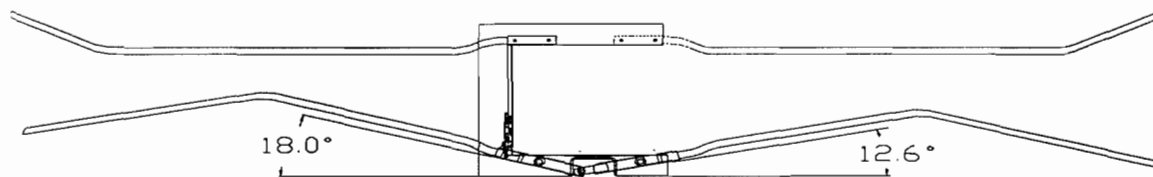


rear sleeve upper slotted connecting link rests against the Drop Box and prevents the system from over-deployment. A closer assembly view of the SF System in the retracted position is shown in Figure 4.7.



**Figure 4.7** *Retracted Secondary Funnel System*

Since the truck cab is narrower than the cone body the front outer funnel section needed more angular retraction than the rear outer funnel. The sleeves were cleverly designed so this angular variance is accomplished by unequal sleeve length. The main difference in sleeve weldment length is due to the slotted connecting links which are permanently mounted to the rear sleeve weldments making them longer. The top view of the right side Drop Box and SF System is clearly shown in Figure 4.8, which also shows the angular displacement of each funnel in the retracted position.



**Figure 4.8** *Top View of Retracted Right Side Secondary Funnel System*

At the end tip of the outer funnel section, no downward pointing drag devices were specified at the design stage. It was unknown at this point how a forward pointing funnel would behave on the open road, especially when it needs to move or deflect over bumps. Either non-sparking wire, a semi-circular UHMW Polyethylene shape, or a caster could be a consideration for the funnel ends. The actual device used will be determined during the testing phase.

Another item not yet finalized is the strut (third bar) assembly. This strut will be mounted from the strut mounting hole on the second bar link to the truck frame. Since the exact location of the Drop Box with respect to the truck frame and cab is uncertain, the correct strut configuration cannot be determined until the system is mounted on the truck. The operating room and clearances for the strut are expected to be very little and tight, respectively.

The new SF System design as a whole seems very promising. It is very robust and modular and will effectively guide the cones to the RA System. The only drawback is that in the extreme retraction position, the sleeve weldment will extend slightly beyond the outer edge of the Drop Box. However, the distance is only a fraction of an inch and

the transition is smooth should anything ever side-swipe the Drop Box. All the positive attributes of this design certainly outweigh the small and insignificant drawbacks.

## **4.7 Summary**

The designs for the RA and SF Subsystems are very effective, yet they are simple in nature. Both designs utilize high quantity of commercially available parts and standard, easily obtainable, stock metal configurations. The amount of machining and fabrication was also considered and kept to a minimum. The RA is very adaptable to various cones. Both Subsystems are much narrower than their predecessors.

The next chapter will show the designed systems built and will discuss the testing and any required modification(s). The RA System already received some initial testing but it may still need some small adjustments or modifications. The SF System's main configuration and operation is the same as before, and the only major change is the retraction mechanism. Therefore, little or no change is expected, except maybe some modifications in the outer funnel's overall length.

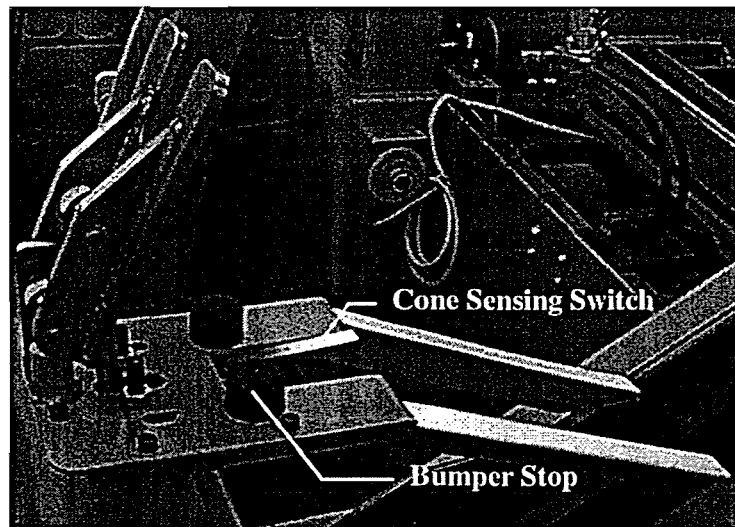
## **CHAPTER FIVE: TESTING, MODIFICATIONS, AND IMPROVEMENTS OF RETRIEVAL ARM AND SECONDARY FUNNEL SYSTEMS**

The focus of this chapter is the testing of the designs developed in the previous chapter. Initially each subsystem was tested in manual mode to make sure that the correct operation and motion occurred. During this manual testing, the need for some preliminary modifications became apparent which were then performed prior to full automation mode testing. The testing of the Retrieval Arm (RA) and Secondary Funnel (SF) Subsystems in that automated mode was again done simultaneously since the two subsystems interface so closely.

### **5.1 Fabrication, Manual Operational Testing, and Modifications of the Retrieval Arm and Secondary Funnel Systems**

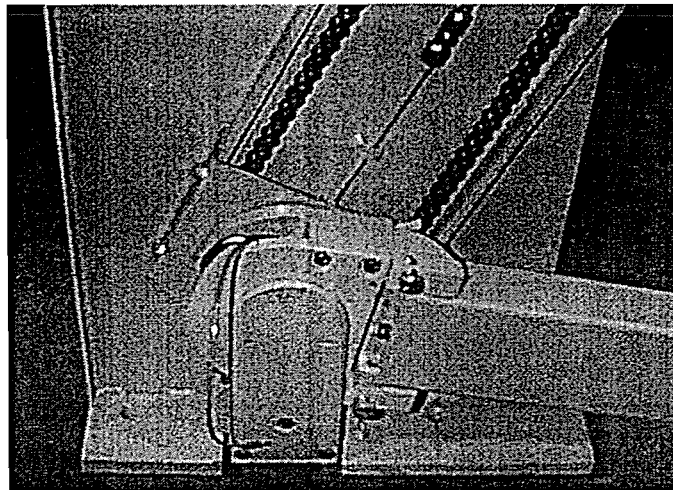
#### **5.1.1 Retrieval Arm System**

After fabrication the RA System had its operation manually tested in both a laboratory setting and on the road. The arm was built to the design specifications and the arm's as-built top portion is shown in Figure 5.1. The Cone Sensing Switch and the Bumper Stops are labeled in this Figure. The Bumper Stops were specified in the design to stop the Upper Clamp so that the hydraulic cylinder is prevented from bottoming out when accidentally actuated for the case when no cone is present. A cylinder that bottoms out could be damaged.



**Figure 5.1** *Retrieval Arm As-built*

The rotational and break away mechanisms at the bottom of the arm are shown in Figure 5.2. In the Figure, the cover for the chain housing has been removed to show extra detail, including the chain and the hydraulic fluid line traveling up the center of the housing. Also shown is the Cone Sensing Switch wire coming out of the bottom of the rotational mechanism.



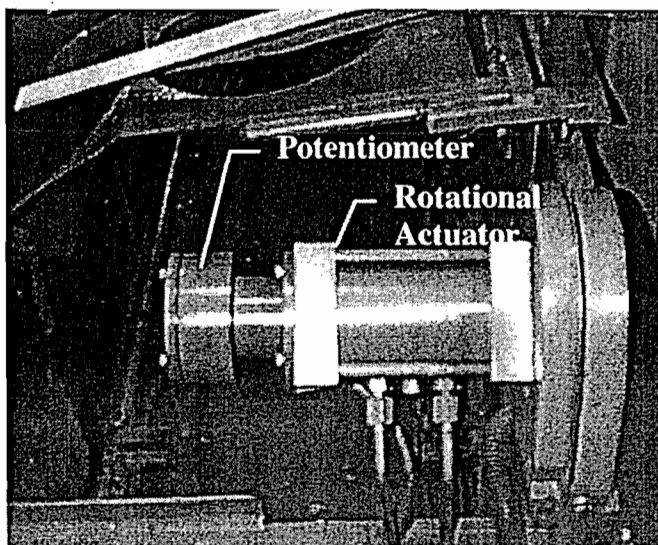
**Figure 5.2** *Retrieval Arm Rotational and Break Away Mechanisms*

The Retrieval Arm System, in operation, is shown in Figure 5.3.



**Figure 5.3** *Retrieval Arm in Operation*

The rotational actuator is mounted in the front-top corner of the Drop Box with the potentiometer attached to its back surface, as shown in Figure 5.4.



**Figure 5.4** *Rotational Actuator with Potentiometer*

Early in the manual testing it was revealed that the Cone Sensing Switch was not adequately rugged and sometime had its stainless steel sensing strip permanently bent or deflected. Another problem with the Cone Sensing Switch occurred when the cone

bottom plane would not perfectly meet the top cover plate plane of the RA due to relative road height variations. This sporadic occurrence resulted in the prevention or the delay of the activation of the switch. The solution was a sensing plate mounted above of the Cone Sensing Switch. The sensing plate was mounted with a spring compliant hinge which would allow the plate to rotate downwards when contacted by a cone and thus activate the Cone Sensing Switch. The spring compliant hinge would also return the sensing plate to its original position when not contacted. The original switch is activated by the sensing plate tap pointing towards and positioned directly above the original sensing strip. The sensing strip was cut shorter to accommodate the sensing plate. This modification would allow activation of the Cone Sensing Switch even when the cone was not perfectly aligned with the top of the RA, and would also protect the sensing strip from permanent deflection. Another benefit of this solution is that it maintained the original switch which is waterproof and cost-effective. The only drawback of this solution was the necessity of removing the Bumper Stops. The Cone Sensing Switch along with the shortened original sensing strip, the sensing plate tap, and the sensing plate are shown in Figure 5.5.

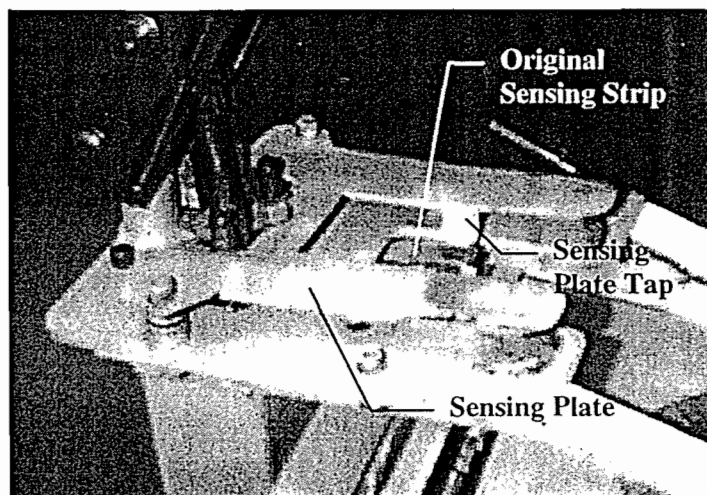
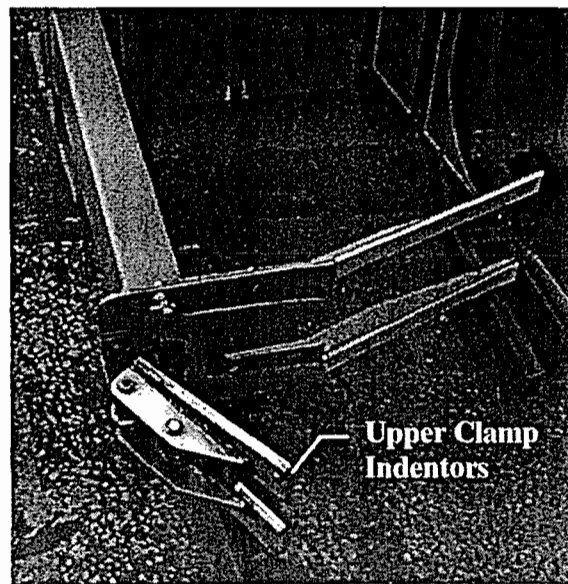


Figure 5.5 *Cone Sensing Plate*

Another problem encountered during manual testing of the RA System was an occasional loose grip on the cone. This occurred more frequently when other hydraulics were in operation, which effectively lowered the hydraulic pressure to the cylinder in the RA System. The loose grip was also exacerbated by the jerkier arm motion encountered during manual operation. The solution called for adding indentors to the Upper Clamp which would enhance the grip by slightly indenting the top surface of the cone base. This quick fix was readily accomplished by inserting cap bolts in the Upper Clamp. In Figure 5.6 the RA, in the ready to receive a cone position, shows the Upper Clamp with indentors.

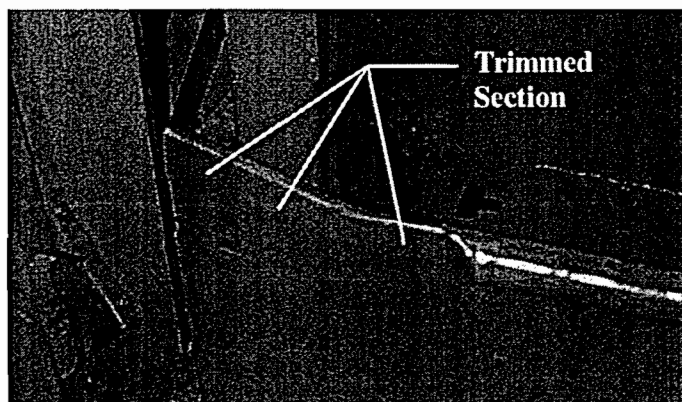


**Figure 5.6** *Retrieval Arm in Cone Receiving Position*

During the assembling of the PACM, the Drop Box location deviated from the original intended position. This location deviation had some beneficial effects, but some detrimental effect as well. One detrimental effect was on the RA System, in that the cone base would come into contact with the cone body during the upward rotation of the RA. The exact location of this contact was at the circular upper edge of the bucket seat area.



The quickest and best solution to this problem was trimming a section of the bucket seat area's edge. The trimmed section area is shown in Figure 5.7.

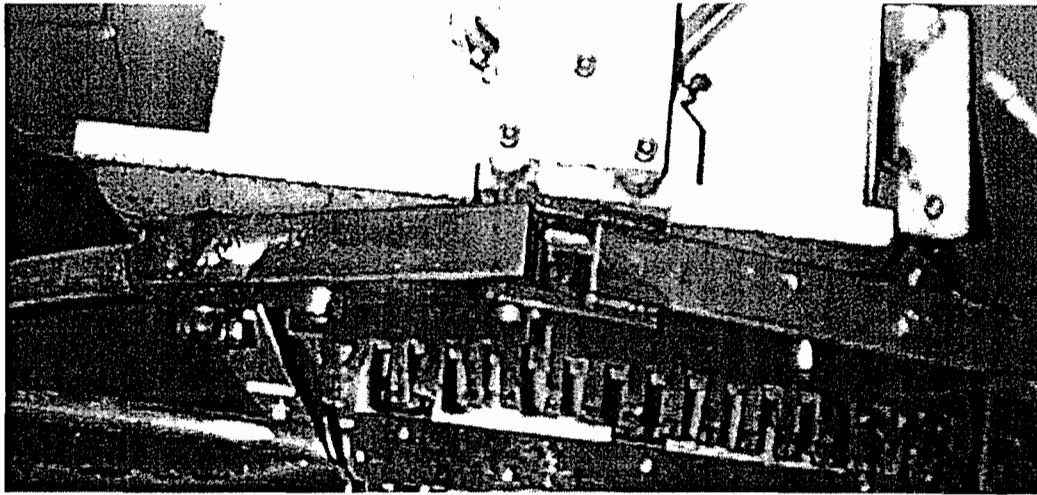


**Figure 5.7** *Trimmed Section of Cone Body's Bucket Seat Edge*

Besides some of the minor complications and corrections discussed above, the RA System tested very well during the manual testing and will be further tested in the automated mode.

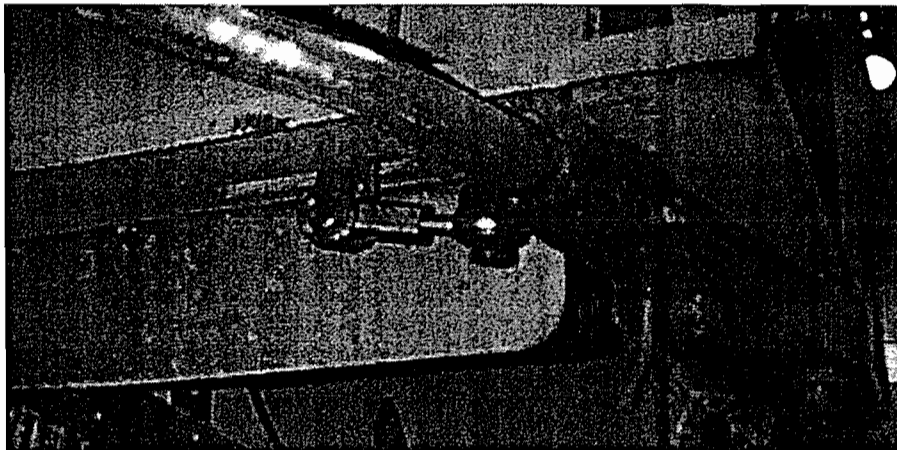
### **5.1.2 Secondary Funnel System**

Like the RA System, the SF System was fabricated and had its operation manually tested in both a laboratory setting and on the road. The SF System was built to specification and the underside of the Drop Box with the SF folding mechanism attached, in the stowed position, is shown in Figure 5.8.



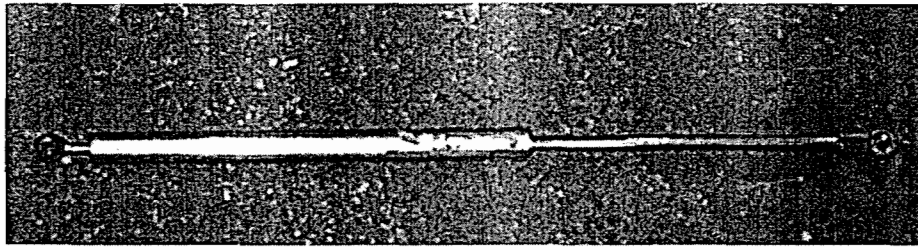
**Figure 5.8** *Stowed Secondary Funnel Folding Mechanism*

The second bar link of the SF folding mechanism consists of ball joints and is shown in Figure 5.9.



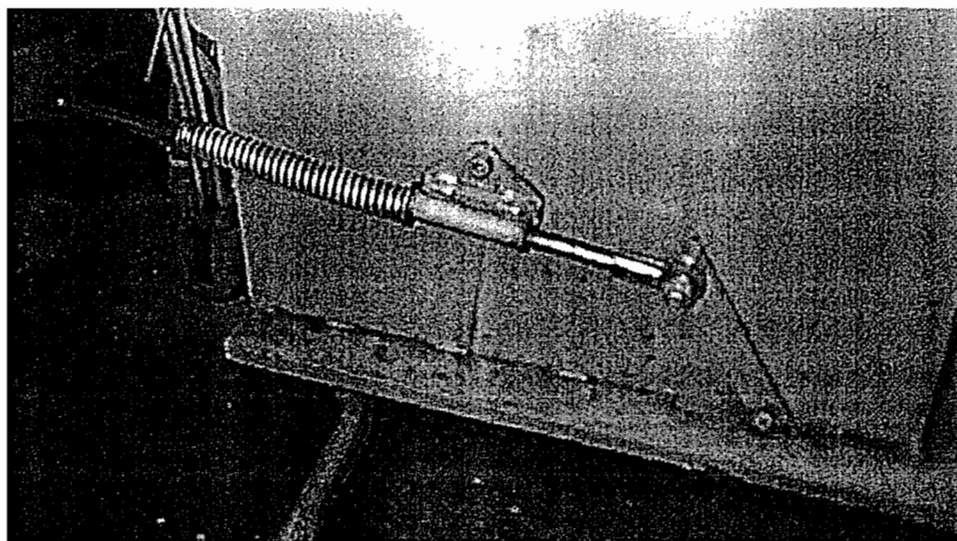
**Figure 5.9** *Ball Joint Link of Secondary Funnel Folding Mechanism*

The strut link that was originally designed and manufactured for the third and final link of the SF folding mechanism is shown in Figure 5.10.

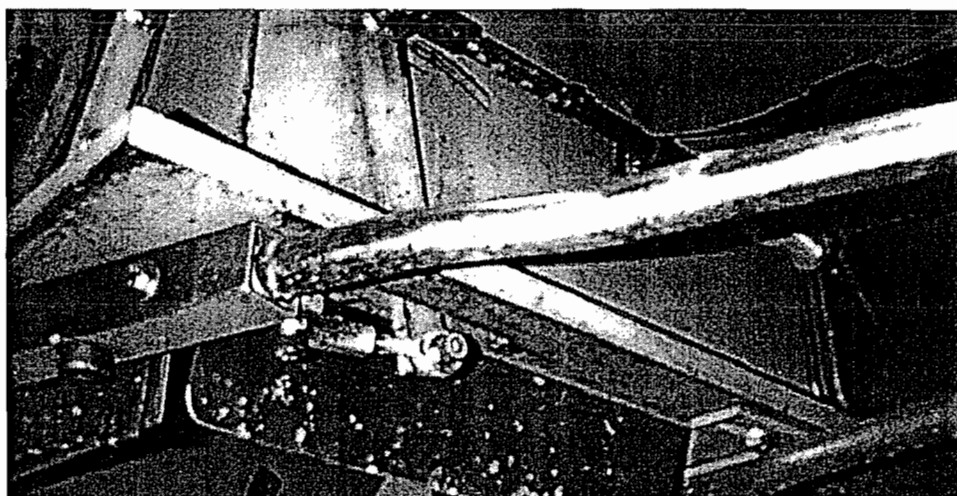


**Figure 5.10** *Secondary Funnel Folding Mechanism Strut Link*

The deviation of the Drop Box location had another detrimental effect on the SF System in that it limited the mounting room for the strut link. The truck cab consistently came in contact with the strut link of the SF folding mechanism. The other problem experienced, although minor, with the link rigidly attached to the truck's frame was flexure. When the truck was driven over uneven terrain or when the engine created a significant amount of torque, the flexing in the frame would create relative motion in the strut link. The solution to this problem would be a link that was narrower and was not rigidly mounted to the truck frame. The new resulting link is mounted on the side of the Drop Box and deploys the SF by spring action. During retraction of the Drop Box this link comes in contact with the truck frame. As the Drop Box continues to retract the rod is forced through its holder and compresses the spring, thus retracting the SF. This new link is shown in the deployed position in Figure 5.11 and in the retracted position in Figure 5.12.



**Figure 5.11** *Left Side Final Strut Link in Deployed Position*

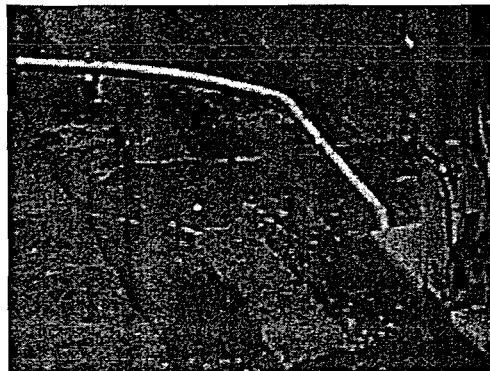


**Figure 5.12** *Right Side Secondary Funnel in Retracted Position*

The main beneficial effect of the deviation in Drop Box location is that the previously required dip in the outer SF funnel for the Upper Clamp motion is no longer needed. This greatly simplifies the outer Secondary Funnel. Also, as previously discussed in Section 4.4, the RA system no longer needs the tip of the cone longitudinally oriented at the time of retrieval. This was known to result in a shorter outer secondary funnel. However, once the manual testing of the SF System commenced it was discovered that the outer funnel could be even shorter than originally anticipated.

The only aspect of the SF System that was not yet determined in the design phase was the best way to keep the ends of the outer secondary funnels from dragging on the road. The current solution derived during the manual testing was the mounting of a caster at the funnel ends. The casters would normally not come in contact with the road surface, and only touch the surface when abnormal elevation differences were encountered.

The changes just discussed resulted in outer secondary funnels that deviated significantly from the original design. These changes were made during the manual testing of the SF, and the final outer secondary funnel configuration is shown in Figure 5.13.



**Figure 5.13** *Final Outer Secondary Funnel Configuration (Left Front)*

The SF System and folding mechanism functioned very well during the manual testing. The outer funnel configuration received some modification during the manual testing of the SF, but the final outer secondary funnel configuration functions in the same manner as the previous funnels. The strut link of the folding mechanism received a major modification but created an overall improvement to the system. The SF System will be tested in the automated mode along with the RA System.

## 5.2 Testing and Modifications of the Retrieval Arm and Secondary Funnel in Automated Mode

After concluding the manual testing described above, the PACM was further developed and the automated controls were implemented. During these changes the machine was continuously tested to ensure that all the subsystems were in prime operational condition and interfaced properly with each other. Many tests were performed before all the fine tuning and adjustments were completed. During these tuning runs the RA and SF Systems did not receive any further modification beyond the ones performed during the manual testing.

The only serious retrieval problem encountered was due to road height variation with respect to the RA System. With severe road height variations the edge of the cone base could be either gripped too high or too low. As a result, when the RA releases the retrieved cone to slide onto the Lateral Conveyor Belt, it would not be properly aligned and would be prevented from moving up the Wing Actuator. To solve this problem, the guides that align the cone on the Wing Actuator were extended to align a cone while it is sliding down the RA ramp. However, since room for these guides is limited, the solution will not work when the road variations are extreme.

The final automated test run of the RA and SF Systems on the right side of the ACM was performed on April 18, 1998. The left side systems are identical and will receive all the same modifications and tuning at which point it will be operating identically to the right side. The results for these test are listed below in Table 5.1.

Test Direction	Test Side	Number of Attempts	Successful Retrievals	Percentage
Forward	Right Side	11	11	100%
Backward	Right Side	10	10	100%

**Table 5.1** *Final Test Results of the Right Side Retrieval Arm and Secondary Funnel*

The final test results are extremely promising; the right side RA and SF functioned extremely well, and no retrieval problems occurred. The only problem still very sporadically encountered is due to extreme road height variation with respect to the RA System.

### **5.3 Recommended Improvements**

Since the RA and SF System were functioning so well during the automated testing only minor further modification are recommended, most of which are cosmetic.

Since the original Bumper Stoppers were removed from the RA, the hydraulic cylinder in the RA shaft should have a rubber collar mounted around its shaft to prevent the cylinder from bottoming out. This collar could be further enhanced with a bellows which would provide the cylinder rod with extra protection from any moisture or dirt that may enter the RA's rectangular shaft.

The RA System would also benefit from a hydraulic cylinder with a slightly bigger diameter. This would provide the additional force needed to prevent the possibility of a loose grip on a cone base. An alternative solution would be the fabrication of cleaner hemispherical indentors which should be an integral part of the Upper Clamp. This would be more aesthetically pleasing than the current cap screws in the Upper Clamp.

The Upper Clamp also does not require the oil impregnated bushings around the pins through the Upper Clamp. Experience with the RA has shown that the ball joints are very effective, have minimal friction, and will always rotate prior to the pins rotating in the Upper Clamp.

The rotational mechanism at the bottom of the RA should receive further work. For one, a slip ring contact needs to be incorporated for the Cone Sensing Switch wiring.

This mechanism also needs the break away mechanism operational. Both of these modifications are currently under development.

The last modification recommended for the RA System would be to find a way to provide more cone guides at the Wing Actuator. This would correct retrieval errors when extreme road height variances are encountered.

The SF System is currently operating very effectively. The only improvement would be to replace the end of the outer funnel casters with a better system for preventing the funnel tips from scraping the road. If the PACM were to go into production, then the rectangular tubing at the SF System sleeve weldments should be specified as seamless. This will prevent the manual labor of removing the seam inside the tube weldments so insertion of the funnel sections is readily possible.

The two new subsystems designed and created for the PACM have proven to be very effective in accomplishing their tasks and duties. All the changes made during the transition from the TBACM to the PACM have created a much more effective, utilizeable, and safer machine. The next chapter will provide some overall conclusions and recommendations.



## CHAPTER SIX: CONCLUSIONS AND RECOMMENDATIONS

### 6.1 Conclusions

This thesis discussed the transition of a Test Bed Automated Cone Machine (TBACM) into a Prototype Automated Cone Machine (PACM). More specifically, it presented the development of the Retrieval Arm and Secondary Funnel Subsystems for this newly fabricated PACM. The previously developed TBACM validated many of the concepts and the machine as a whole, thus justifying the continued development of the PACM. The PACM is expected to be introduced into the Caltrans' fleet of vehicles to provide more specific feedback from the end-user. The introduction of this machine is certain to create a safer working environment for the cone truck operators and workers. It will also prevent many of the repetitive motion injuries which are often sustained by the cone workers.

The PACM is a considerable improvement over the TBACM and certainly over any other machine currently available. Also, the PACM is specifically designed to meet Caltrans' needs and operational specifications. The PACM is able to dispatch cones from either side of the truck while traveling forward and is able to retrieve the cones from both sides and travel directions without any manual change over. All this is automatically set up and controlled from within the safe confines of the truck cab. The introduction of a machine that specifically meets the Caltrans cone operation criteria, and is still usable as a multi-purpose vehicle, is much more economical than other options. These options include the purchase of a task specific cone machine currently on the market. The PACM provides an effective, valuable machine that is operable in all weather conditions. However, the PACM is still operable as a standard manual Caltrans cone truck should the need ever arise.

Once the PACM has been tested and used by the end-user the machine will be enhanced and improved further. Once this is accomplished, it is expected that the PACM

will be incorporated into the Caltrans fleet on a wide scale and possibly be introduced to other states, municipalities and private industries.

## **6.2 Recommendations**

The completed PACM has proven to be extremely effective and reliable in accomplishing its task. The machine is much improved since the inception of the concept, but in retrospect there are always some minor improvements that would have enhanced the design. Also, after many modifications that further enhanced the machine, there is still some room for improvement besides those discussed in Section 5.3. There are also some additional components that could be designed and added to the PACM to increase its overall utility. The following will briefly outline some changes and additions that would enhance and improve the PACM.

The PACM cone capacity is somewhat diminished due to encroachment of the automating equipment into the cone storage conveyor area. The capacity is still at the original 80 cones when the feet of the cone base are removed. This, however, is not a desirable modification. The solution to this dilemma would be to create a double stacking mechanism on the Main Conveyor Belt System. The double cone stacking mechanism would of course be automated and could easily increase the cone capacity twofold.

The PACM as a whole would also greatly benefit from a better electrical generation and storage system since the additional automated systems added to the truck require a significant amount of electricity during their operation. Some electrical

components will fail if the supply voltage drop below their operating threshold level. The remedy for this includes adding another vehicle battery to the electrical system and replacing the current alternator with a higher amperage output model.

The only improvement to the hydraulic system would be the addition of a heating unit to the fluid reservoir. This prevents sluggish operation of systems using hydraulic fluid during cold weather. Also with this addition, the PACM would always be ensured hydraulic fluid at the proper temperature since a heat exchanger that will keep the fluid cool is already installed. Prior to implementing an electrical heater, the electrical system should be enhanced, as discussed above, since the heater element will definitely draw a significant amount of current. An alternative heater solution could be circulating hot engine coolant in another heat exchanger thus providing heat energy to the hydraulic reservoir. This solution will not require any electrical power, but might not be sufficient in extremely cold temperatures.

The last operational improvement would be to the Stowage System. This system operated remarkably well but still has a weakness in the gripper assembly. The cone has a tendency to slip off the stowage gripper, especially during hot weather. This current Stowage System problem could be readily solved by adding confinements around the cone base so the cone is unable to expand due to the gripper force. The other solution would be to design some sort of positive hold on the cone base with grippers that reach around the base and secure the cone onto the gripper.

The PACM would also benefit from being more water resistant, since the machine is inevitably going to be operated in the rain or other wet conditions. Better water

resistivity will also prevent rust built-up if the machine were to be stored in an area where moisture will be present.

The machine could also be enhanced with respect to safety. The gripping and clamping mechanisms should be shielded to prevent human limbs from being injured. Some of the automated machinery could also be better secured to prevent equipment from coming dislodged during an accident. The Drop Box System is a prime example, since the boxes are mounted by only three v-grooved rollers that could easily snap or break during an impact. Safety straps mounted to the Drop Boxes would prevent the creation of dangerous heavy projectiles during an accident.

Overall the PACM is a superior product that will receive even more testing with the Caltrans cone workers and other personnel. This will invariably provide more useful input for further improvements to the machine. Then, if a significant amount of these machines were to be produced, the automated equipment should be integrated with the Cone Body.

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## APPENDIX A

### List of Acronyms

AHMCT	Advanced Highway Maintenance and Construction Technology
CSF	Cone Support Fixture
DBS	Drop Box System
DC	Direct Current
GMC	General Motors Corporation
ISM	Infrared Sensor Mount
LCB	Lateral Conveyor Belt
LCG	Lateral Cone Guide
MCBS	Main Conveyor Belt System
PACM	Prototype Automated Cone Machine
PFS	Primary Funnel System
PVC	Poly-Vinyl Chloride
RA	Retrieval Arm
SF	Secondary Funnel
TBACM	Test Bed Automated Cone Machine
UCD	University of California, Davis
UHMW	Ultra High Molecular Weight
U.S.	United States

## APPENDIX B

### Calculations

#### B.1: Calculation for Maximum Force Produced by Retrieval Arm (RA) Hydraulic Cylinder:

$$F_C = P \cdot A = P \cdot \pi \cdot (r_c^2 - r_r^2)$$

Where:

$F_C$  = Force in Hydraulic cylinder (N)

$P$  = Maximum Applied Hydraulic Pressure = 6.894 MPa (1,000 lb<sub>f</sub>/in<sup>2</sup>)

$A$  = Area of Applied Pressure (m<sup>2</sup>)

$r_c$  = Radius of Hydraulic Cylinder = 0.0127 m (0.5 in)

$r_r$  = Radius of Hydraulic Cylinder Rod = 0.0064 m (0.25 in)

Thus:

$$F_C = 6,894,757 \cdot \pi \cdot [(0.0127)^2 - (0.0064)^2] = \underline{2,620 \text{ N}} (589 \text{ lb}_f)$$

#### B.2: Calculation for Stress in Retrieval Arm's Top Clamp Plate:

Worse case scenario occurs when the Top Clamp Plate will only clamp with one finger.

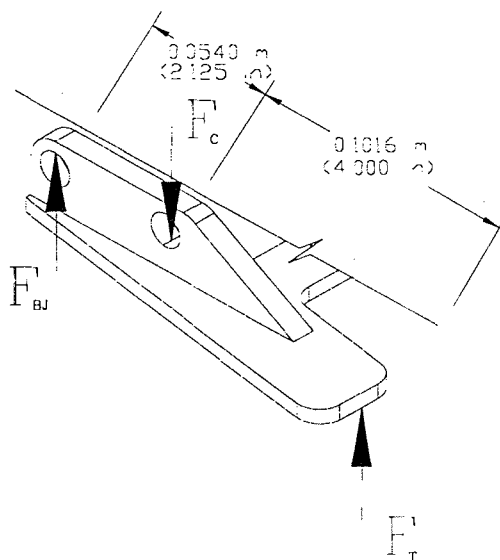
This situation is illustrated in reference drawing Figure B.1.

Where:

$F_C$  = Force in Hydraulic cylinder (N)

$F_{BJ}$  = Force in Rear Ball Joint (N)

$F_T$  = Force in Finger Tip of Top Clamp (N)



**Figure B.1** *Reference Drawing for Top Clamp Forces Calculations*

From sum of moments about the rear ball joint:

$$\Sigma M = -F_C \cdot 0.0540 + F_T \cdot (0.0540 + 0.1016) = 0$$

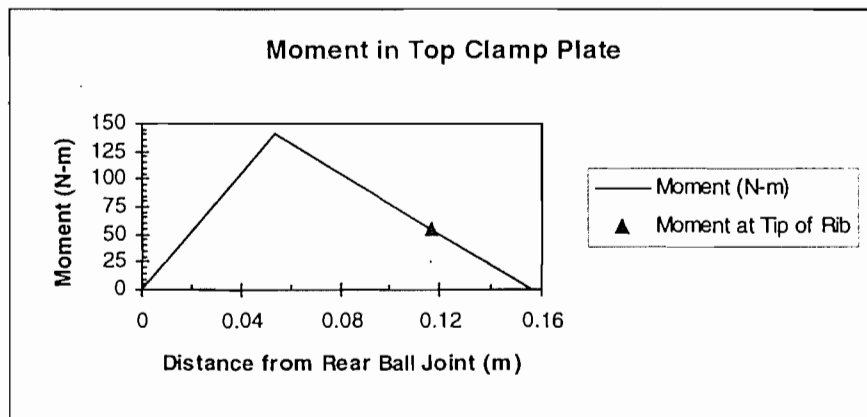
When  $F_C = 2,620 \text{ N}$ ,  $F_T = 907 \text{ N}$  (204 lbf)

From sum of forces equal to zero:

$$\Sigma F = 0, F_{BJ} = F_C - F_T = 2,620 - 907 = 1,713 \text{ N} \text{ (385 lbf)}$$

The resulting moment diagram for this configuration shown in Figure B.2:





**Figure B.2** *Moment in Top Clamp Plate*

The maximum moment is at the cylinder ball joint, where there is a hole in the cross section for the pin. But the moment at the tip of the rib should also be analyzed since the cross sectional area consists only of a thin plate and there is no rib. From simple beam theory, the stress from a moment load is provide by the flexural formula:

$$\sigma_{Max} = \frac{My}{I}$$

Where:

y = Distance from Neutral Axis = 1.137E-2 m (0.448 in) from the calculations below:

	Area (m <sup>2</sup> )	Yi	Ai*Yi
Rib above Hole	0.635E-4	2.590E-2	1.645E-6
Rib below Hole	1.079E-4	1.201E-2	1.296E-6
Plate	1.210E-4	3.175E-3	3.842E-7
Sum:	2.924E-4		3.325E-6
	y:	$\frac{\sum AiYi}{\sum A}$	1.137E-2 m (0.448 in)

**Table B.1** *Neutral Axis Calculation*

$I$  = Moment of Inertia with use of the Parallel Axis Theorem =  $\Sigma I_x + Ad^2 =$

$$2.674E-8 \text{ m}^4 (0.0643 \text{ in}^4)$$

$M$  = Moment = 141.43 N-m (1252 in-lb<sub>f</sub>) located at the cylinder ball joint

$$\text{Thus: } \sigma_{Max} = \frac{141.43 \cdot 1.137E-2}{2.674E-8} = 60.137 \text{ MPa (8,709 lb}_f\text{/in}^2\text{) in tensile loading.}$$

Similarly, the compression loading would be 94.146 MPa (13,655 lb<sub>f</sub>/in<sup>2</sup>) with the

Distance to Neutral Axis = 1.780E-2 m (0.71 in)

304 Stainless Steel has an Ultimate Yield Strength ( $S_u$ ) of 860 Mpa (125,000 lb<sub>f</sub>/in<sup>2</sup>).

Using Mischke (87), the Endurance Limit  $S_e = 0.504 \cdot S_u = 433 \text{ Mpa (63,000 lb}_f\text{/in}^2\text{)}$ ,

which will ensure an infinite life cycle endurance.

Thus the factor of safety, assuming the cross section at the welds is homogeneous:

$$n = \frac{S_e}{\sigma_{Max}} = 4.6$$

The maximum moment at the tip of the rib of the Top Clamp Plate is 54.25 N-m (481 in-lb<sub>f</sub>) (as shown in Figure B.2), and by the flexural formula:

$$\sigma_{Max} = \frac{My}{I}$$

Where:

$$I = \text{Moment of Inertia: } \frac{1}{12} b h^3 = \frac{1}{12} \cdot 3.810E-2 \cdot 6.350E-3^3 =$$

$$8.130E-10 \text{ m}^4 (1.95E-3 \text{ in}^4)$$

$y$  = Distance from Neutral Axis = 3.175E-3 m (0.125 in)

$M$  = Moment = 54.25 N-m (481 in-lb<sub>f</sub>)

$$\text{Thus: } \sigma_{Max} = \frac{54.25 \cdot 3.175E-3}{8.130E-10} = 211.874 \text{ MPa (30,729 lb}_f\text{/in}^2\text{)}$$

304 Stainless Steel has an Ultimate Yield Strength ( $S_u$ ) of 860 Mpa (125,000 lb<sub>f</sub>/in<sup>2</sup>).

Using Mischke (87), the Endurance Limit  $S_e = 0.504 \cdot S_u = 433$  Mpa (63,000 lb<sub>f</sub>/in<sup>2</sup>),

which will ensure an infinite life cycle endurance.

Thus the factor of safety:

$$n = \frac{S_e}{\sigma_{Max}} = 2.0$$

Thus the minimum factor of safety in the Top Clamp Plate using only one finger is  $n = 2.0$ , which is not the typical load cycle. During the normal cycle both fingers will be used to clamp the cone thus the minimum factor of safety in the Top Clamp Plate would be closer to  $n=4.0$

### **B.3: Calculation for Factor of Safety in Ball Joint used on Top Clamp Plate:**

Maximum load in rear ball joint, from calculation B.2, is 1,711 N (385 lb<sub>f</sub>).

Maximum load in cylinder ball joint, from calculation B.2, is 2,620 N (589 lb<sub>f</sub>).

Since both ball joint are the same part, the higher force of 2,620 N (589 lb<sub>f</sub>) is used as  $F_{max}$  in this calculation.

The specifications for the specified commercially available ball joint are:

$F_{ys}$  = Maximum Static Load = 23,797 N (5,350 lb<sub>f</sub>)

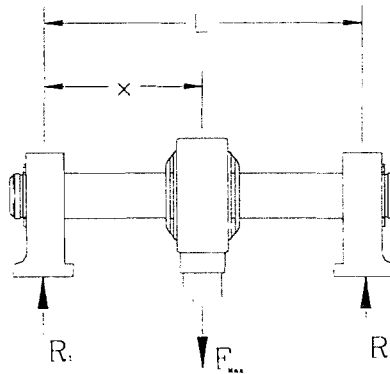
$F_{yc}$  = Maximum Dynamic Load = 44,482 N (10,000 lb<sub>f</sub>) @ 15 RPM

The failure of the ball joint will most likely be in the bearing. The factor of safety, using the lower static yield strength for  $F_u$ , is:

$$n = \frac{F_u}{F_{max}} = 9.0$$

#### B.4: Calculation for Maximum Stress in Top Clamp Plate pins:

The Top Clamp Plate pins are center loaded with simple end supports. The cylinder and rear ball joints are loaded similarly but the ball joint at the cylinder carries the maximum load and will therefore be analyzed. The loading configuration is shown in Figure B.3.



**Figure B.3** *Top Clamp Plate Pin Loading*

The maximum moment, located in the center of the pin, is:

$$M = 0.5 \cdot F_{\max} \cdot X$$

Where:

$M$  = Moment (in-lb<sub>f</sub>)

$F_{\max}$  = Force in Hydraulic Cylinder = 2,620N (589 lb<sub>f</sub>)

$L$  = Length of the Pin = 6.10E-2 m (2.4 in)

$X$  = Location of Load = 0.5 ·  $L$  = 3.05E-2 m (1.2 in)

Thus:

$$M = 0.5 \cdot 2,620 \cdot 3.05E-3 = 39.93 \text{ N-m (353.58 in-lb}_f\text{)}$$

By the flexural formula, the maximum stress is:

$$\sigma_{Max} = \frac{My}{J}$$

Where:

$$J = \text{Polar Moment of Inertia: } \pi \frac{1}{64} D^4 \text{ (m}^4\text{)}$$

Where:

$$D = 1.111\text{E-2 m (7/16 in)}$$

$$\text{Thus: } J = 7.485\text{E-10 m}^4 \text{ (1.798E-3 in}^4\text{)}$$

$$y = \text{Distance from Neutral Axis} = 5.556\text{E-3 m (7/32 in)}$$

$$M = \text{Moment} = 39.93 \text{ N-m (353.58 in-lb}_f\text{) from above}$$

$$\text{Thus: } \sigma_{Max} = \frac{39.93 \cdot 5.556\text{E-3}}{7.485\text{E-10}} = 296.34 \text{ MPa (42,988 lb}_f\text{/in}^2\text{)}$$

Hardened Stainless Steel has an Ultimate Yield Strength ( $S_u$ ) of over 965.27 MPa (140,000  $\text{lb}_f\text{/in}^2$ ). Using Mischke (87), the Endurance Limit  $S_e = 0.504 \cdot S_u = 486.49 \text{ MPa}$  (70,560  $\text{lb}_f\text{/in}^2$ ), which will ensure an infinite life cycle endurance. Thus the minimum factor of safety:

$$n = \frac{S_e}{\sigma_{Max}} = 1.6$$

The pins however do receive fixed end support from the Top Clamp Plate. If it is assumed to receive full fixed end support the factor of safety would increase to 3.2. Since the actual loading is somewhere in between, the safety factor will also be between the 1.6 and 3.2 values.

#### B.5: Calculation for Maximum Stress in Threaded Rod:

The maximum stress in the threaded rod between the cylinder and the ball joint is:

$$\sigma_{Max} = \frac{F_{Max}}{A}$$

Where:

$F_{max}$  = Force in Hydraulic Cylinder = 2,620 N (589 lbf)

$A$  = Area of Treated Rod =  $\pi \cdot r^2$  where  $r_{min} = 5.384E-3$  m (0.212 in) thus

$$A = 9.109E-5 \text{ m}^2 \text{ (0.1412 in}^2\text{)}$$

$$\text{Then: } \sigma_{Max} = \frac{2620}{9.109E-5} = 28.762 \text{ MPa (4,172 lbf/in}^2\text{)}$$

From Modified Goodman Theory, the factor of safety is:

$$n = \frac{S_u}{\sigma_{Max} + \sigma_a}$$

Where:

$$\sigma_a = \text{Average Stress during Cycle} = \frac{1}{2} \sigma_{Max} \text{ since the minimum load is zero}$$

$S_e$  = Endurance Limit = 206.84 MPa (30,000 lbf/in<sup>2</sup>) for Stainless Steel Bolts

which includes fatigue endurance limit, surface finish, and notch sensitivity.

Thus the factor of safety, ensuring an infinite life, is:

$$n = \frac{S_e}{1.5\sigma_{Max}} = \frac{206.84}{1.5 \cdot 28.762} = 4.8$$

#### **B.6: Safety Factor Calculation for Hardware used with Hydraulic RA Cylinder:**

The maximum force the mounting hardware will experience is 2,620 N (589 lbf) due to the RA hydraulic cylinder action. The mounting hardware specified with this RA

cylinder is commercially available and has a specified yield strength of 8,869 N (2,000 lb<sub>f</sub>), which most likely will already include a safety factor.

Thus the minimum factor of safety is:

$$n = \frac{F_{ys}}{F_{max}} = \frac{8,896}{2,620} = \underline{3.4}$$

### **B.7: Calculation for Maximum Stress in Clevis Bracket Mounting Bolts:**

The maximum stress in the clevis bracket mounting bolts holding the RA hydraulic cylinder is:

$$\sigma_{Max} = \frac{F_{Max}}{A_{tot}}$$

Where:

$F_{max}$  = Force in Hydraulic Cylinder = 2,620 N (589 lb<sub>f</sub>)

$A$  = Total Area of each Mounting Bolts =  $\pi \cdot r^2$  where  $r_{min} = 3.787E-3$  m (0.1491 in) thus

$A = 4.506E-5$  m<sup>2</sup> (0.0698 in<sup>2</sup>) per bolt. Since two bolts are used the total area is:

$$A_{tot} = 2 \cdot A = 9.011E-5 \text{ m}^2 (0.138 \text{ in}^2)$$

Then:

$$\sigma_{Max} = \frac{2,620}{9.011E-5} = 29.075 \text{ MPa (4,268 lb}_f\text{/in}^2\text{)}$$

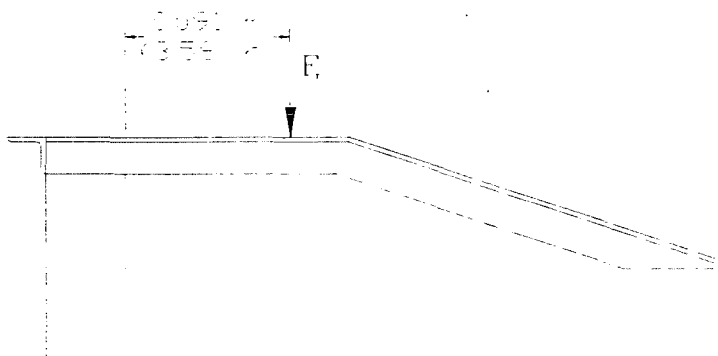
From Shigley et al, 1989, the fully corrected Endurance Limit  $S_e = 128.24$  MPa (18,600 lb<sub>f</sub>/in<sup>2</sup>) for plain steel, grade five bolts, which includes corrections for fatigue endurance limit, proper preload, surface finish, and notch sensitivity.

Thus the factor of safety, ensuring an infinite life, is:

$$n = \frac{S_e}{\sigma_{Max}} = \frac{128.24}{29.075} = 4.4$$

### B.8: Calculation for Maximum Stress in Sliding Ramp Angle Iron:

The maximum stress during to the normal operation in the sliding ramp is due to the maximum clamping force ( $F_T$ ) by the Top Clamp Plate. This maximum force, created by one Top Clamp finger, was determined to be 909 N (204 lbf) in calculation B.2. The loading configuration for this calculation is illustrated in Figure B.4.



**Figure B.4** *Forces in the Retrieval Arm Sliding Ramp*

The stress due to bending in the unsymmetrical angle iron segment is:

$$\sigma_{Max} = \frac{M(y - x \tan(\alpha))}{I_x - I_y \tan(\alpha)}$$

Where:

$$M = \text{Moment} = F_T \cdot D = 909 \cdot 0.091 = 82.719 \text{ N-m (732.03 in-lbf)}$$

$$y = \text{Distance from Neutral Axis} = 7.366\text{E-3 m (0.29 in)} \text{ (From Shigley et al, 1989, for a } 1 \times 1 \times 1/8 \text{ angle iron)}$$



$x$  = Distance from Neutral Axis =  $7.366\text{E-}3$  m (0.29 in) (From Shigley et al, 1989, for a  $1 \times 1 \times 1/8$  angle iron)

$I_x$  = Moment of Inertia =  $8.740\text{E-}9$  m<sup>4</sup> ( $0.021$  in<sup>4</sup>) (From Shigley et al, 1989, for a  $1 \times 1 \times 1/8$  angle iron)

$I_{xy} = \Sigma(A \cdot x \cdot y) = -5.308\text{E-}9$  m<sup>4</sup> ( $-0.0128$  in<sup>4</sup>)

$\alpha$  = Orientation of Neutral Axis =  $\frac{I_{xy}}{I_y}$  (for load at 90 degree angle) =  $\frac{-5.308\text{E-}9}{8.740\text{E-}9} =$

$-0.610$  rad or  $-34.9^\circ$

Thus:  $\sigma_{Max} = \frac{82.719((7.366\text{E-}3) - (7.366\text{E-}3) \cdot \tan(-34.9))}{8.740\text{E-}9 - (-5.308\text{E-}9) \cdot \tan(-34.9)} =$

$118.34$  MPa ( $17,165$  lb<sub>f</sub>/in<sup>2</sup>) in tensile loading.

Using this same process with  $y = -1.80\text{E-}2$  m ( $-0.71$  in) and  $x = 7.366\text{E-}3$  m (0.29 in) results in  $\sigma_{Max} = -121.72$  MPa ( $-17,654$  lb<sub>f</sub>/in<sup>2</sup>) in compression loading.

Typical Carbon Steel has an Ultimate Yield Strength ( $S_u$ ) of  $400$  Mpa ( $58,015$  lb<sub>f</sub>/in<sup>2</sup>).

Using Mischke (87), the Endurance Limit  $S_e = 0.504 \cdot S_u = 201.6$  Mpa ( $29,240$  lb<sub>f</sub>/in<sup>2</sup>), which will ensure an infinite life cycle endurance.

Thus the factor of safety:

$$n = \frac{S_e}{\sigma_{Max}} = 1.7$$

It should be noted that the Tube Cover Plate will be bolted to the sliding ramp and RA tube thus greatly enhancing the sliding ramp angle iron strength. The single finger loading will only occur sporadically thus the typical cyclic loading is half of the loading considered here which will double the safety factor. Also note worthy is that the same

loading will occur if a 889.6 N (200 lbf) operator will step on the sliding ramp of the RA System.

### **B.9: Calculation for Amount Return Force needed by Springs in the RA Tube:**

The total return force to be produced by the return springs is a combination of lifting the weight of the moving clamping part and overcoming the back pressure in the RA hydraulic cylinder. The total weight of the moving clamping part ( $F_w$ ) is:

Part Name	Total Weight (N)
Top Clamp Plate	10.5
Threaded Rod	2.9
Upper Clamp Pin	0.8
Moving Ball Joint	1.1
Upper Clevis Bracket	2.2
<b>TOTAL:</b>	$F_w = 17.5 \text{ N (3.9 lbf)}$

**Table B.2** *Weight of Moving Clamping Parts*

It should be noted that the center of gravity for Top Clamp Plate is very close to the cylinder ball joint location and therefore it is assumed that the total weight of the Top Clamp Plate needs to be lifted when in closed (clamped) position.

The back pressure force in the hydraulic cylinder is:

$$F_{BP} = P \cdot A = P \cdot \pi \cdot (r_o^2 - r_i^2)$$

Where:

$F_{BP}$  = Back Pressure Force in Hydraulic cylinder (N)

$P$  = Maximum Back Pressure = 689.5 KPa (100 lb<sub>f</sub>/in<sup>2</sup>)

$A$  = Area of Applied Pressure (m<sup>2</sup>)

$r_c$  = Radius of Hydraulic Cylinder = 0.0127 m (0.5 in)

$r_r$  = Radius of Hydraulic Cylinder Rod = 0.0064 m (0.25 in)

Thus:

$$F_C = 689,475 \cdot \pi \cdot [(0.0127)^2 - (0.0064)^2] = 262.0 \text{ N (58.9 lb}_f\text{)}$$

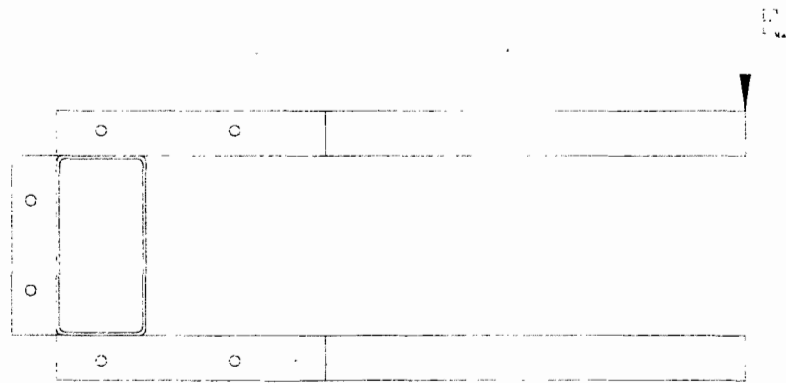
Thus the total return force to be produced by the return springs is:

$$F_W + F_{BP} = 262.0 + 17.5 = \underline{279.5 \text{ N (62.8 lb}_f\text{)}}$$

#### **B.10: Calculation for Amount of Angular Deflection in the RA Tube:**

The maximum loading in the RA tube does not occur due to the forces during upward angular acceleration but rather when a cone operator accidentally steps on the RA tube sliding ramp as illustrated in Figure B.5. This is a likely possibility and needs to be considered since the RA, in the ready to receive a cone position, is very low to the ground and near the Cone Bed bucket seat where operator might be getting in and out.

The maximum load ( $F_{Max}$ ) in this situation would be a 889.6 N (200 lb<sub>f</sub>) force on the sliding ramp.



**Figure B.5** *Forces on the Retrieval Arm Tube*

The angular deflection is calculated by:

$$\theta = \frac{T_0 L}{K G}$$

Where:

$$T_0 = \text{Maximum Torsional Load} = F_{\text{Max}} \cdot L$$

Where:

$$F_{\text{Max}} = \text{Weight of Operator} = 889.6 \text{ N (200 lb}_f\text{)}$$

$$L = \text{Maximum Moment Arm Length} = 0.363 \text{ m (14.28 in) (length of sliding ramp)}$$

$$\text{Thus: } T_0 = 889.6 \cdot 0.363 = 322.68 \text{ N}\cdot\text{m (2,856 in}\cdot\text{lb}_f\text{)}$$

$$L = \text{Length of RA Tube} = 0.467 \text{ m (18.38 in)}$$

$$G = \text{Modulus of Rigidity} = 79 \text{ GPa (11.5E06 lb}_f\text{/in}^2\text{) (for plain steel)}$$

$$K = \text{Torsional Constant} = \frac{2 t^3 (w-t)^2 (h-t)^2}{wt + ht - 2t^2} \text{ (m}^4\text{)}$$

Where:

$$w = \text{Width of Tube} = 0.051 \text{ m (2 in)}$$

$h$  = Height of Tube = 0.102 m (4 in)

$t$  = Wall Thickness of Tube = 1.52E-3 m (0.06 in)

Resulting in  $K = 4.963\text{E-}7 \text{ m}^4$  (1.1923 in<sup>4</sup>)

Thus:

$$\theta = \frac{322.68 \cdot 0.467}{4.963\text{E-}7 \cdot 79\text{E}09} = 0.0038 \text{ (rad)} = 0.219 \text{ (degrees)}$$

### **B.11: Calculation for Maximum Stresses in the RA Tube:**

The maximum loading configuration in this calculation, the same as in the previous calculation (B10), is a cone operator stepping on the RA system sliding ramp as illustrated in Figure B.5. The resulting load is a torque and a moment. The shear stress resulting from the torque is:

$$\tau = \frac{T}{2 A_m t}$$

Where:

$t$  = Wall Thickness of Tube = 1.52E-3 m (0.06 in)

$T$  = Maximum Torsional Load =  $F_{\text{Max}} F \cdot L$

Where:

$F_{\text{Max}}$  = Weight of Operator = 889.6 N (200 lb<sub>f</sub>)

$L$  = Maximum Moment Arm Length = 0.363 m (14.28 in) (length of sliding ramp)

Thus:  $T = 889.6 \cdot 0.363 = 322.68 \text{ N-m}$  (2,856 in-lb<sub>f</sub>)

$A_m$  = Area bounded by centerlines =  $(w-t) \cdot (h-t)$

Where:

$w$  = Width of Tube = 0.051 m (2 in)

$h$  = Height of Tube = 0.102 m (4 in)

$t$  = Wall Thickness of Tube =  $1.52E-3$  m (0.06 in)

Resulting in  $A_m = 4.93E-3 \text{ m}^2$  (7.64 in<sup>2</sup>)

Thus the Shear Load is:

$$\tau = \frac{322.68}{2 \cdot 4.93E-3 \cdot 1.52E-3} = 21.48 \text{ MPa (3,115 lb}_f\text{/in}^2\text{)}$$

This same loading configuration will also result in a moment which will create normal stress calculated by the flexural formula:

$$\sigma = \frac{My}{I}$$

Where:

$$I = \text{Moment of Inertia: } \Sigma \frac{1}{12} b h^3 = \left( \frac{1}{12} \cdot 0.051 \cdot 0.102^3 \right) - \left( \frac{1}{12} \cdot 0.048 \cdot 0.098^3 \right) = 6.32E-7 \text{ m}^4 (1.52 \text{ in}^4)$$

$y$  = Distance from Neutral Axis = 0.051 m (2 in)

$M$  = Moment =  $F_{\max} \cdot L$

Where:

$F_{\max}$  = Weight of Cone Operator = 889.6 N (200 lb<sub>f</sub>)

$L$  = Maximum Moment Arm Length = 0.467 m (18.38 in) (length of the arm tube)

Thus:  $M = 889.6 \cdot 0.467 = 415.44 \text{ N}\cdot\text{m (3,676 lb}_f\text{-in)}$

$$\text{Then: } \sigma = \frac{415.44 \cdot 0.051}{6.32E-7} = 33.34 \text{ MPa (4,837 lb}_f\text{/in}^2\text{)}$$

By Principle of Superposition all the stresses can be added together:

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

Where:

$$\sigma_x = 0 \text{ MPa (lb}_f\text{/in}^2\text{)}$$

$$\sigma_y = 33.34 \text{ MPa (4,837 lb}_f\text{/in}^2\text{)}$$

$$\tau = 21.48 \text{ MPa (3,115 lb}_f\text{/in}^2\text{)}$$

$$\text{Thus: } \sigma_{\max} = \frac{0 + 3334E6}{2} + \sqrt{\left(\frac{0 - 3334E6}{2}\right)^2 + 2148E6^2} = 43.86 \text{ MPa (6,362 lb}_f\text{/in}^2\text{)}$$

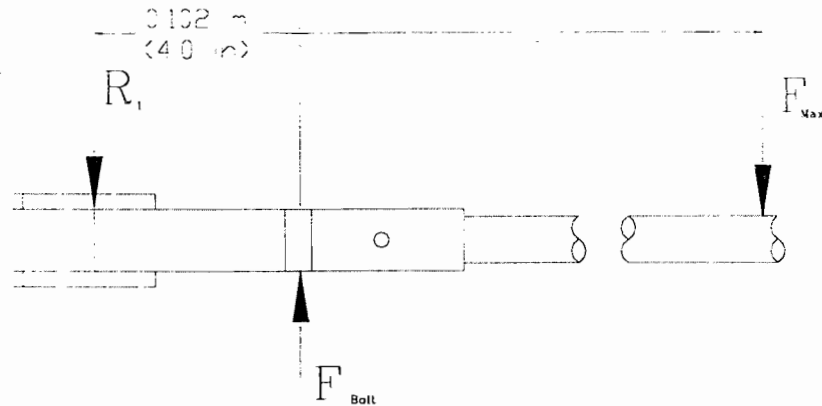
The typical carbon steel has an approximate tensile yield strength of 21.37 MPa (31,000 lb<sub>f</sub>/in<sup>2</sup>), thus the factor of safety is:

$$n = \frac{\sigma_y}{\sigma_{\max}} = 4.9$$

## **B.12: Calculation for Maximum Stress in the Secondary Funnel Sleeve Weldment**

### **Mounting Bolt:**

The Secondary Funnel (SF) Hinge is mounted to the Drop Box by 0.0191 m (0.75 in) diameter Shoulder Bolts. These bolts carry all the loads in the hinge. The SF funnel tube is specified as thin wall conduit which is designed to buckle during any overloading such as collision with a curb. The maximum loading in the SF system occurs when a cone operator will accidentally step on a funnel tubes. If the load is more than three feet away from the Drop Box the funnel tubes will deflect and be supported by the road surface. The maximum load on the shoulder bolt will occur when a load is applied closer to the Drop Box as illustrated in Figure B.6.



**Figure B.6** *Loading on Secondary Funnel Hinge Weldment*

Where:

$F_{Max}$  = Weight of Cone Operator = 889.6 N (200 lbf)

$F_{Bolt}$  = Reaction Force in Shoulder Bolt (N)

$R_1$  = Reaction Force against Drop Box (N)

$L$  = Distance  $F_{max}$  is applied from the Shoulder Bolt = 0.610 m (24.0 in)

From sum of moments, about the  $R_1$ , equal to zero:

$$\Sigma M = -F_{Max} \cdot (0.610 + 0.102) + F_{Bolt} \cdot 0.102 = 0$$

When  $F_{Max} = 889.6$  N,  $F_{Bolt} = 6,228$  N (1400 lbf)

The maximum stress in the Threaded section of the Shoulder Bolt is:

$$\sigma_{max} = \frac{F_{Bolt}}{A}$$

Where:

$F_{Bolt}$  = Reaction Force in Shoulder Bolt = 6,228 N (1400 lbf)



$A$  = Area of Treated Section of the Shoulder Bolt =  $\pi \cdot r^2$  where  $r_{\min} = 7.77\text{E-}3$  m (0.306 in) thus  $A = 1.90\text{E-}4$  m (0.294 in<sup>2</sup>)

$$\text{Then: } \sigma_{\max} = \frac{6,228}{1.90\text{E-}4} = 32.81 \text{ MPa (4,759 lb}_f\text{/in}^2\text{)}$$

From Modified Goodman Theory, the factor of safety is:

$$n = \frac{S_u}{\sigma_{\max} + \sigma_a}$$

Where:

$$\sigma_a = \text{Average Stress during Cycle} = \frac{1}{2} \sigma_{\max} \text{ since the minimum load is zero}$$

$S_e$  = Endurance Limit = 206.84 MPa (30,000 lb<sub>f</sub>/in<sup>2</sup>) for Stainless Steel Bolts

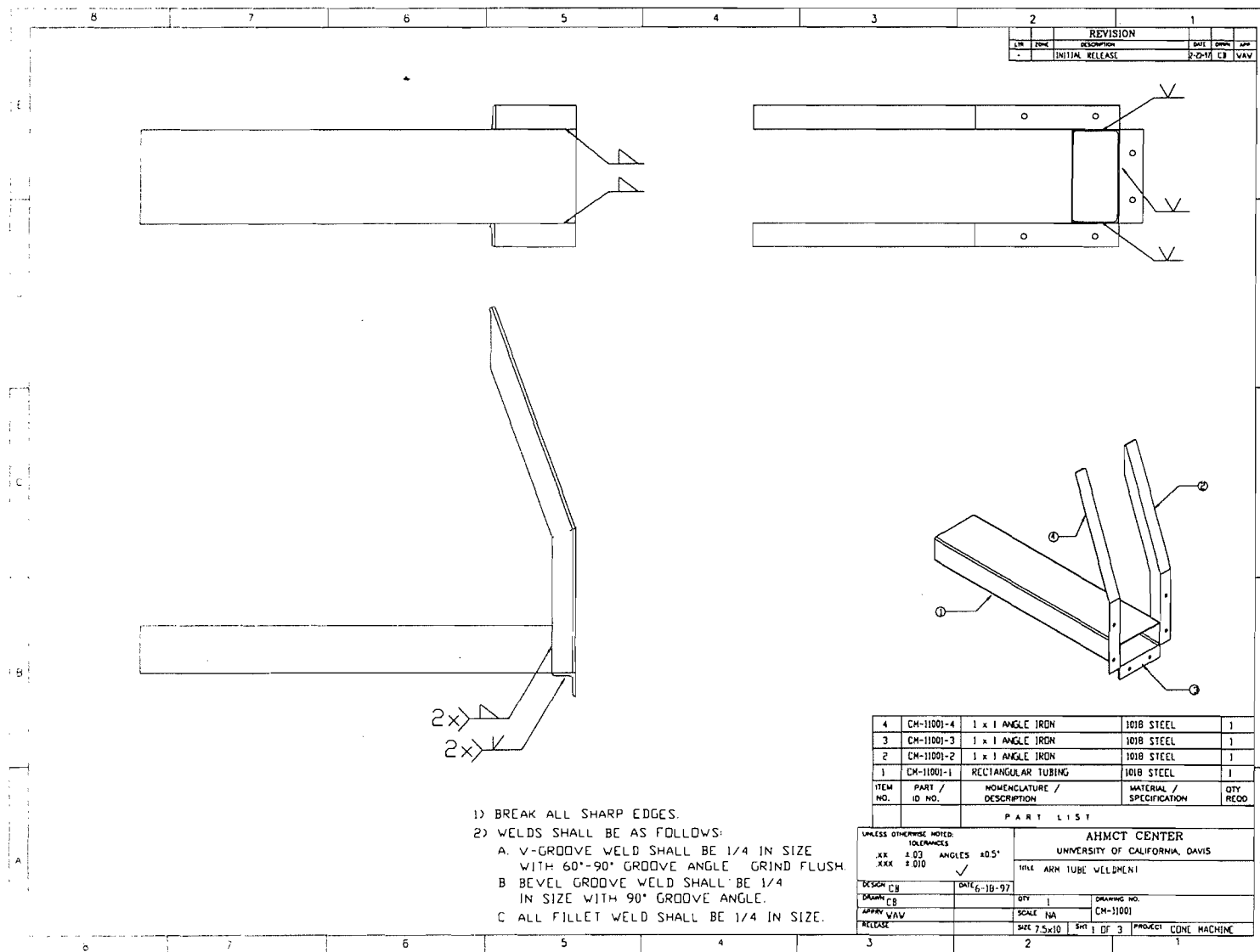
which includes fatigue endurance limit, surface finish, and notch sensitivity.

Thus the factor of safety, ensuring an infinite life, is:

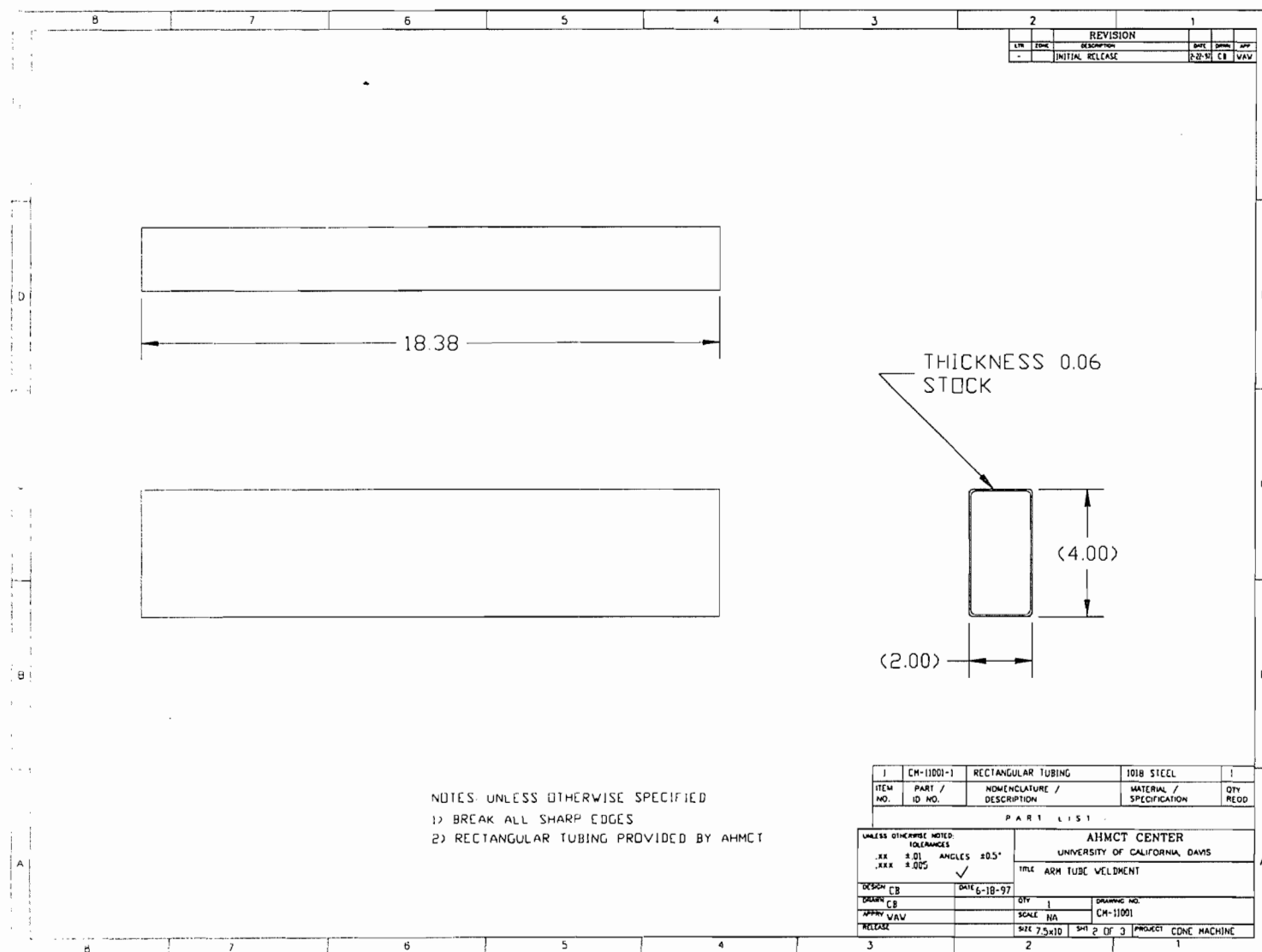
$$n = \frac{S_e}{1.5\sigma_{\max}} = \frac{206.84\text{E}6}{1.5 \cdot 32.81\text{E}6} = 4.2$$

# APPENDIX C

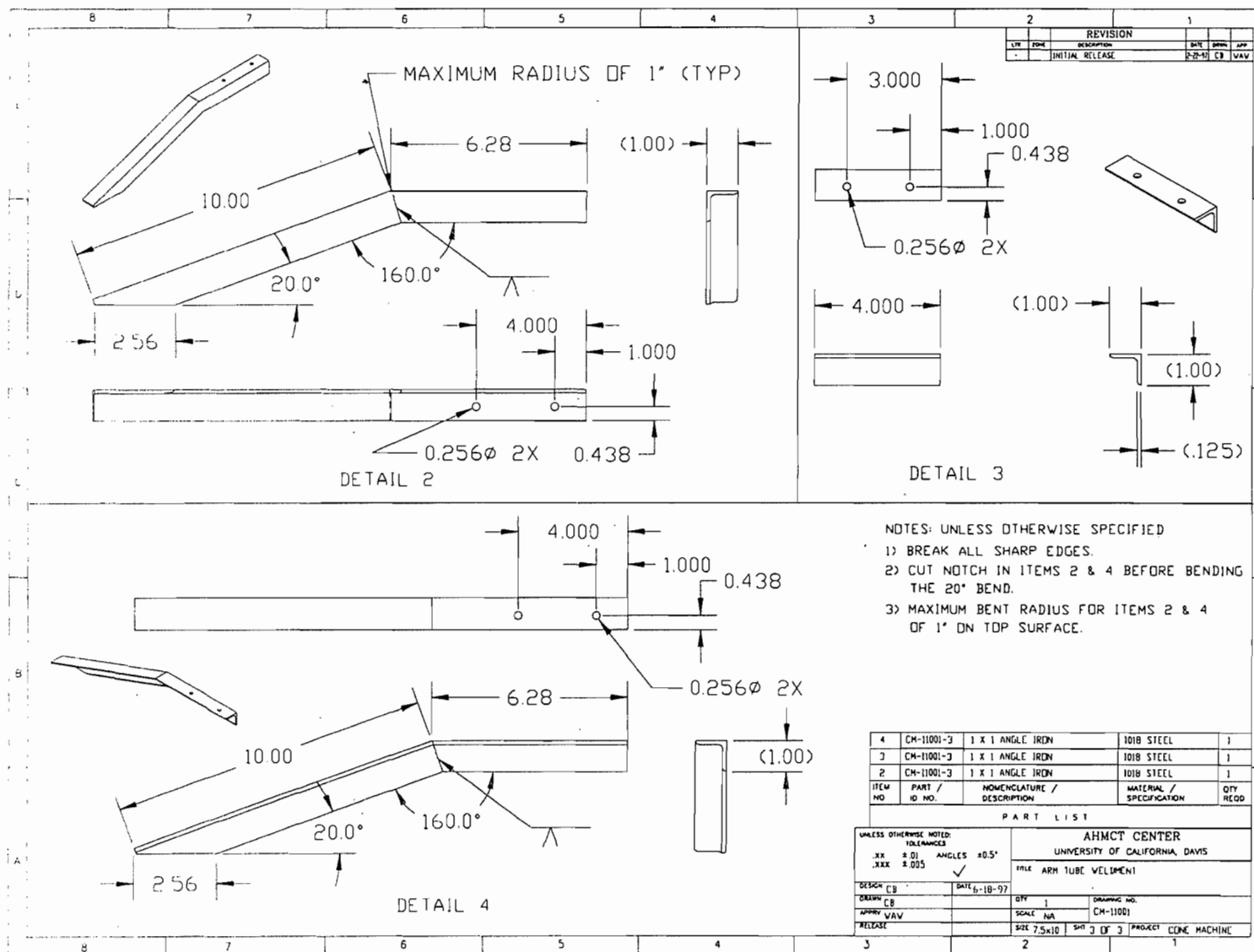
## Detail Drawings of Retrieval Arm Components



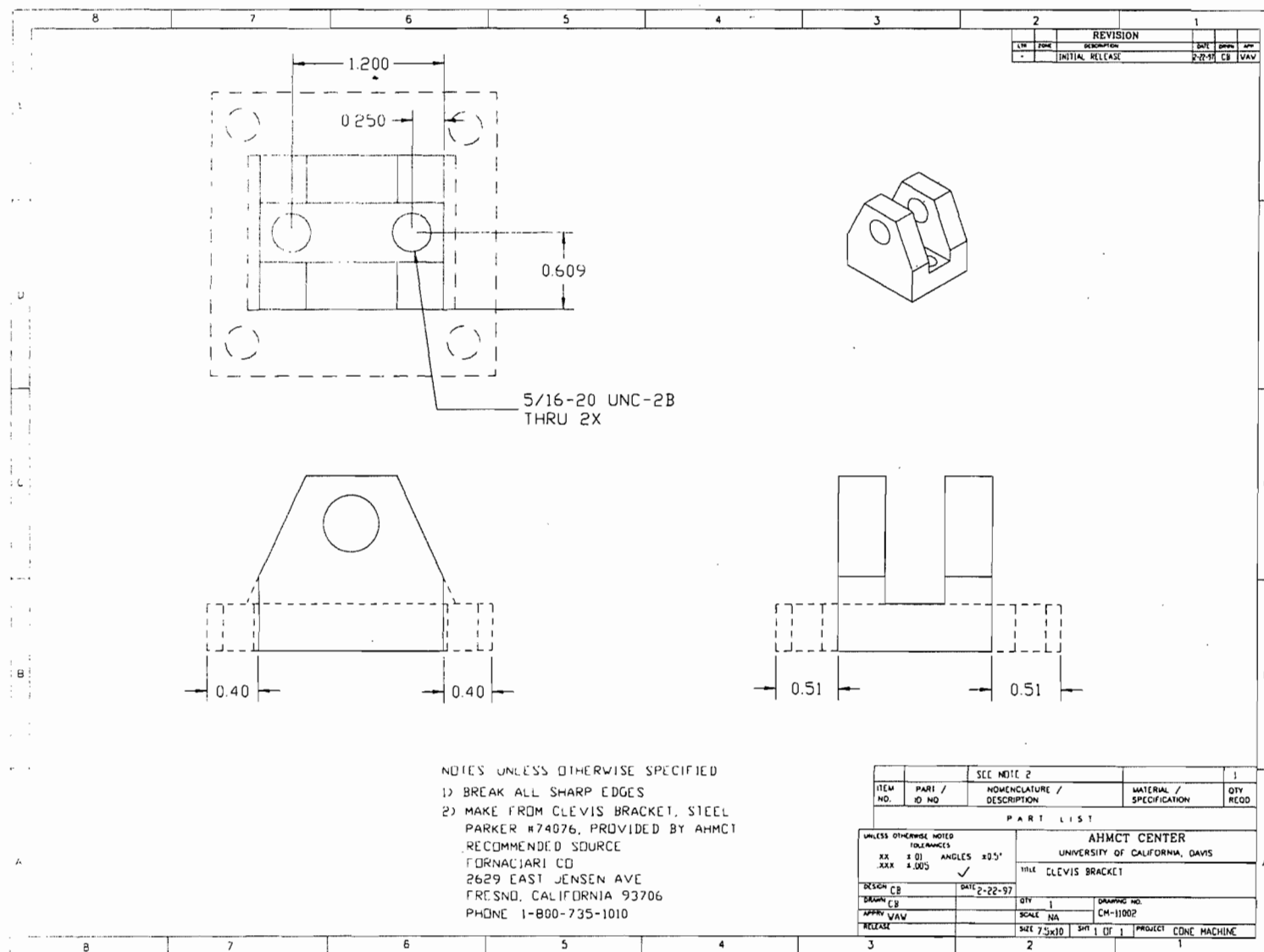
Detail Drawings of Retrieval Arm Components



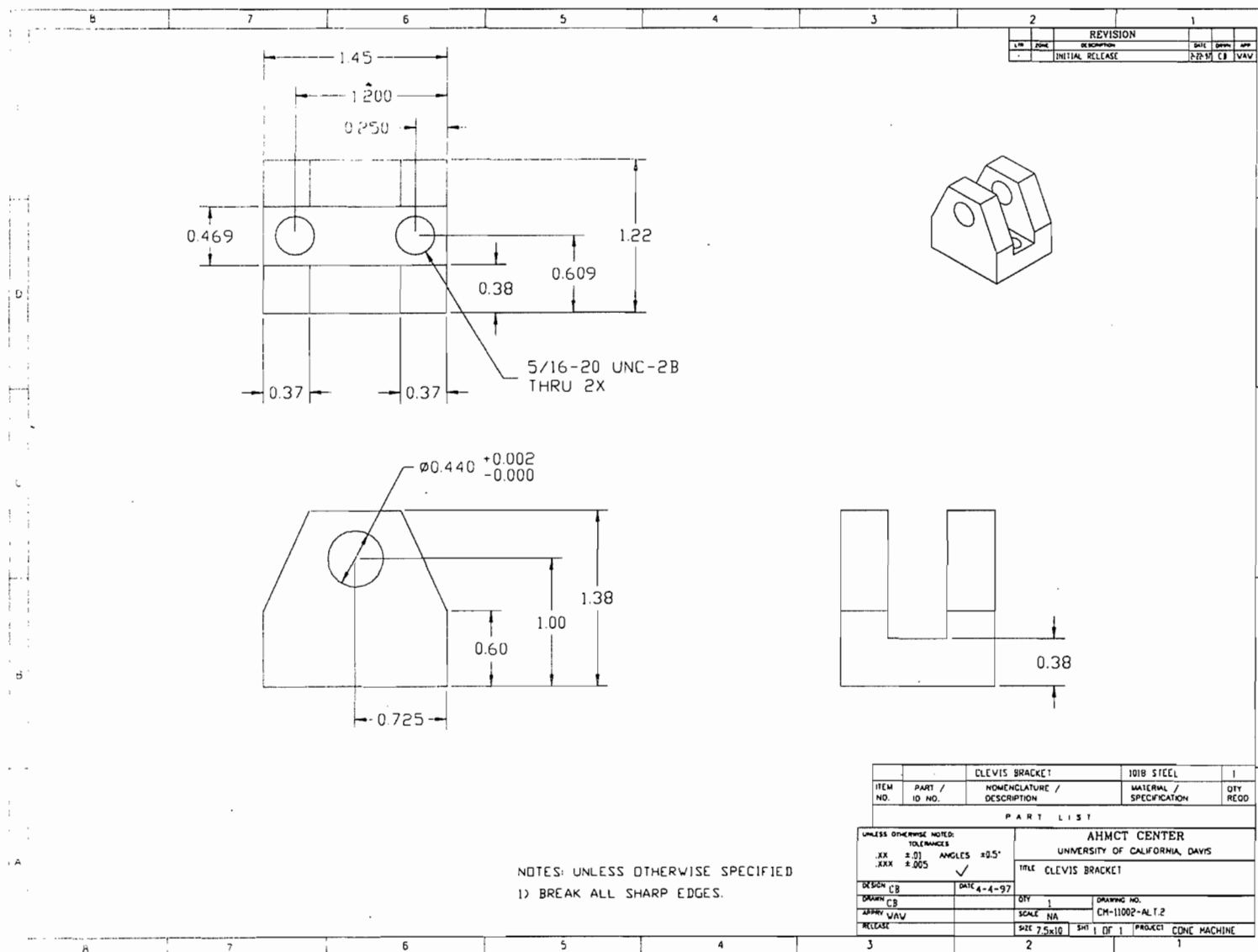
# Detail Drawings of Retrieval Arm Components



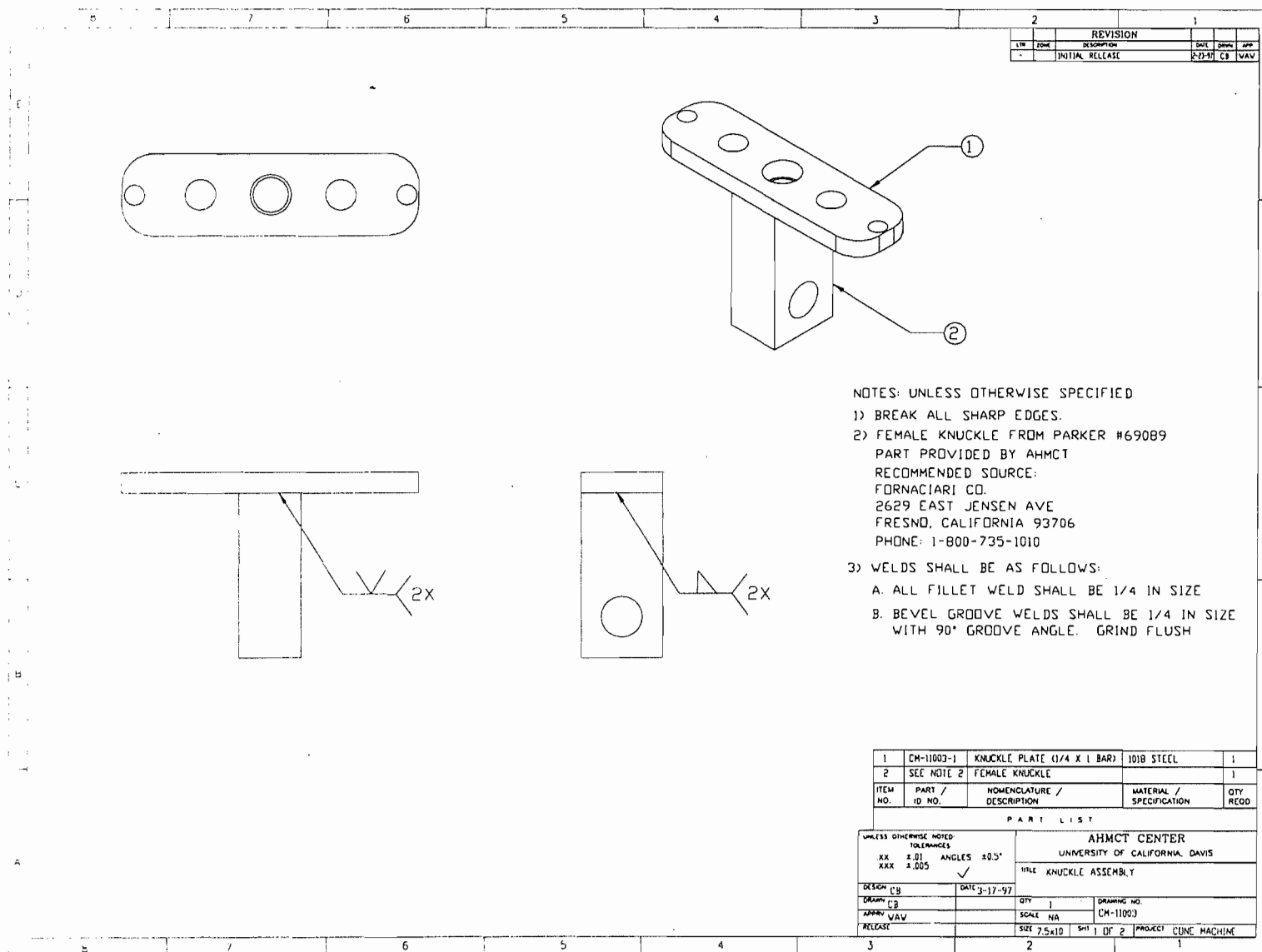
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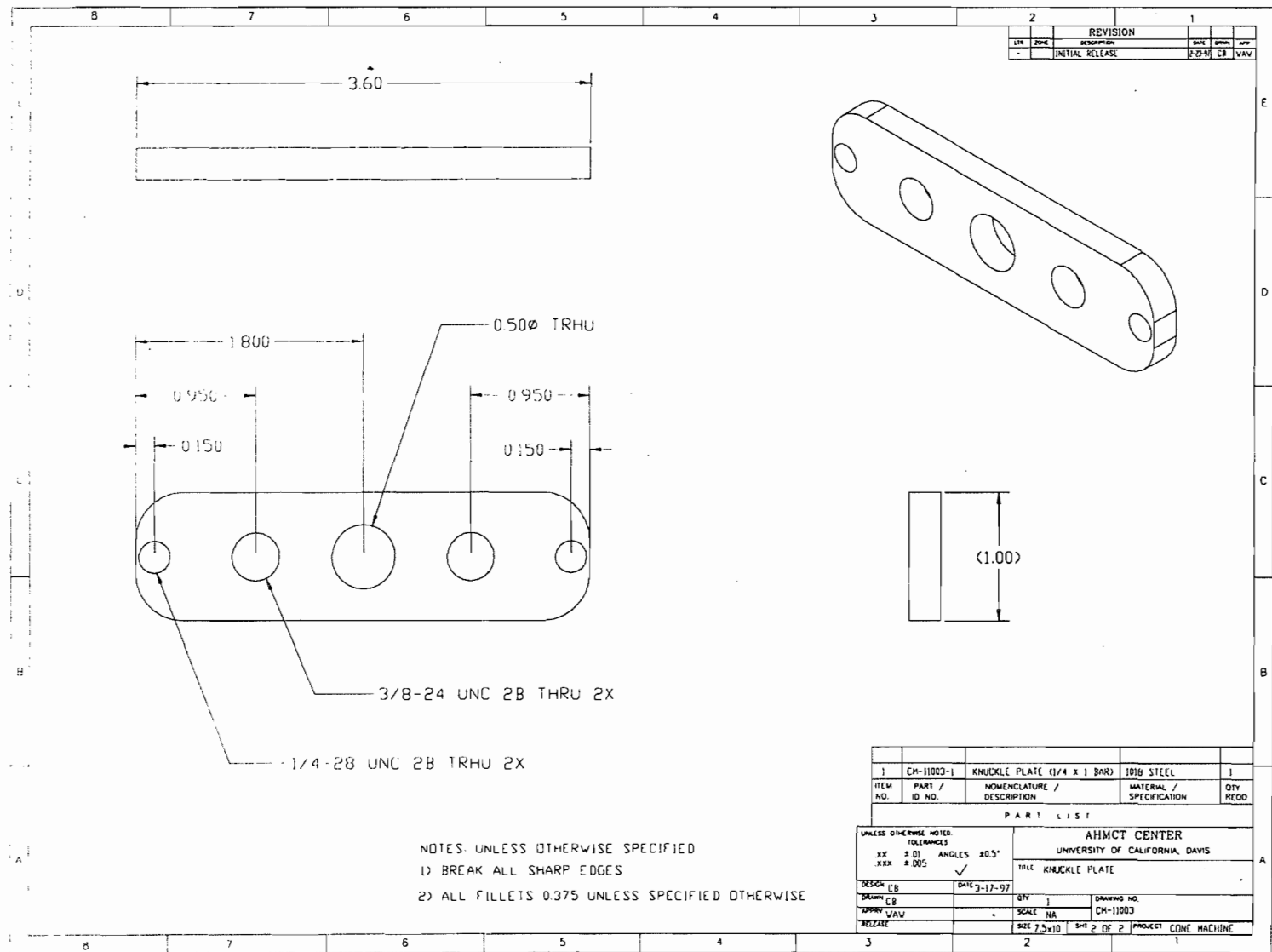
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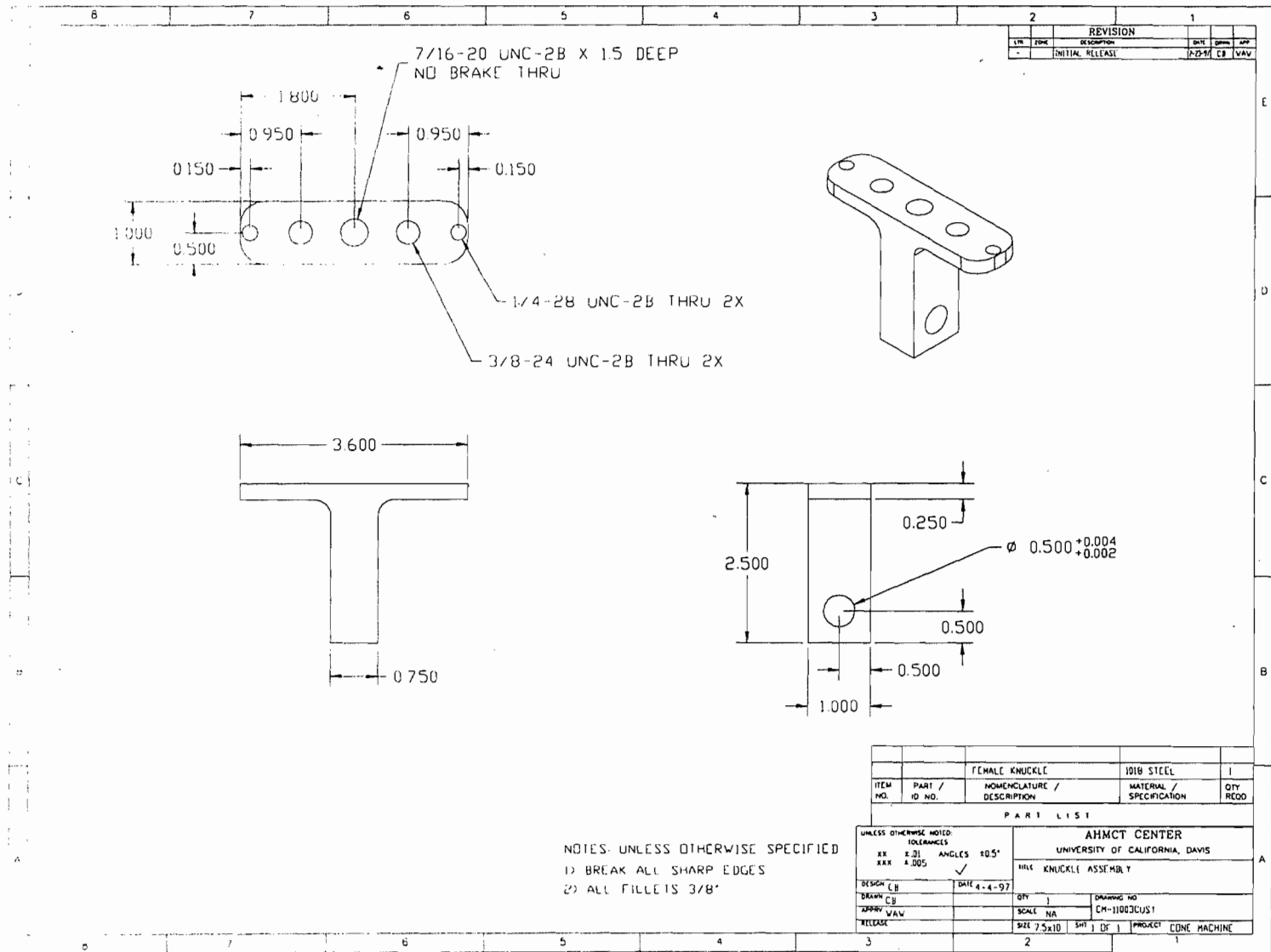
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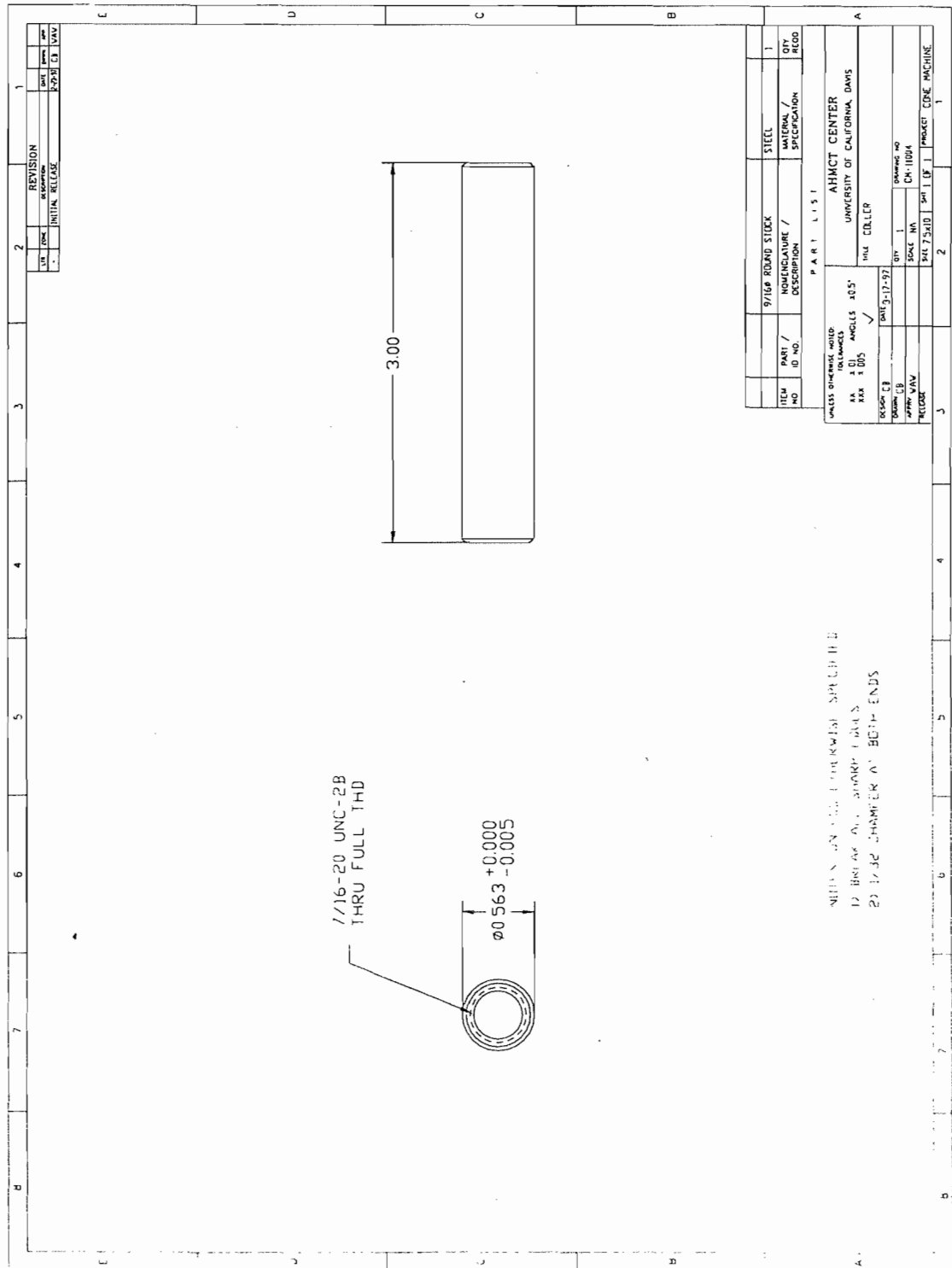
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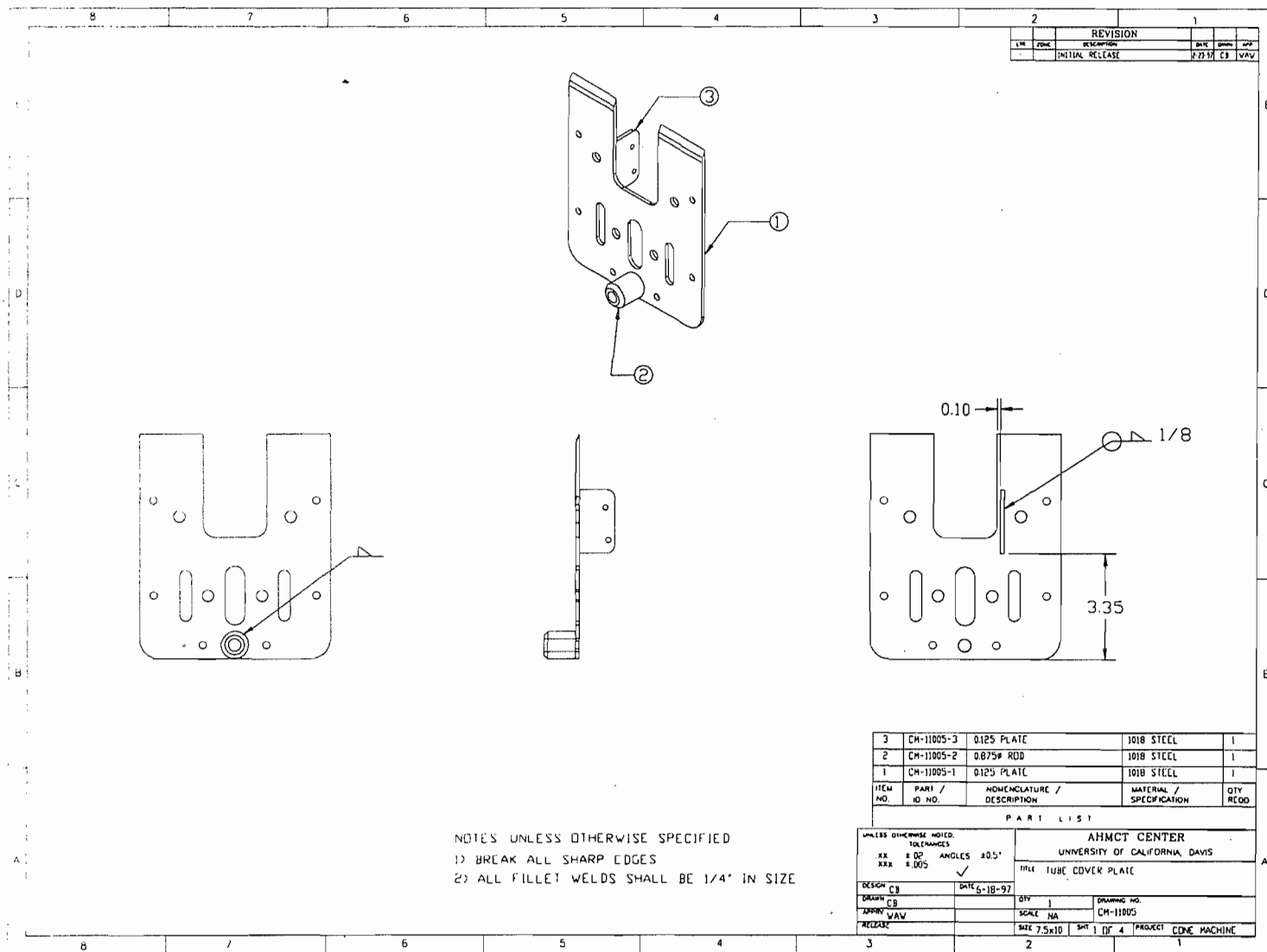




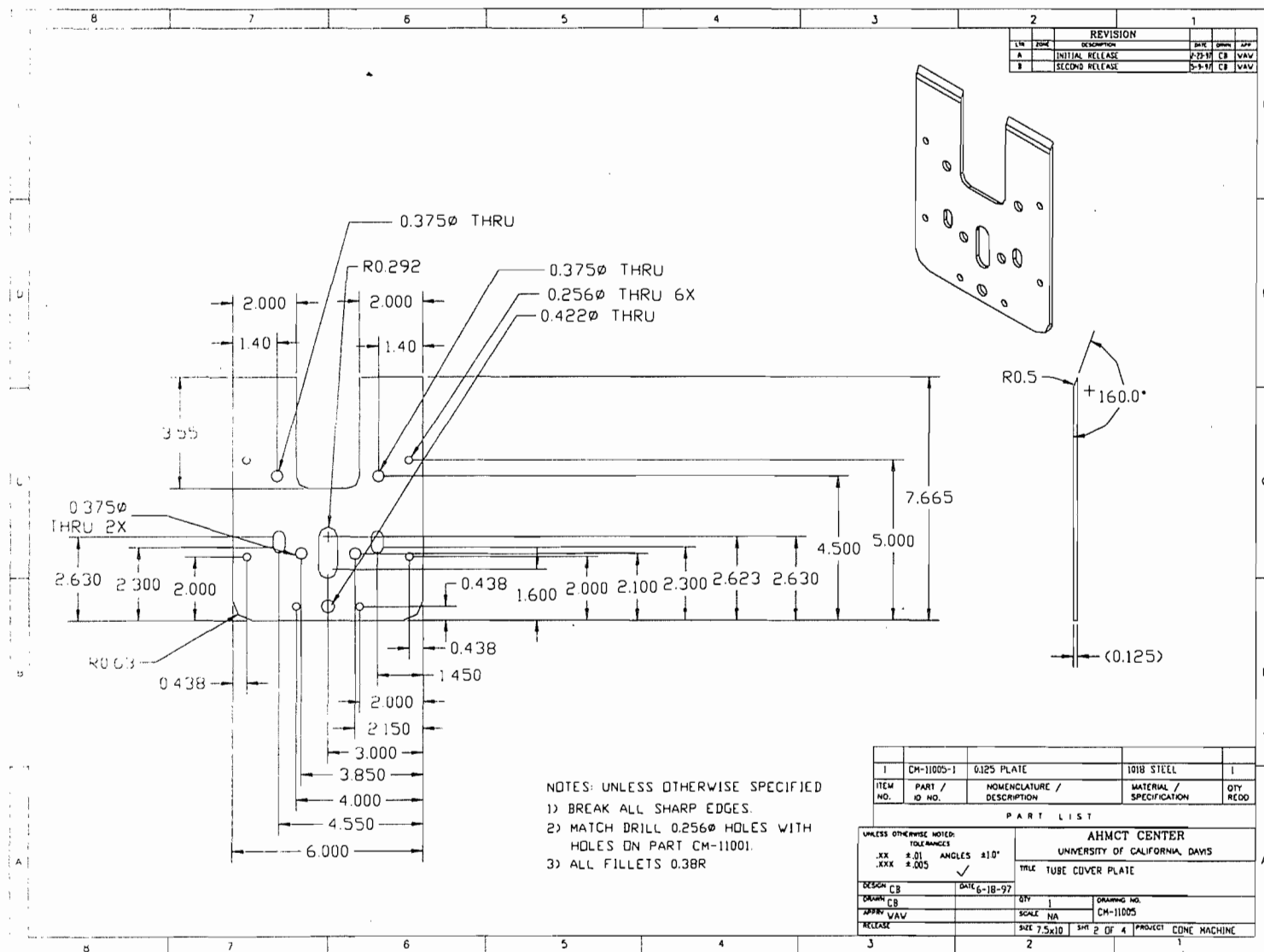
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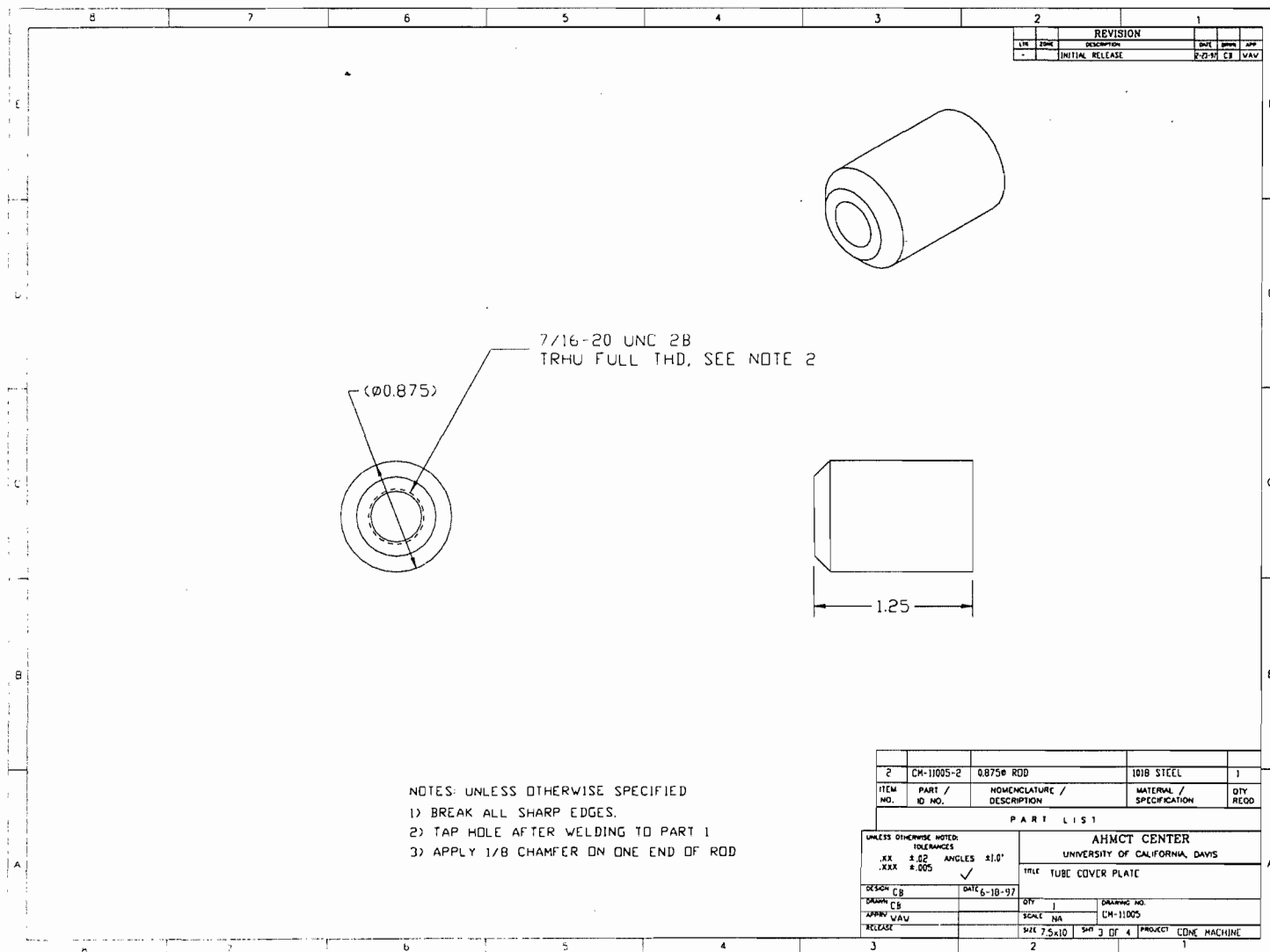
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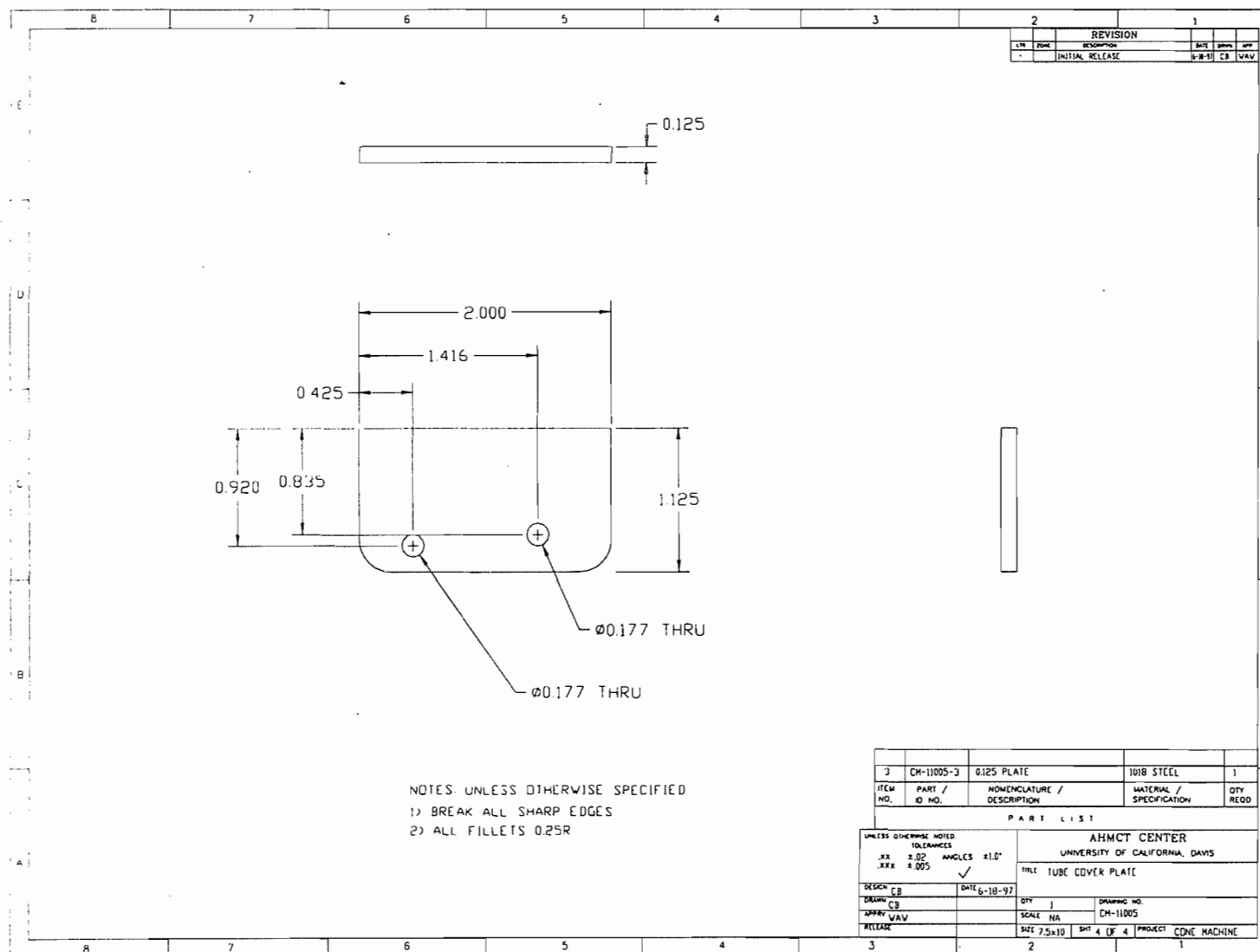
# Detail Drawings of Retrieval Arm Components



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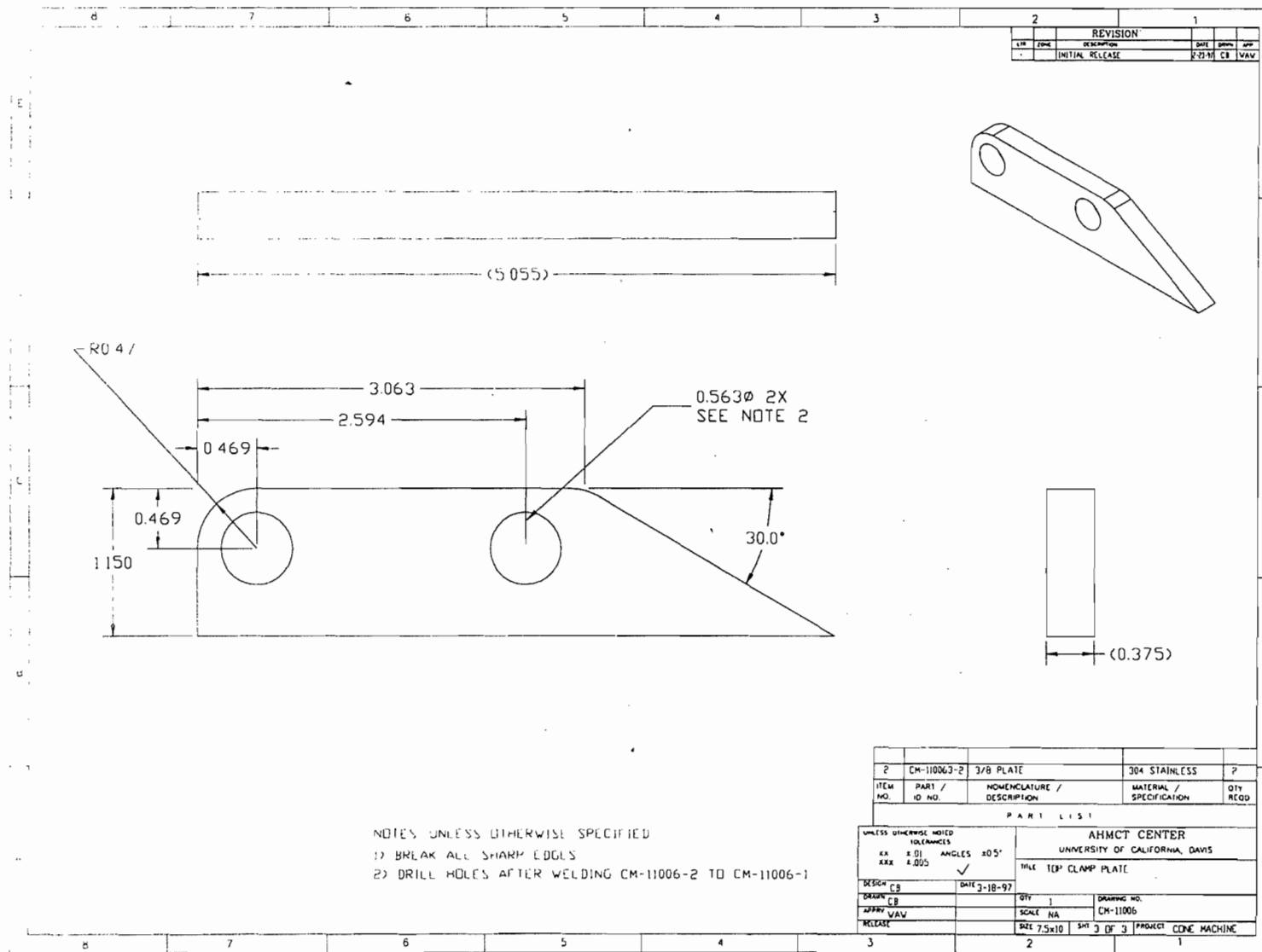
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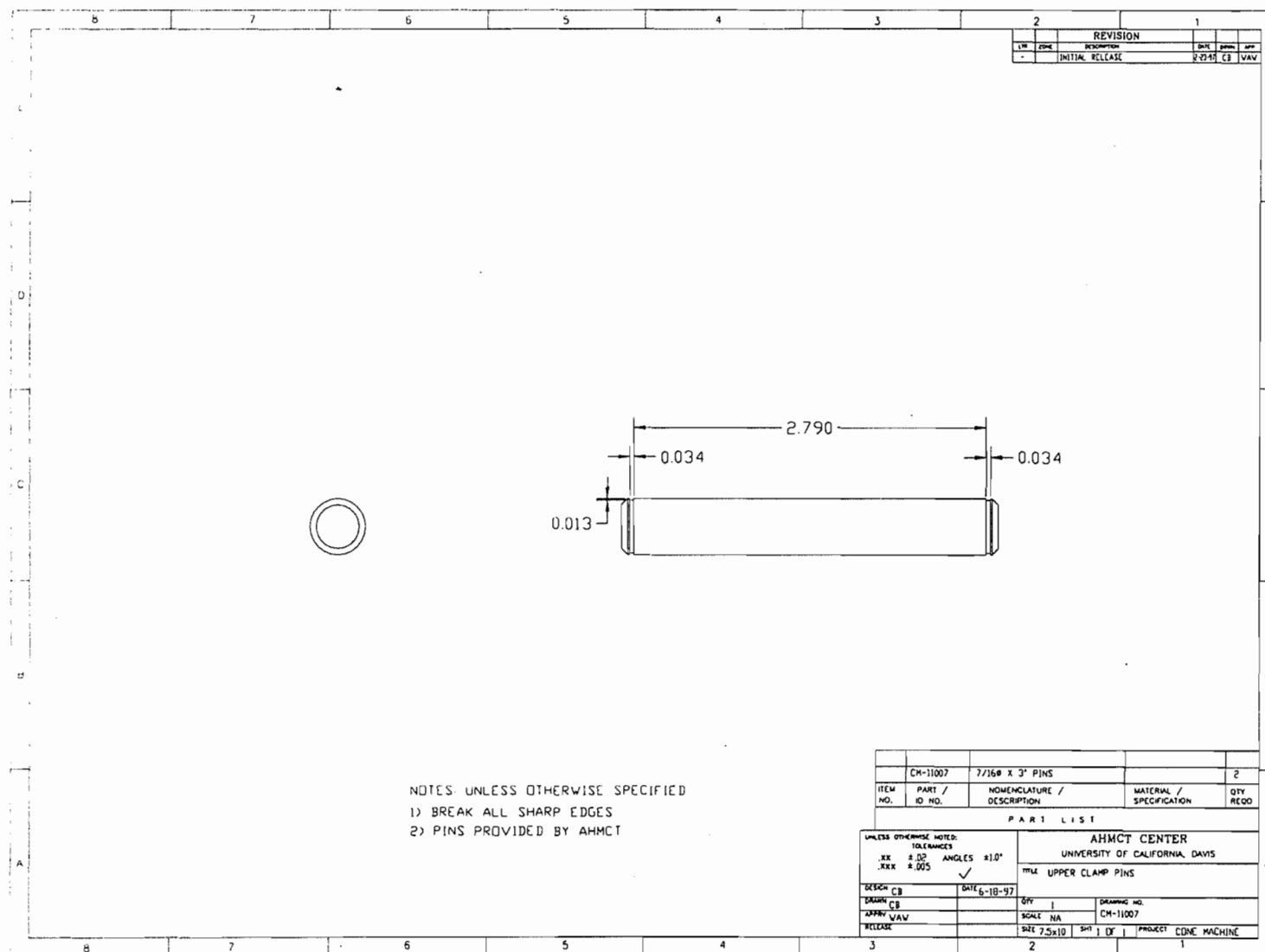




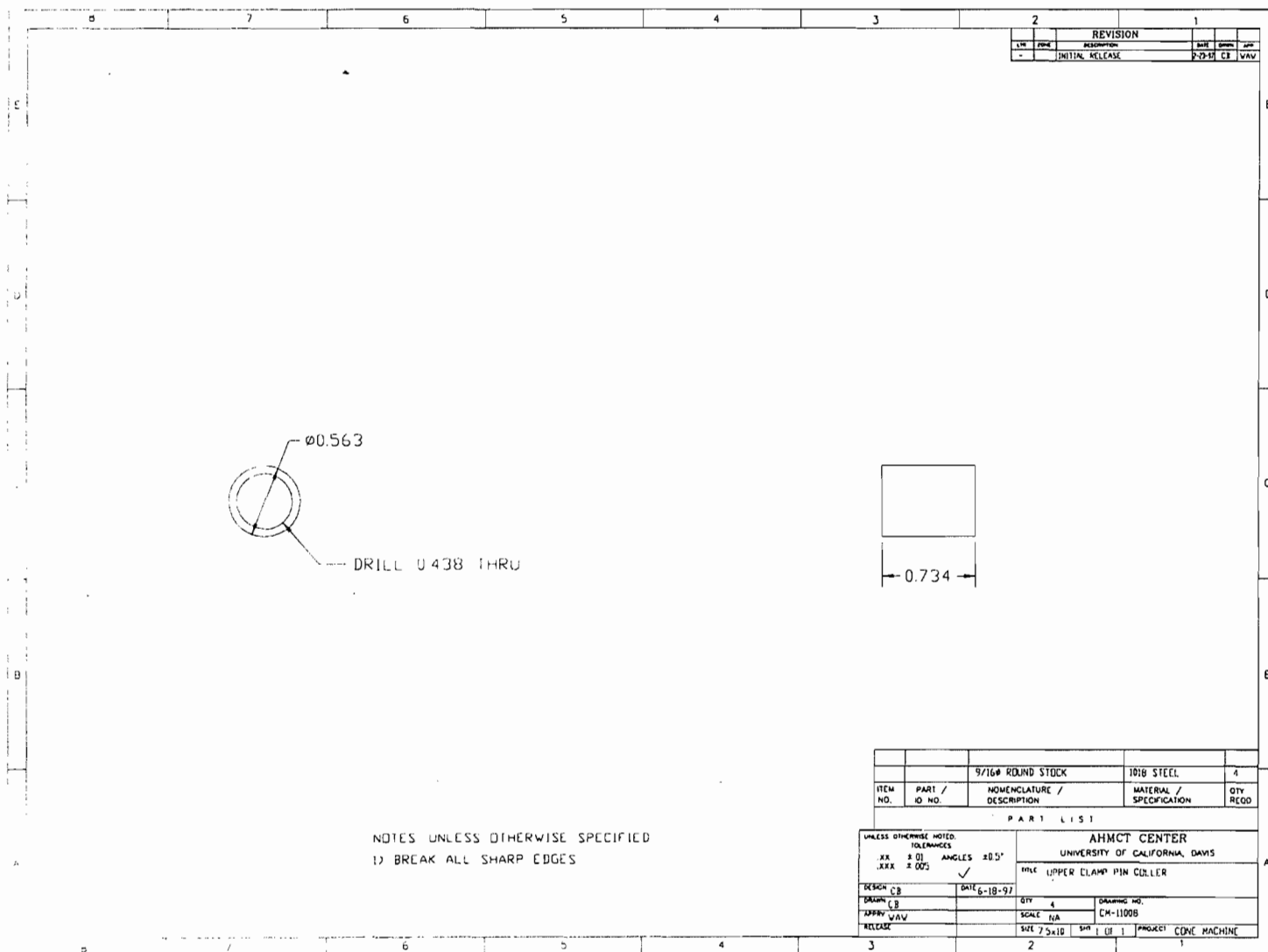
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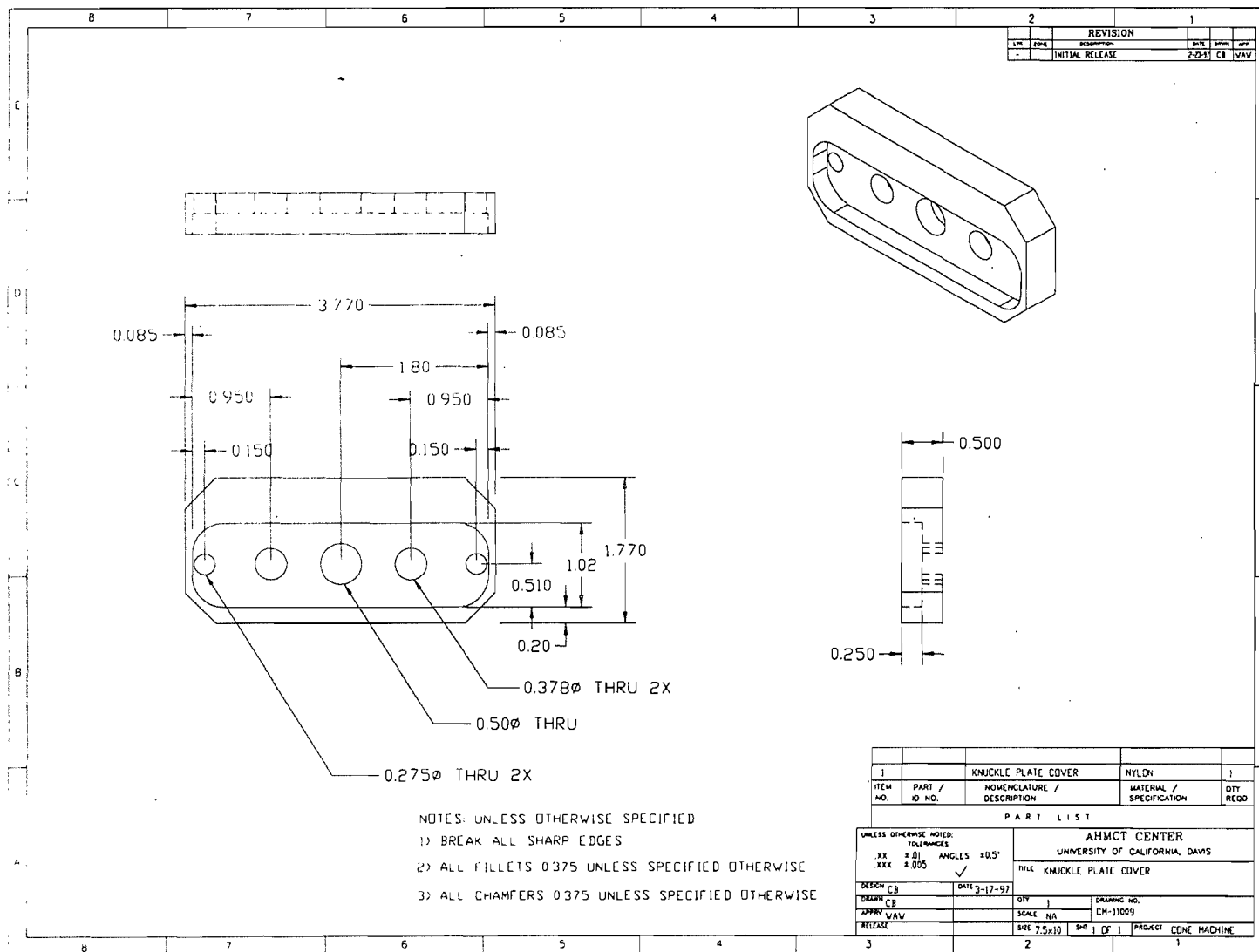
# Detail Drawings of Retrieval Arm Components



# Detail Drawings of Retrieval Arm Components

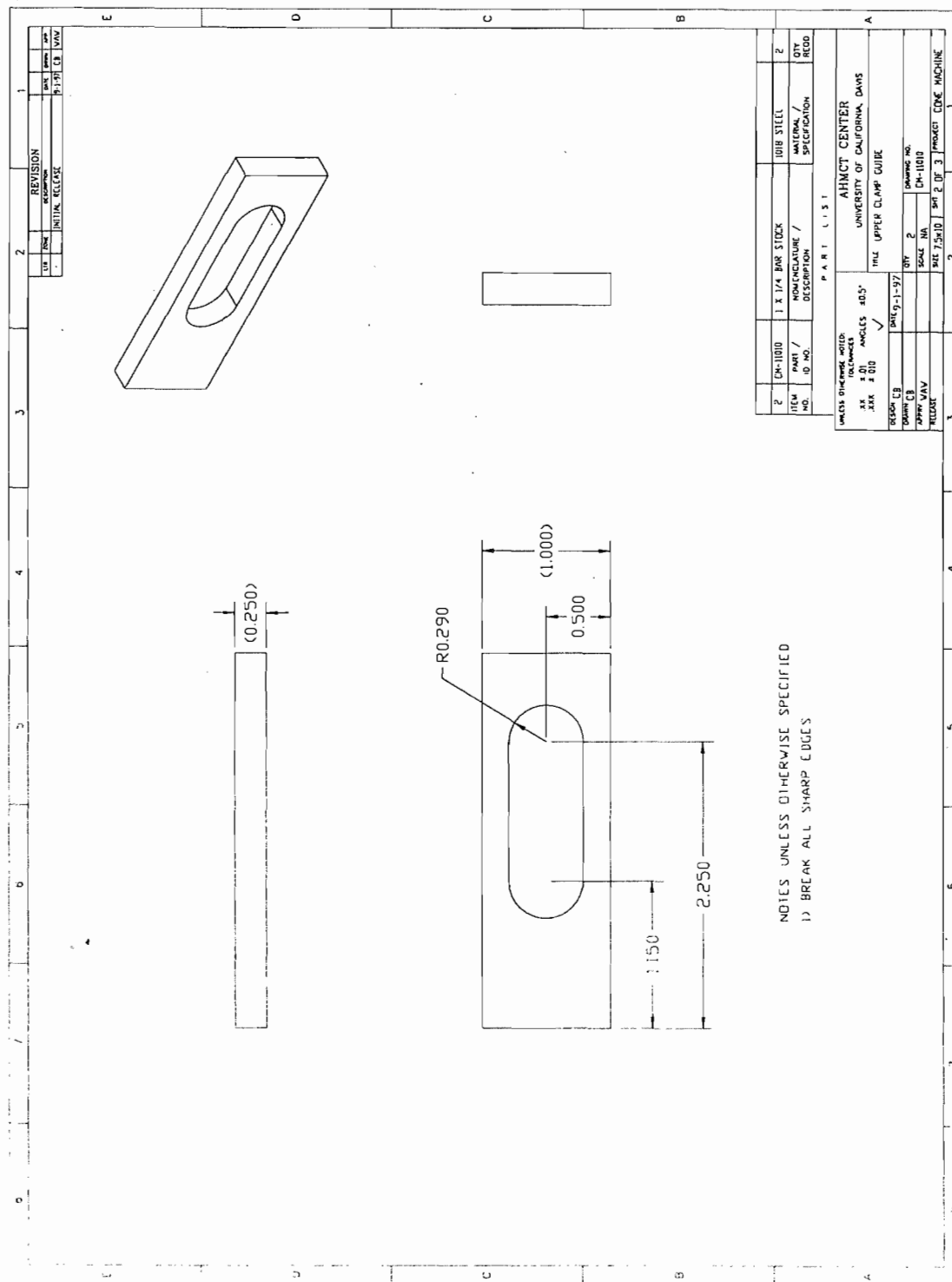


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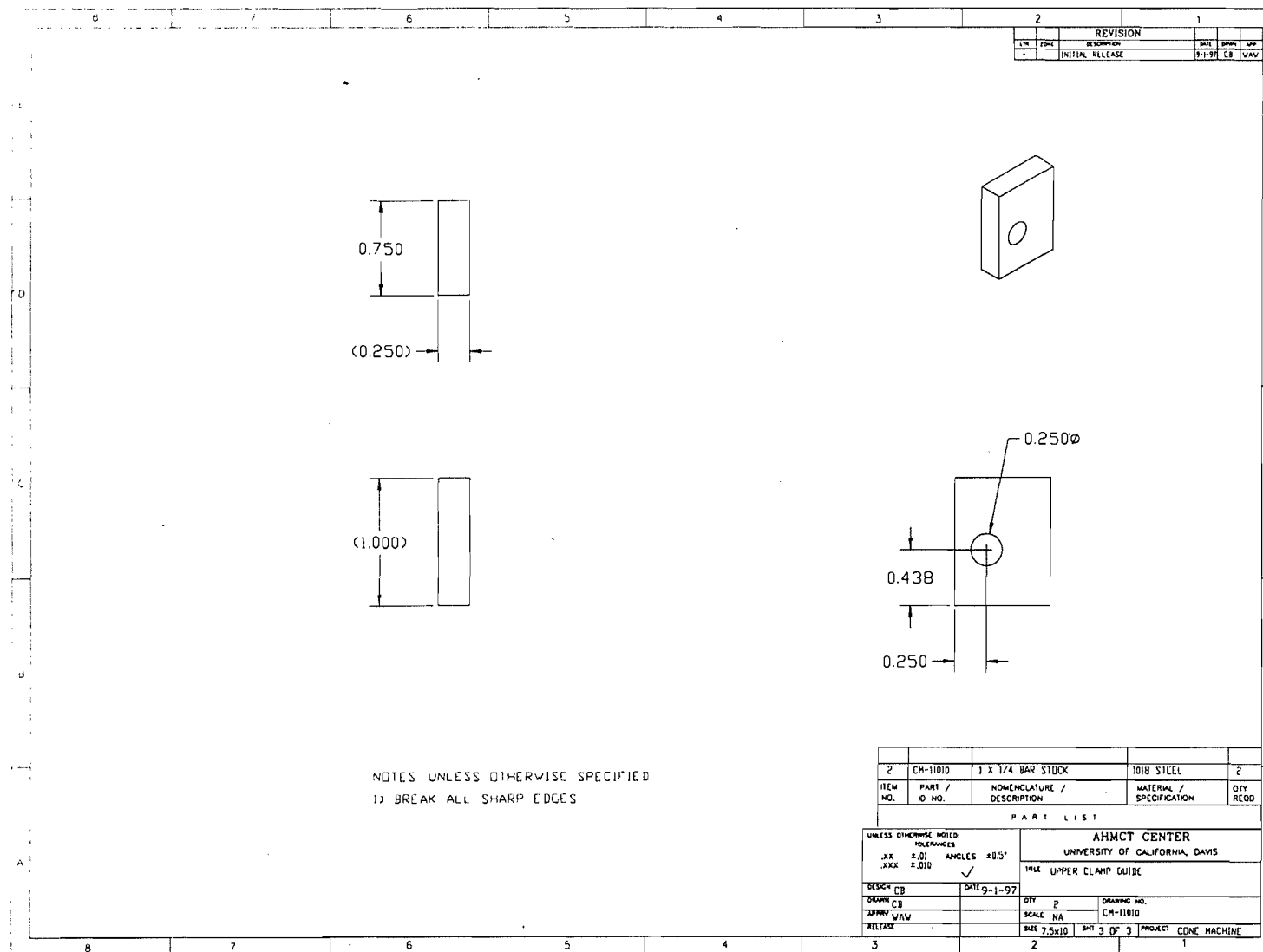


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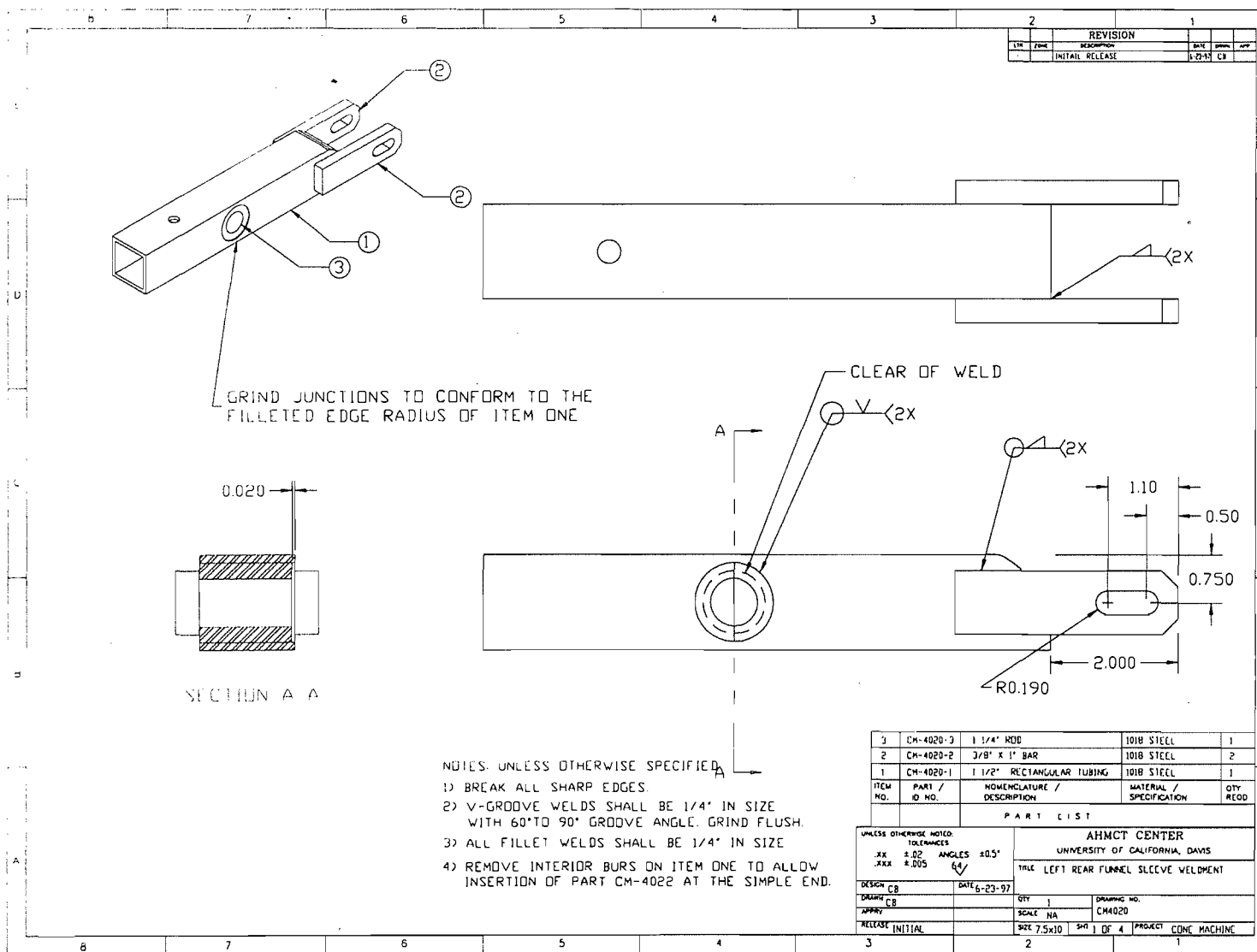
## Detail Drawings of Retrieval Arm Components



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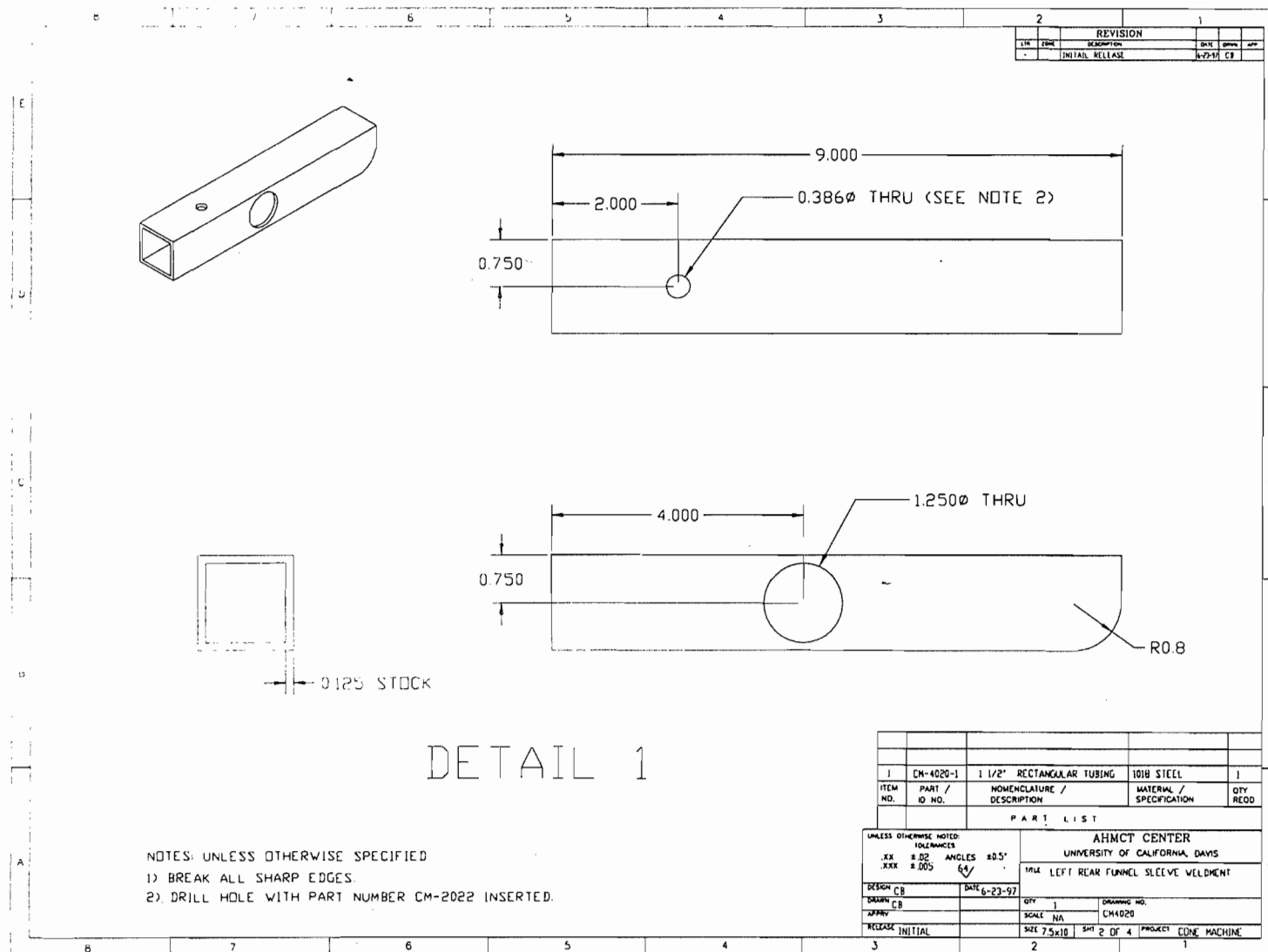


# Detail Drawings of Left Side Secondary Funnel System

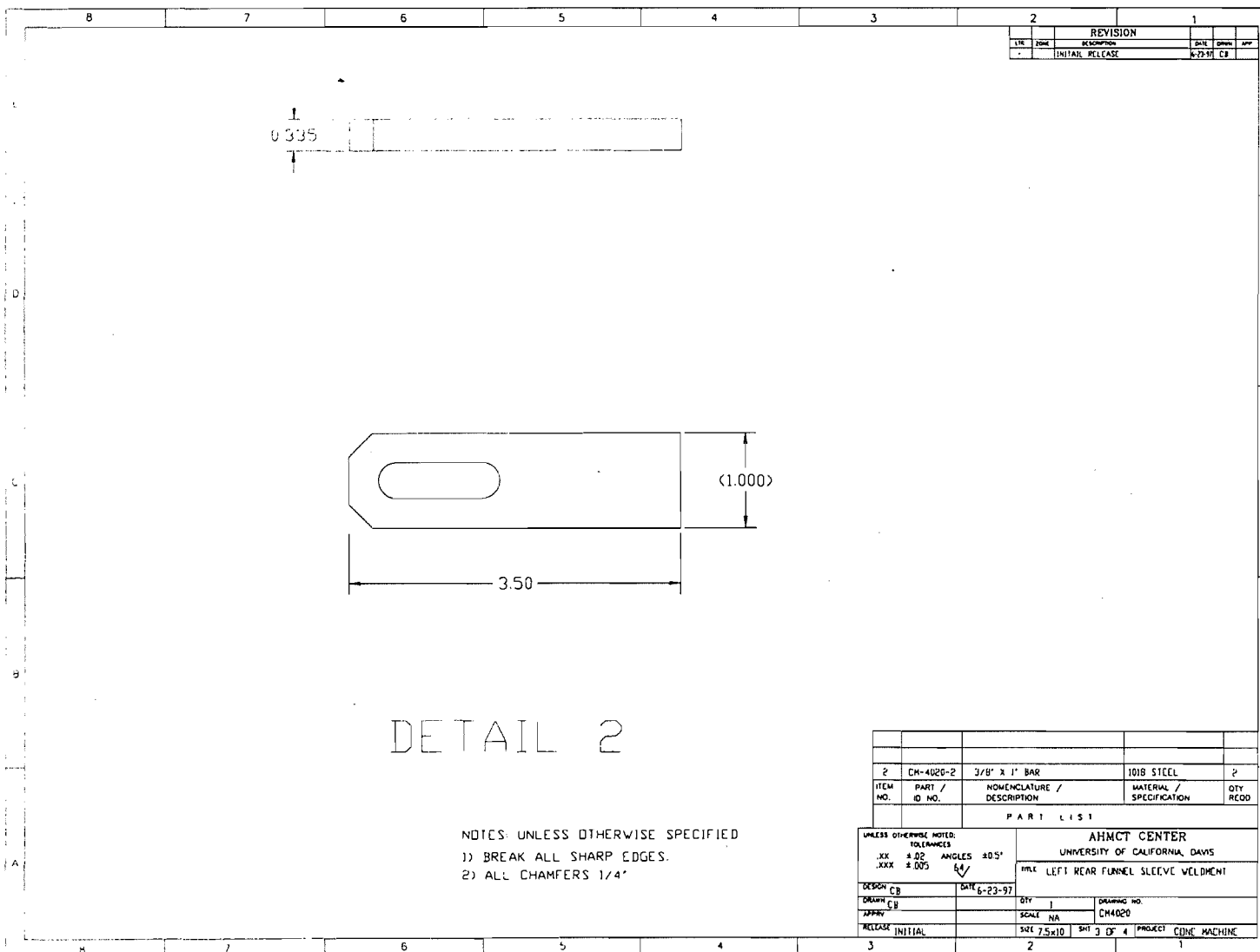




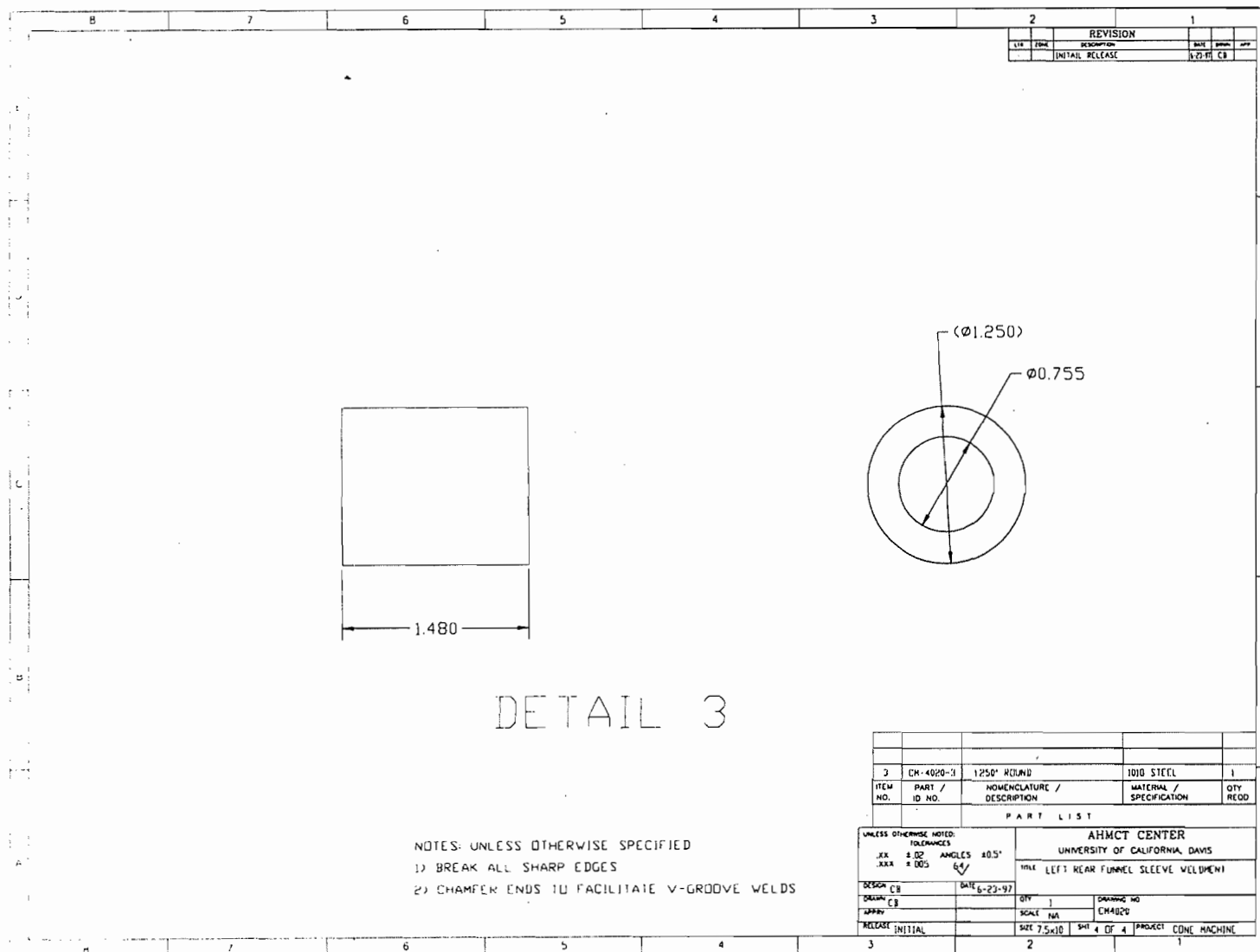
# Detail Drawings of Left Side Secondary Funnel System



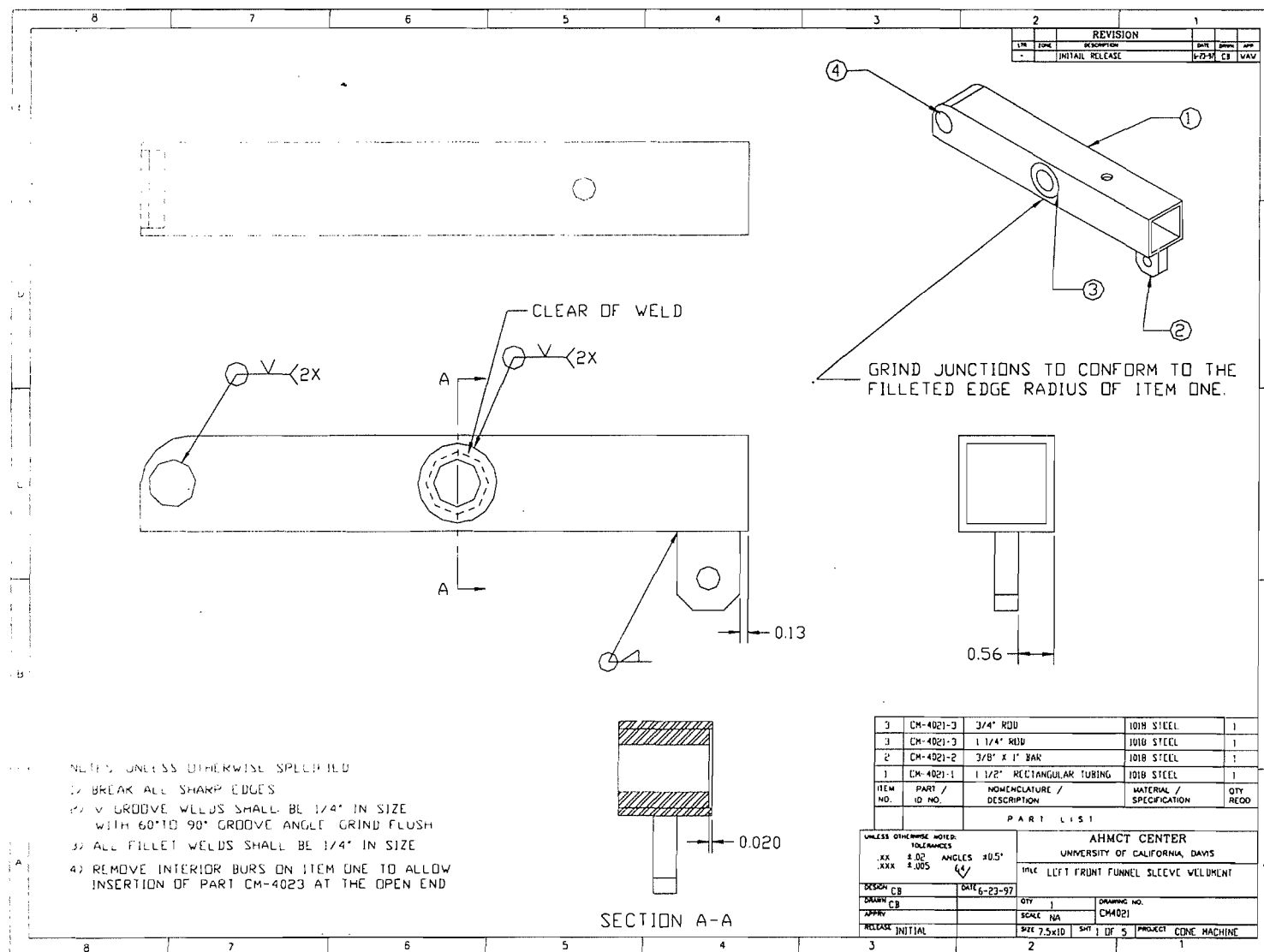
Detail Drawings of Left Side Secondary Funnel System



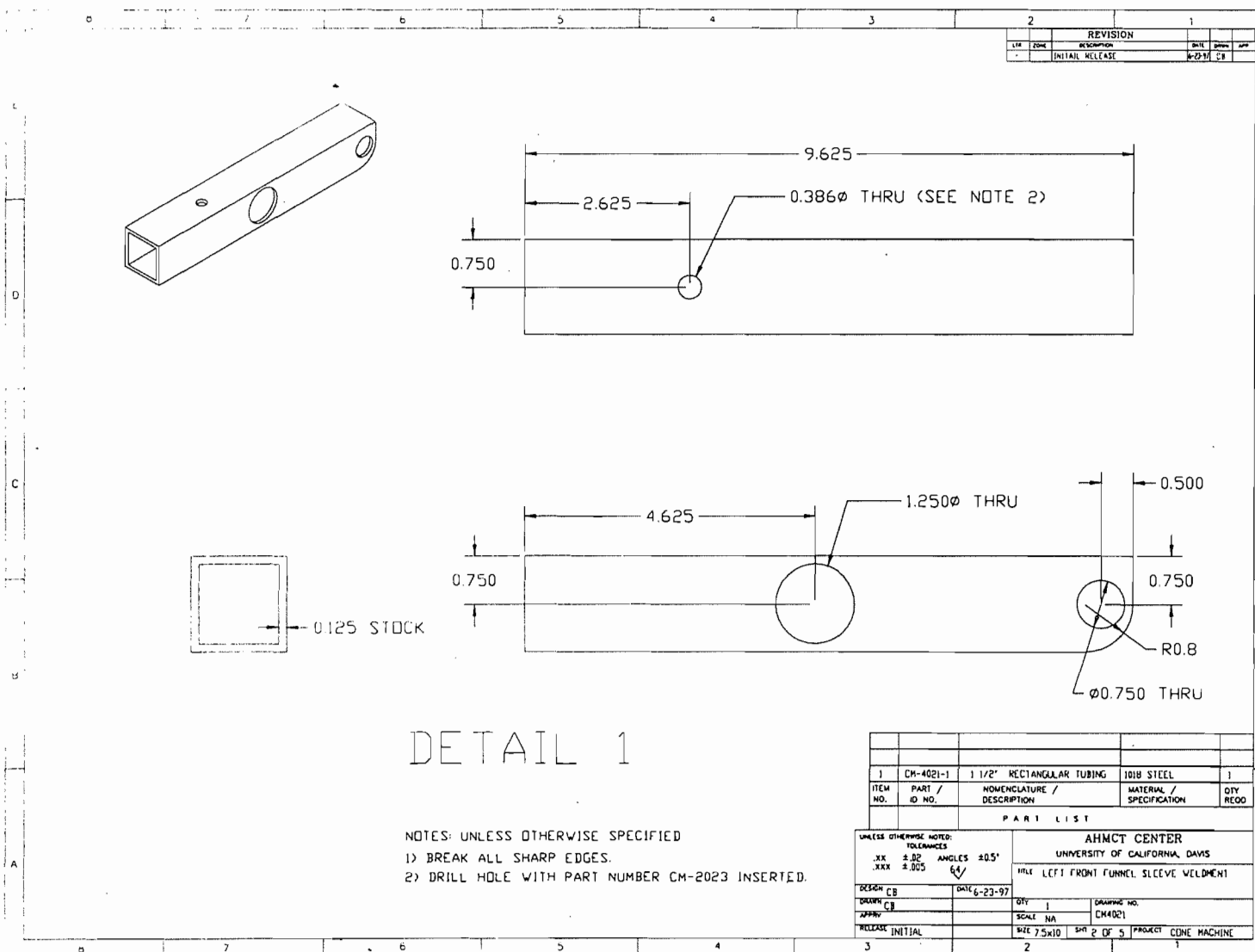
Detail Drawings of Left Side Secondary Funnel System



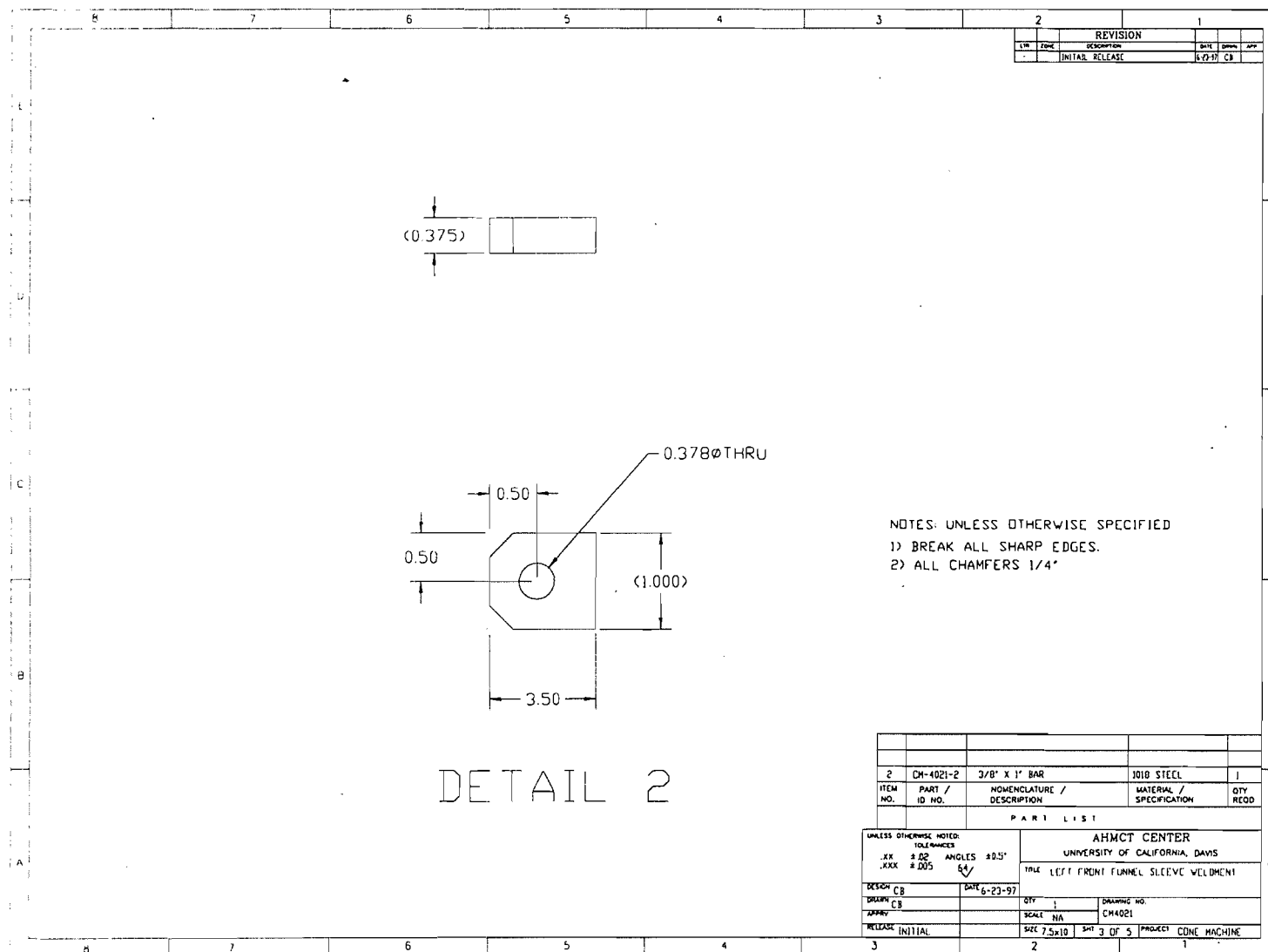
# Detail Drawings of Left Side Secondary Funnel System



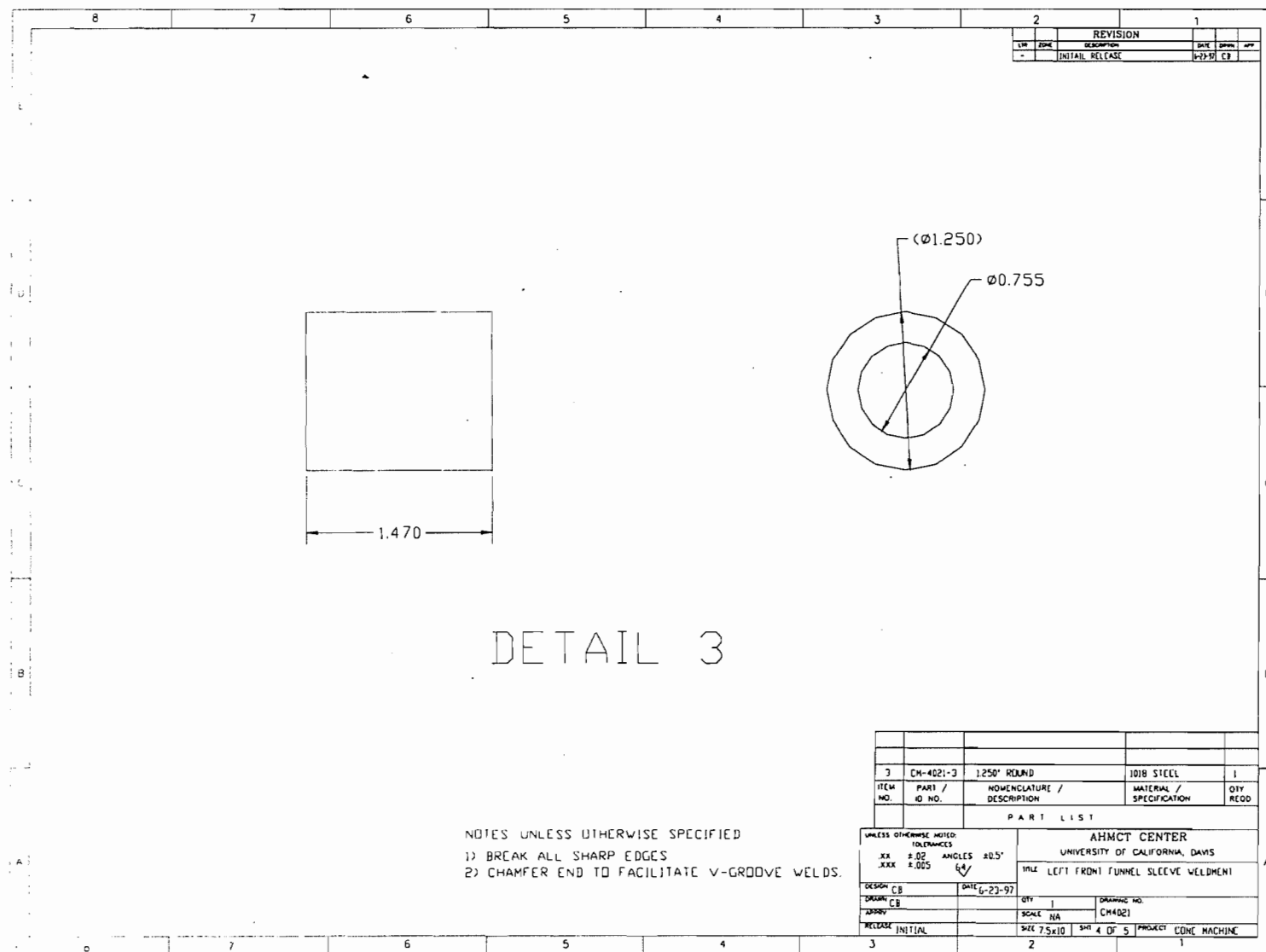
# Detail Drawings of Left Side Secondary Funnel System



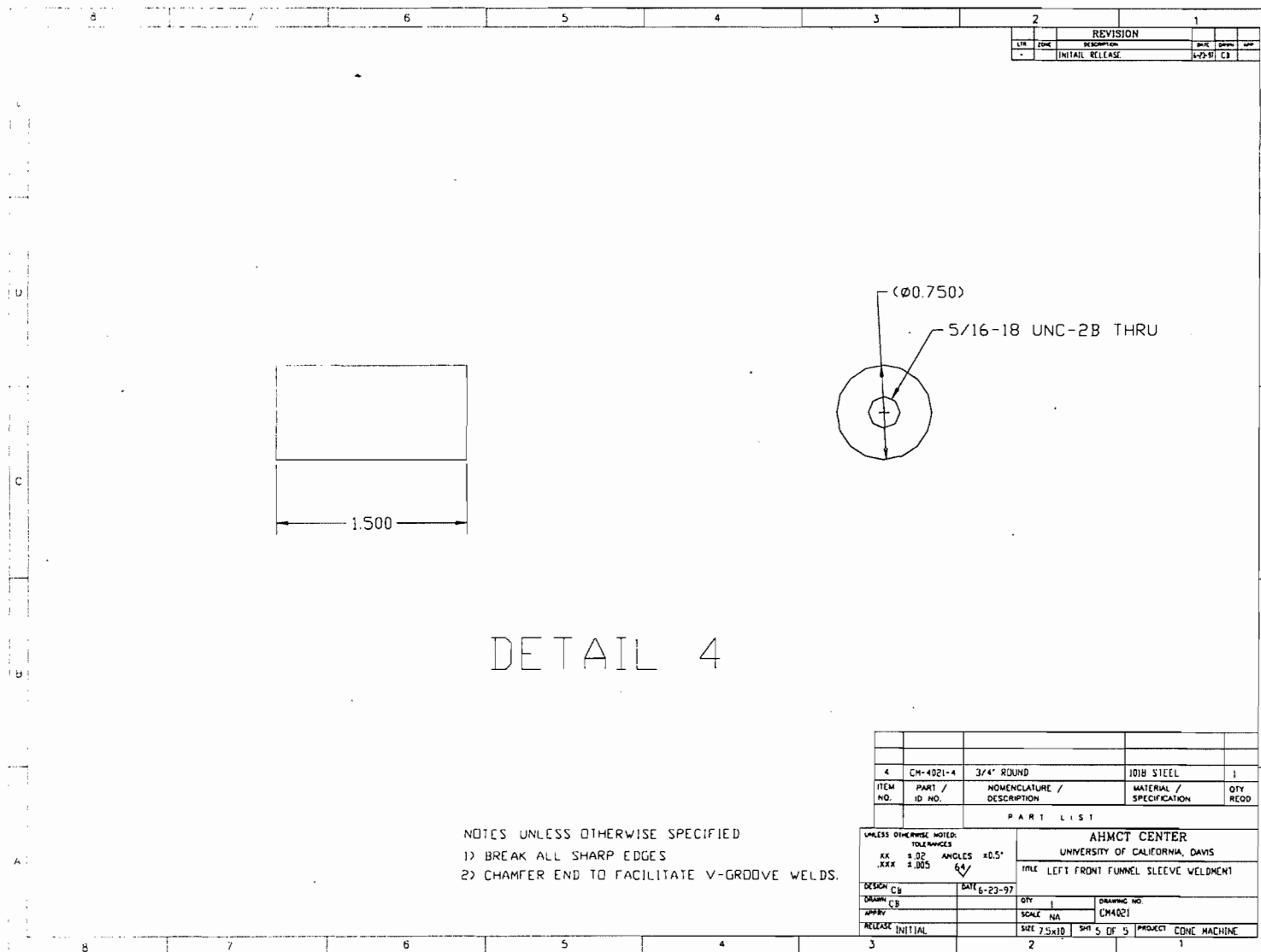
Detail Drawings of Left Side Secondary Funnel System



# Detail Drawings of Left Side Secondary Funnel System

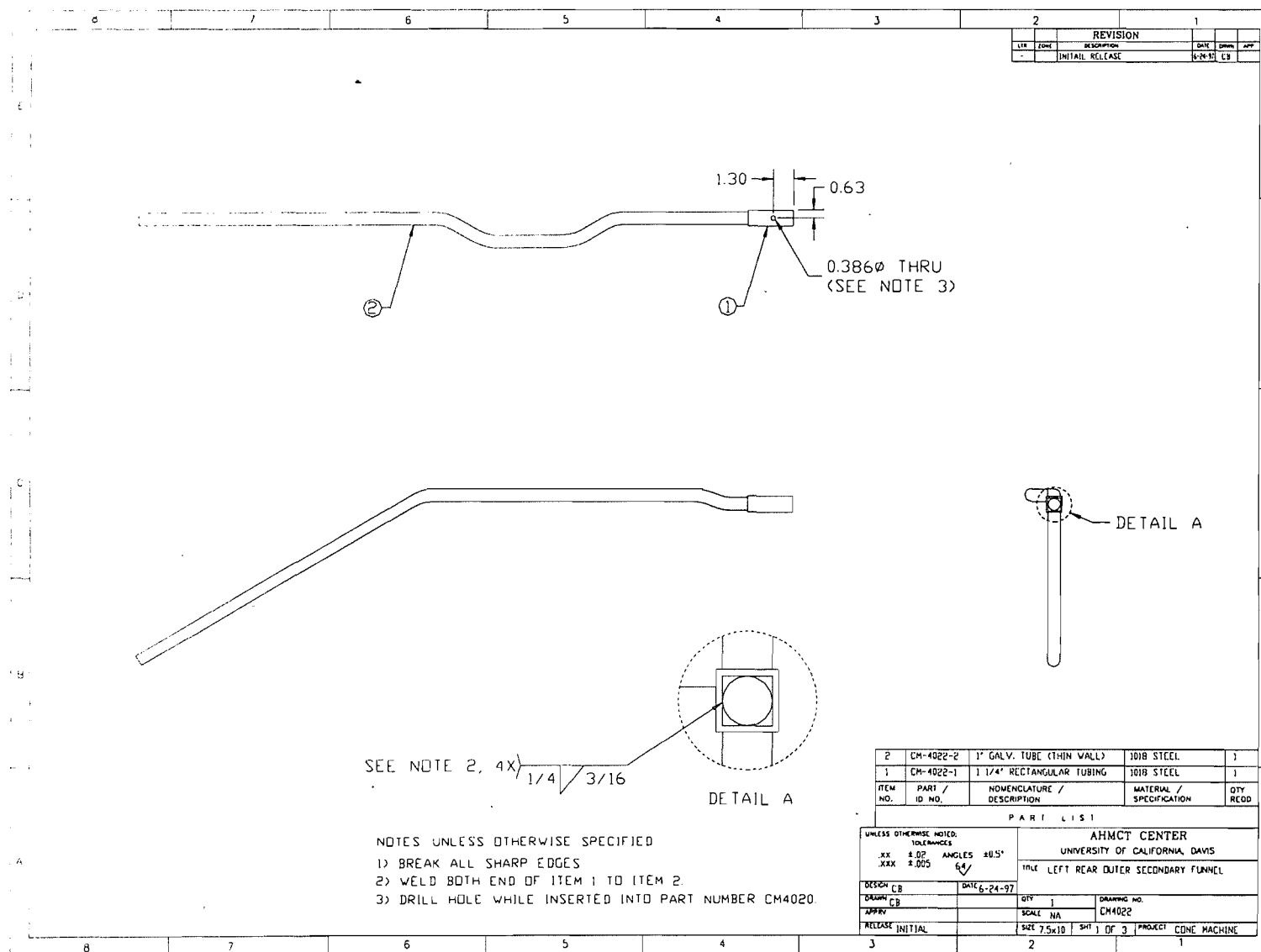


Detail Drawings of Left Side Secondary Funnel System

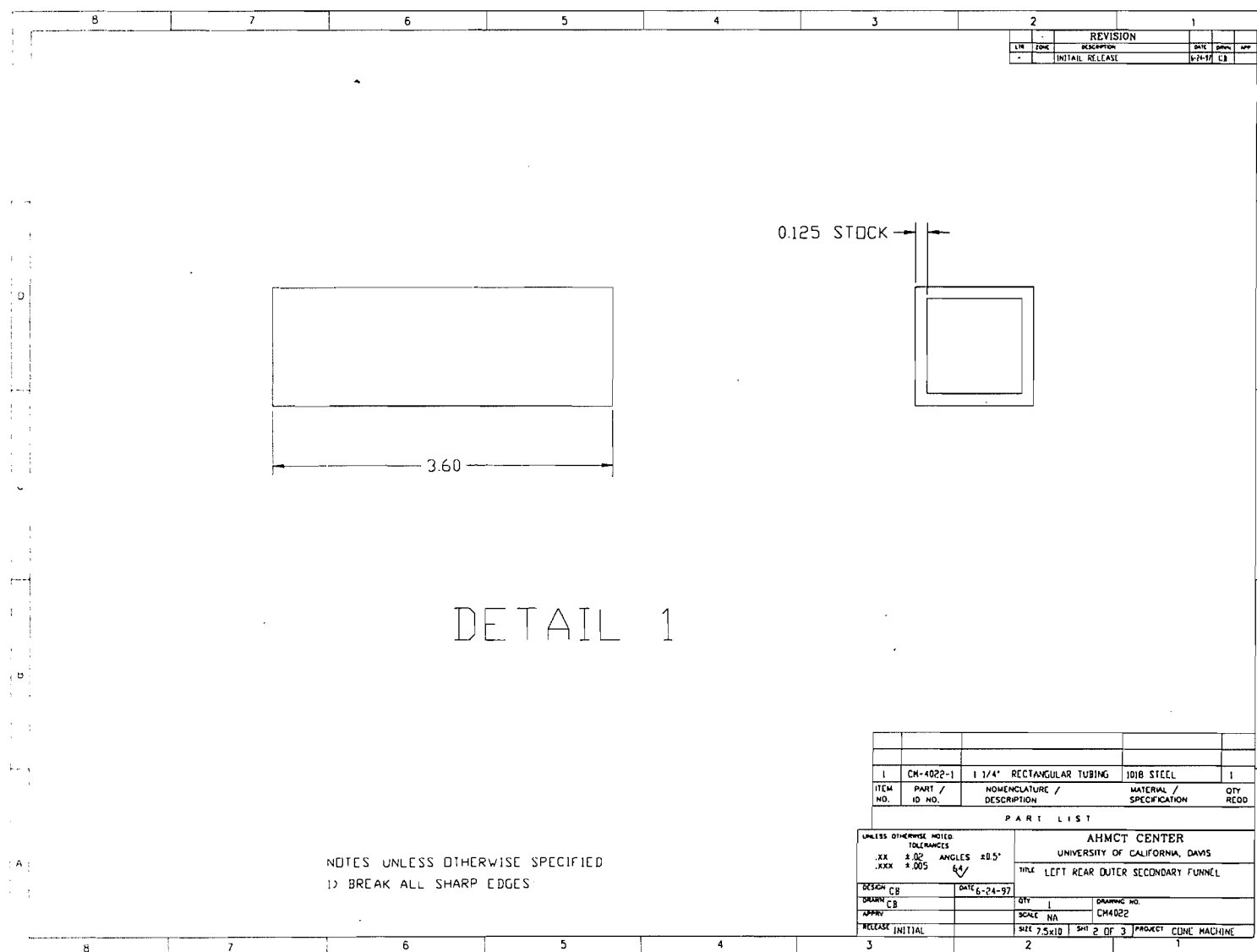




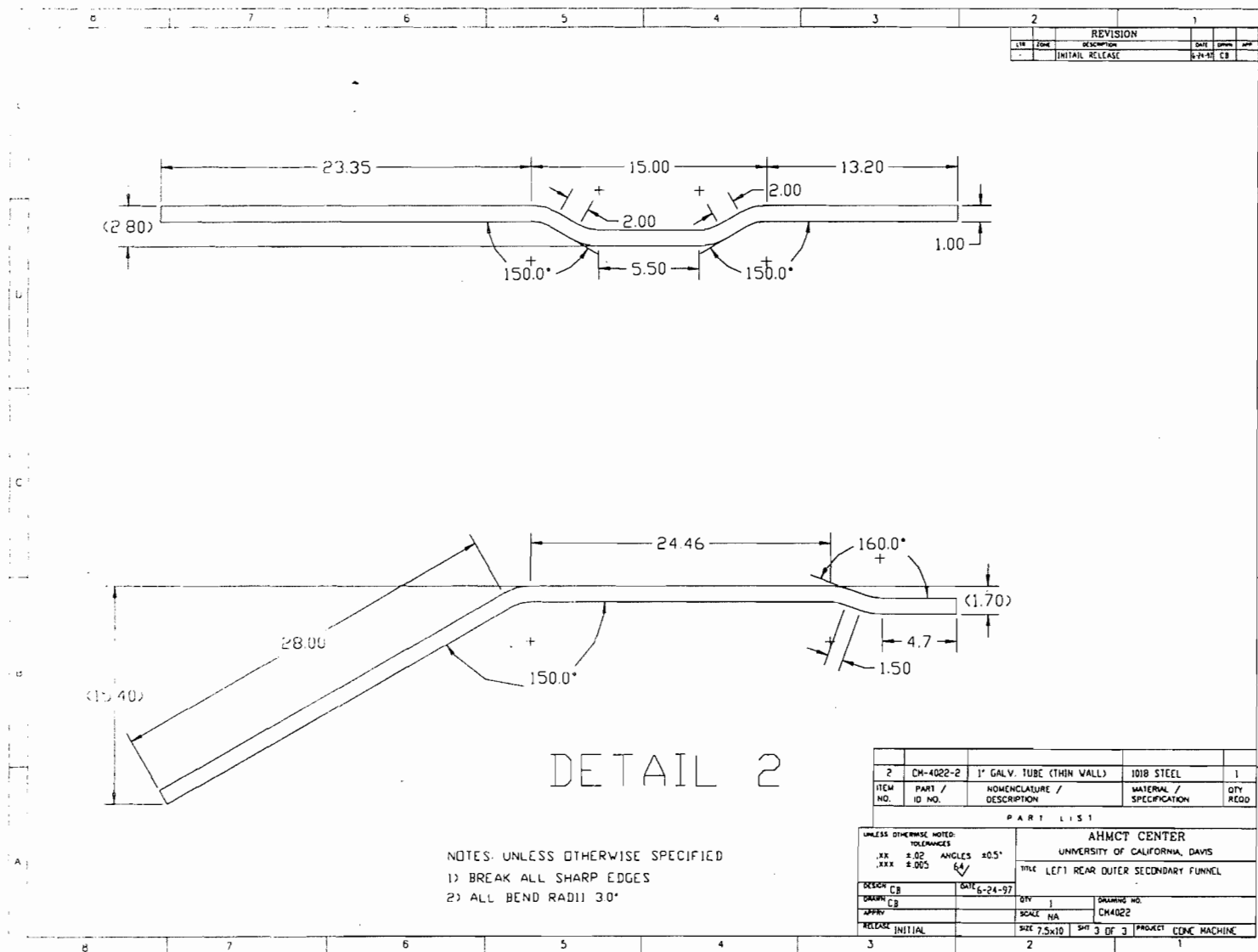
# Detail Drawings of Left Side Secondary Funnel System



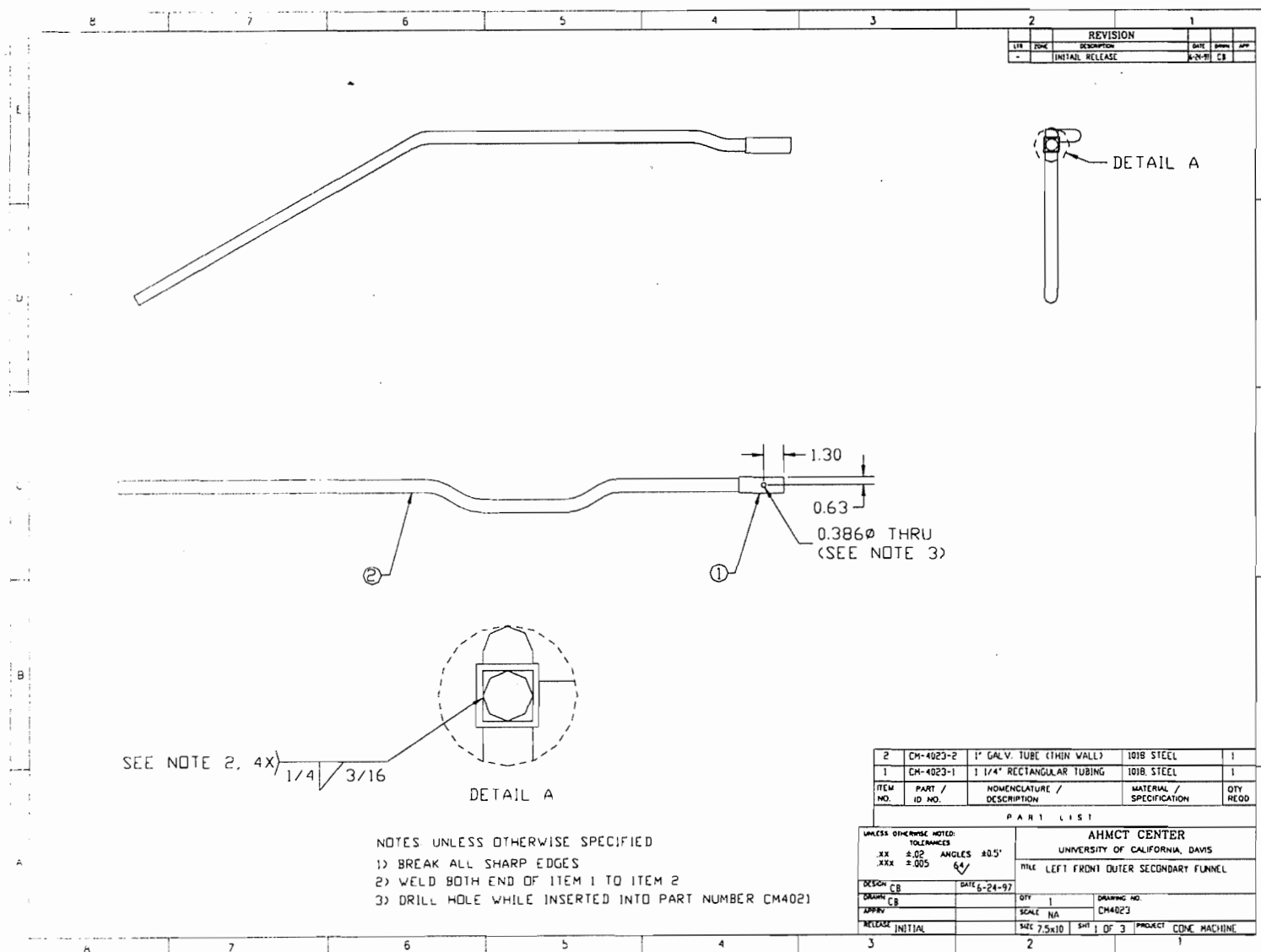
# Detail Drawings of Left Side Secondary Funnel System



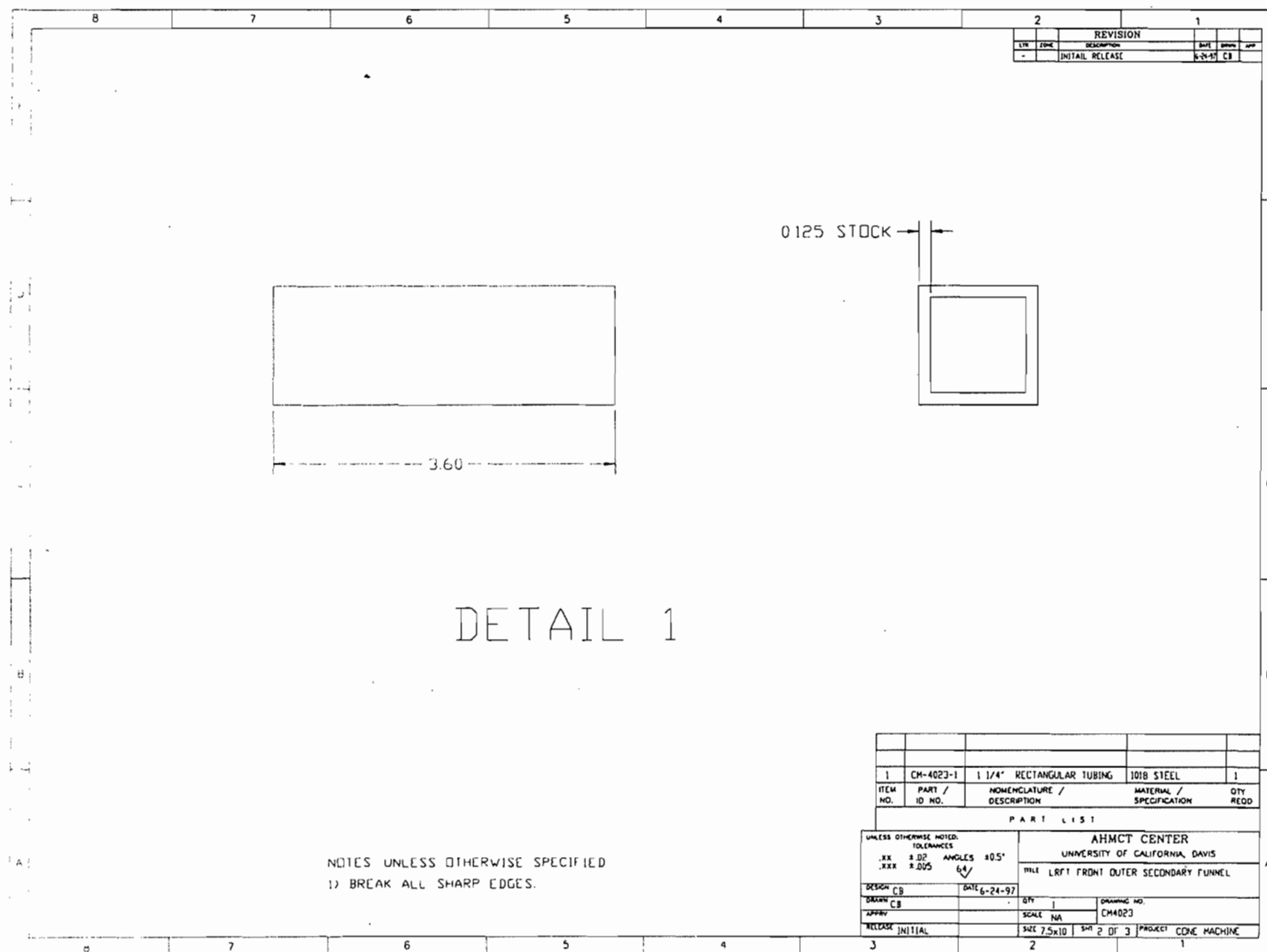
Detail Drawings of Left Side Secondary Funnel System



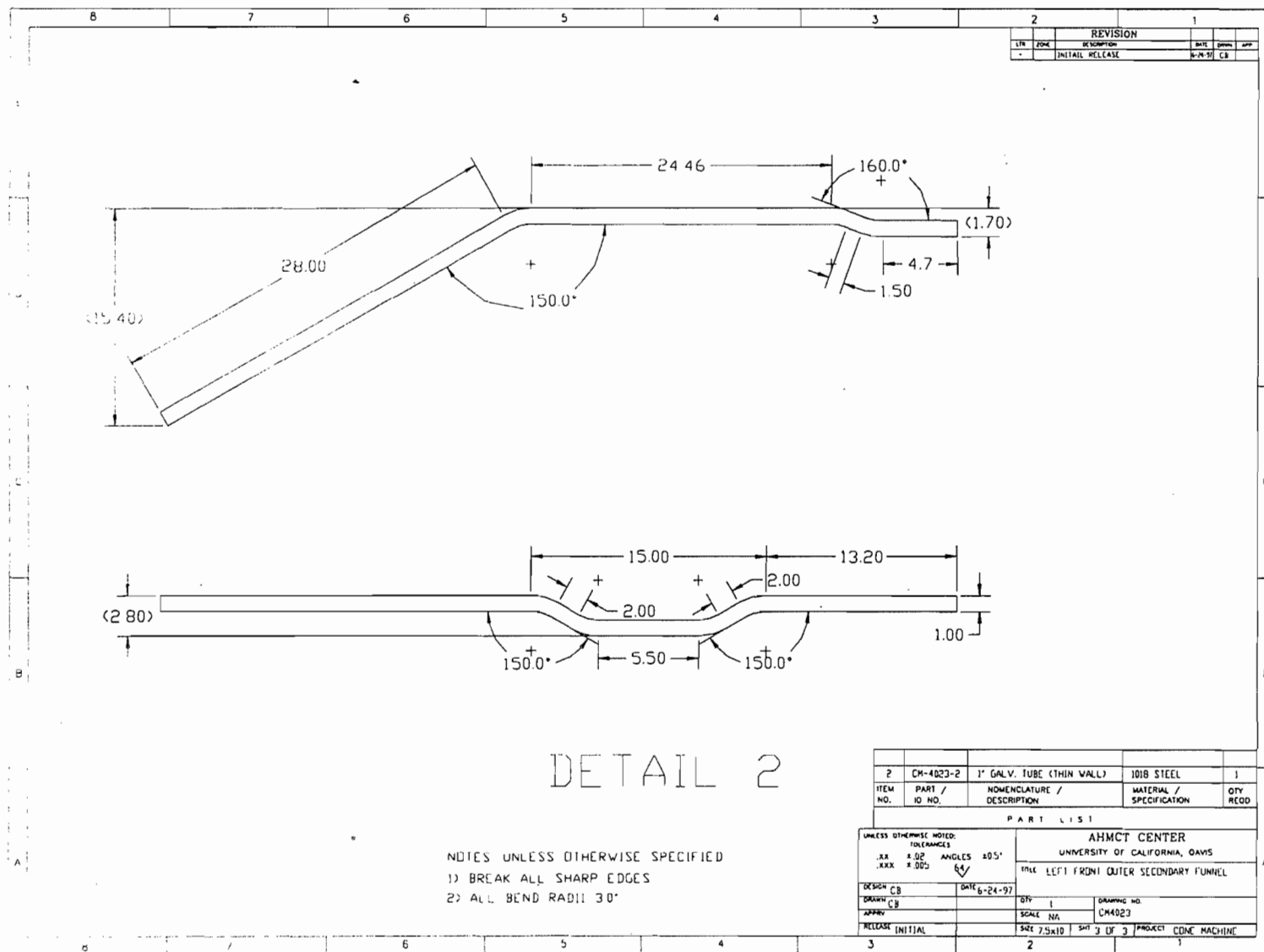
# Detail Drawings of Left Side Secondary Funnel System



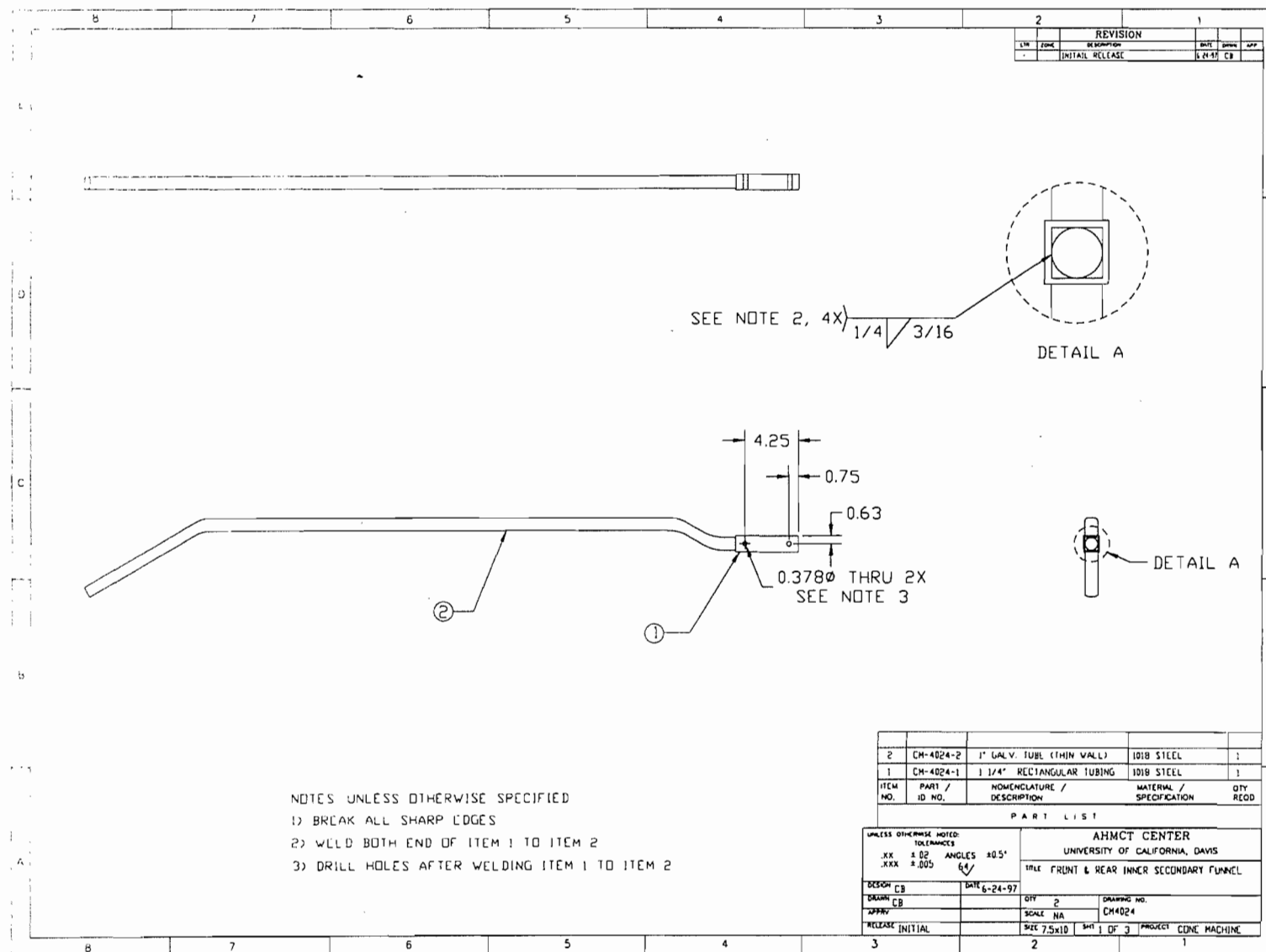
# Detail Drawings of Left Side Secondary Funnel System



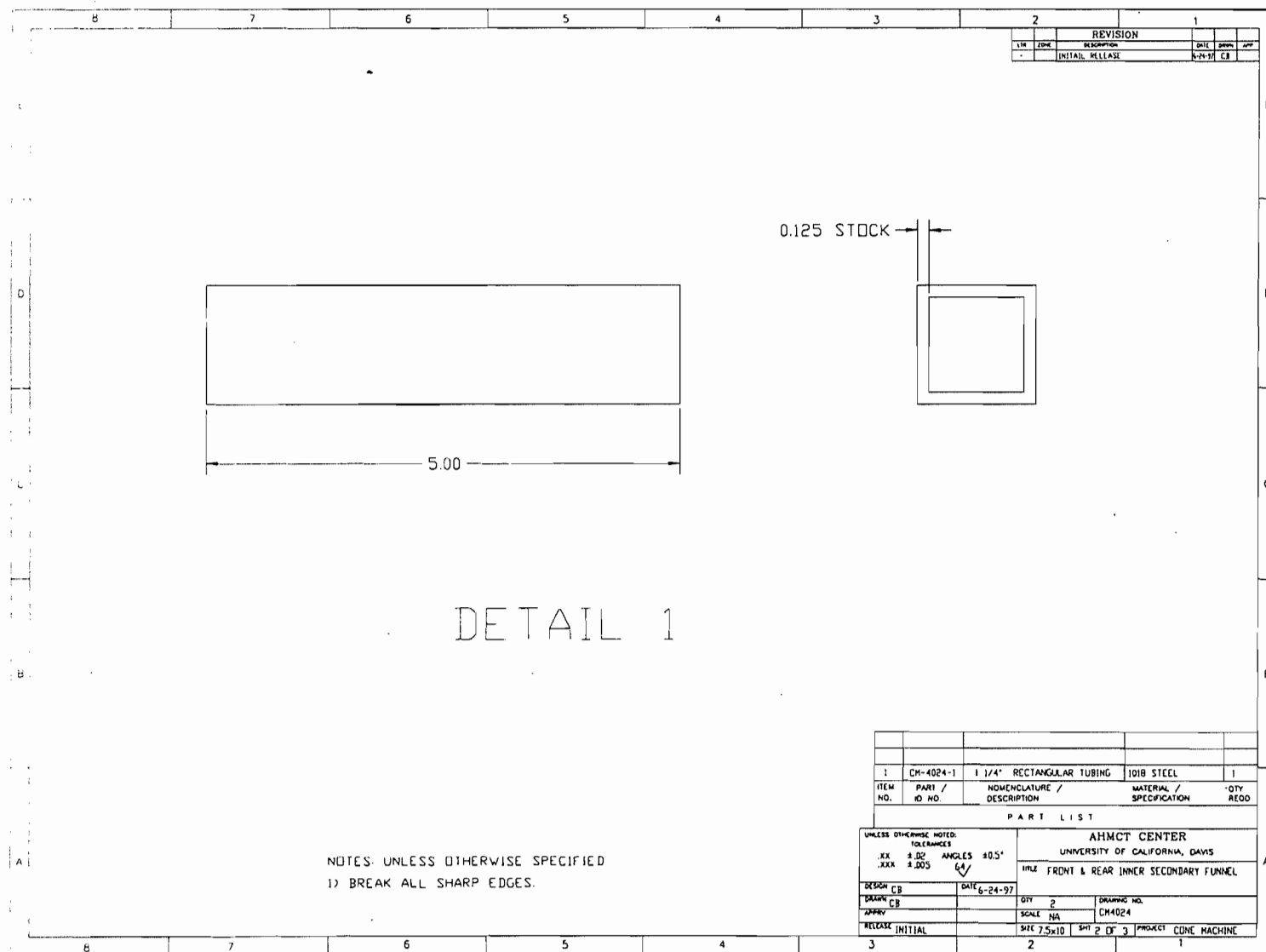
Detail Drawings of Left Side Secondary Funnel System



# Detail Drawings of Left Side Secondary Funnel System

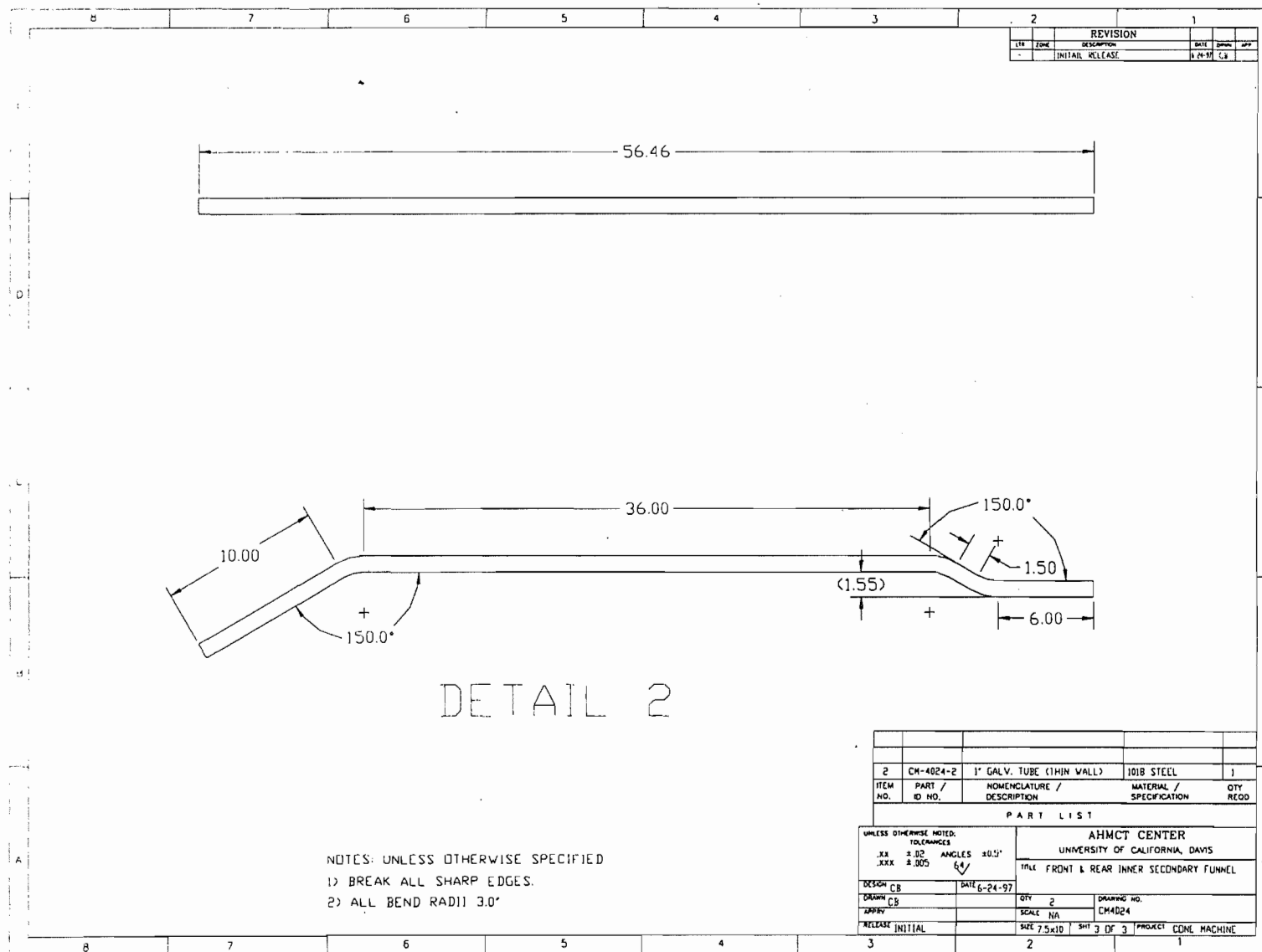


# Detail Drawings of Left Side Secondary Funnel System

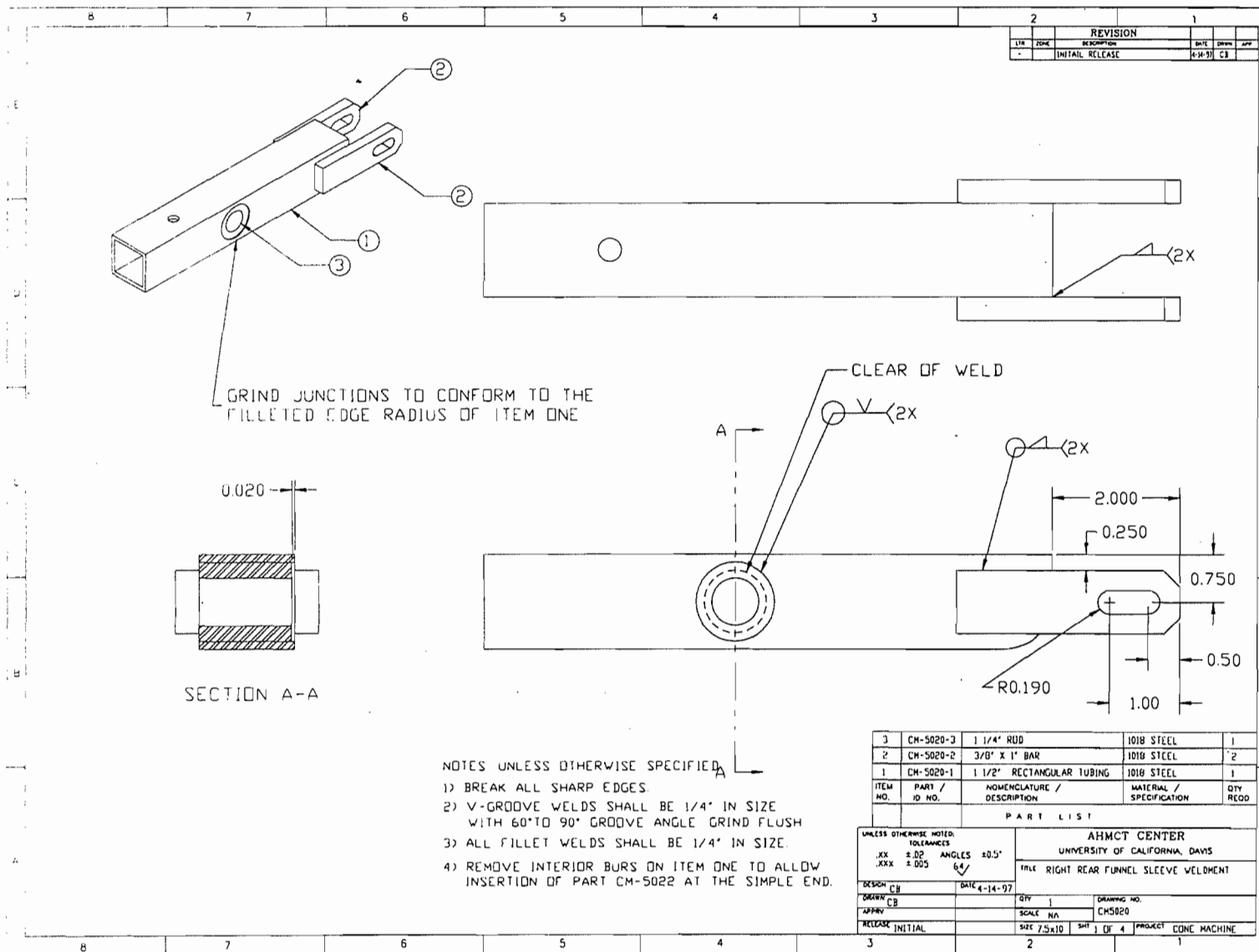




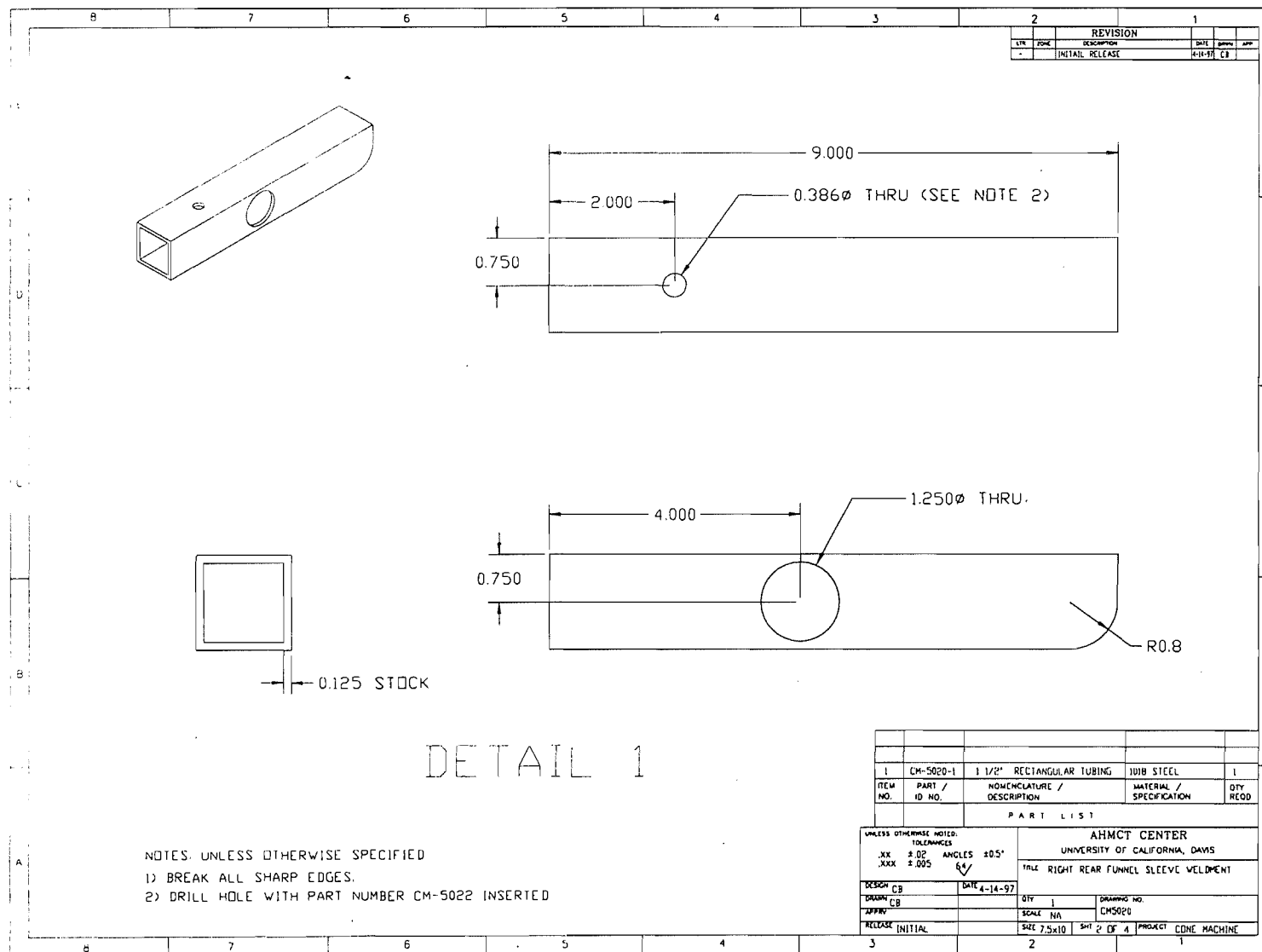
# Detail Drawings of Left Side Secondary Funnel System



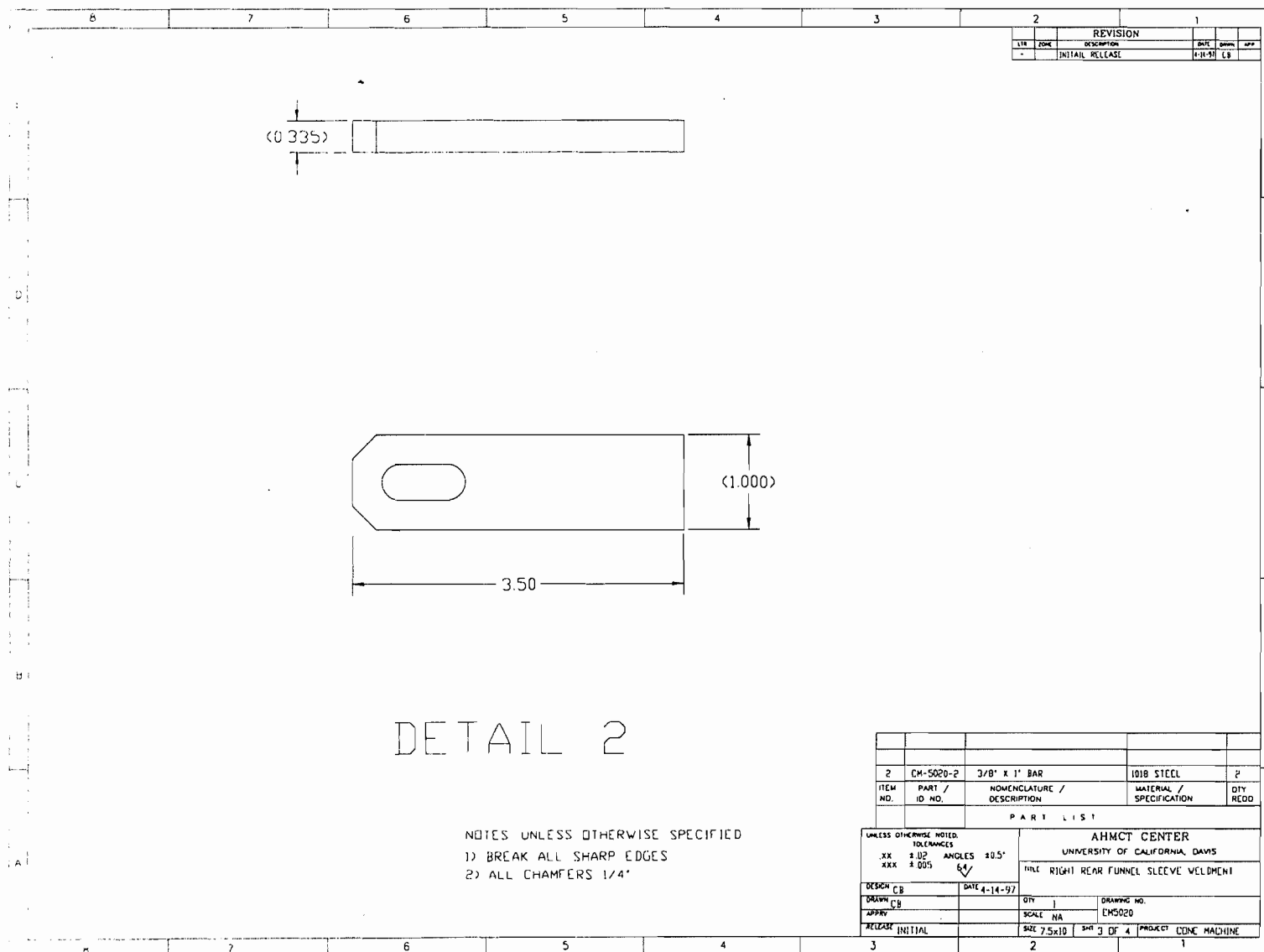
### Detail Drawings of Right Side Secondary Funnel System



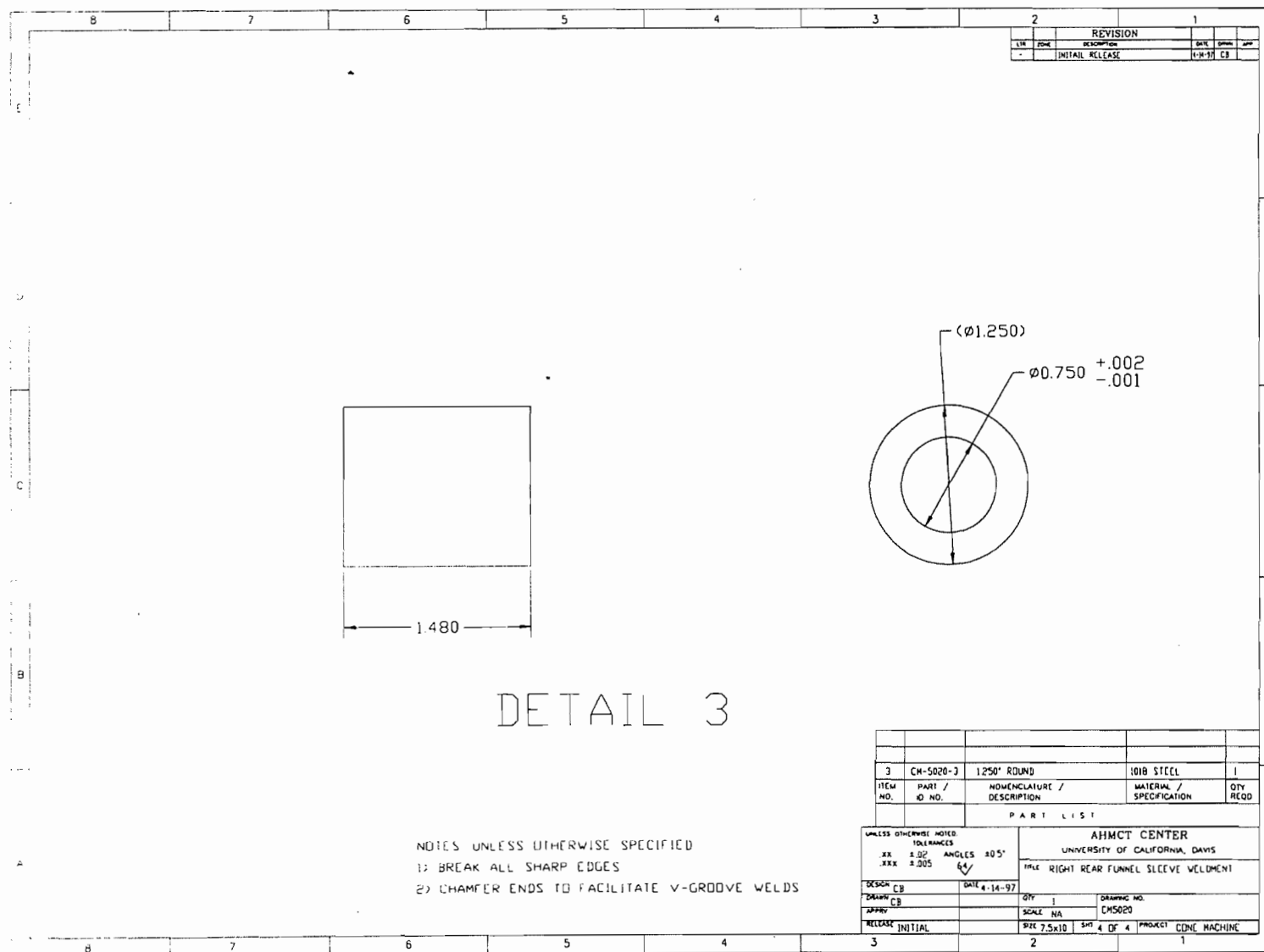
Detail Drawings of Right Side Secondary Funnel System



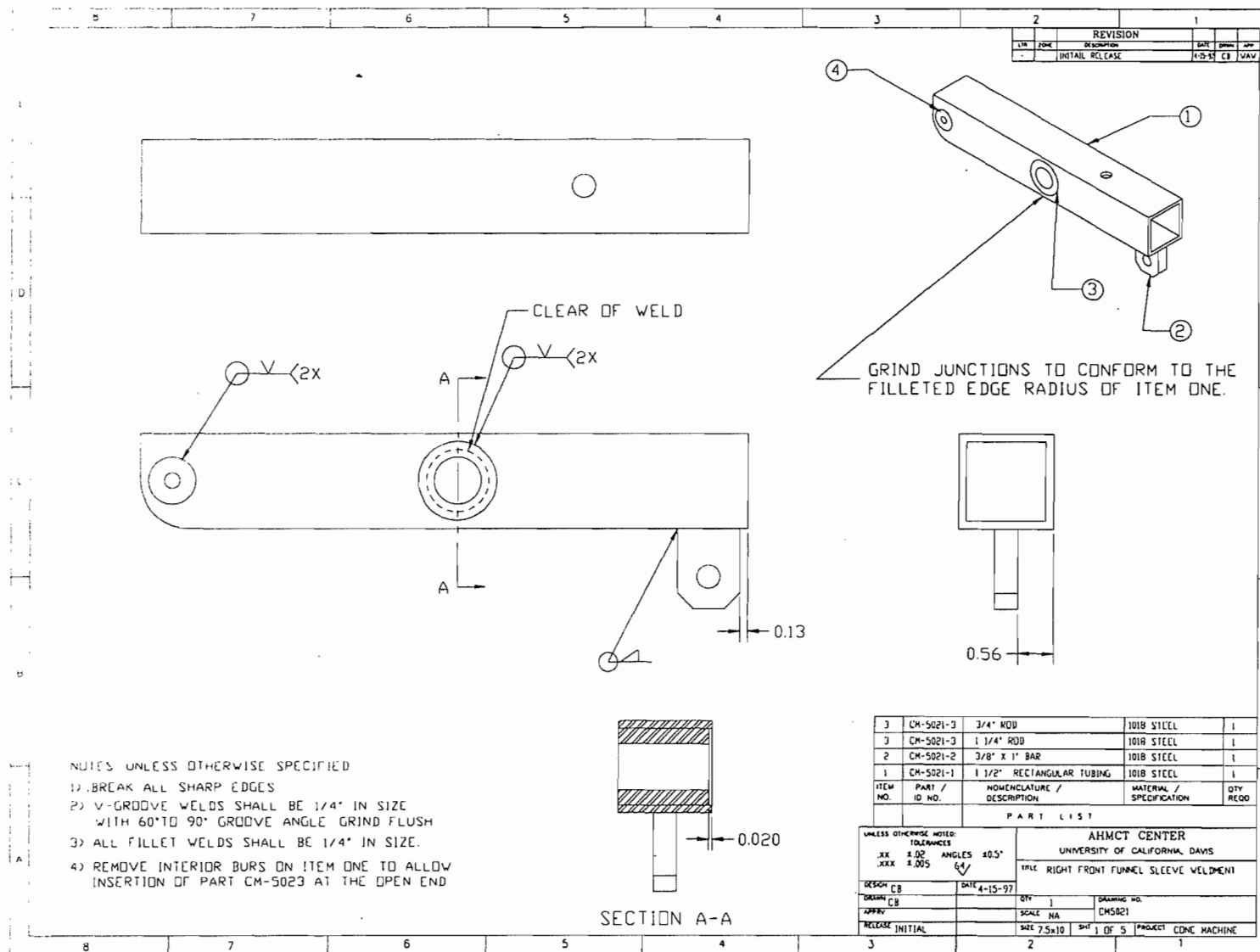
# Detail Drawings of Right Side Secondary Funnel System



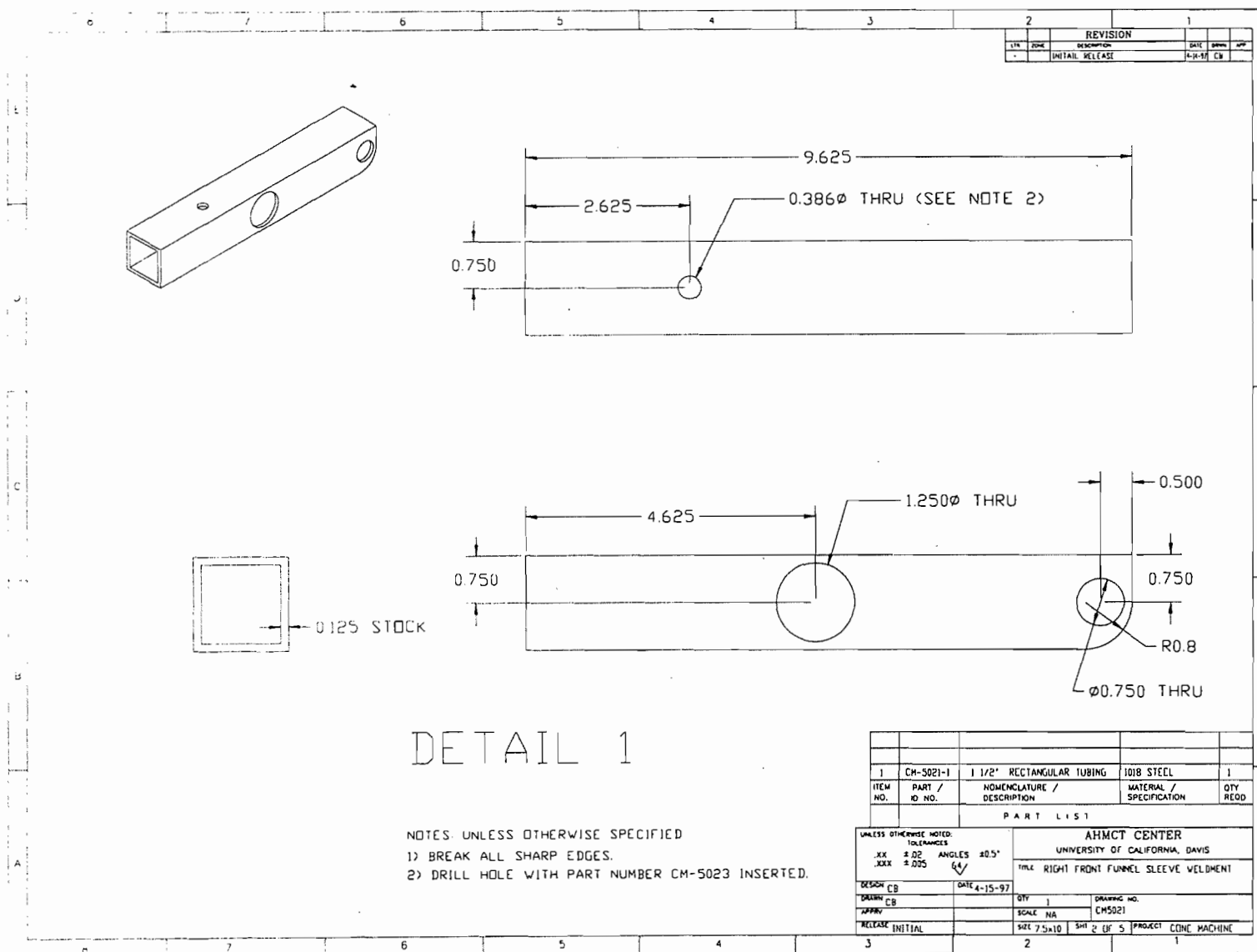
Detail Drawings of Right Side Secondary Funnel System



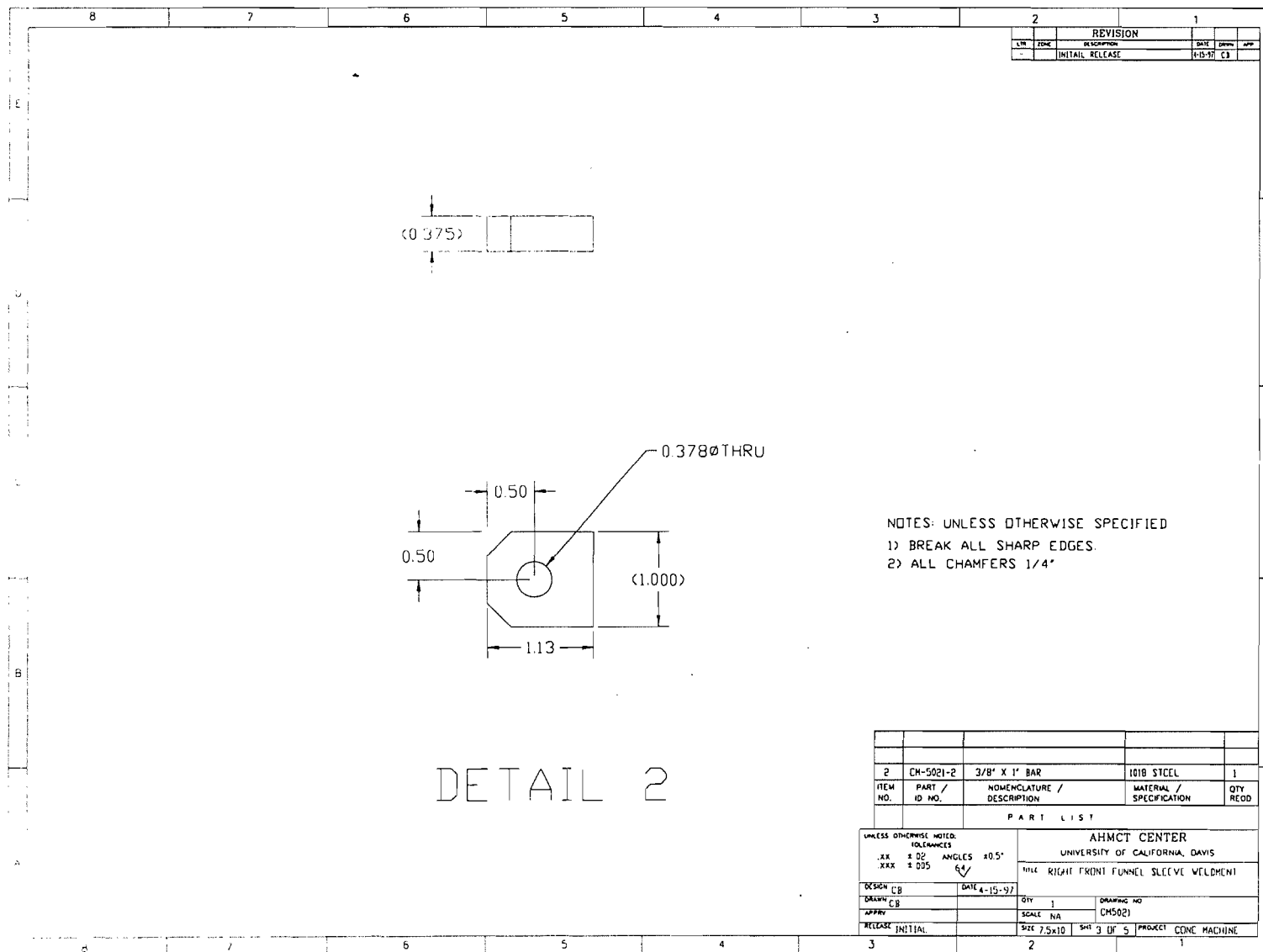
Detail Drawings of Right Side Secondary Funnel System



Detail Drawings of Right Side Secondary Funnel System

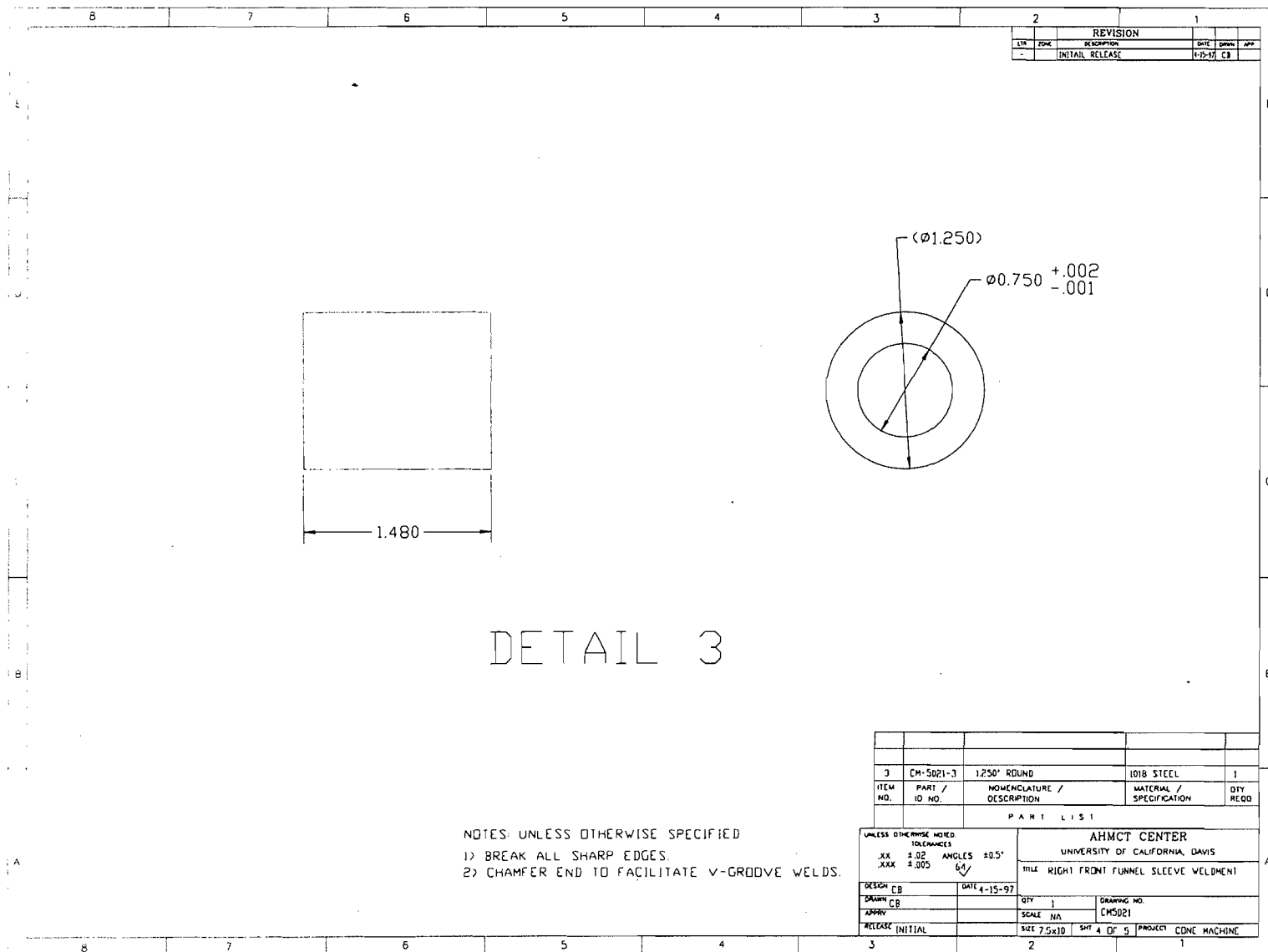


Detail Drawings of Right Side Secondary Funnel System

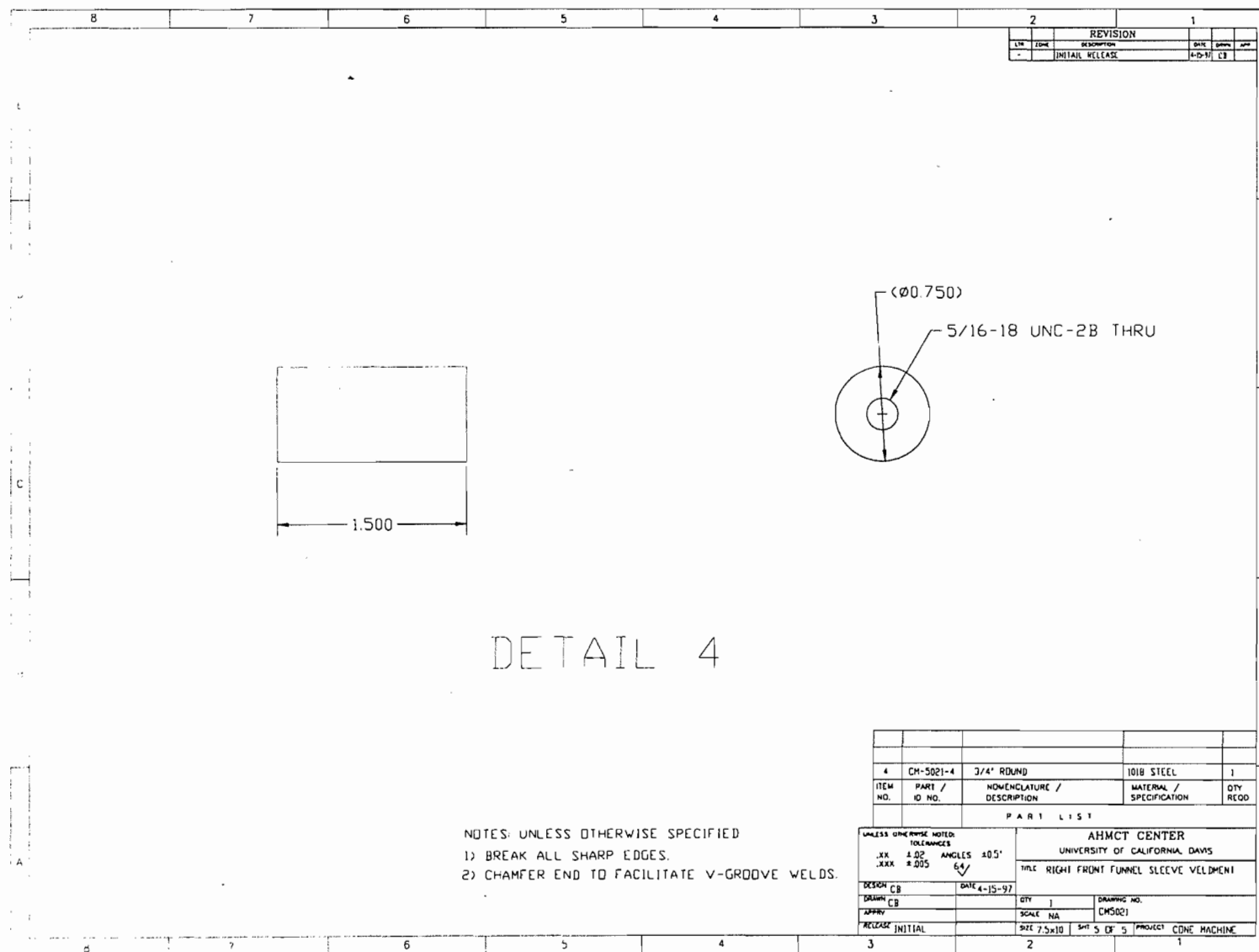




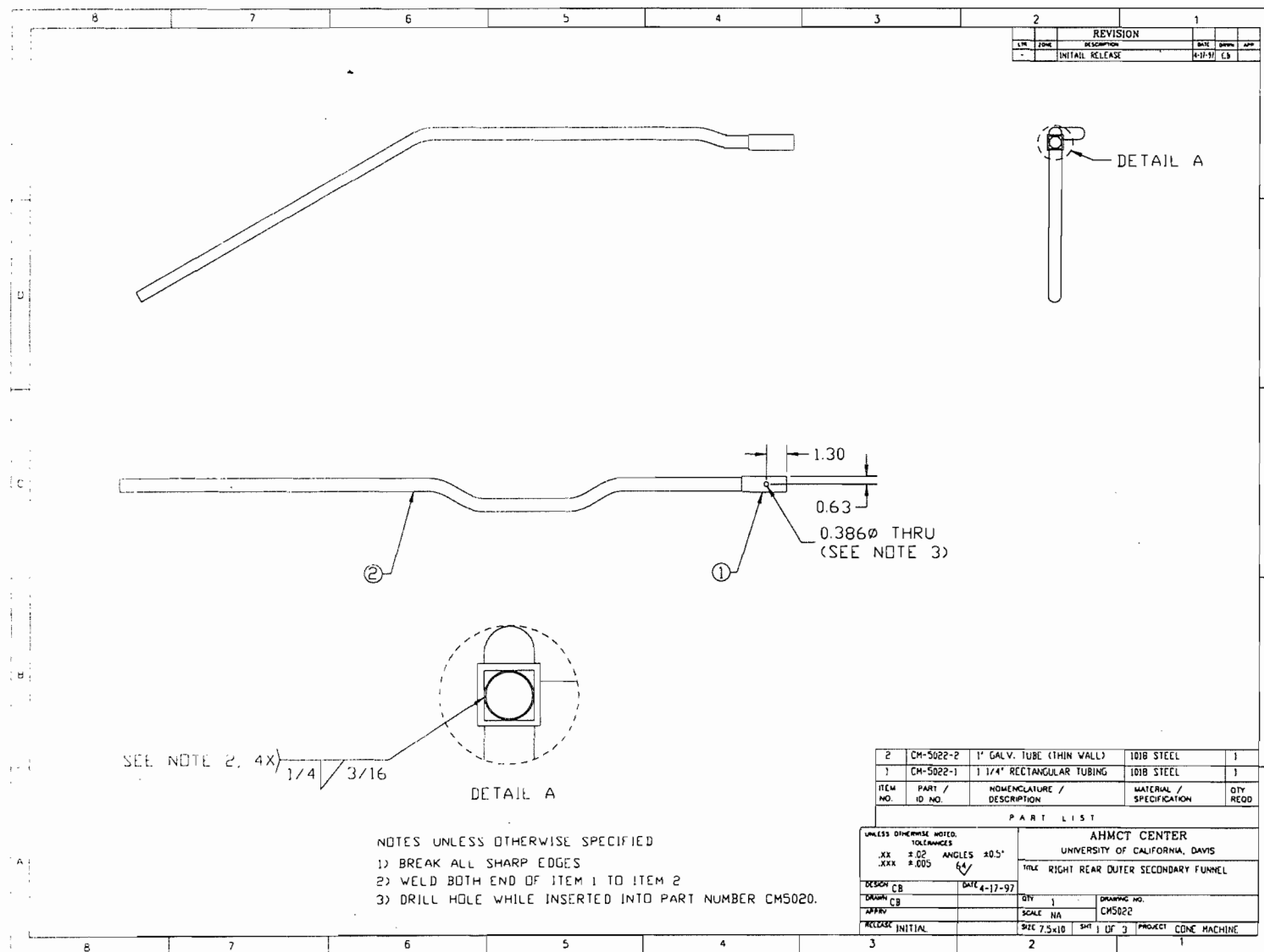
Detail Drawings of Right Side Secondary Funnel System



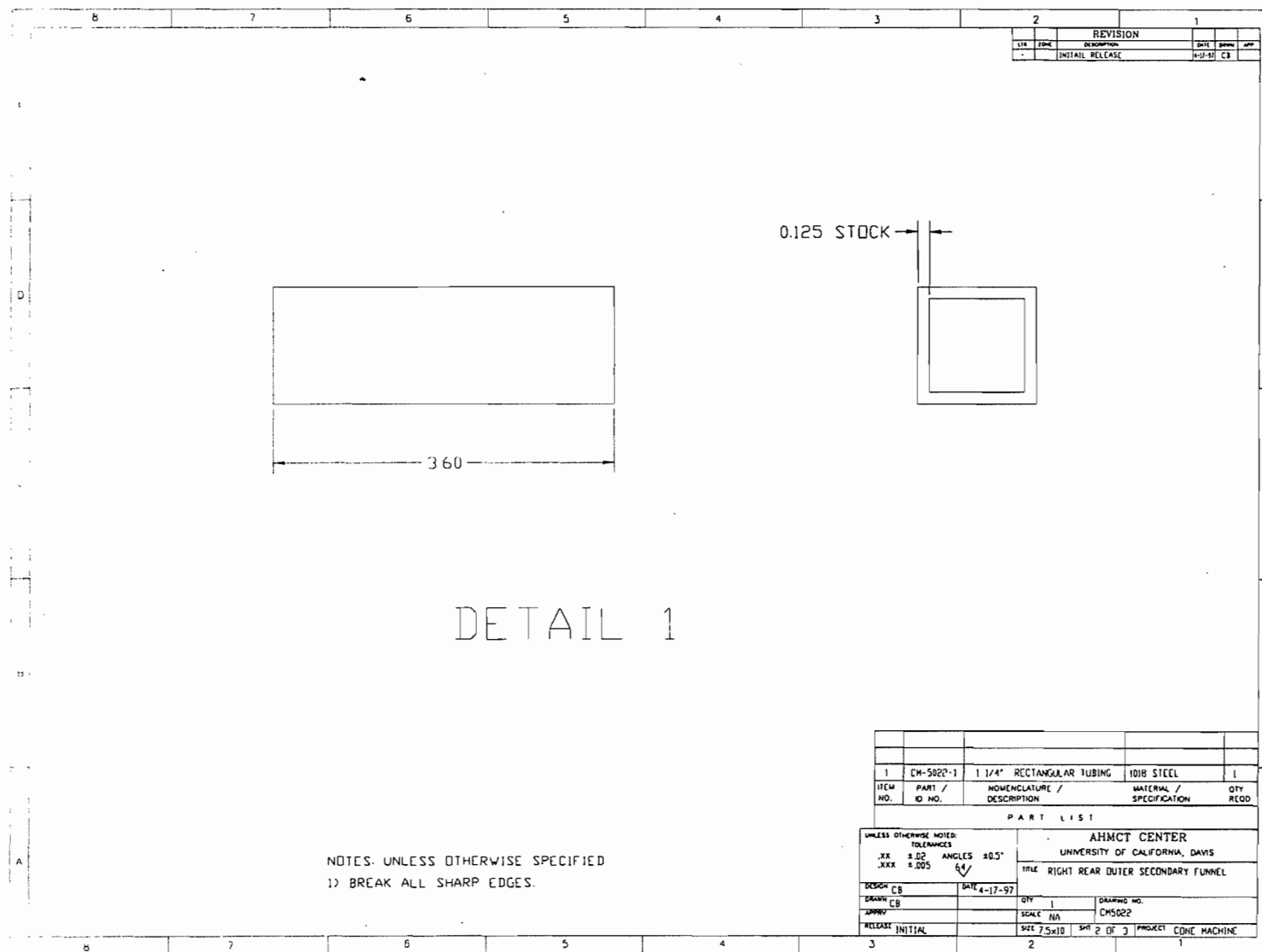
Detail Drawings of Right Side Secondary Funnel System



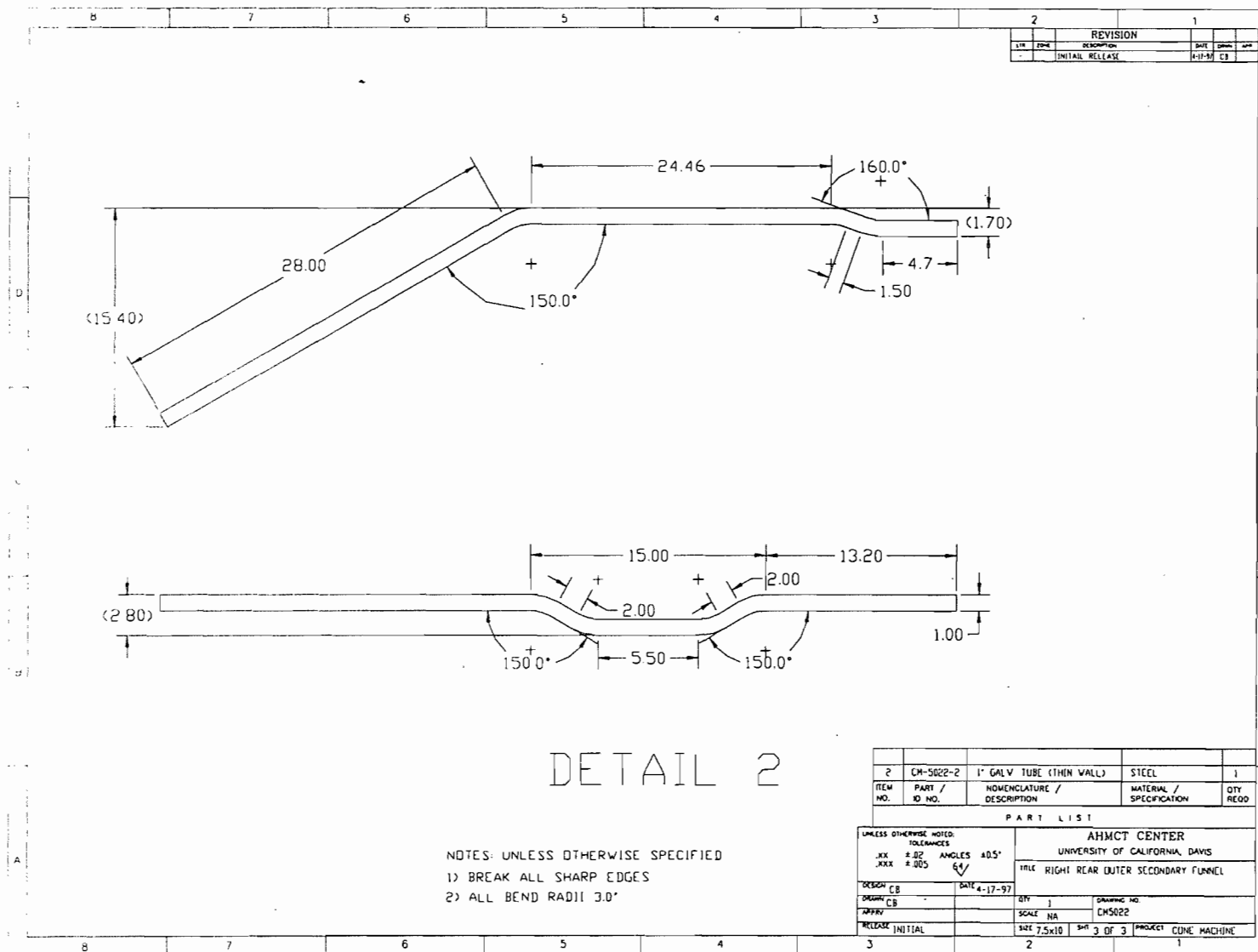
# Detail Drawings of Right Side Secondary Funnel System



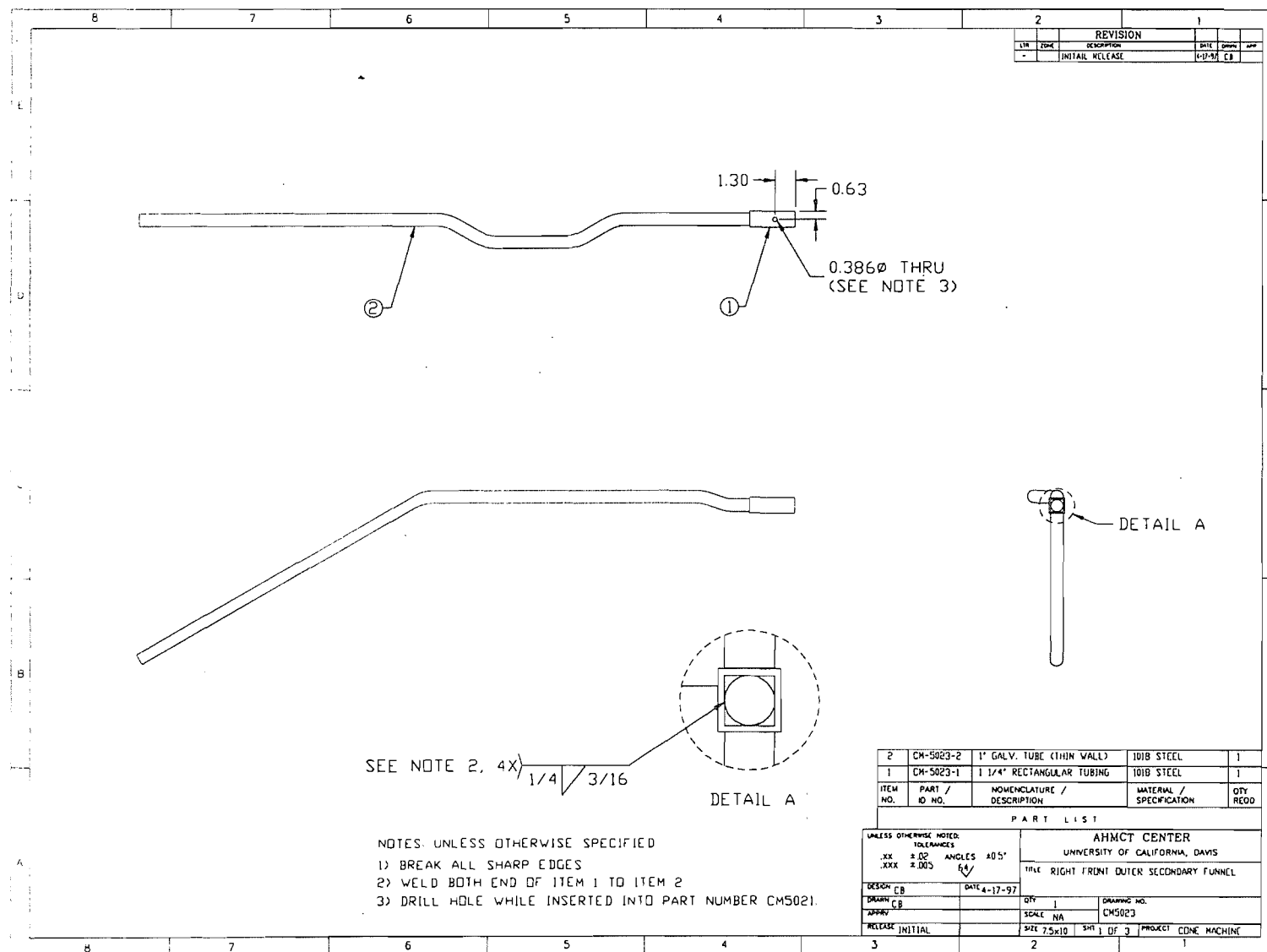
# Detail Drawings of Right Side Secondary Funnel System



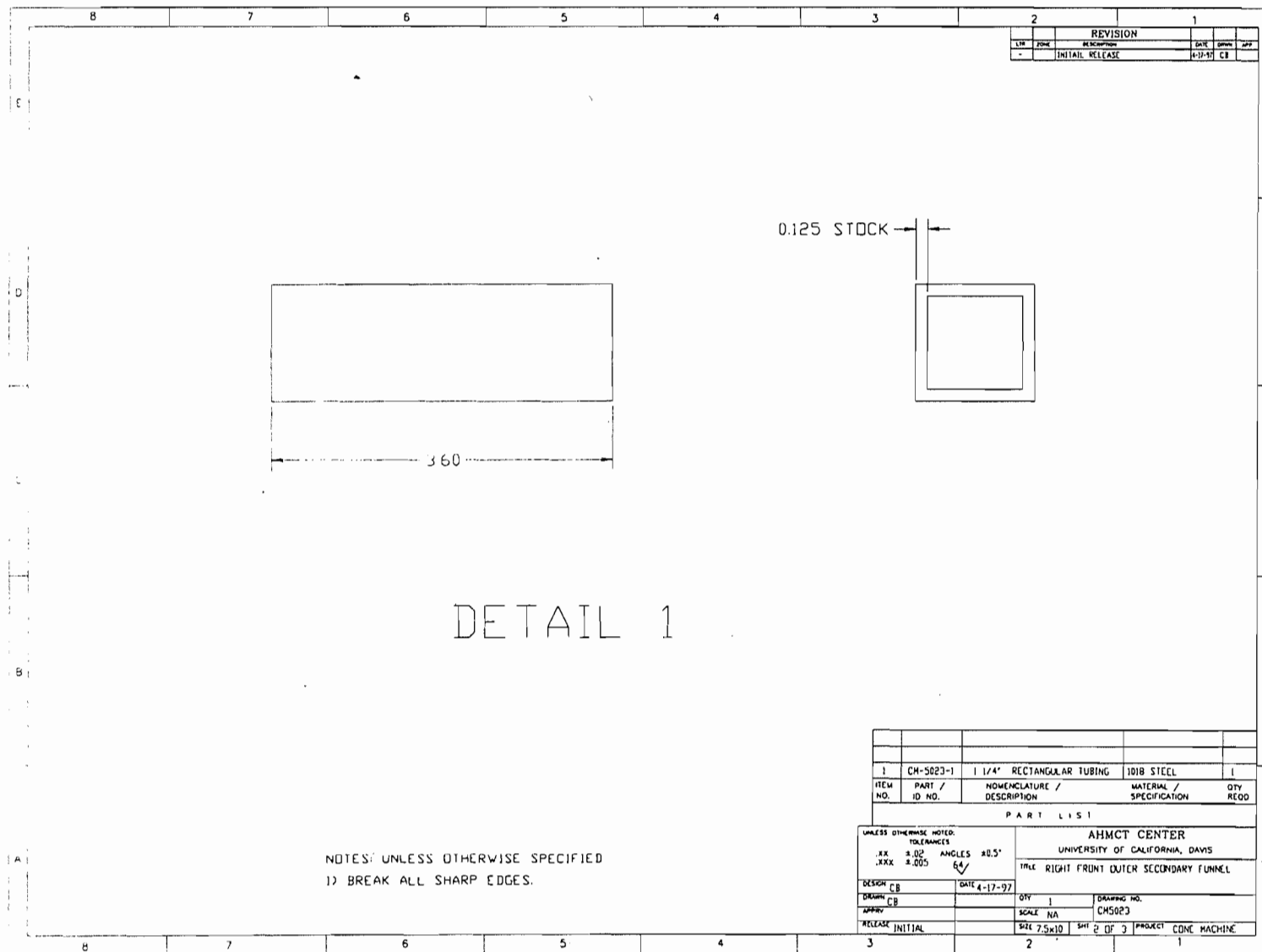
Detail Drawings of Right Side Secondary Funnel System



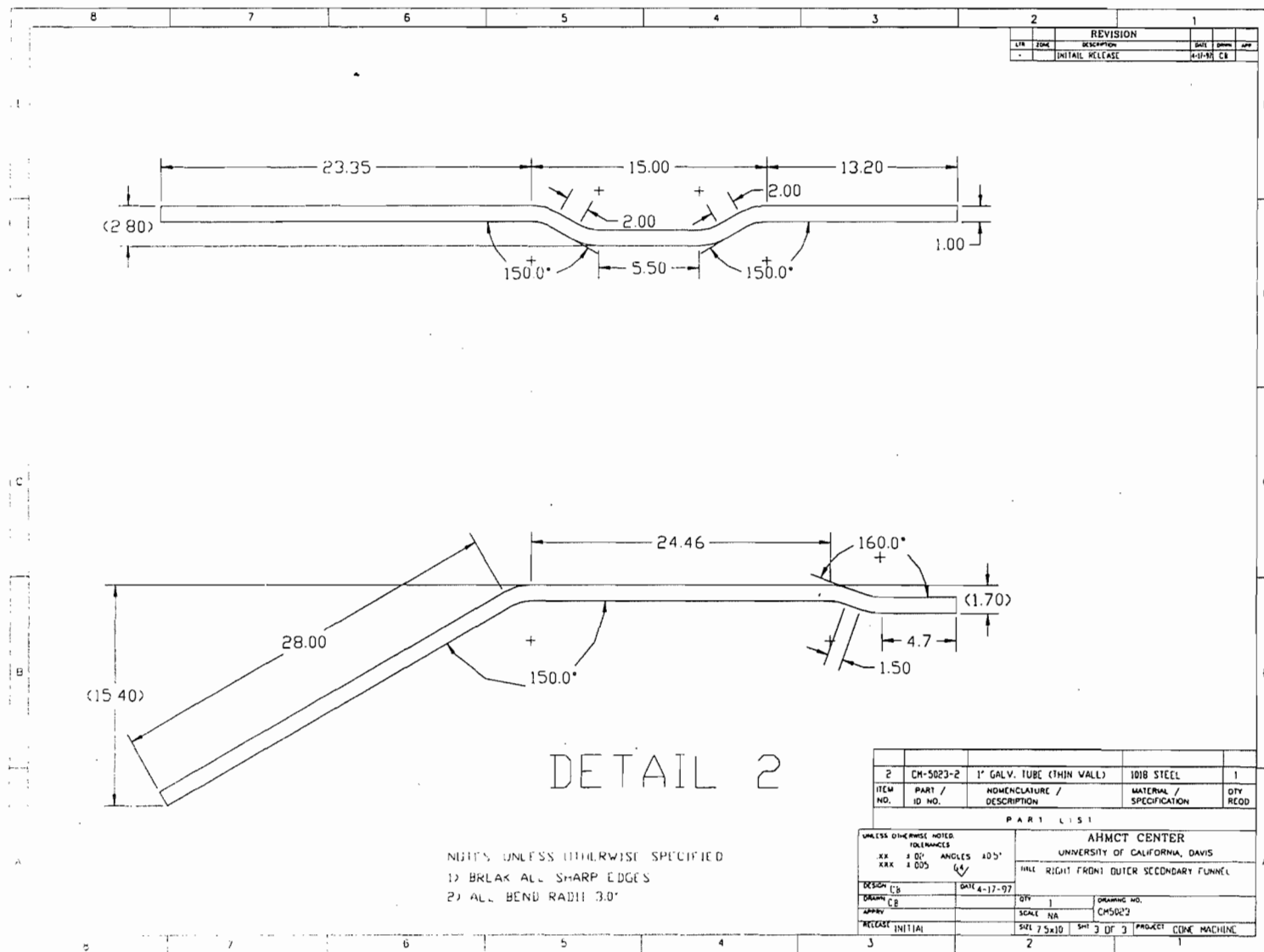
# Detail Drawings of Right Side Secondary Funnel System



Detail Drawings of Right Side Secondary Funnel System

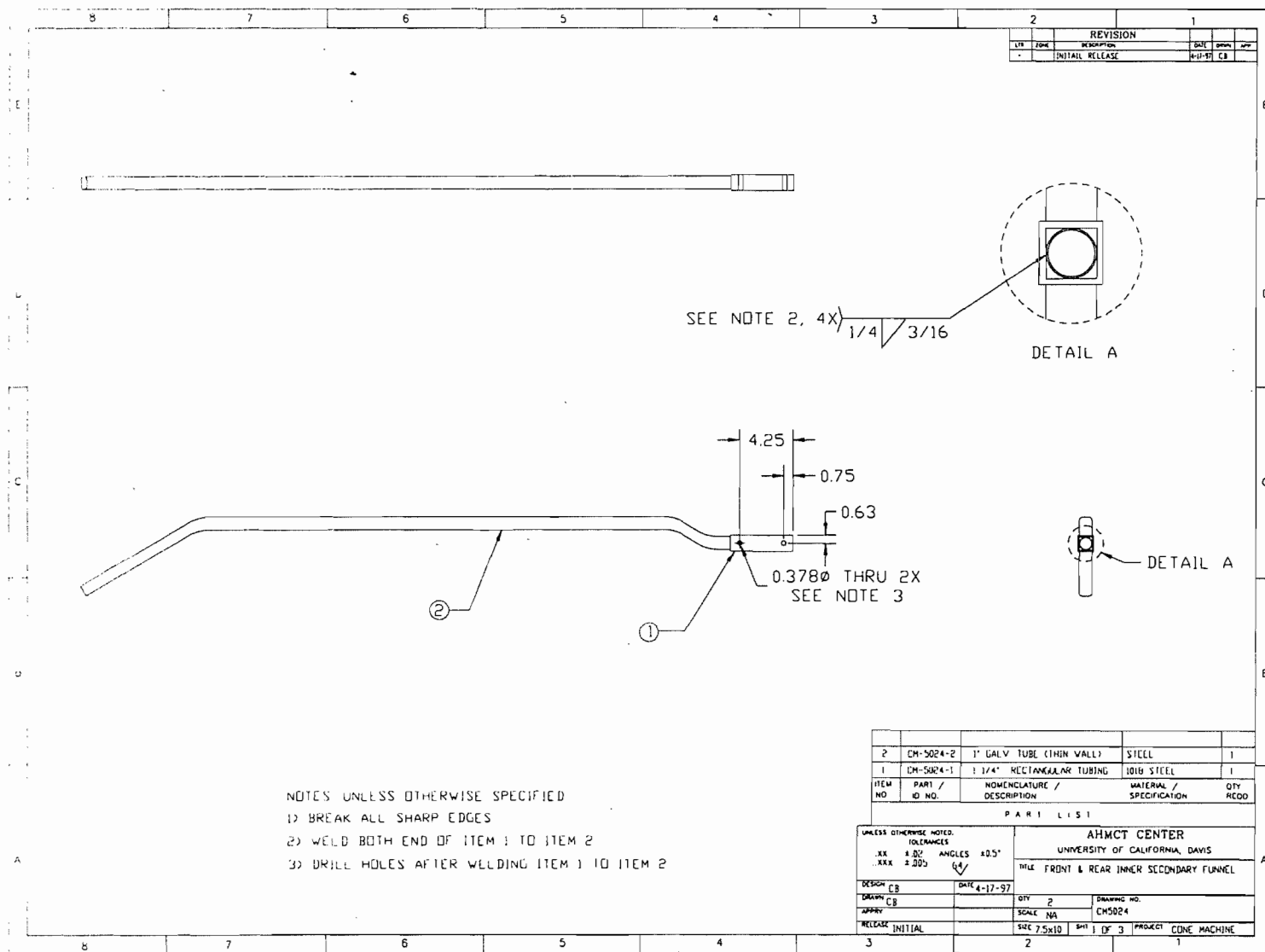


Detail Drawings of Right Side Secondary Funnel System

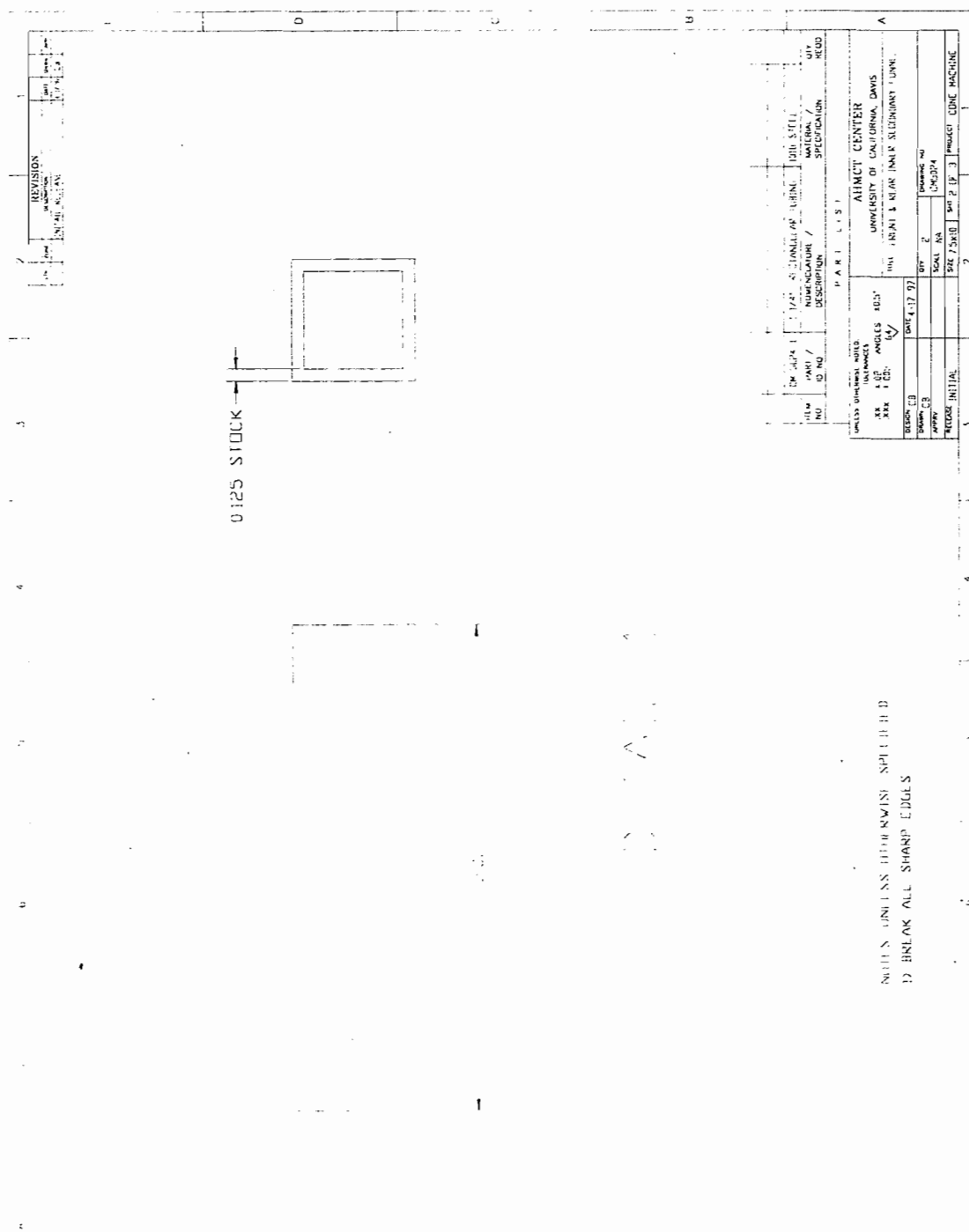




# Detail Drawings of Right Side Secondary Funnel System



# Detail Drawings of Right Side Secondary Funnel System



### Detail Drawings of Right Side Secondary Funnel System

