Development of Second Generation Stowage System for the Automated Cone Machine

BY

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ABSTRACT

This thesis documents the evolutionary development of a major subsystem, the cone stowage system, for the first generation integrated prototype Automated Cone Machine (ACM) developed at the University of California, Davis in conjunction with the California Department of Transportation (Caltrans). The design process for this subsystem progressed from extensive system testing and modifications of the first generation, or testbed, ACM system into the completed prototype ACM.

The purpose or objective of the prototype ACM is to provide Caltrans with a working prototype vehicle to demonstrate that maintenance worker safety for the current lane closure methodology can be vastly improved by automation. The testbed system was used as an internal proof of concept before proceeding with the actual integrated prototype system. Lessons learned from the testbed stowage system were directly integrated into the design of the prototype stowage system.

The cone stowage system is the subsystem of the prototype ACM that transfers cones between the storage and delivery or retrieval segments of the completed system. This thesis strongly emphasizes the development of this stowage system from the testbed system through conceptual design and into prototype testing and modifications.

CHAPTER 1: INTRODUCTION

1.1 Introduction

This chapter discusses both the technique and equipment involved in lane closure operations in California, the perceived need for automation of this process, and currently available equipment that attempts to meet these needs. Finally, a simplified set of performance and safety parameters will be established to assist in the design and evaluation of the automated system.

1.2 Background

The rise of the automobile as an American symbol of affluence mixed with rebellious freedom has placed a heavy burden on State agencies to support the necessary highway infrastructure. The California Department of Transportation (Caltrans) is the local agency that must answer this demand for Californians. Caltrans is tasked with maintaining the highways and interstates of this state in a safe and efficient manner for drivers, pedestrians, and work crews. This last category is often dangerously overlooked or ignored by the general public. These maintenance workers are not only regularly exposed to the expected maelstrom of high speed traffic and flying debris, but also to the insidious effects of poor ergonomics. To help alleviate these dangers, Caltrans created and instituted a maintenance methodology that combines specialized equipment and technique to protect workers and motorists.

1.3 Caltrans Maintenance Methodology - Specialized Equipment

At the core of the this maintenance methodology are three pieces of specialized equipment: the traffic marker, the cone body, and the shadow vehicle. Although several types of markers exist, the most common type of marker is the traffic cone consisting of two polyvinyl chloride plastic (PVC) sections joined together. The first section is a thin-walled conical piece with an orange exterior for high visibility and decreased vehicular damage in the event of impact. The second section consists of a gray weighted base ring with 0.019 m (0.0625 ft) tall feet to provide stability for the first section against tipping by wind gusts or close moving traffic. The combined sections produce a traffic cone that is 0.710 m (2.33 ft) tall, weighs an average of 4.5 kg (10 lb), and internally stacks.

The development of a function-specific vehicle for cone placement or retrieval was driven by concerns over worker safety. Previously, the typical method for manual cone deployment consisted of a worker placing cones by hand from the tailgate or a small platform attached to the rear of a truck. To lessen the considerable risk to the worker, Caltrans designed the cone body -- a custom frame that fits on the chassis rails of a standard 4500 kg (9900 lb) capacity truck. The critical safety feature of this custom frame is the relocation of the worker from the tailgate or rear platform to one of two centrally located buckets behind the truck cab. Each bucket contains a seat with an integral seat belt that can orient forwards or rearwards with minimal effort to facilitate cone operations. Additionally, these buckets are heavily reinforced against vehicle impact and are positioned low in the vehicle to ease cone retrieval and placement ergonomics. A full-length longitudinal main conveyor is stationed between the two buckets and provides storage for eighty cones in two rows. Foot switches are located in each bucket for conveyor control. Behind the buckets and flanking the longitudinal conveyor are two rear storage bins for miscellaneous implements and signage.

To assist in protecting the maintenance crew of the cone body, a vehicle called the shadow vehicle was developed. This vehicle follows the cone body during deployment and retrieval operations and is designed to absorb high speed collisions from other vehicles. The shadow vehicle consists of a large truck with a specially designed energy absorbing structure that suspends from the rear of the vehicle.

1.4 Caltrans Maintenance Methodology - Technique

The maxim behind the Caltrans maintenance technique is a strict segregation of the roadway to divide the flow of traffic from the maintenance location and workers (California Department of Transportation, 1992). The continuities of these separation areas are critical to the safety of both the workers and the motorists. Any deviation of traffic from the prescribed separation can potentially be fatal. To decrease this likelihood and to increase the robustness of the separation, visible traffic markers are used. The design of these traffic cones provides motorists with visual, audible, and tactical feedback to reinforce traffic separation. To guarantee separation area uniformity and continuity, Caltrans developed a lane closure technique consisting of three different sections, each with its own specific purpose. These three sections are the advance warning area, the transition area, and the buffer and work area. A Caltrans crew of two maintenance workers and one cone body is necessary for a typical lane closure operation.

The first section, called the advance warning area, contains four warning signs to inform oncoming traffic that construction work is occurring ahead and which lane or lanes will be closed. The first three warning signs are diamond shaped and are individually assembled onto small tripods that are typically weighted down by sand bags. The crew is required to exit the vehicle to assemble and place each of these signs. These signs warn of road construction ahead and are usually placed with a single traffic cone at intervals of 213 to 305 m (700 to 1000 ft). At the end of the advance warning area is positioned a trailer mounted and flashing signboard that indicates the correct direction to merge.

The next section, called the transition area, begins at the signboard in the advance warning area and extends 305 m (1000 ft) for each lane of closure. In this area, traffic cones spaced 15 m (50 ft) apart are placed diagonally across the lane or lanes in a straight line. For this part of the lane closure, one maintenance worker transfers to a bucket and faces forward. From this location, the worker removes a traffic cone from the stack on the longitudinal main conveyor and places it next to the truck as the second worker slowly drives forward and diagonally across the lane or lanes.

The third and last section, termed the buffer and work area, starts at the end of the transition area and continues 30 m (100 ft) past the work site. The traffic cones in this section are positioned in a straight line 0.3 to 0.6 m (1 to 2 ft) inside of the lane edge (to avoid being struck by vehicles) and are located every 30 m (100 ft). Traffic cone deployment is again accomplished in the same manner as before, except the truck is driven at a higher speed of 16 km/hr (10 mph). Traffic cone spacing is visually approximated by observing the number of bott dots placed in the ground at 15 m (50 ft) intervals.

Removal of a lane closure operation occurs in the reverse order. For cone retrieval, the bucket is reconfigured with the seat facing rearwards, and the vehicle is driven backwards. The maintenance worker in the bucket is required to retrieve the traffic cone from the roadway and replace it in the stack on the longitudinal main conveyor. The driver must maintain a close position to the traffic cones on the roadway so that the second worker can retrieve them.

1.5 Perceived Need for Automated Cone Machine (ACM)

The creation and implementation of the Caltrans maintenance methodology, as evidenced by the development of the cone body and the lane closure technique, are attempting to successfully provide higher levels of protection for motorists and maintenance workers. The cone body configuration provides better protection against traffic collisions and flying debris than the tailgate method. This equipment, combined with a stringently controlled lane closure, is effective in creating a safer work zone.

Although this maintenance methodology is successful in providing a safer work environment, injuries are still common. Flying debris can cause grievous harm to face and eye tissue and fatal accidents are still possible, even in the cone body buckets. However, most of these injuries are caused by the repetitive motions required in cone deployment and retrieval. Lower back and shoulder injuries are difficult to avoid in long lane closure operations that can require over eighty cones to be placed and then retrieved in a single day. These facts showed the Advanced Highway and Maintenance Construction Technology Center (AHMCT) personnel that substantial improvements could be made in maintenance worker safety if the workers could remain inside of the vehicle during cone deployment and retrieval. A proposal of an Automated Cone Machine (ACM) was forwarded to Caltrans as a revolutionary step in the development of specialized equipment to support lane closure operations.

1.6 Search and Evaluation of Existing Equipment

As a first step in the development of the ACM, a search for patented concepts or systems to deliver and retrieve cones was initiated using the Derwent World Patent System and CASSIS in addition to the Official Gazette of the US Patent and Trademark office. These searches turned up three very different systems that are capable of handling traffic cones. A more recent search also revealed that three additional patents had been issued for automated cone handling equipment.

The first patent was a large vehicle named the Traffic Cone Retriever (see Figure 1.1). Traffic cones were retrieved by two revolving paddle wheels that placed the cones onto a sloped conveyor where they were transferred towards the rear of the vehicle. The cones were vertically stacked at the top of this conveyor and then stowed rearwards and laterally on sloped rollers. Although this vehicle never saw production, it could retrieve between 1500 and 2000 cones at speeds in excess of 56 km/hr (35 mph) and required only one operator. However, the machine was very bulky, could not deliver cones, and was unable to retrieve cones that were not standing. For these reasons, this machine would be unable to perform the necessary tasks of cone deployment and retrieval that are required by a typical Caltrans lane closure operation.

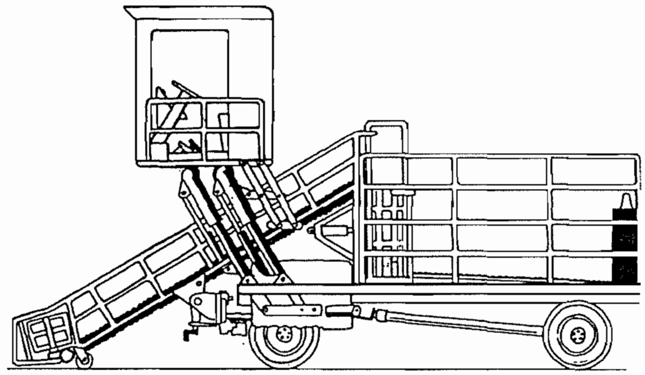

Figure 1.1 *Traffic Cone Retriever*

The second system patent describes a French machine called the Baliseur Cone Picker produced by the SEP company (see Figure 1.2). This machine can retrieve and deploy up to 240 cones at speeds of 18 km/hr (11 mph) and can handle overturned cones. Traffic cone retrieval begins with cones being oriented base forward by a series of bars and guides. As the vehicle drives forward, one of multiple prongs attached to a chain link conveyor enters the base of the cone. Once a prong enters the cone base, the cone is then transferred vertically by the conveyor. At the top of the conveyor, the cone is then stripped off the prong by a bar mechanism while the tip is held by v-shaped guide. The cone then falls base first into a small guide chute that directs the cone into one of ten larger vertical storage areas mounted on a rotating drum. Deployment is accomplished by small finger-like mechanisms that release only the bottom cone from a storage bin to drop onto the roadway where guides position and keep the cone upright. Once correctly placed, the cones are released. This design can deploy multiple cones at once and has an excellent retrieval and deployment rate, but requires the use of specialized hard plastic cones. While these cones are similar in size to Caltrans cones, they do not meet the weight requirement. Another problem with this machine is the expense that would be required to convert the Renault truck frame design to retrofit onto an American vehicle.

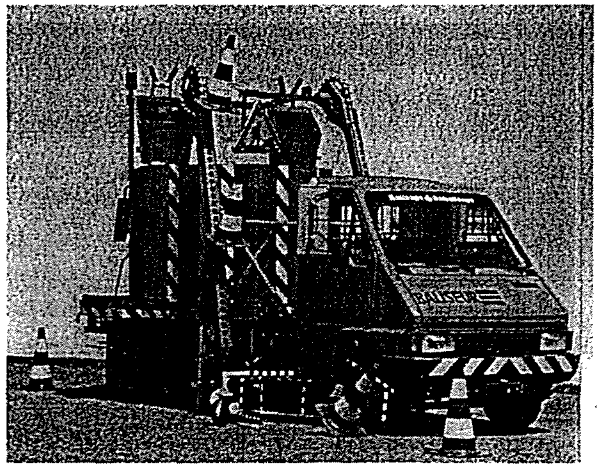

Figure 1.2 *Baliseur Cone Picker*

The third and final patent is for the Addco Cone Wheel produced in the United States (see Figure 1.3). This machine consists of a large rotating wheel mechanism that is connected to the side of a large truck. This motorized wheel mechanism combines two disks spaced to wedge cones between them. Deployment occurs with a cone being manually dropped into a chute that feeds the cone onto the wheel. The wheel in turn rotates toward the ground where the cone is stripped off the wheel and placed upright by guides. Retrieval consists of the wheel running over the cone and rotating the cone upwards where it is stripped off by another bar and hand stacked on the bed of the truck. For transit, the wheel is manually moved behind the truck cab via a rail mechanism. This machine can only handle standing cones but can retrieve them at high speeds of 40 km/hr (25 mph). Also, a crew member is still required in the back of the vehicle for the stacking operation and is exposed to vehicle impact and to flying debris. Therefore, the Addco Cone Wheel is not a feasible solution for the Caltrans lane closure operation.

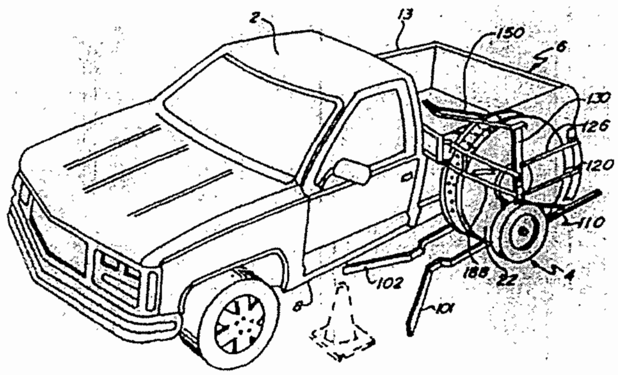

Figure 1.3 *Addco Cone Wheel*

In conclusion, an evaluation of these three patented methods or technologies for traffic cone handling determined that none of these cases can provide a safer working environment for the crew while meeting Caltrans lane closure and equipment requirements. The Baliseur Cone Picker clearly illustrated to the AHMCT Center that an automated machine can reliably and successfully handle traffic cones in a manner that does not compromise maintenance worker safety. The development of a machine that complies with Caltrans lane closure and equipment requirements could produce a commercially viable vehicle that satisfies the urgent need for a safer alternative to the current cone body.

A more recent patent search, executed after the creation of the first generation integrated ACM, revealed the existence of three additional patents for automated handling of traffic cones. The first patent, issued in Europe, describes a conveyor apparatus for cone deployment that assists in decelerating the cone prior to contact with the road surface to maintain proper placement and orientation. The second patent details the design of an updated version of the Baliseur machine with a modified drum assembly that laterally repositions for cone deployment and retrieval. The chain link conveyor is replaced by a prong and parallelogram linkage for retrieval while the finger-like mechanisms have been replaced by a segmented spiral surface underneath the drum assembly. The final patent describes a Japanese system for deploying and retrieving cones utilizing complicated separation and placement devices located at the vehicle rear.

1.7 General Specifications of the ACM

To best fulfill this perceived gap in the Caltrans fleet, the ACM needed to meet the existing functionality of the current manual operation with the cone body vehicle while using existing traffic cones. This system would need to be easily retrofitted onto the existing fleet to minimize incurred costs and must operate in the various extremes of the California climate without requiring major system changes or adjustments. Graceful failure modes and the option for manual cone handling operations were additional specifications combined with field serviceability requirements. Finally, the critical issue of maintenance worker safety needed to be strongly addressed to provide the safest possible working environment by eliminating worker access to mechanisms and parts.

1.8 Detailed Specifications of the ACM

Development of the first generation, or testbed ACM, required the creation of a detailed set of performance specifications or design goals. Specifically, the original machine was designed to fit within the dimensions of a modified cone body extended 0.432 m (1.4 ft) in length. All additional hardware required for automation was required to fit within this increased envelope. Furthermore, any portions of the mechanism that extended past the legal vehicle envelope during operation must be automatically retractable for transit. Any vehicle set-up would not be performed at the work site. All standard operations could be performed with only one driver/operator and without requiring he/she to exit the vehicle. The ACM would be able to deploy and retrieve eighty cones from both sides of the vehicle in any configuration from the roadway at speeds up 16 km/hr (10 mph). Retrieval could occur forwards or backwards, but deployment would be limited to forwards only. The machine would be able to easily change from deployment to retrieval with minimal delay and be capable of automatic cone deployment at intervals of 7.6 m (25 ft), 15 m (50 ft), and 30 m (100 ft).

1.9 Chapter Summary

This chapter has described current Caltrans lane closure methodology and specialized equipment while demonstrating the need for increased safety by process automation. The evaluation of the three currently available automated cone machines clearly illustrates that none of these designs will satisfy current Caltrans requirements and that a new design is both necessary and feasible. Finally, generic and detailed performance and safety specifications have been created for the design and evaluation of the first generation integrated automated cone machine prototype.

CHAPTER 2: DESIGN OF THE TESTBED ACM

2.1 Introduction

This chapter will detail the assumptions made during the design of the testbed ACM, while explaining the vehicle's five separate systems required to accomplish lane closure tasks. Also, the operational methodology of the ACM will be documented.

2.2 Background and Assumptions

Upon generation of general and detailed sets of performance specifications, the design of the testbed ACM commenced (Tseng, et al, 1996). As a prelude to the detailed design of the unit, traffic cones were purchased from multiple vendors and evaluated to determine their physical properties and average variations in these properties. It was found that while the average weight of the cones was similar to the Caltrans requirement, the dimensions of the cones varied dramatically. Although this variation would not cause problems with a manual cone deployment or retrieval operation, it would be very difficult to handle with an automated system. To alleviate this concern from the design process, it was decided that the ACM would only use cones from vendors that closely matched the physical dimensions of the Caltrans requirements. Two vendors, A&B Reflectorizing and Traffic Safety Services, fit this profile. Further study of the cones exposed an inversely proportional relationship between temperature and cone rigidity. Increasing temperature would cause decreasing cone stiffness. The ACM would be required to easily handle cones in a variety of temperature zones without requiring major system changes.

Some additional assumptions about the ACM performance were necessary before the inception of the design phase. The machine would not be required to assemble or place the warning signs that are part of a lane closure warning system. These signs would require the ACM operator and a second worker to manually setup and locate them after leaving the safety of the vehicle. Some setup of the ACM components was acceptable if not necessary at the actual work site and could be performed at a safer location. Finally, the ACM would not be obligated to handle damaged cones to help simplify the mechanism design. These damaged cones would be handled manually. With these assumptions, the design of the testbed ACM was completed.

2.3 ACM Systems Descriptions

The following sections briefly describe the five major functional components of the initial ACM testbed (see Figure 2.1). The components are described in order of operation for a cone retrieval operation.

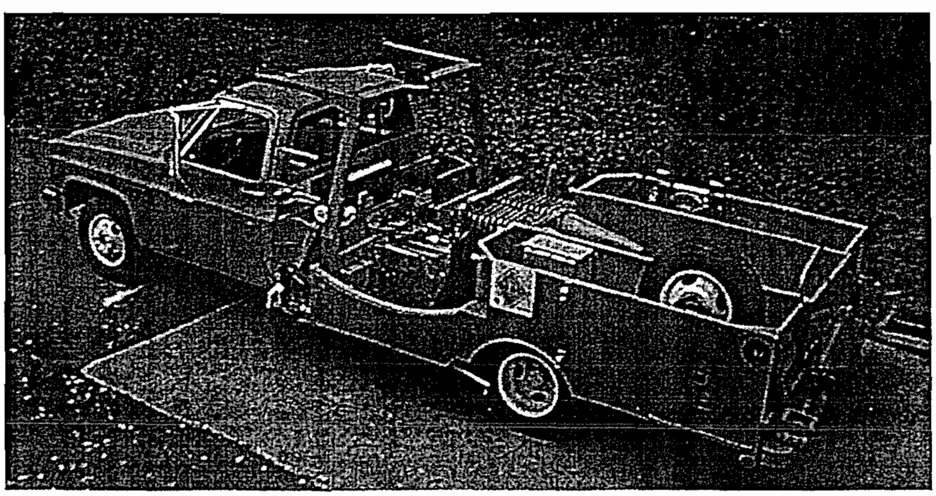

Figure 2.1 *Testbed ACM*

2.3.1 Funnel System

The purpose of the funnel system is to place traffic cones in the proper position to be retrieved by the Integrated Dispensing and Retrieval Configuration (IDRC) (see Figure 2.2). Accomplishment of this goal necessitates two separate tasks that are facilitated by a Primary Funnel Component (PFC) and a Secondary Funnel Component (SFC). The PFC is tasked with positioning cones into a horizontal, base first configuration for the SFC that is then tasked with final placement of the cones for the IDRC.

The PFC is constructed in a modular fashion that allows placement of the unit at any of the vehicle's four corners depending on the required operation. The unit itself consists of an inverted u-shaped lateral frame with a solenoid actuated gate mechanism that connects to the middle member of the lateral frame, or tipping bar. The solenoid then connects to a rotating bar that locks the gate in place when energized. The locked gate is used to flip cones that enter tip first into the proper base first orientation. The entire assembly connects to a hydraulic vane actuator that automatically stows and deploys the unit from one of four mounting locations on the vehicle's front and rear bumpers.

Manufactured from two specifically bent tubes, the SFC connects to the bottom of the IDRC and accurately places cones for retrieval. The tubes are shaped to capture and direct cones leaving the PFC without requiring the ACM operator to laterally reposition the vehicle. Small sections of cables, called whiskers, are located vertically and ventrally at the ends of the main tubes. These whiskers help position the cone by preventing the cone tip from becoming entangled and thereby moving the cone out of position. The SFC must be manually extended before cone deployment and retrieval operations.

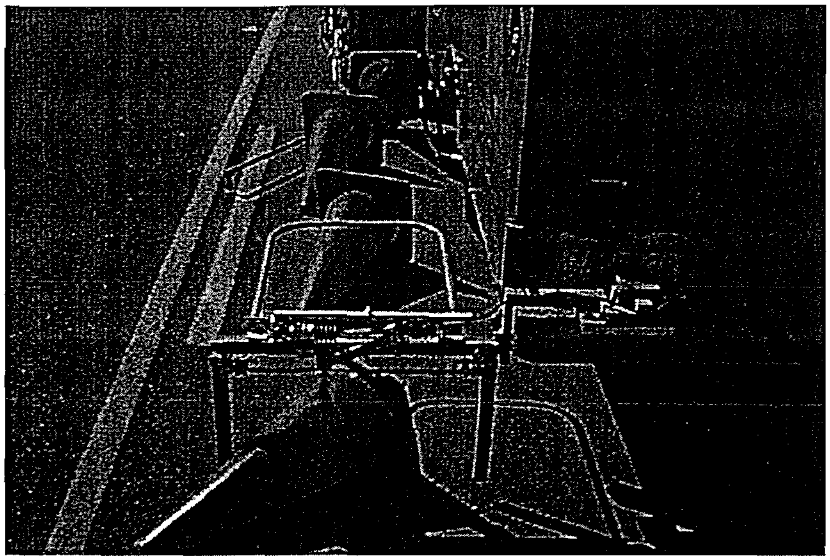

Figure 2.2 *Primary and Secondary Funnel Components*

2.3.2 Integrated Dispensing and Retrieval Configuration (IDRC)

The Integrated Dispensing and Retrieval Configuration (IDRC) provides the interface for the cone transition from the roadway to the ACM and contains five separate components (see Figure 2.3). The first two components, the collapsible arm and Advanced Timing System (ATS), are used only for retrieval and transfer the cones from the ground between the SFC to a third component, the Lateral Conveyor System (LCS). The last two components, the drop box and angled brushes, are used only for deployment and guide the cones from the LCS to the roadway.

The collapsible arm is connected to the side of the drop box by a rotary hydraulic actuator and is designed to retrieve cones as the upper section of the arm enters the cone base. The arm then rotates to lift the cone onto the LCS when a set of sensors located on the upper arm are triggered. As the arm rotates upwards, the cone is only constrained by gravity on the end of the upper arm. The range of motion of the collapsible arm is limited by an adjustable set of hard stops that must be repositioned for forward or rearward retrieval.

The ATS is assembled from three subassemblies that are the Advanced Timing Plate (ATP), upper arm lock mechanism, and the Cone Stripping Plate (CSP). After a prescribed amount of rotation, the collapsible arm engages the first two subsystems of the ATS. A roller on the upper section of the collapsible arm contacts the specially contoured surface of the ATP and allows the upper section of the arm to counter rotate in respect to the lower section. At the same time the upper arm lock system, consisting of a cam and spring system, disengages and permits the upper section to move relative to the lower section of the collapsible arm. As the arm collapses, the cone base contacts the CSP and is stripped off the upper section of the arm to drop onto the LCS. The arm remains collapsed until the LCS removes the cone and then the arm resets for the next cone.

The drop box integrates a support frame for the collapsible arm, ATP, upper arm lock mechanism, CSP, and SFC, with a guide system that keeps the traffic cones from rotating and tipping during deployment. These guides consist of a set of simple delrin plates to position the cone with a minimum of friction to reduce jamming. Cones traveling from the LCS utilize gravity to travel through the drop box to the roadway. Extension and stowage of the drop box are accomplished through electric motors connected to acme screws.

The final component of the IDRC is a set of angled brushes, later replaced by delrin shoes, that are attached to the lower rear of the drop box and provide stability for deployed cones. As the cones drop through the drop box, they have a tendency to tip over as they contact the moving road surface. By forcing the cone base to stay flat after impact with the roadway, the brushes (and shoes) guarantee the cones remain upright as they slide and decelerate.

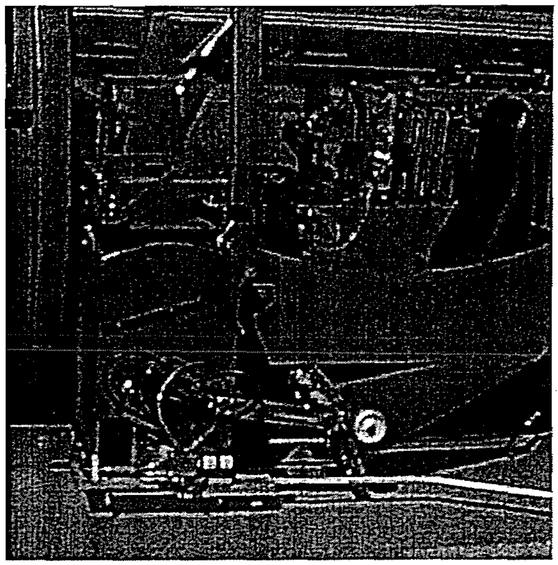

Figure 2.3 *Integrated Dispensing and Retrieval Configuration*

2.3.3 Lateral Conveyor System (LCS)

The Lateral Conveyor System (LCS) interfaces between the IDRC and the Automated Cone Stowage System (ACSS) and is composed of two retractable wing conveyors, a central conveyor, and a set of gates. The purpose of this system is to transport cones from the IDRC to one of two positions from which the ACSS can stow them or to transport cones from the ACSS to the IDRC for deployment (see Figure 2.4). For all of the conveyors in the LCS, two sections of parallel 0.05 m (0.17 ft) toothed belting was chosen and implemented to provide a stable surface for cone transit.

The retractable wing conveyors provide a left and right side platform for cone retrieval within the IDRC. Motion of the wing conveyor towards the center of the vehicle engages a clutch assembly on that side which rotates the corresponding wing platform into place beneath the CSP. This provides a platform for cones to drop onto after being stripped from the collapsible arm. The cones land onto the moving wing conveyor and transfer to the central conveyor. Opposite motion of the wing conveyor will disengage the clutch mechanism and cause the wing platform to lower for cone deployment. Cones will now be able to drop through the drop box onto the roadway. The wing conveyors are driven by direct connections from the central conveyor.

The central conveyor connects the wing conveyors to the ACSS. Four separate sections of drive belt constitute this unit. The first section of belt is closest to the ACM cab and spans the entire length of the central conveyor. The rear parallel track of belting divides into three sections to allow a working envelope for the ACSS. All sections of belting are directly connected and driven by a hydraulic gear motor. Located on each end of the central conveyor are individual switches that are used to notify the Coordinated Control Unit (CCU) to reset the collapsible arm once the cone has cleared the arm's working envelope.

The LCS needs two sets of gates to correctly position the cones for the ACSS. The outer gates are located at each end of the central conveyor and attached to the drop boxes. Deployment of a drop box lowers the outer gate on that side to allow passage of cones. The outer gates are normally extended when the drop boxes are stowed. The middle gate is centrally located on the LCS and is solenoid actuated to rotate into position as required. Both sets of gates contain contact switches that notify the CCU when a cone is in position for stowage by the ACSS. The CCU then stops the LCS conveyors and sends a signal to the ACSS to stow the cone.

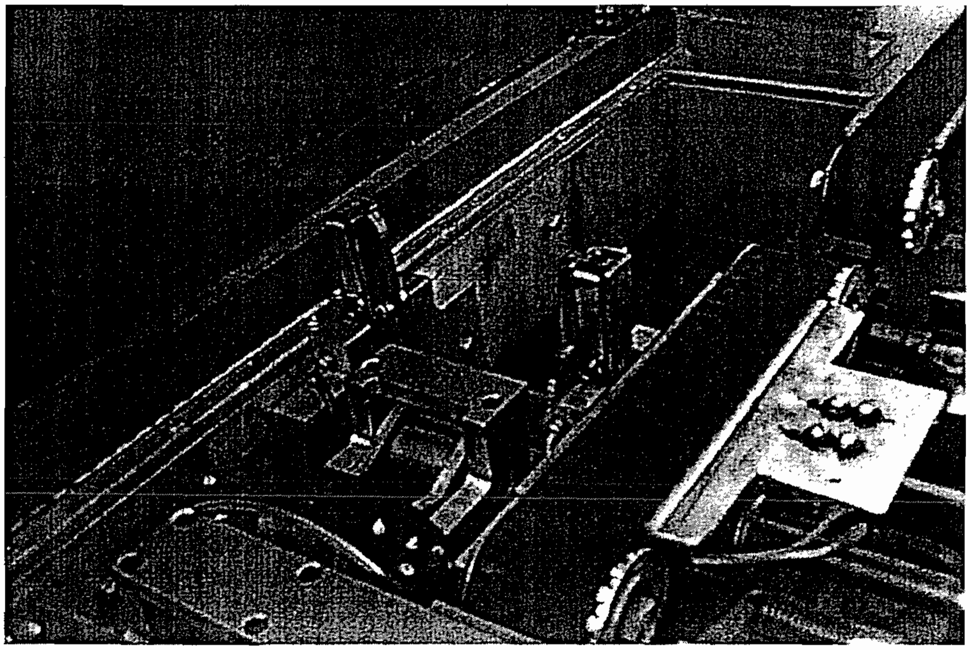

Figure 2.4 *Middle Gate and Central Conveyor of Lateral Conveyor System*

2.3.4 Automated Cone Stowage System (ACSS)

The Automated Cone Stowage System (ACSS) provides the final physical interface on the ACM by transferring cones from a vertical orientation on the LCS to a horizontal orientation on the cone stack. The system accomplishes this motion using two trolley mechanisms on a linear track system (see Figure 2.4). The trolleys are connected by a 0.03 m (0.09 ft) toothed belt system that is driven by two hydraulic gear motors and coupled to move in opposite directions. As one trolley moves forward, the other trolley moves backward. A linkage system connected to an arm on each trolley is actuated by a set of ramps at the front 0.08 m (0.25 ft) of the system. This mechanism rotates the arm from a vertical to a horizontal position for forward motion of the trolley and rotates the arm back to vertical for rearward trolley motion. One set of gripper arms is located at the end of each trolley arm and hydraulically driven to expand and contract to internally grip and release the cones. Once the cone is internally gripped and rotated, the cone tip enters the stack and provides a self-centering function for stowage.

Two different types of sensors are required to control the functions of the ACSS. Magnetic reed sensors are located at the front of each track and inform the CCU when the corresponding trolley arm is correctly positioned to either grip or release the cone. The second sets of sensors are photoeyes that are necessary to properly locate the cone stack on the main conveyor for cone stowage or deployment.

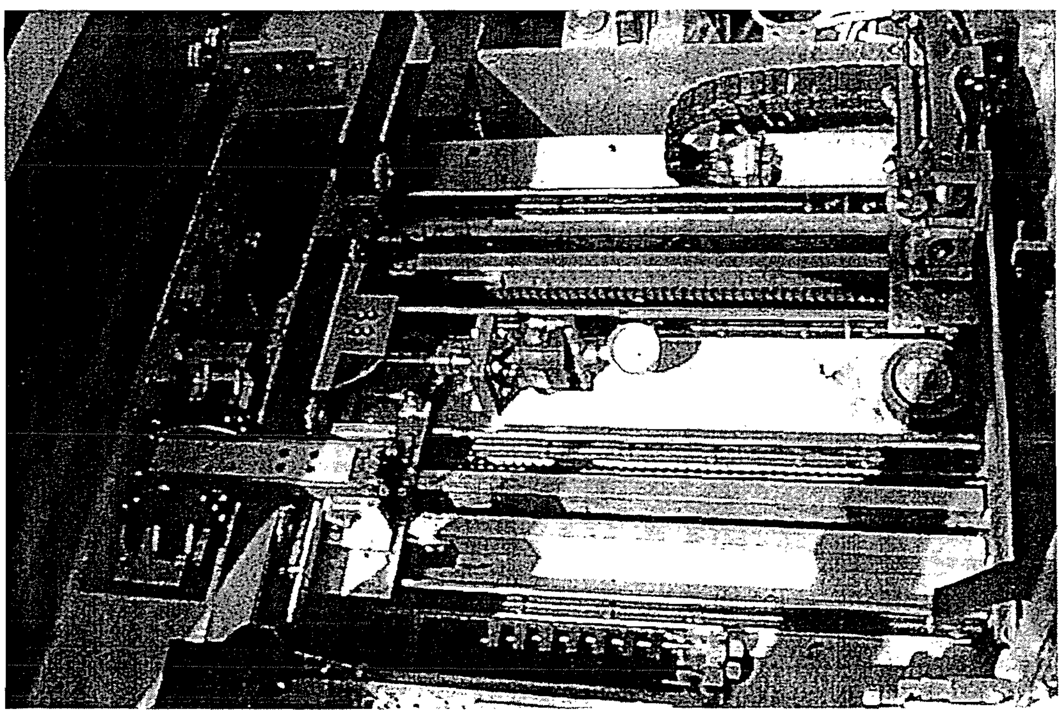

Figure 2.5 *Automated Cone Stowage System*

2.3.5 Coordinated Control Unit (CCU)

The Coordinated Control Unit (CCU) provides the integration link between all vehicle IO functions and subsystems by providing a micro controller programmed with a logical series of operational procedures. The CCU is configured in a master and slave configuration. The master controller is located in the ACM cab and accepts operator input for operation type and setup though a touch pad and LCD display. The slave controller is located in the left stowage bin and controls the relay and IO boards (see Figure 2.6). For safety purposes, a set of hard wired emergency switches are located in the cab and both rear buckets.

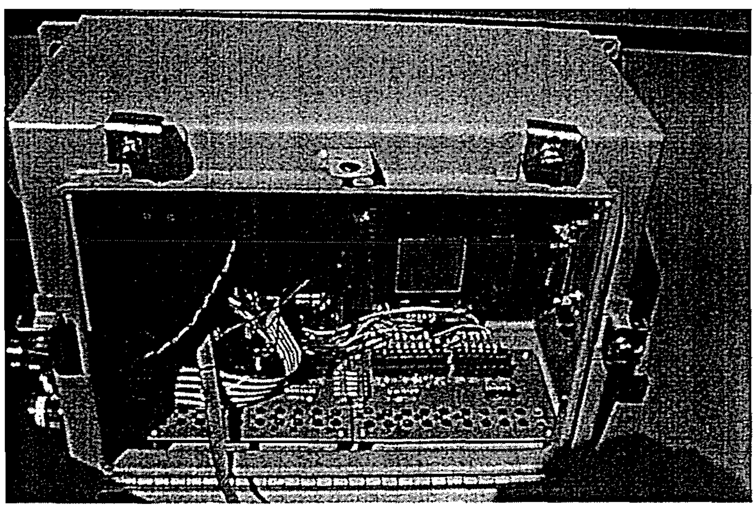

Figure 2.6 *Slave Controller of Coordinated Control Unit*

2.4 ACM Operational Methodology

The basic operations of the ACM can be subdivided into four categories: setup, cone deployment, lane maintenance, and cone retrieval.

2.4.1 Setup

Two different types of manual setup are required prior to ACM operation. Machine configuration is the first variety of setup and can be performed at the maintenance yard if the necessary lane closure parameters are known. First, the PFC must be relocated to the proper corner of the vehicle after being unbolted and electrically and hydraulically disconnected. After reconnection, the PFC is only functional for that quarter of the vehicle. Second, the collapsible arm on the IDRC must be configured for forward or rearward cone retrieval. This configuration process requires repositioning the ATP, upper arm lock mechanism, and CSP. Both of these setup procedures are time and labor intensive and are not feasible to perform at the roadside of a work site.

The second type of manual setup required is a simple extension of the outer tube of the SFC into the operating position. The outer tube folds under the vehicle for transit to decrease vehicle width. This tube is extended with the drop box stowed and can be rapidly performed at the work site.

2.4.2 Traffic Cone Deployment

Once the initial vehicle setup is completed, cone deployment is an easy and straightforward operation (see Figure 2.7). All operational commands are entered into the touch pad based upon numeric selections from the LCD. The first operation is to deploy the IDRC from the roadside at the beginning of the advanced warning area. After manual assembly of the warning signs, the ACM is used in single drop mode to place a cone near each sign. Upon reaching the beginning of the transition area, the ACM is switched into 15 m (50 ft) drop mode and proceeds to deploy cones as the driver creates the transition area taper. At the end of the transition area, the driver changes the ACM into 30 m (100 ft) drop mode and creates the buffer and work area. Operation of the ACM is identical to a standard lane closure operation with one major exception: no worker is placed at risk in either of the buckets.

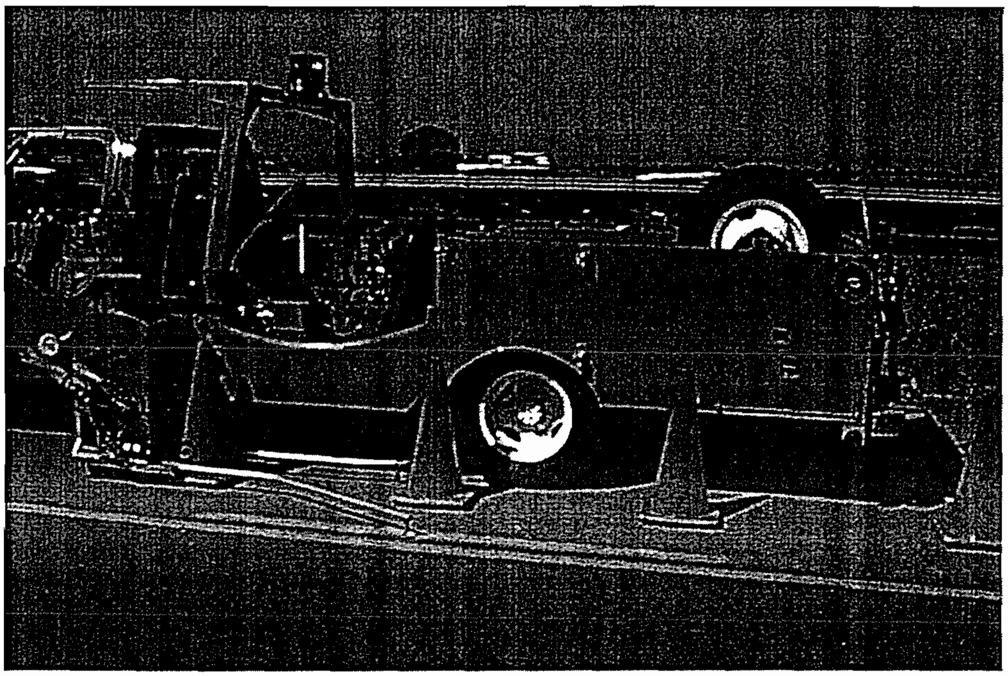

Figure 2.7 *Traffic Cone Deployment*

2.4.3 Lane Maintenance

After completion of the lane closure, the ACM is used to maintain the integrity of the lane closure by correcting cone displacement due to impact or wind gusts caused by moving traffic. In actuality, lane maintenance is a combination of a cone retrieval followed immediately by a cone deployment operation. The ACM is positioned near the errant cone and switched into retrieval mode. As the operator drives forwards or backwards over the cone, the ACM retrieves the cone and stows it into the main stack.

After repositioning the ACM to the correct cone location, the driver switches into single drop mode and deploys the cone.

2.4.4 Traffic Cone Retrieval

Depending upon prior setup, relocation of the PFC and adjustment of the IDRC may be required. Retrieval begins with deployment of the IDRC and the PFC. The driver then changes into retrieval mode and drives in reverse from the end to the beginning of the lane closure in the identical manner to a standard lane closure (see Figure 2.8). The PFC must correctly orient three different configurations of traffic cones on the roadway by either knocking over, orienting, or flipping over the cones. Upon completion of cone retrieval, the crew manually retrieves the warning signs and leaves the work site.

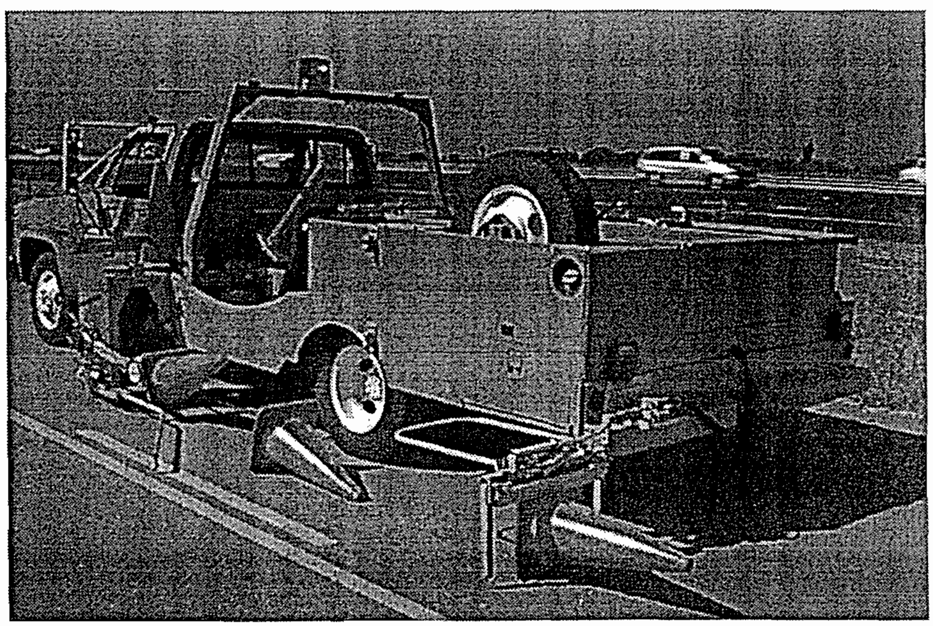

Figure 2.8 *Traffic Cone Retrieval*

2.5 Chapter Summary

This chapter covered the detailed final design of the funnel, IDRC, LCS, ACSS, and CCU systems. Additionally, the ACM operational methodology for the typical lane closure operations of setup, deployment, maintenance, and retrieval was documented.

CHAPTER 3: TESTING AND MODIFICATIONS TO THE TESTBED AUTOMATED CONE STOWAGE SYSTEM

3.1 Introduction

The testing and subsequent modifications to the testbed stowage system are illustrated and documented in this chapter. Additionally, these modifications will be evaluated to determine their effectiveness.

3.2 Background

The completed testbed ACM lacked several of the original design features due to time and resource constraints. The ACM was only capable of deploying and retrieving cones from the left side of the vehicle in the forward and reverse directions respectively. Although installed, the right side IDRC was never functional, and only one outer gate was permanently mounted on the right side surface of the LCS. In spite of these handicaps, the ACM admirably served as an informational testbed to gain insight and experience in automated cone handling.

3.3 System Testing

During the time span of six months, the ACM was extensively tested and modified to produce a functional unit. Testing occurred in summer and winter weather conditions on several different road surfaces and the resulting information was used to make system modifications to improve performance. Initially, the existing stowage system did not meet performance expectations in laboratory testing. A maximum reliability rate of eighty to ninety percent was achieved, while road testing further reduced this percentage. The system needed several modifications to improve consistency and improve successful cone deployment or retrieval performance. Stowage system modifications were divided into three major problem areas: trolley arm, stowage drive belt, and main conveyor.

3.4 Trolley Arm Modifications

Initially, the trolley arm was the most critical of the three problem areas. During transition from vertical to horizontal or vice versa, the traffic cones would undergo high accelerations and decelerations that would cause the gripper shoes to lose retention of the cone. Once the system lost grip on the cone, the stowage mechanism would invariably jam and create very high stresses in the system components. This retention problem mainly appeared during the cone retrieval operation where the cones transitioned from vertical to horizontal, prior to stowage in the main stack. However, the problem would also sometimes occur in the deployment operation. The gripper shoes simply could not provide enough moment resistance to offset the abruptness of this transition due to poor placement and low friction. The lateral opening action of the grippers did not provide a very large lever arm to resist the bending moment caused by the distance between the cone's center of gravity and the engagement location of the grippers. Also, the composition of the traffic cones resulted in a very low coefficient of friction. The varying expansion rates of the cones with temperature also greatly exacerbated both of these effects. Since time constraints did not allow for a complete redesign, a quick and temporary correction was necessary that did not involve major component changes. As a temporary solution to this problem, large machine screws were inserted tips outward into the gripper shoes to bite into the cones and provide additional friction (see Figure 3.1).

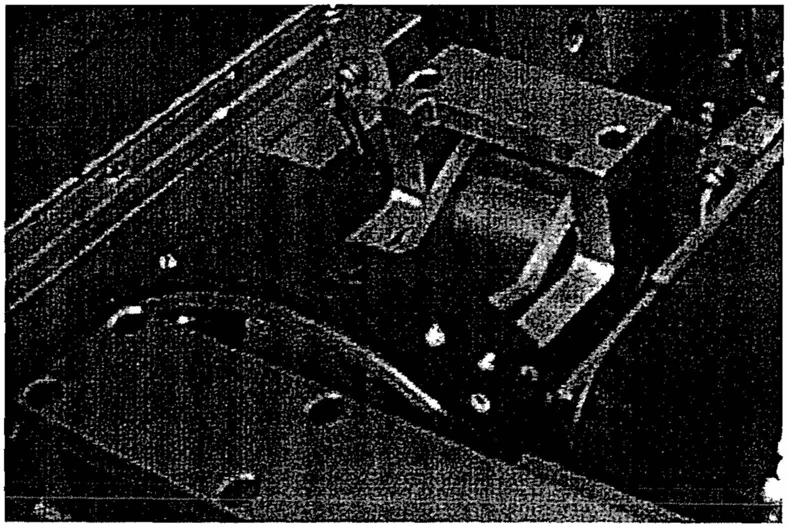

Figure 3.1 *Addition of Machine Screws to Gripper Shoes*

An additional problem with the trolley arm was the lack of a hard stop for the condition in which the arm rotated forward to a horizontal position. When a cone was retained in the grippers, the cone hitting the top of the LCS provided a flexible stop for the trolley arm. However, when a cone was not present on the trolley arm, the arm bearings themselves provided the hard stop. Over time, the repeated damage caused the bearings to develop excessive play which in turn resulted in increased friction for the stowage drive belt system. A further concern was the variance in gripper engagement depth inside the cone due to the lack of a set positioning device. To correct these problems, an adjustable hard stop consisting of a steel bar and a rubber bumper bonded to a stud was added (see Figure 3.2).

Figure 3.2 *Trolley Arm Adjustable Hard Stop*

3.5 Stowage Belt Tensioning Modifications

The second problem manifested itself as belt slippage over the drive pulleys as the system was subjected to the heavy lifting loads induced by the traffic cone transitioning from a vertical to a horizontal orientation. The required force to lift and rotate the cones was twice the anticipated value. This indicated that the amount of friction or stiction in the mechanism was higher than the conceptual values due to loose tolerances in the machined parts and the excessive play generated in the bearings. A spring mechanism was added to assist the belt in providing additional force during cone transition (see Figure 3.3).

Figure 3.3 *Spring Assist Mechanism*

Belt slippage over the drive pulleys would cause damage to the teeth on the belt and would perpetuate the slippage. To decrease this effect two spring tensioning devices were added. The first device constituted several short overlapping pieces of shaped spring steel clamped between the belt and the right stowage trolley. Additional testing determined that this still did not provide enough force to eliminate belt slippage and another tensioning device was added. The second tensioner, located on the left trolley, consisted of a spring loaded lever that rotated around a shoulder bolt to provide the additional amount of belt take-up and tensioning required.

3.6 Main Conveyor Cone Retention Modifications

The last problem area for the testbed stowage system was the interface between the stowage system and the main conveyor cone stack. The first cone in either side of the stack had a tendency to slide forward and off the main conveyor's forward roller and jam the stowage system trolleys. The problem was caused by the design of the trolley systems that placed the cones just forward of the roller crown so that any type of vibration or truck motion would provoke slippage onto the stowage system. A simple weldment, containing a steel bar and two mounting tabs, was added just forward of the conveyer crown to function as a cone retention device (see Figure 3.4). The bar placement was designed to keep the cones on the conveyor without overly impeding gripper retention of the cones during deployment. Additional modifications, in the form of material removal by grinding, were performed on the rear segments of the stowage trolleys to help alleviate the problem by moving the cone placement point on the main conveyor rearwards by 0.06 m (0.2 ft).

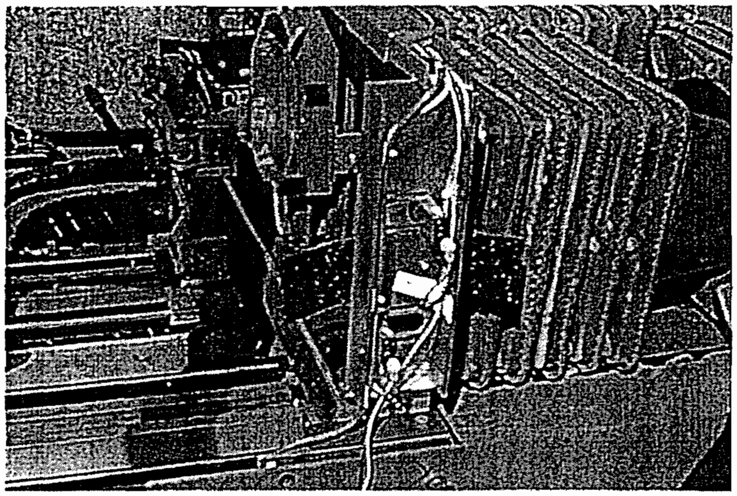

Figure 3.4 *Cone Retention Device*

3.7 Evaluation of Modifications

The modifications to the trolley arms, stowage belt system, and the main conveyor dramatically improved the performance of the stowage system. However, none of these modifications could be considered complete solutions to these problems. Addition of the machine screws to the gripper shoes had the obvious detriment of ruining the cones over time, but did provide a simple solution to the retention problem. After installation, the two stowage system tensioning devices decreased the slippage to an acceptable amount, but did not eliminate the problem. The drive belt would still occasionally slip and cause itself damage, especially when operating in wet conditions. Finally, the cone retention device worked very well, but harsh vehicle motions could still cause cone loss. Additionally, the modified system did not meet the cycle times of 1 to 1.5 seconds required to deploy cones at 16km/hr (10 mph). The best recorded cycle times averaged at 3.4 seconds for a set of five cycles. Proper solutions to these problems would require the complete redesign of the stowage system.

3.8 Chapter Summary

This chapter documented the modifications to the testbed stowage system, after extensive testing, and proved that a redesign of the stowage system would be required to produce a functional and reliable first generation integrated prototype ACM.

CHAPTER 4: CONCEPTUAL DESIGN AND DEVELOPMENT OF THE SECOND GENERATION AUTOMATED CONE STOWAGE SYSTEM

4.1 Introduction

In this chapter, the development of the second generation stowage system will be covered. This development will include the creation of multiple design concepts for the gripper assembly, transfer mechanism, and drive system. After the generation of new design parameters, the final designs will be chosen and integrated into a complete system.

4.2 Conceptual Design Requirements

Based upon the testing and modification of the existing testbed stowage system, it was decided that a second generation system was required to correct the deficiencies. This iteration of the stowage system would be designed for a new cone body vehicle that would become the first integrated prototype for the ACM. New parameters for the second generation stowage system included increasing cone retention during rotational motion, decreasing force required for cone transit, simplifying mechanism complexity, and increasing cone retrieval and deployment speeds. A further design consideration was the diminished working envelope from the original system. The new truck frame was located 0.05 m (0.17 ft) higher in relation to the cone body, requiring a similar reduction in the stowage system depth. The second generation stowage system was also required to interface to redesigns of the LCS and main conveyor designs using the existing interface schemes. Combining these new parameters with the original testbed parameters produced a complete set of design criteria for the conceptual design of the second generation stowage system.

4.3 Stowage System Concepts

Conceptual design of the stowage system began with a subdivision of stowage system operational tasks into three separate subsystems: gripper assembly, transfer mechanism, and drive system. Each subsystem was evaluated independently of the other two subsystems and system interface issues were ignored by selection of concepts with similar interfaces. Several brainstorming sessions were performed by the ACM group for each of these subsystems to produce a multitude of conceptual ideas. These concepts were then culled to produce a final set of feasible solutions that included three gripper concepts, two transfer mechanism concepts, and two drive concepts.

4.3.1 Gripper Concepts

The grippers are the only stowage system component that form the physical link or interface to retain the traffic cone during operation. The three gripper concepts consist of two internal system concepts and one external system concept. The two internal concepts are the modified testbed and the quad system concepts.

4.3.1.1 Modified Testbed Concept

The first gripper system concept is a redesigned version of the original testbed gripper system (see Figure 4.1). Instead of the original T-shaped upper arm configuration, the grippers are rotated 90° to form an I-shaped upper arm. Rotating the grippers into this longitudinal or vertical orientation provides a larger resistance to the cone tipping off of the grippers during rotational motion. This increased moment resistance translates into less required surface area for the gripper shoes due to the decrease in the necessary amount of friction at the gripper shoe to cone interface. The modified testbed concept also places the double-acting hydraulic piston over the gripper arm linkage pivots to minimize depth. Both the decrease of gripper shoe size and the relocation of the hydraulic linear actuator produce an extremely compact system.

Operation of the modified testbed concept is identical to the original system except for the gripper reorientation. For retrieval, after the cone is properly positioned by the LCS and the gate mechanisms, one port of the hydraulic piston is energized and the grippers open into the cone base. The piston is preset to the pressure required to generate the necessary force at the gripper shoe to cone interface. The gripper arms continue to open and expand the cone base until the arms hit a set of adjustable hard stops that limit excessive cone deformation. Cone deployment is similar to retrieval once the cone is properly positioned by the main conveyor and photoeye array. After transit by the transfer mechanism, the hydraulic pressure to the piston ports is reversed and the gripper arms release the cone base and retract. The cone is placed on the LCS or main conveyor stack depending upon the type of operation.

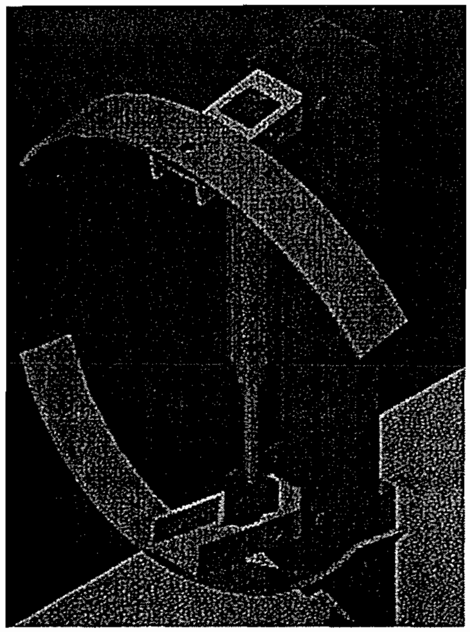

Figure 4.1 *Modified Testbed Gripper Concept*

4.3.1.2 Quad Concept

The second gripper concept is a combination of the original testbed and the first gripper concept by combining a lateral or horizontal set of grippers with another set of longitudinal or vertical grippers (see Figure 4.2). Both sets of grippers are actuated by a double-acting piston that connects to the gripper arms by individual linkages. These linkages are L-shaped with the shorter leg connecting to the other side of the gripper arm pivots from the shoes. One end of the piston is rigidly fixed to the upper arm assembly while the rod end is free to move to simplify hydraulic connections. This concept allows the use of very small gripper shoes while still maintaining excellent cone retention. Furthermore, this arrangement of four evenly spaced grippers causes uniform expansion and deformation of the cone base cause.

Due to the quad gripper arrangement, operation of this concept differs slightly from the modified testbed concept. Proper location of the cones is still ensured by either the LCS and gates or the main conveyor and photoeye array depending upon the type of operation. After cone positioning, the hydraulic piston is extended and forces the linkages to pull open the grippers to grasp the cone base. The transfer system then rotates the trolley upper arm to vertical and transfers the trolley assembly. Upon completion of deployment or retrieval, the piston is retracted and forces the grippers to rotate shut and release the cone onto the LCS or main conveyor.

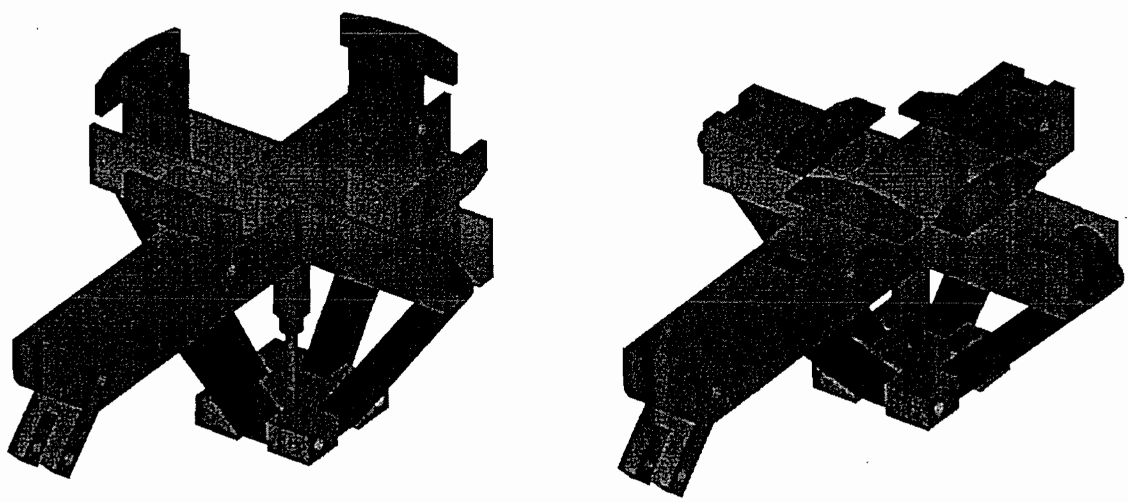

Figure 4.2 *Quad Gripper Concept*

4.3.1.3 External Concept

The last gripper system is radically different from the other systems by operating on the outer surface of the cone base instead of expanding the interior and can apply more clamping force than the other concepts (see Figure 4.3). This system is assembled from a machined tube, two gripper arms, and a double-acting hydraulic piston. Similar to the modified testbed concept, the external grippers are oriented longitudinally or vertically and the trolley upper arm is I-shaped. This orientation is not necessary to resist the tipping moment, but keeps the cone from deforming due to inertia during the transfer motion. The piston is required to be positioned behind the gripper arm pivots to not interfere with cone retention. This system is able to handle variations in cone base size and is unaffected by varying cone stiffness due to temperature. Also, the system envelope is very compact.

The external system concept retrieval and deployment operations begin with proper location of the cones by the LCS and gates or the main conveyor and photoeye array. Once placement is accomplished, the hydraulic piston is extended, causing the gripper arms to rotate over the cone base and clamp the base firmly against the flat surface of the trolley upper arm. The system is now prepared for transit. During the end of the transit cycle, the piston is retracted and the gripper arms rotate away from the cone base surface to provide clearance for the cone to disengage onto the LCS or the main conveyor.

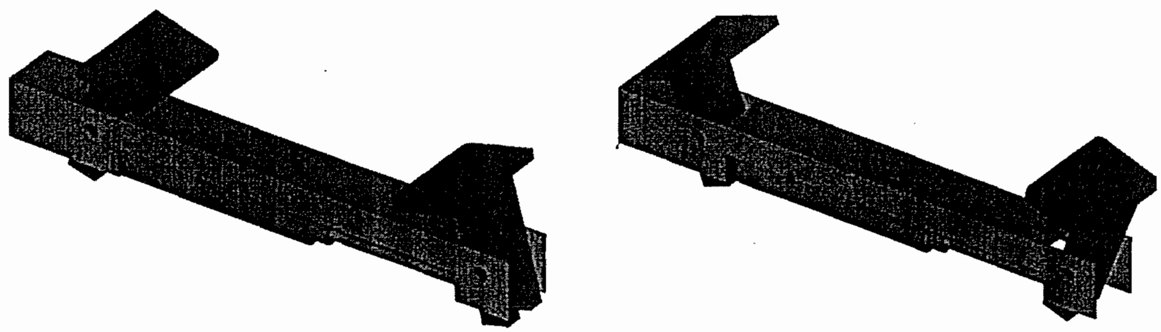

Figure 4.3 *External Gripper Concept*

4.3.2 Transfer Mechanism Concepts

The transfer mechanism is the stowage system component that rotates and transfers the entire trolley assembly to either deploy or retrieve cones between the LCS and main conveyor. The two transfer mechanism concepts combine rotary and linear motion into compact systems and are the simple track system and the actuator system.

4.3.2.1 Simple Track System Concept

The first transfer concept utilizes a roller and track system to perform both rotary and linear motion requirements (see Figure 4.4). The two components of the transfer concept are the trolley and track assemblies. The trolley assembly consists of the upper arm, lower arm, and cart subassemblies. The upper arm subassembly provides a mounting frame for the gripper system and connects to the lower arm that contains the arm pivot bearings and two cam rollers located on opposite sides of the pivot point. These combined subassemblies connect to the cart subassembly that interfaces to the track assembly. The cart subassembly includes the arm pivot mount and three vertically mounted v-wheels that ride on a matching set of rails connected to the track frame. The rails, track frame, upper track, and lower track form the completed track assembly. The upper and lower tracks provide contact surfaces for the cam followers to perform the rotational motions for deployment and retrieval. The upper track runs the entire length of the stowage system and combines a short circular section at the front of the track frame with a flat section that constitutes the remainder of the track. The lower track is a short sloping section at the bottom front of the track frame. The entire trolley and track assemblies form a compact and space efficient unit. Linear movement of the trolley assembly is accomplished by a single rotary actuator connected to the drive assembly (see Section 4.2.3).

The operational sequences for the simple track concept vary for retrieval and deployment operations. The retrieval operation begins with retention of the cone on the LCS by the gripper system. At this stage of the cycle, the trolley assembly is located at the front of the track assembly. Once the cone is captured by the grippers, the cart subassembly is transferred rearwards by the drive assembly and forces the upper cam follower to roll on the upper track. Since the first section of this track is circular, the arm subassemblies are forced to rotate upwards until the cam follower reaches the second section of the upper track. Once at this section of flat track, the upper cam follower forces the arm subassemblies to remain vertical for the remainder of the trolley transfer. The lower cam follower and lower track are not used during retrieval operations. At the end of the trolley transfer, the cone is released by the grippers and deposited on the main conveyor.

The deployment operation begins with the trolley assembly positioned at the rear of the track assembly with the arm subassemblies in the vertical position. After the cone is retained from the main conveyor by the gripper system, the trolley assembly transfers forward as the upper cam follower rides on the second section of the upper track and maintains the vertical orientation of the arm subassemblies. Once the trolley assembly reaches the location of the lower track, the lower cam follower on the lower arm assembly is forced to lag behind the cart subassembly. This forces the arm subassemblies to rotate until the center of gravity of the cone is over the upper and lower arm pivot point. Once the cone center of the gravity passes over the pivot point, the lower cam follower loses contact with the lower track as the upper cam follower contacts the circular section of the upper track. Gravity forces the arm subassemblies to complete the rotation to a horizontal position at the LCS where the cone is released by the grippers.

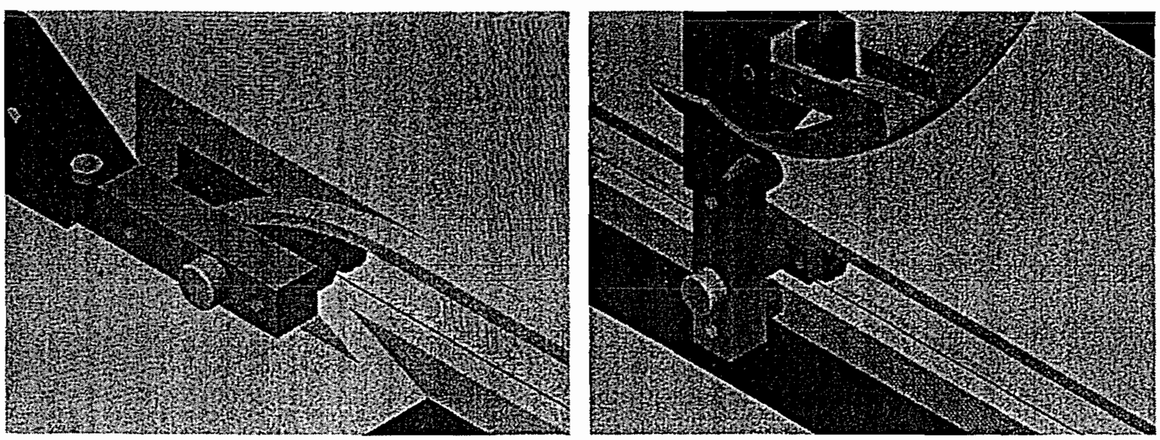

Figure 4.4 *Simple Track Transfer Concept*

4.3.2.2 Actuator System Concept

The final transfer mechanism concept involves the use of a double-acting hydraulic linear actuator to facilitate the rotary motion of the trolley assembly, while a rotary actuator connected to the drive assembly controls the linear motion along the track assembly (see Figure 4.5). The trolley assembly contains only the arm and cart subassemblies. The gripper system connects to the arm subassembly which consists of a simple set of bearings and an offset linkage point for the hydraulic piston rod end. The linkage is located opposite the grippers in relation to the bearing pivot. The arm subassembly then connects to a set of block bearings mounted on the cart subassembly, while the other end of the piston connects to a fixed linkage attachment on the same subassembly. A set of v-wheels are mounted horizontally to the underside of the cart subassembly and ride on a pair of guide tracks attached to a mounting plate. The guide tracks and mounting plate form the track assembly. Sensors and hard stops located on the cart assembly are required for accurate positioning of the arm subassembly.

Cone retrieval for the actuator concept is a two-step operation that begins with cone retention by the gripper system. The first step is extension of the hydraulic piston that applies force to the offset linkage and rotates the arm subassembly into a vertical configuration. Next, the trolley is transferred rearwards to the main conveyor by the rotary actuator and drive assembly, where the cone is placed into the main stack and released. Deployment reverses the two-step process to place and release cones on the LCS. The actuator concept decouples the linear and rotary motions into separate actions that shorten the length of the working envelope to allow for a longer main conveyor. This translates into more cone storage in the stack.

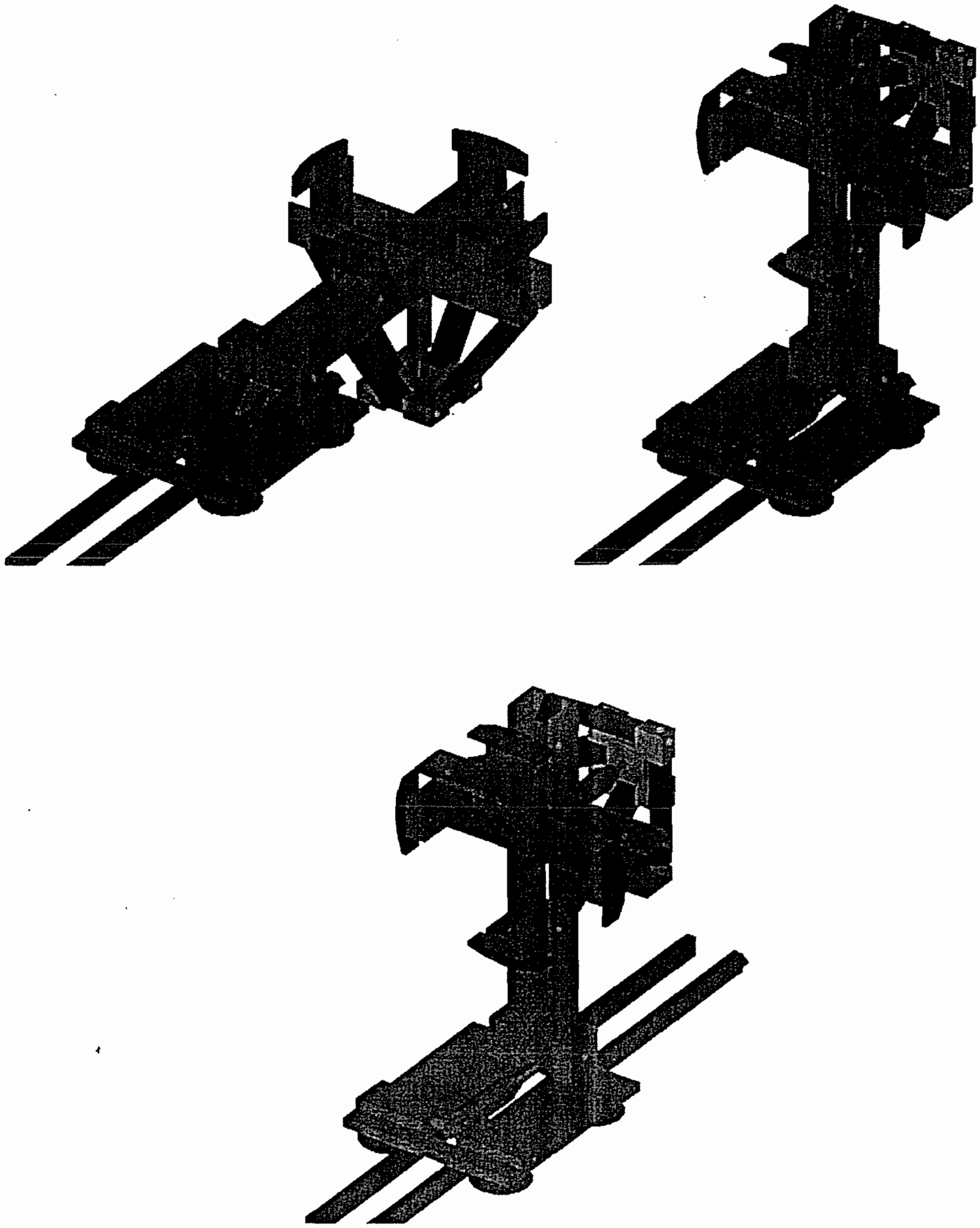

Figure 4.5 *Actuator Transfer Concept*

4.3.3 Drive Concepts

The drive system connects a single hydraulic rotary actuator to the trolley assemblies of the stowage system. Two concepts of belt and chain connections are considered.

4.3.3.1 Belt Concept

The belt connection concept employs a toothed serpentine-style belt to provide power transfer from the rotary actuator to the two parallel trolley assemblies (see Figure 4.6). The belt is powered by a drive sprocket attached to the keyed rotary actuator shaft and is positioned beside the track assemblies with four smooth idler pulleys. Belt tensioning is accomplished by moving the actuator mounting location. The trolley assemblies are individually attached to the belt using machined clamps and are positioned on opposite sides to permit diametric motion.

As the actuator rotates counterclockwise, the left trolley is driven forward while the right trolley is driven rearwards. Motion continues until the trolleys reach hard stops at the end and beginning of the track assemblies. Clockwise rotation of the actuator causes opposite motion in the trolley assemblies. This opposite motion ensures that one of the trolley assemblies is always ready to either deploy or retrieve cones as required.

4.3.3.2 Chain Concept

The chain connection concept is identical in construction and operation to the belt connection concept except for the substitution of a roller chain drive element instead of the serpentine toothed belt element (see Figure 4.6).

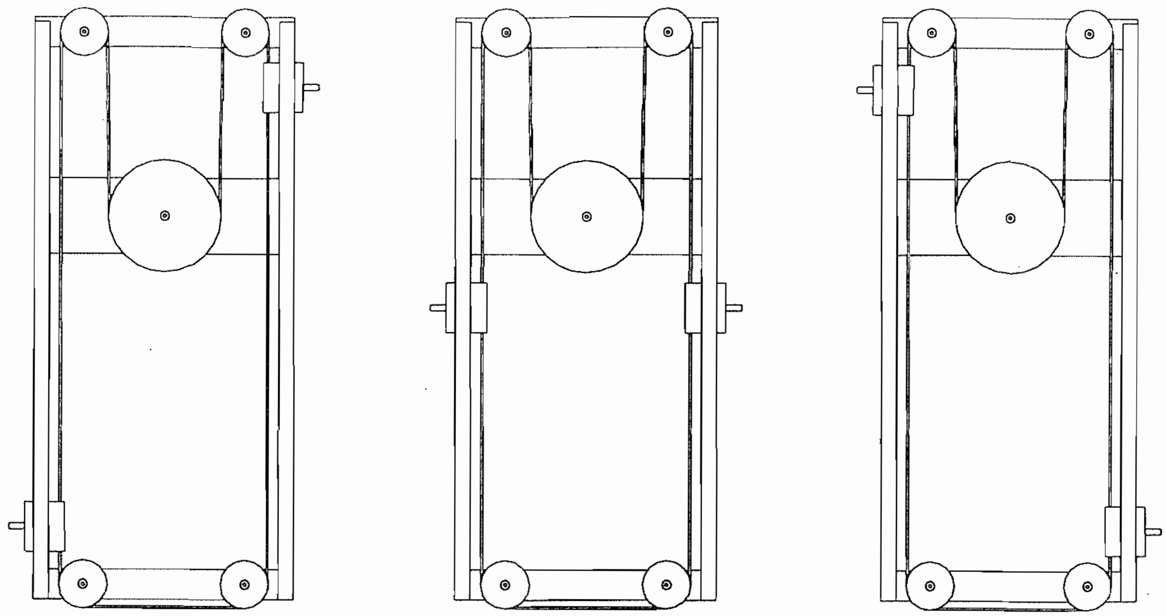

Figure 4.6 *Belt and Chain Drive System Concepts*

4.4 Evaluation of Stowage System Concepts

After creation of multiple concept solutions for each of the three operation tasks, the selection of an optimal concept for each task was required. To facilitate these selections, individual sets of general and weighted criteria were generated for each task. The weighting factors varied from one to three based upon importance of the criteria to completion of the task while the concept rankings varied from zero to two based upon satisfaction of the criteria. Once the selection of three optimal concepts was finished, an integrated concept for the stowage system could be produced.

4.4.1 Evaluation of Gripper Concepts

The critical or primary detailed design parameters for the gripper system concepts are a simplification of interface and mechanism complexity, an increase in cone retention performance, a reduction in working envelope, and an increase in safety features. The concept rankings for the these primary and other secondary and tertiary criteria are illustrated in Table 4.1 for the modified testbed, quad, and external gripper concepts.

The modified testbed gripper concept offers the simplest mechanism, the smallest working envelope, and the least interface modifications of the three concepts. The mechanism is a robust and modular design that requires a simple modification to the central conveyor of the LCS while presenting a large envelope for the central gate system. No main conveyor modifications are required. However, this concept design provides the least tolerance in cone variation and the lowest cone retention force.

While the quad gripper concept presents minimal changes to the main conveyor interface and the simplest hydraulic connections, this system is too bulky and requires major redesign of the LCS. The large dynamic envelope provides little space for the gate mechanisms and can potentially interfere with the truck frame. Furthermore, the mechanism durability is questionable due to the number and complexity of the linkages.

The external gripper concept is the best concept for providing maximum cone retention and tolerance to cone variations. Additionally, this concept offers a visually clean appearance and excellent flexibility. Unfortunately, this concept requires a complete redesign of the main conveyor and moderate modifications to the LCS. These redesigns will add extensive time to the design cycle for the ACM and are unfeasible.

Table 4.1 *Ranking System Table for Conceptual Gripper Designs*

DESIGN REQUIREMENTS	Weight Factor	Concept 1 Modified Testbed	Concept 2 Quad	Concept 3 External
A. GENERAL REQUIREMENTS				
1. Does not intrude in bucket seat areas		Yes	Yes	Yes
2. Easily retrofitted		Yes	Yes	Yes
3. Field serviceable		Yes	Yes	Yes
4. Handles climate extremes		Yes	Yes	Yes
5. Limited access to moving parts for safety		Yes	Yes	Yes
6. No patent infringement		Yes	Yes	Yes
7. Option for manual cone handling		Yes	Yes	Yes
8. Works with standard Caltrans cone		Yes	Yes	Yes
B. DETAILED REQUIREMENTS				
1. Aesthetics	2	1	0	2
2. Anticipated time between failure	2	2	1	2
3. Handles variable expansion of cones due to temperature effects	3	0	1	2
4. Minimal alterations to LCS interface	3	2	1	0
5. Minimal alterations to main conveyor interface	2	2	2	0
6. Minimal hydraulic connections	2	1	2	1
7. Minimum sensors	1	2	2	2
8. Minimal setup	1	2	2	2
9. Minimum working envelope	3	2	0	1
10. Minumum linear actuators	2	2	2	2
11. Positive cone retention	3	0	1	2
12. Simplified mechanism	3	2	0	1
13. System flexibility	2	1	1	2
14. System modularity	1	2	0	1
15. Worker safety	3	1	1	1
TOTAL		45	32	44

4.4.2 Evaluation of Transfer Mechanism Concepts

For the two transfer mechanism concepts, the primary detailed requirements are minimum static and dynamic working envelopes, minimum interface redesign for LCS, fewest hydraulic connections, simplified mechanism design, and worker safety. Depth is the most critical of the working envelope dimensions due to the raised frame on the new truck. Important secondary requirements are failure frequency, minimum modifications to main conveyor interface, and debris tolerance. Some tertiary considerations are cone storage capacity and system modularity. These criteria and concept rankings are displayed in Table 4.2 for the simple track and actuator transfer concepts.

The simple track system supplies a very compact and elegantly simple solution that requires no hydraulic connections and provides a smooth and low force transfer mechanism. This concept is extremely modular and allows changing the gripper subassembly or drive assembly without serious effort. While no interface changes are necessary for the main conveyor, some minor modifications are required for the LCS interface. The two major caveats about this concept are questionable durability of the cam follower and v-wheel components of the lower arm and cart subassemblies and decreased cone storage capacity. The first problem of component durability can be alleviated by careful detailed design and selection of final components. However, the second problem cannot be corrected. Although the overall working envelope is smaller than the original ACSS, the envelope length has increased to provide a longer transition area for the rotary motion. This increase in system length dramatically smoothes the motion and decreases the required force but causes a corresponding length decrease in the main conveyor.

The main attributes of the actuator transfer mechanism concept are robustness and extreme flexibility. By decoupling the rotational and linear motions of the stowage system, this concept requires less overall force input and can transition the cone from vertical to horizontal without any linear motion. This translates into a decreased length of 0.3 m (1 ft) from the working envelope of the simple track concept. Increasing the length of the main conveyor by this amount adds additional storage capacity for twelve cones in the stack. However, this system still requires a larger system envelope to accommodate the larger trolley assemblies caused by the linear actuator. These larger trolley assemblies also necessitate extensive modifications to both the LCS and main conveyor interfaces. A final problem with this concept is the added hydraulic and electrical connections needed for the linear actuators and sensors on the trolley assemblies.

Table 4.2 *Ranking System Table for Conceptual Transfer Mechanism Designs*

DESIGN REQUIREMENTS	Weight Factor	Concept 1 Simple Track	Concept 2 Actuator
A. GENERAL REQUIREMENTS			
1. Compatible with two horizontal cone stacks		Yes	Yes
2. Does not intrude in bucket seat areas		Yes	Yes
3. Easily retrofitted		Yes	Yes
4. Field serviceable		Yes	Yes
5. Handles climate extremes		Yes	Yes
6. Limited access to moving parts for safety		Yes	Yes
7. No patent infringement		Yes	Yes
8. Option for manual cone handling		Yes	Yes
9. System will operate on both sides of stack		Yes	Yes
10. Transfers cones from LCS to main conveyor		Yes	Yes
11. Works with standard Caltrans cone		Yes	Yes
B. DETAILED REQUIREMENTS			
1. Aesthetics	2	2	1
2. Anticipated time between failures	2	1	2
3. Cycle time of 1.5 seconds maximum	2	2	2
4. Maximum depth envelope of 0.015m (6 in) over frame rails	3	2	1
5. Minimal alterations to LCS interface	3	2	1
6. Minimal alterations to main conveyor interface	2	2	0
7. Minimal electrical connections	2	2	1
8. Minimal force for cone transit	2	1	2
9. Minimal hydraulic connections	3	2	0
10. Minimum rotary actuators	2	1	1
11. Minimum working envelope	3	2	0
12. Minumum linear actuators	2	2	1
13. Minumum sensors	2	2	1
14. Minimal setup	2	2	2
15. Simplified mechanism	3	2	1
16. Storage capacity for 80 cones	1	0	2
17. System flexibility	2	0	2
18. System modularity	1	2	1
19. Tolerance of debris	2	2	2
20. Worker safety	3	1	1
TOTAL		73	49

4.4.3 Evaluation of Drive Concepts

Since the two concepts are identical except for the drive element, the only required evaluation is the determination of whether a belt or a chain is a better drive component for this application. Primary, secondary, and tertiary criteria and concept rankings are shown in Table 4.3 for the belt and chain drive concepts.

While the belt concept provides the highest load capacity and shock resistance with the lowest friction and noise, it is not compatible with current Caltrans equipment and is expensive. Furthermore, belts are prone to slippage under severe loads and must be replaced when damaged. Complicated tensioning systems are often necessary to accommodate belt flex and stretch under load.

The chain concept is compatible with current Caltrans equipment practices, inexpensive, and repairable. Chain slippage is impossible when properly tensioned and chain links can be replaced or overall chain length shortened in the field with minimal trouble. However, chains have a lower load capacity and will break when subjected to high shock loading.

Table 4.3 *Ranking System Table for Conceptual Drive Designs*

DESIGN REQUIREMENTS	**Weight Factor**	**Concept 1 Belt**	**Concept 2 Chain**
DETAILED REQUIREMENTS			
1. Caltrans compatability	3	0	2
2. Cost	3	0	2
3. Friction	2	2	0
4. Load Capacity	3	2	0
5. Noise	1	2	0
6. Repairability	3	0	2
7. Slippage Resistance	3	1	2
8. Shock Resistance	2	2	0
TOTAL		19	24

4.5 Selection of Stowage System Concepts

From the proceeding tables, the modified gripper concept combined with the simple track transfer concept and the chain drive concept proved to be the optimal solution for the second generation stowage system for the integrated prototype ACM. The final integrated concept combines all of these subsystems into a unified system that efficiently transfers cones between the LCS and main conveyor and provides a large improvement over the first generation system.

4.6 Chapter Summary

This chapter has documented the conceptual design process that was utilized to produce the final integrated system concept for the integrated prototype ACM. This integrated system consists of the modified gripper, simple track transfer, and chain drive concepts.

CHAPTER 5: DETAILED DESIGN OF THE SECOND GENERATION AUTOMATED CONE STOWAGE SYSTEM

5.1 Introduction

This chapter will cover the four part detailed design phase of the second generation stowage system. Specifically, the steps of detail creation, material selection, strength calculations, and manufacturing documentation are explained for the stowage system subsystems.

5.2 Design Methodology

After completion of the conceptual design phase with the selection of an integrated stowage system concept, the detailed design phase commenced. This design phase entailed the transformation of the integrated system concept into a detailed and documented design ready for manufacture. This transformation process was separated into the following four distinct actions: creation of design details, selection of components and materials, analysis of components, and documentation of design.

The first action, creation of design details, involved the generation of CAD models for all manufactured assemblies and subassemblies contained within the stowage system. These 3D models were used to perform motion studies and to assure that the completed stowage system design performed as intended. Furthermore, these models were also used to verify the correct tolerancing and dimensioning for all fabricated system components. Careful use of the Mechanical Desktop CAD package from Autocad, assured a proper fit and eliminated rework for design mistakes.

After creation of the CAD models, the material selection was made for the fabricated parts. For the second generation stowage system, structural steel was chosen as the material of choice for most parts and assemblies. Where required, other materials were used. Also, commercially off the shelf (COTS) components like hydraulic actuators, bearings, mounting hardware were selected and purchased.

The third action, analysis of components, was performed only on critical assemblies due to the brevity of the detailed design phase. The trolley assembly was analyzed to assist in selection of COTS components and to assure robustness. All other components were over designed to avoid any complications with part failure or breakage due to underestimation of operational loads and forces.

The final action, design documentation, again utilized the Mechanical Desktop CAD package to produce 2D drawings from the 3D models. These drawings were sent to machining shops for quotation and manufacture of the fabricated components.

A critical issue during this design phase was the abbreviated schedule. Due to the extensive amount of testing and demonstrations performed with the initial ACM testbed, work on this system proceeded past the estimated project completion date. This time overrun needed to be addressed by decreasing the scheduled time for the ACM prototype to keep the project completion date on schedule.

5.3 Gripper Assembly Design

As the system with the most problems on the testbed, the detailed design of the gripper assembly was placed first. The upper arm subassembly from the trolley concept and the gripper assembly concept were unified into a single design by using the upper arm as the mounting frame for the grippers. To decrease the working envelope, the gripper arms were downsized and the pivots cantilevered from the side of the upper arm. Shoulder bolts inside of bronze sintered bushings formed the gripper arm pivots and bearing surfaces. Threaded holes were tapped into the gripper arms to allow for easy gripper shoe change out to facilitate testing while slots were machined into the backs of the gripper arms to provide mounts for the hydraulic actuators. The chosen hydraulic actuators were a shorter model of the AllenAir pistons used for the testbed grippers due to rapid availability and proven reliability. Welded bosses were added to the upper arm and threaded to provide hard stops for the gripper arms. The final gripper assembly produced a very compact envelope that only required a 0.06 m (0.21 ft) gap in the LCS belts for retrieval and deployment operations (see Figure 5.1). The created a very generous envelope for the central and outer gate mechanisms. For detailed information on this and other assemblies illustrated in this chapter, refer to Appendix B for all detailed system drawings.

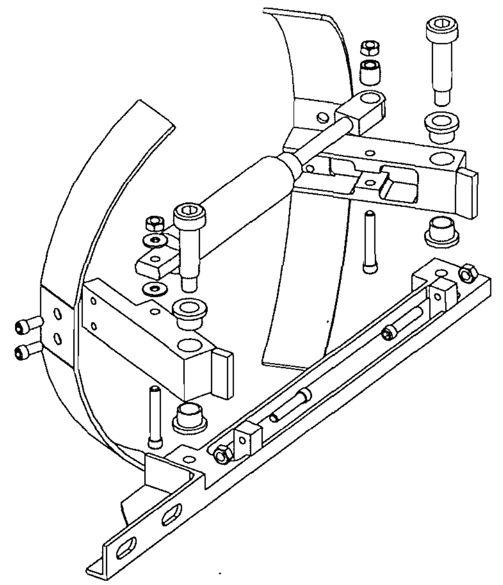

Figure 5.1 *Gripper Assembly*

5.4 Trolley Assembly Design

With the integration of the upper arm subassembly into the gripper assembly, the trolley assembly was simplified into the lower arm and cart subassemblies (see Figure 5.2). The lower arm subassembly consisted of only the lower arm frame, bearings, hydraulic connection manifold, and cam followers for the upper and lower tracks. Again, bronze sintered bushings were chosen in place of roller bearing elements for their simplicity and self lubricating properties. As the bushings and cam followers were critical links in this subassembly, the resultant stresses in these components were analyzed for the worst case condition of a stalled upper arm during retrieval (see Calculation 5.1 in Appendix A). Given these results, the bushings and cam followers were chosen accordingly. The small hydraulic manifold contained two rotary hydraulic fittings and two fixed fittings to provide hydraulic pressure from the vehicle system to the gripper assembly. Flexible hosing was to be routed to the gripper pistons after stowage system construction and installation on the prototype ACM to avoid interference with LCS systems.

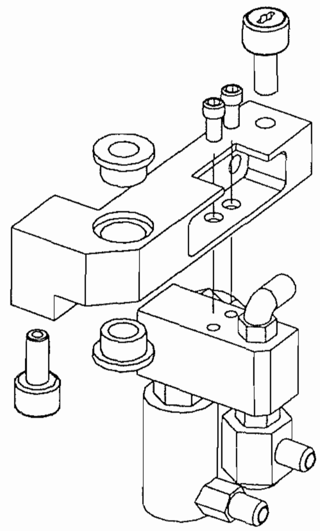

Figure 5.2 *Trolley Lower Arm Subassembly*

The cart subassembly provided the pivot location for the gripper assembly and the lower arm subassembly and the interfaces to the track and drive assemblies. This subassembly consisted of three v-wheels sandwiched between two mounting plates with shoulder bolts functioning as axles (see Figure 5.3). Proper selection of the v-wheel components required analysis of the cart subassembly for the same worst case condition as Calculation 5.1. After solution of the forces, the v-wheels were sized accordingly (See Calculation 5.2 in Appendix A). The thicker mounting plate contained the welded pivot shaft and mounting holes for the shoulder bolts while the thinner mounting plate contained the through holes for the bolts and a threaded spring plunger. This component was a COTS tooling fixture that supplied a removable connection to the drive assembly chain. During a system failure, the trolley assemblies could be removed from the drive assembly and positioned forward for manual operation.

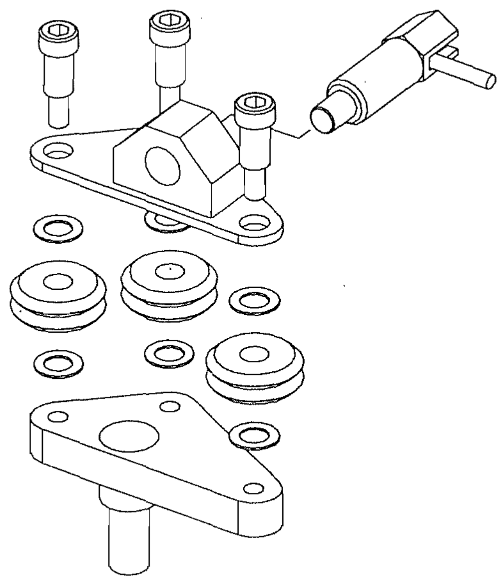

Figure 5.3 *Trolley Cart Subassembly*

5.5 Track Assembly Design

As the track assembly evolved from the simple track concept, it was decided to reinforce the assembly to provide mounting locations for all other assemblies. This would allow assembly of the entire stowage system away from the vehicle except for the mounting interfaces, hydraulic plumbing, and electrical connections to the vehicle systems. The track frame was divided into three separate sections that were welded together to form the completed unit (see Figure 5.4). The right and left sections integrated the upper track geometry with the mounting holes for the v-wheel rails and lower track. These pieces were individually billeted from steel plate to assure strength and dimensional accuracy. The lower tracks were created from large structural angle with the required path curvature machined into them. The center section of the track frame was a weldment constructed from structural angle spaced to accommodate the drive assembly mounts. The final track assembly produced a compact and robust mounting frame.

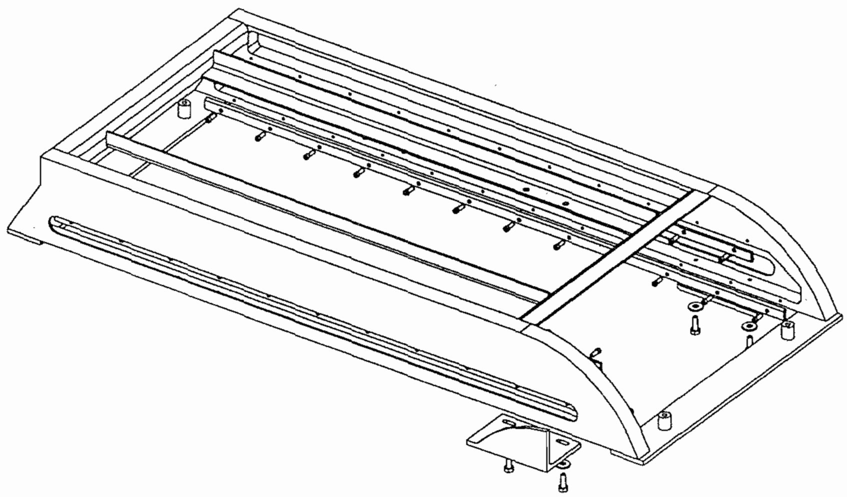

Figure 5.4 *Track Assembly*

5.6 Drive Assembly Design

The drive assembly required some modification from the original concept to fit into the decreased working envelope provided by the final design of the track assembly. To determine the amount of force required for the rotary actuator, the calculated values from the proceeding design were used as a starting point. The gear motors used in the first generation system had large problems with stiction due to the high pressure and low flow rates observed. To alleviate this problem, a vane type of rotary actuator with taper bearings for higher load capacity was selected. This same actuator had been used very successfully on the previous system in different configurations. However, these types of actuators only provided 270° of rotation and gearing would be required to achieve the necessary 0.79 m (2.58 ft) of linear travel. Also, the size of the gears was limited by the frame spacing to accommodate the width of standard traffic cone bases. A multiple chain and gearing system needed to be used to accomplish the amount of gear augmentation required within the necessary envelope. For compatibility with other systems on the prototype ACM, a type forty chain was selected. The vane actuator was mounted to a flat plate that connected to the underside of the track assembly and a single gear sprocket was attached to the keyed shaft of the actuator. For the gearing augmentation, two different gear sprockets were welded together and machined on both sides to permit insertion of sealed roller bearings. This completed subassembly was then connected by a large shoulder bolt to a mounting plate. The mounting plate then attached to the central section of the track frame. The first chain connected the gear sprocket on the actuator to the smaller of the two welded gear sprockets. The second chain routed around the larger of the welded gear sprockets and four idler sprockets located at the corners of the track assembly to connect to the trolley assemblies. The resulting drive assembly offered the capability of operation at various speeds without stalling (see Figure 5.5).

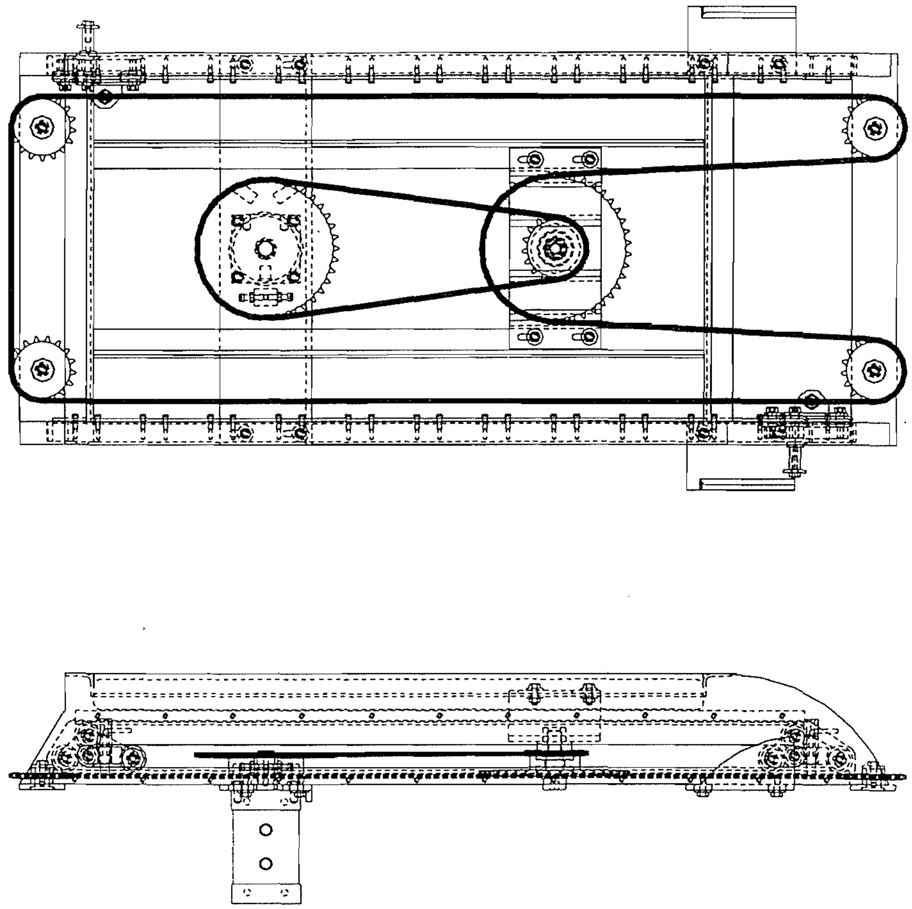

Figure 5.5 *Drive Assembly*

5.7 Chapter Summary

This chapter has explained the design methodology used for the detailed design of the second generation stowage system and documents the design specifics of the gripper, trolley lower arm, trolley cart, track, and drive assemblies and subassemblies.

CHAPTER 6: ASSEMBLY AND TESTING OF THE SECOND GENERATION AUTOMATED CONE STOWAGE SYSTEM

6.1 Introduction

In this chapter the assembly, testing, and modification of the second generation stowage system will be discussed. Also, the issue of the stowage system mounting interfaces will be addressed. System testing will be divided into laboratory and road tests, while modifications will be segregated by subsystem.

6.2 System Fabrication and Assembly

Upon completion of the detailed design phase of the ACM project, the stowage system parts were machined by outside vendors to facilitate rapid completion and consistent quality. As designed, the stowage system gripper, trolley, track, and drive assemblies were individually constructed and then assembled together prior to installation onto the prototype ACM vehicle.

6.3 System Mounting Interfaces

After fabrication and assembly, the stowage system interfaces to the ACM vehicle's frame rails, hydraulic system, and control system needed completion before operation was possible. These interfaces were divided into the following three areas: mounting interfaces, hydraulic interfaces, and electrical interfaces.

6.3.1 Mounting Interfaces

The physical connection of the stowage system onto the vehicle frame rails involved the design and fabrication of front and rear mounting interfaces. A square steel tube was chosen for the front mount support and welded onto the track frame. This tube spanned between the cone body buckets and was drilled on each end to accept two threaded plates that clamped onto the frame rails (see Figure 6.1).

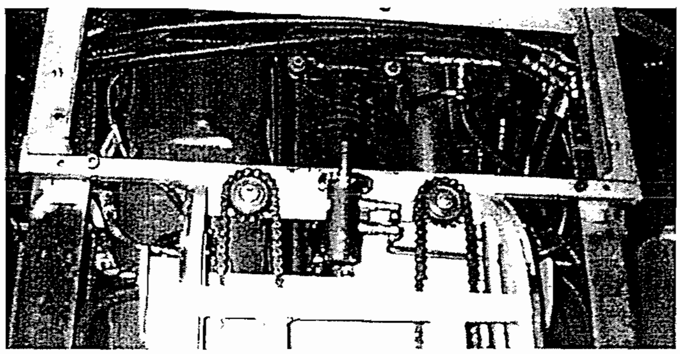

Figure 6.1 *Front Mounting Interface*

For the rear mount, a folded metal tray was welded onto the rear of the stowage track frame and bolted to a vehicle frame cross member. To add additional rigidity and provide a mounting location for the main conveyor front roller, a rectangular tube was welded onto the metal tray with separate right and left mounts that rested on top of the vehicle frame rails. The left mount differed in design from the right mount due the placement of the gasoline filler hose. The main conveyor front roller then mounted directly onto these right and left mounts and assured correct positioning (see Figure 6.2).

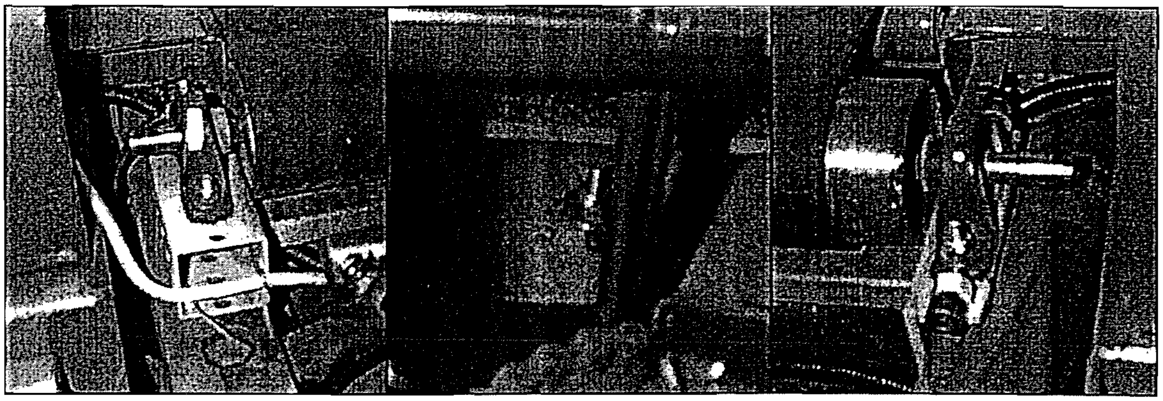

Figure 6.2 *Rear Mounting Interface*

The last mounting interface involved the support of the stowage system hydraulic manifold. A set of angles was welded to the underside of the front mount and provided bolt holes for the manifold.

6.3.2 Hydraulic Interfaces

The stowage system only required three sets of hydraulic connections that were routed after system installation. One set of hydraulic lines connected the vane actuator in the drive assembly to the hydraulic manifold located under the front right of the stowage system. The other two sets connected the same manifold to the right and left gripper assemblies (see Figure 6.3). Two steel weldments were constructed to provide guides for these hydraulic lines. The left side weldment also protected the vehicle gasoline filler tube from chaffing damage caused by the gripper assembly hydraulic lines. The gripper assembly hydraulic lines were later enclosed under a protective cover for system and worker safety.

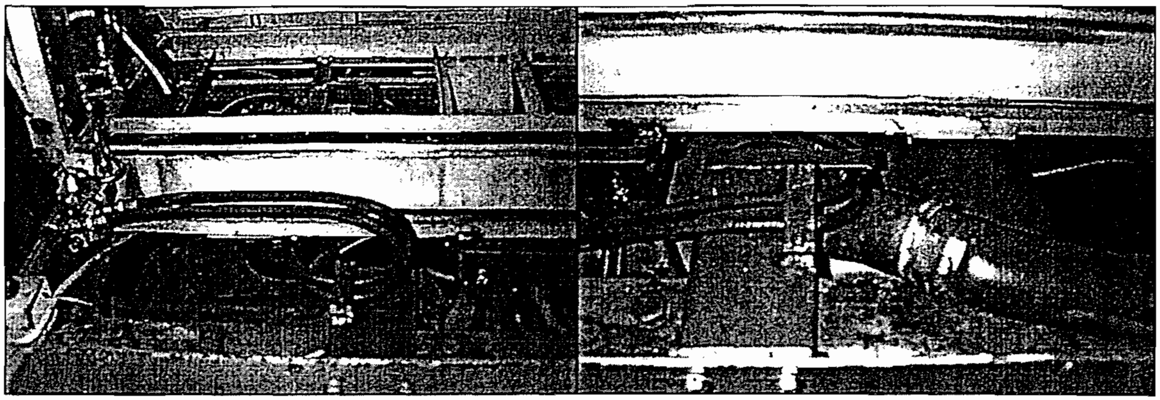

Figure 6.3 *Gripper Assembly Hydraulic Interface*

6.3.3 Electrical Interfaces

Control of the stowage system by the redesigned CCU system would require the addition of two sensor systems. Trolley assembly positioning required that two magnetic reed switches be used to determine which assembly was located forward on the track system. The magnetic part of the sensor was placed on a welded extension connected to the inside mount plate of the cart subassembly. The wired part of the sensor was located on an outrigger welded to the front of the track assembly.

The second required sensor system was the photoeye arrays that are necessary to position the cones on the main conveyor for deployment and retrieval by the gripper assembly. Sheet metal boxes were constructed and then welded to form enclosures for the right and left side arrays. Each enclosure had a slot machined on the front for mounting of the two photoeyes per array. Cone guides were attached to the tops of both enclosures. A center cone guide was also constructed that contained the reflective tape strip required for photoeye operation (see Figure 6.4).

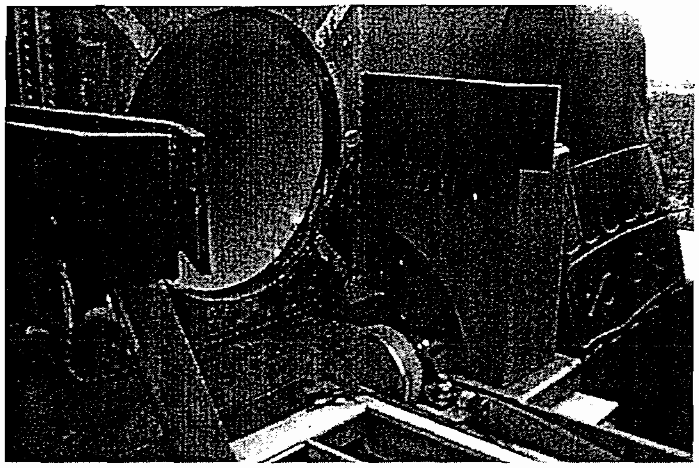

Figure 6.4 *Left Photoeye Array Enclosure*

6.4 System Testing

After installation of the stowage system onto the integrated prototype ACM was completed, extensive system testing was conducted using a two phase methodology. Phase 1 testing consisted completely of manual lab operation of the stowage system to discover problems and prove out the design. As testing progressed, computer control of the stowage system was slowly implemented after successful manual testing. Phase 2 testing consisted only of strenuous automated road testing at different locations and under various conditions. Modifications were made to subsystems as required to best satisfy the original design parameters and produce a functional prototype.

6.4.1 Manual Testing

Lab testing of the stowage system in manual mode demonstrated that the first gripper shoe design did not provide sufficient retention capability to maintain cone engagement during transition for either deployment or retrieval operations (see Figure

6.5). After four different iterations of the gripper assembly, a working design was developed.

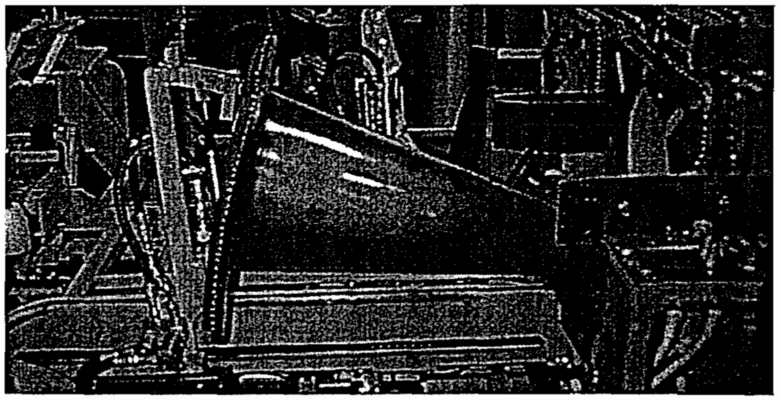

Figure 6.5 *Loss of Cone Retention by Gripper Assembly*

Although not seriously detrimental to retrieval system performance, it was observed that engagement of the gripper shoes was causing excessive cone deformation (see Figure 6.6). This deformation would make cone spacing on the main conveyor inconsistent during retrieval and would cause two cones to be engaged by the gripper system and removed from main stack during deployment. While the stowage system had enough torque to successfully transfer the double load, these cones would jam the LCS. A quick and simple solution to this problem was the implementation of a passive cone separator mounted above the main conveyor front roller (see Figure 6.7). Following several successful weeks of manual testing, control of the stowage system was transferred to the microprocessor and testing continued.

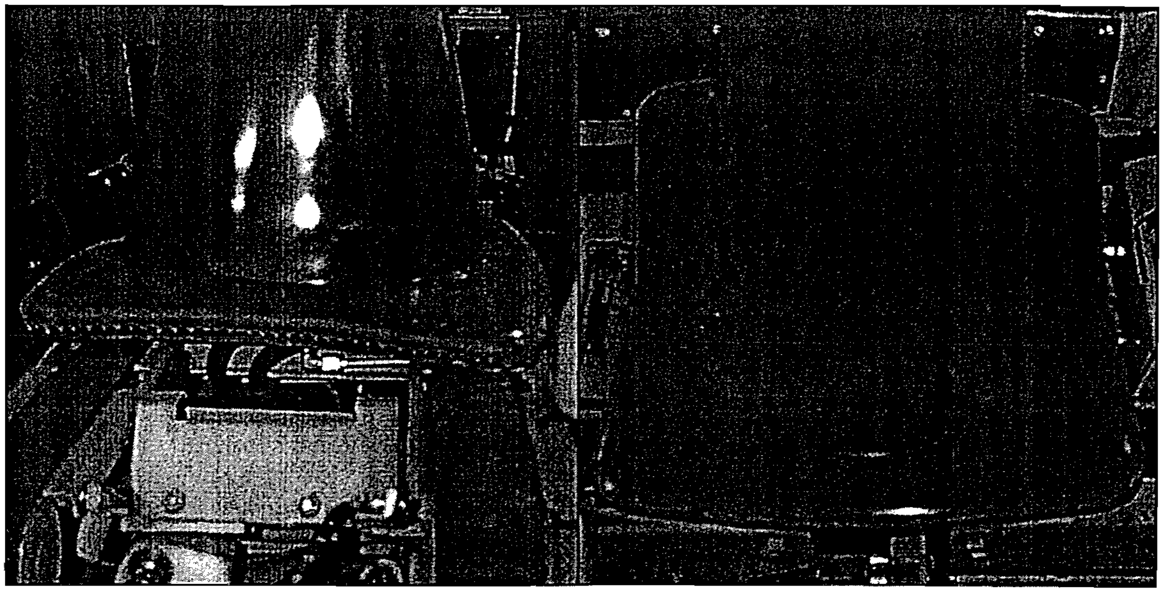

Figure 6.6 *Cone Deformation by the Gripper Shoes*

6.4.2 Automated Testing

Extensive debugging of the control software was required prior to the onset of automated testing. After exhaustive laboratory and road testing, three additional problems with the stowage system required immediate correction. The first problem was very serious and involved the repeated failure of the upper v-wheel component in the left side cart subassembly during cone retrieval (see Figure 6.7). Correction of this problem required careful investigation and a complete redesign of this subassembly.

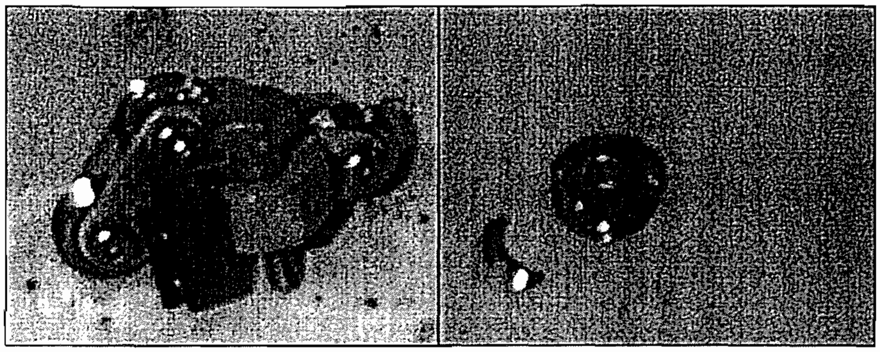

Figure 6.7 *Upper V-Wheel Failure on Cart Subassembly*

The second problem manifested itself as jammed cones during retrieval. The tip on the retrieved cone would catch on the bottom base of the previous cone in the main conveyor stack and cause the stowage system to stall (see Figure 6.8). Although this problem appeared to be a repetition of the gripper assembly retention problem, the real cause of the problem was discovered to be the large amount of slop or gap between the upper cam follower on the lower arm subassembly and the upper track on the track assembly. Two separate modifications to the gripper and track assemblies were required to correct this situation.

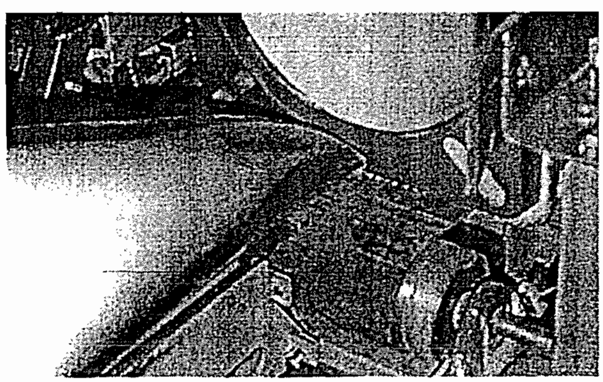

Figure 6.8 *Jammed Cone Tip*

The third problem with automated testing of the stowage system was a slower than expected cycle time. The stowage system operation speed was limited by the transfer mechanism because faster speeds made the transfer motion too abrupt to maintain cone retention. To increase cycle times, a high speed circuit was added to the drive assembly.

6.5 Gripper Assembly Modifications

Given the poor performance of the initial gripper assembly design, a carefully structured iteration program was implemented to form an optimum solution within the shortest time frame. After trying several different coatings and surfaces for the gripper shoes, the original design of smooth curved plates was discarded. This system relied solely upon the friction developed between the gripper shoe surface and the inside of the cone base. The friction coefficient between the two surfaces varied too much based upon temperature and road conditions for the original design to ever be completely successful. A further complication was that new cones would still be coated with mold release that reduced the coefficient to almost zero.

A new concept of selectively expanding the cone base was tried in the first iteration. Small gripper shoes constructed from steel rod were attached to the gripper arms and tested. These shoes were positioned to contact the cone at the interface between the base and conical sections. This interface area was less rigid than the cone base and provided more expansion to firmly encapsulate the gripper shoes and prevent a loss of cone retention. Although the concept was sound, the rods did not provide the correct shape for optimal retention. Testing of various shoe shapes demonstrated that small steel angles curved along the spine of the angle provided the best shape. These new shoes were welded to the gripper arms to become the second design iteration (see Figure 6.9).

Realization that the gripper system would occasionally lose cones, especially damaged ones, prompted the third gripper assembly iteration. Small fingers were welded onto the ends of the gripper arms to provide guides for cones that lost contact with the gripper shoes (see Figure 6.9). As the stowage system continued retrieval motion, these fingers would keep the fallen cone centered and push the cone into the main conveyor stack.

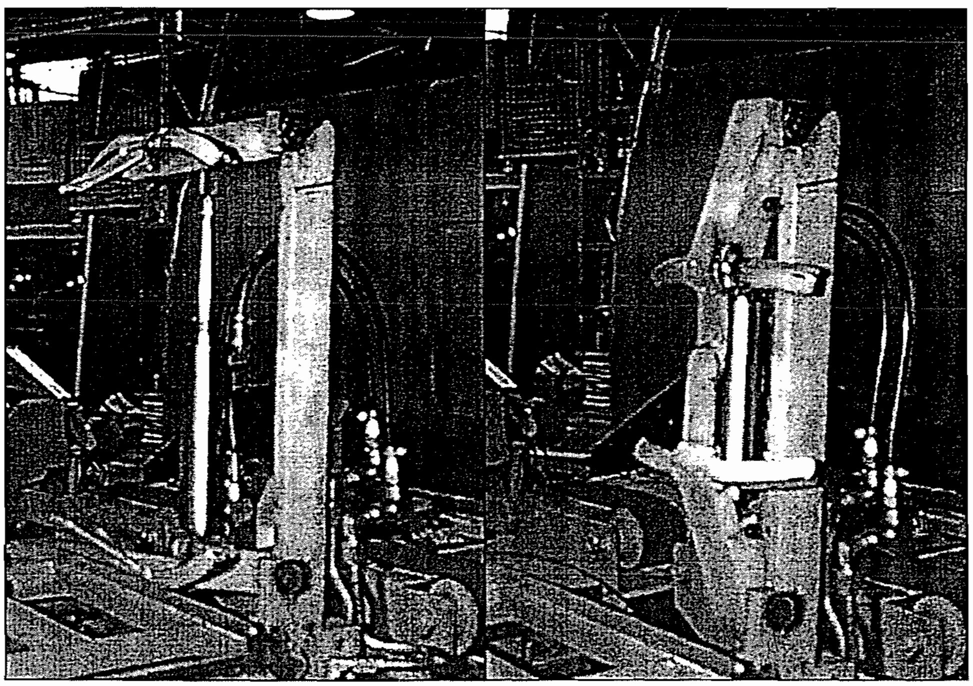

Figure 6.9 *Second and Third Gripper Assembly Iterations*

While previous iterations did dramatically improve performance, the gripper assembly still did not perform at the necessary level that continuous automated operation required. A fourth iteration was designed that included a small plate at the top of the gripper assembly to provide a clamping action between the cone base and the upper gripper shoe (see Figure 6.10). This iteration finally provided the expected level of performance from the gripper assembly.

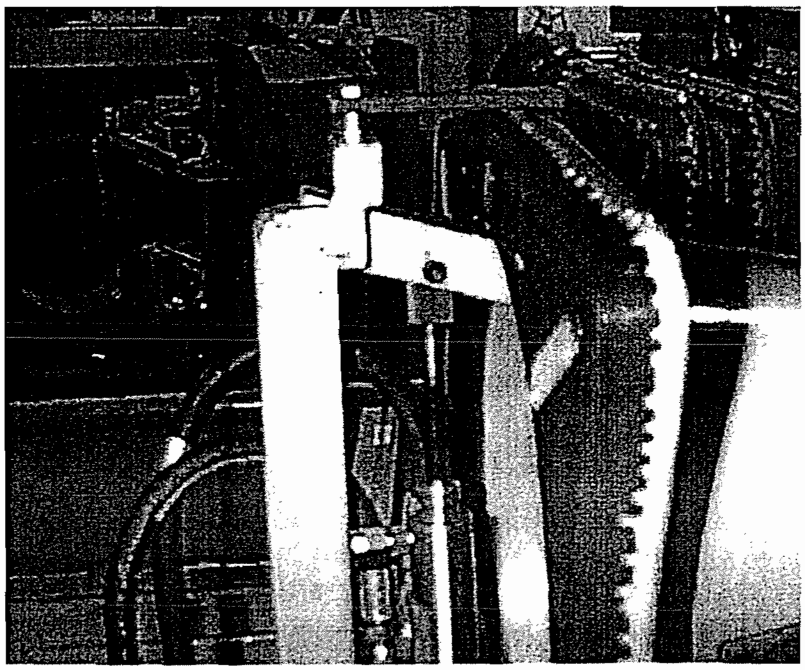

Figure 6.10 *Fourth Gripper Assembly Iteration*

The fifth and final iteration of the gripper assembly was required to partially alleviate the slop between the upper cam follower and the upper track. A small steel block was welded onto the bottom of the upper arm to provide a mount for a second cam follower (see Figure 6.11). The addition of this second cam follower provided another contact point on the upper track to prevent forward rotation of the cone during retrieval.

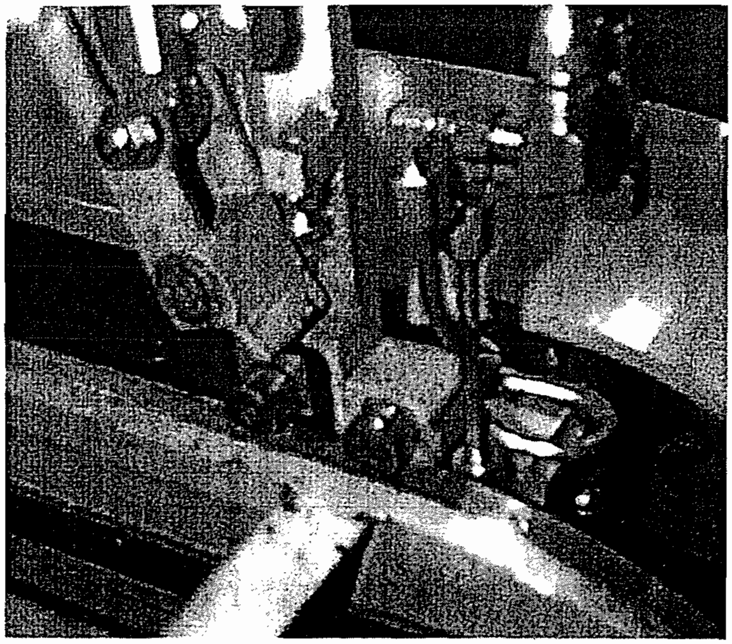

Figure 6.11 *Fifth Gripper Assembly Iteration*

6.6 Trolley and Track Assemblies Modifications

As the critical components of the trolley assembly, failure of one of the v-wheels would render the stowage system completely inoperable and would require manual operation to complete deployment or retrieval tasks. Very careful and painstaking investigation of the problem revealed that poor dimensional tolerances in the left and right sections of the track frame would allow uneven loading of the v-wheels to occur. Since most of the loading during the retrieval operation was centered on the upper v-wheel, this was the most likely candidate for failure. Due to time constraints, remanufacture of the track frame was impractical so the cart subassembly was redesigned to accommodate four v-wheels instead of three (see Figure 6.12). The right and left sections of the track frame required some modification to accept the redesigned cart subassembly. While this redesign improved the failure rate of the v-wheels, severe jamming could still cause a failure.

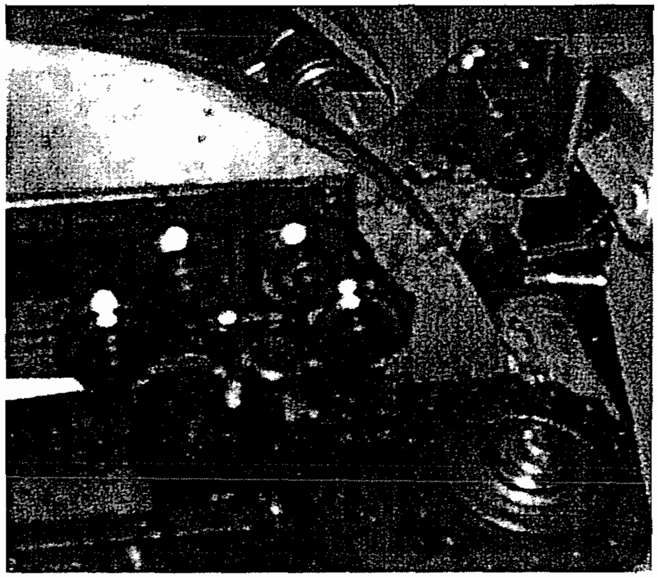

Figure 6.12 *Trolley Assembly Modification*

The second modification to solve the slop problem between the upper cam follower and upper track, required the addition of a guide rail for the lower cam follower on the lower arm subassembly (see Figure 6.13). The left and right guide rails were attached to mounts welded onto the sides of the track frame subassembly. The function of these rails was to force the cone to maintain an exact horizontal position for 0.3 m (0.75 ft) of motion after transition from vertical to horizontal during retrieval. The guide rails were only necessary until the cone tip entered into the base of the preceding cone in the cone stack. This modification, combined with the addition of a second cam follower onto the gripper assembly, provided a satisfactory solution to the cone tip jamming problem.

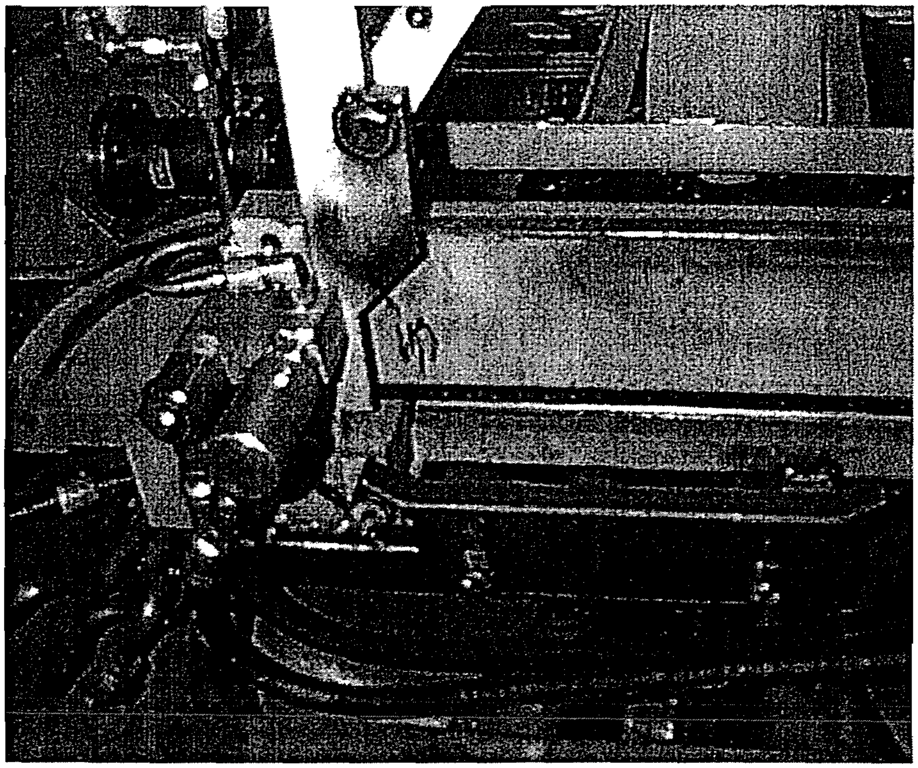

Figure 6.13 *Track Assembly Modification*

6.7 Drive Assembly Modifications

Increased cycle times required the addition of a high speed hydraulic circuit into the manifold feeding the drive assembly actuator. When energized, a solenoid in the stowage system manifold increased the flow rate into the vane actuator to increase rotational speed. However, the high speed circuit could only be engaged after or before the circular segment of the upper track on the frame assembly depending on the operation type. For a retrieval operation the solenoid would not be energized until after the rotary transfer had occurred and would be de-energized prior to placing the cone into the main stack. A roller contact switch and guide track was added to the main drive gear sprocket to facilitate the necessary timing (see Figure 6.14). This modification reduced the average cycle times from 2.4 to just under 2 seconds.

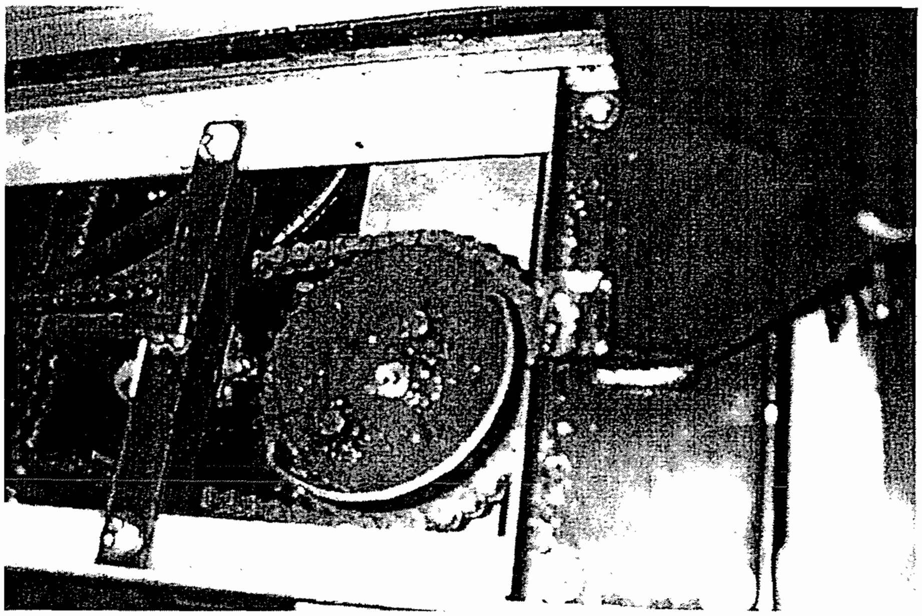

Figure 6.14 *Drive Assembly Modification*

6.8 Additional Modifications

The final modification to the stowage system involved the placement of the passive cone separator onto the cone body frame over the front of the main conveyor roller (see Figure 6.15). This system was designed with a set of specially placed hinges that prevented the gripper assembly from deploying two cones at the same time. The hinges were placed high enough for a free cone to pass under. Once the gripper system engaged the inside of the cone base for deployment, the deformation or expansion of the cone would cause the second cone to be stripped off the engaged cone as the system transferred. Although this solution was inelegant and required frequent adjustment, it did solve the problem.

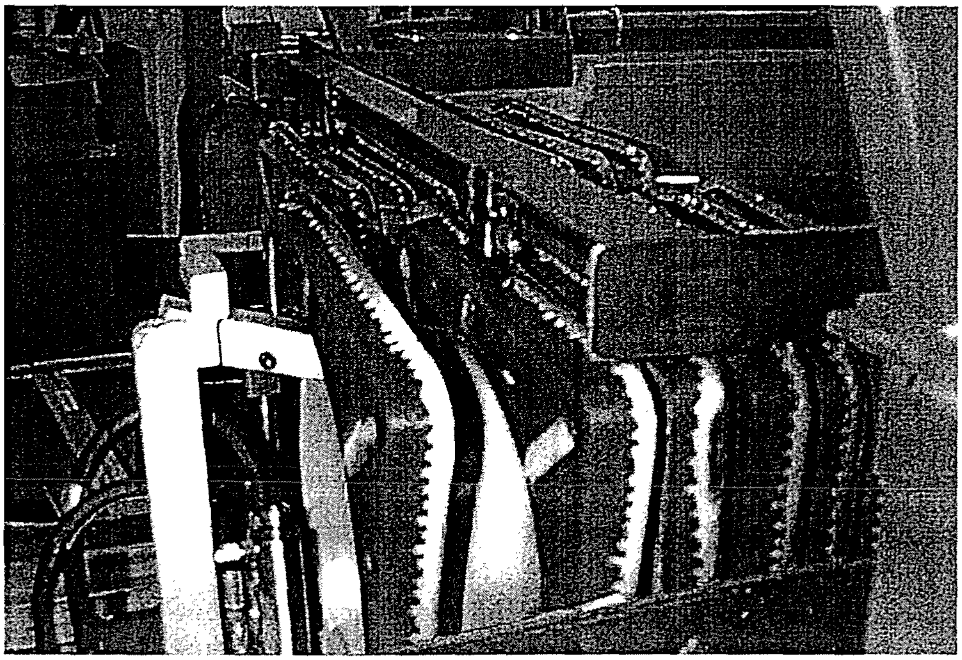

Figure 6.15 *Passive Cone Separator Modification*

6.9 Chapter Summary

In this chapter, the assembly, testing, and modifications required to make the second generation stowage system fully operational are documented. Specifically, the completion of the mounting, hydraulic, and electrical interfaces is discussed along with the gripper assembly, track and trolley assemblies, drive assembly, and other assembly modifications.

CHAPTER 7: CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

The development of the second generation stowage system for the ACM prototype produced a functional unit that successfully met most of the general and detailed design requirements. The new system increased cone retention during rotational motion, decreased the required transit forces, simplified the level of mechanism complexity, increased operational cycle times, and dramatically decreased the working envelope. However, the system was still restricted to one cone size and suffered from durability issues in the trolley assembly design. Even given these caveats, the second generation system was a vast improvement in performance from the testbed system.

A further issue was the success of the evolutionary design cycle that started with testing and modifications to the original testbed system and ended with a completed second generation prototype. The major strength of this methodology was the direct implementation of the experiences, data, and information gained from the previous design into producing the next design iteration in an accelerated manner while still producing a superior product. Lessons learned in the original system did not have to be painfully relearned in the next system.

The evolutionary design of the second generation stowage system created a working subsystem that complemented the redesigned LCS, IDRC, CCU, and funnel systems in the prototype ACM. The completed ACM prototype system successfully proved that automation of cone handling operations is feasible and provides a major improvement in maintenance worker safety.

7.2 Recommendations

Even though the second generation stowage system was successful, improvements need to made in several areas to assure consistent performance. The key areas that require development are safety, reliability, and performance.

The ever critical issue of worker safety was not adequately addressed during this development. Due to the type of mechanism required, the only way to guarantee worker safety is to place mesh guards around the stowage system while providing a large enough working envelope for cone transitions.

System reliability is suspect in the gripper and trolley assemblies. The hydraulic connections to the gripper piston are constantly in motion and proved to be prone to leakage. Using a single acting piston would decrease the number of connections but would require extensive packaging to accommodate the additional piston length caused by the return spring. A design of linear sliding gripper arms and shoes would allow the gripper assembly to easily handle wide variation in cone sizes but would add system complexity.

As the weakest link in the system, the trolley assembly would require careful attention to improve reliability. Using higher capacity v-wheels and tracks and modifying the system to alleviate side loading would provide a large improvement in durability and decrease the failure rate.

A final recommendation is the design and addition of an active cone separator unit to positively control the interface between the stowage system and the main conveyor systems. This unit would prevent the engagement of multiple cones by the gripper assembly and could replace the photoeye array to provide a locating device for cone retrieval and deployment operations.

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Appendix A

Calculation 5.1

Problem: Need to solve for the force acting on the cam follower for a stall condition during cone retrieval.

Variables:

$F_{X_{JOINT}}$	Joint force in X direction
$F_{Y_{JOINT}}$	Joint force in Y direction
$F_{Z_{JOINT}}$	Joint force in Z direction
$M_{X_{JOINT}}$	Joint moment in X direction
$M_{Y_{JOINT}}$	Joint moment in Y direction
$M_{Z_{JOINT}}$	Joint moment in Z direction
F_{CAM}	Cam force
$F_{Z_{STALL}}$	Stall force
$L_{X_{CAM}}$	Distance from joint center to cam force in X direction
$L_{Y_{CAM}}$	Distance from joint center to cam force in Y direction
$L_{Y_{STALL}}$	Distance from joint center to stall force in Y direction
θ	Cam force application angle in YZ plane

Assumptions:

1. Rigid and massless
2. Joint is frictionless

Solution:

From assumtion 2:

$$M_{X_{JOINT}} = 0$$

All forces and moments are summed around the joint center:

$$\sum F_X = F_{X_{JOINT}} = 0 \qquad (1)$$

$$\sum F_Y = F_{Y_{JOINT}} + F_{CAM}\cos\theta = 0 \qquad (2)$$

$$\sum F_Z = F_{Z_{JOINT}} + F_{Z_{STALL}} + F_{CAM}\sin\theta = 0 \qquad (3)$$

$$\sum M_X = F_{CAM}\sin\theta \cdot L_{Y_{CAM}} + F_{Z_{STALL}} \cdot L_{Y_{STALL}} = 0 \qquad (4)$$

$$\sum M_Y = M_{Y_{JOINT}} - F_{CAM}\sin\theta \cdot L_{X_{CAM}} = 0 \qquad (5)$$

$$\sum M_Z = M_{Z_{JOINT}} + F_{CAM}\cos\theta \cdot L_{X_{CAM}} = 0 \qquad (6)$$

From Calculation 5.2, $F_{Y_{JOINT}} = -174.3 \text{ lbf}$

$$\text{Eq. (2)} \Rightarrow F_{CAM} = -\frac{F_{Y_{JOINT}}}{\cos\theta} = -\frac{-174.3 \text{ lbf}}{\cos(30.5)} = 202.3 \text{ lbf} \qquad (7)$$

$$\text{Eq. (4)} \Rightarrow F_{Z_{STALL}} = -\frac{F_{CAM}\sin\theta \cdot L_{Y_{CAM}}}{L_{Y_{STALL}}} = -\frac{(202.3 \text{ lbf})[\sin(30.5)](4.0 \text{ in})}{4.438 \text{ in}}$$

$$= -92.5 \text{ lbf} \qquad (8)$$

$$\text{Eq. (3)} \Rightarrow F_{Z_{JOINT}} = -F_{Z_{STALL}} - F_{CAM}\sin\theta = -(-92.5 \text{ lbf}) - (202.3)\sin(30.5)$$

$$= -10.2 \text{ lbf} \qquad (9)$$

$$\text{Eq. (5)} \Rightarrow M_{Y_{JOINT}} = F_{CAM}\sin\theta \cdot L_{X_{CAM}} = (202.3)[\sin(30.5)](0.766)$$

$$= 78.6 \text{ in-lb} \qquad (10)$$

$$\text{Eq. (6)} \Rightarrow M_{Z_{JOINT}} = -F_{CAM}\cos\theta \cdot L_{X_{CAM}} = -(202.3)[\cos(30.5)](0.766)$$

$$= -133.5 \text{ in-lb} \qquad (11)$$

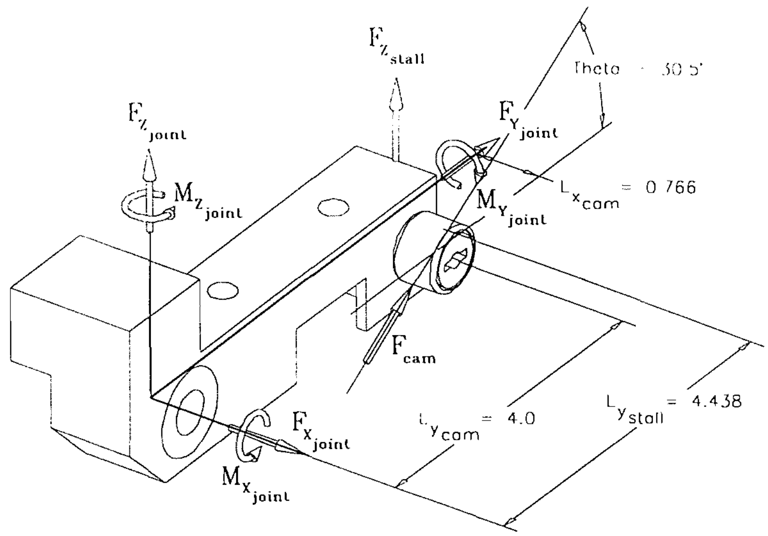


Figure A.1 *Reference Drawing for Calculation 5.1*

Calculation 5.2

Problem: Need to solve for the moments acting on the v-wheels for a stall condition during cone retrieval.

Variables:

$F_{X_{JOINT}}$	Joint force in X direction
$F_{Y_{JOINT}}$	Joint force in Y direction
$F_{Z_{JOINT}}$	Joint force in Z direction
$M_{X_{JOINT}}$	Joint moment in X direction
$M_{Y_{JOINT}}$	Joint moment in Y direction
$M_{Z_{JOINT}}$	Joint moment in Z direction
$F_{Y_{CHAIN}}$	Chain force
$F_{X_{WHEEL1}}$	Wheel 1 force in X direction
$F_{Y_{WHEEL1}}$	Wheel 1 force in Y direction
$F_{X_{WHEEL1}}$	Wheel 1 force in Z direction
$F_{X_{WHEEL2}}$	Wheel 2 force in X direction
$F_{Y_{WHEEL2}}$	Wheel 2 force in Y direction
$F_{Z_{WHEEL2}}$	Wheel 2 force in Z direction
$F_{X_{WHEEL3}}$	Wheel 3 force in X direction
$F_{Y_{WHEEL3}}$	Wheel 3 force in Y direction
$F_{Z_{WHEEL3}}$	Wheel 3 force in Z direction
$L_{X_{CHAIN}}$	Distance from cart origin to chain force in X direction
$L_{X_{JOINT}}$	Distance from cart origin to joint center in X direction
$L_{Y_{WHEEL1}}$	Distance from cart origin to wheel 1 in Y direction
$L_{Y_{WHEEL2}}$	Distance from cart origin to wheel 3 in Y direction
$L_{Z_{CHAIN}}$	Distance from cart origin to chain force in Z direction
$L_{Y_{WHEEL2}}$	Distance from cart origin to wheel 2 in Z direction
$L_{Y_{WHEEL3}}$	Distance from cart origin to wheel 3 in Z direction

Assumptions:

1. Rigid and massless
2. Joint, wheel bearings, and wheel surfaces are frictionless

Solution:

From assumption 2:

$$M_{X_{JOINT}} = F_{Y_{WHEEL1}} = F_{Y_{WHEEL2}} = F_{Y_{WHEEL3}} = 0$$

All forces and moments are summed about cart origin:

$$\sum F_X = F_{X_{WHEEL1}} + F_{X_{WHEEL2}} + F_{X_{WHEEL3}} - F_{X_{JOINT}} = 0 \qquad (1)$$

$$\sum F_Y = -F_{Y_{CHAIN}} - F_{Y_{JOINT}} = 0 \qquad (2)$$

$$\sum F_Z = F_{Z_{WHEEL1}} - F_{Z_{WHEEL2}} + F_{Z_{WHEEL3}} - F_{Z_{JOINT}} = 0 \qquad (3)$$

$$\sum M_X = F_{Z_{WHEEL1}} \cdot L_{Y_{WHEEL1}} - F_{Z_{WHEEL3}} \cdot L_{Y_{WHEEL3}} - F_{Y_{CHAIN}} \cdot L_{Z_{CHAIN}} = 0 \qquad (4)$$

$$\sum M_Y = F_{X_{WHEEL2}} \cdot L_{Z_{WHEEL2}} - \left(F_{Z_{WHEEL3}} + F_{Z_{WHEEL1}}\right) \cdot L_{Z_{WHEEL3}} - F_{Z_{JOINT}} \cdot L_{X_{JOINT}} - M_{Y_{JOINT}} = 0 \qquad (5)$$

$$\sum M_Z = F_{X_{WHEEL3}} \cdot L_{Y_{WHEEL3}} - F_{X_{WHEEL1}} \cdot L_{Y_{WHEEL1}} + F_{Y_{JOINT}} \cdot L_{X_{JOINT}} - M_{Z_{JOINT}} - F_{Y_{CHAIN}} \cdot L_{X_{CHAIN}} = 0 \qquad (6)$$

$$T_{ACTUATOR} = (900\text{ psi})\left(\frac{140\text{ in - lb}}{100\text{ psi}}\right) = 1260\text{ in - lb} \qquad (7)$$

$$F_{Y_{CHAIN}} = \frac{T_{ACTUATOR}}{r_{gear3}}(\text{gear reduction}) = \frac{T_{ACTUATOR}}{r_{gear3}}\left(\frac{r_{gear2}}{r_{gear1}}\right) = \left(\frac{1260\text{ in - lb}}{3.2\text{ in}}\right)\left(\frac{1.35\text{ in}}{3.05\text{ in}}\right) = 174.3\text{ lbf} \qquad (8)$$

$$\text{Eq. (2)} \Rightarrow F_{Y_{JOINT}} = -F_{Y_{CHAIN}} = -174.3 \text{ lbf} \qquad (9)$$

From Calculation 5.1:

$F_{X_{JOINT}} = 0 \text{ lbf}$

$F_{Z_{JOINT}} = -10.2 \text{ lbf}$

$M_{Y_{JOINT}} = 78.6 \text{ in - lb}$

$M_{Z_{JOINT}} = -133.5 \text{ in - lb}$

$$\text{Eq. (1)} \Rightarrow F_{X_{WHEEL2}} = -F_{X_{WHEEL1}} - F_{X_{WHEEL3}} = 0 \qquad (10)$$

$$\text{Eq. (5)} \Rightarrow -\left(F_{X_{WHEEL1}} + F_{X_{WHEEL3}}\right)(1.375) - \left(F_{X_{WHEEL1}} + F_{X_{WHEEL3}}\right)(0.625) - (-10.2)(1.624)$$
$$-(78.6) = 0 \qquad (11)$$

$$\text{Eq. (11)} \Rightarrow F_{X_{WHEEL1}} = -F_{X_{WHEEL3}} - 31.0 \qquad (12)$$

$$\text{Eq. (6)} \Rightarrow F_{X_{WHEEL3}}(1.0) - \left[-F_{X_{WHEEL3}} - 31.0\right](2.0) + (-174.3)(1.624)$$
$$-(-133.5) - (174.3)(0.874) = F_{X_{WHEEL3}} + 2F_{X_{WHEEL3}} + 62.0 - 283.1$$
$$+133.5 - 152.3 = -F_{X_{WHEEL3}} - 80.0 = 0 \qquad (13)$$
$$\therefore F_{X_{WHEEL3}} = -80.0 \text{ lbf}$$

$$\text{Eq. (12)} \Rightarrow F_{X_{WHEEL1}} = -(-80.0) - 62.0 = -18.0 \text{ lbf} \qquad (14)$$

$$\text{Eq. (10)} \Rightarrow F_{X_{WHEEL2}} = -(-18.0) - (-80.0) = 98.0 \text{ lbf} \qquad (15)$$

Calculate M_Y for each v - wheel

$$M_{Y_{WHEEL1}} = -F_{X_{WHEEL1}} \cdot r_{wheel} = -(-18.0)(0.5) = 9.0 \text{ in - lb}$$

$$M_{Y_{WHEEL2}} = -F_{X_{WHEEL2}} \cdot r_{wheel} = -(98.0)(0.5) = -49.0 \text{ in - lb}$$

$$M_{Y_{WHEEL3}} = -F_{X_{WHEEL3}} \cdot r_{wheel} = -(-80.0)(0.5) = 40.0 \text{ in - lb}$$

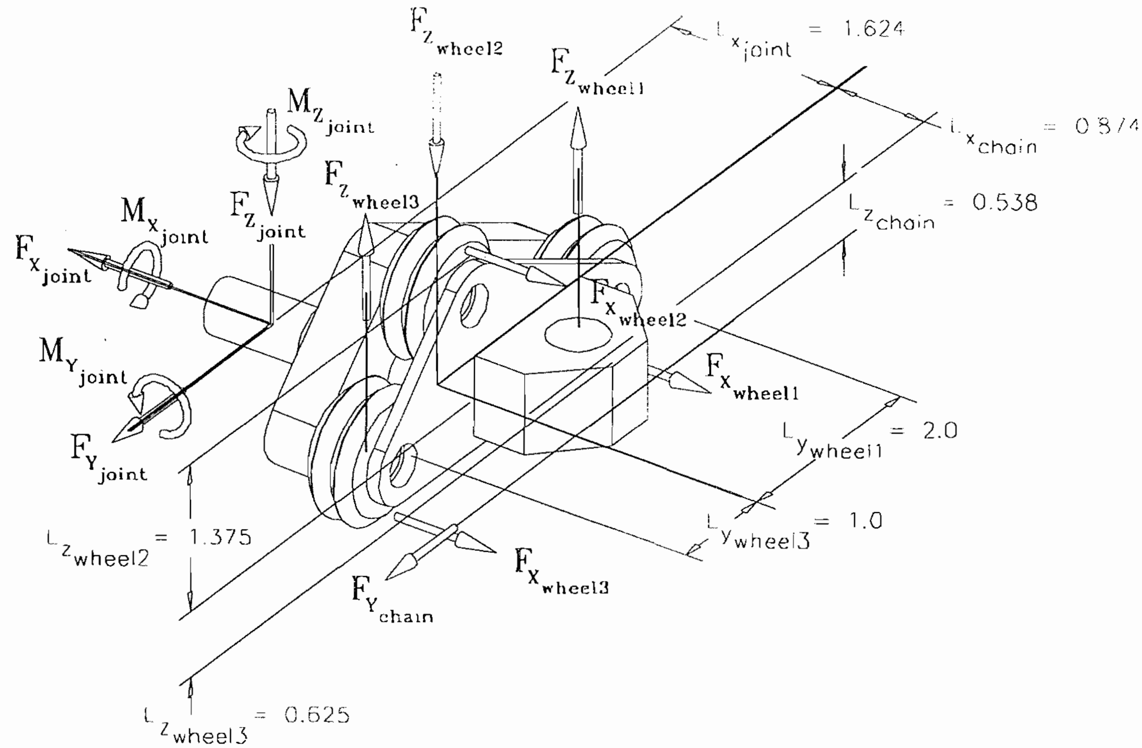
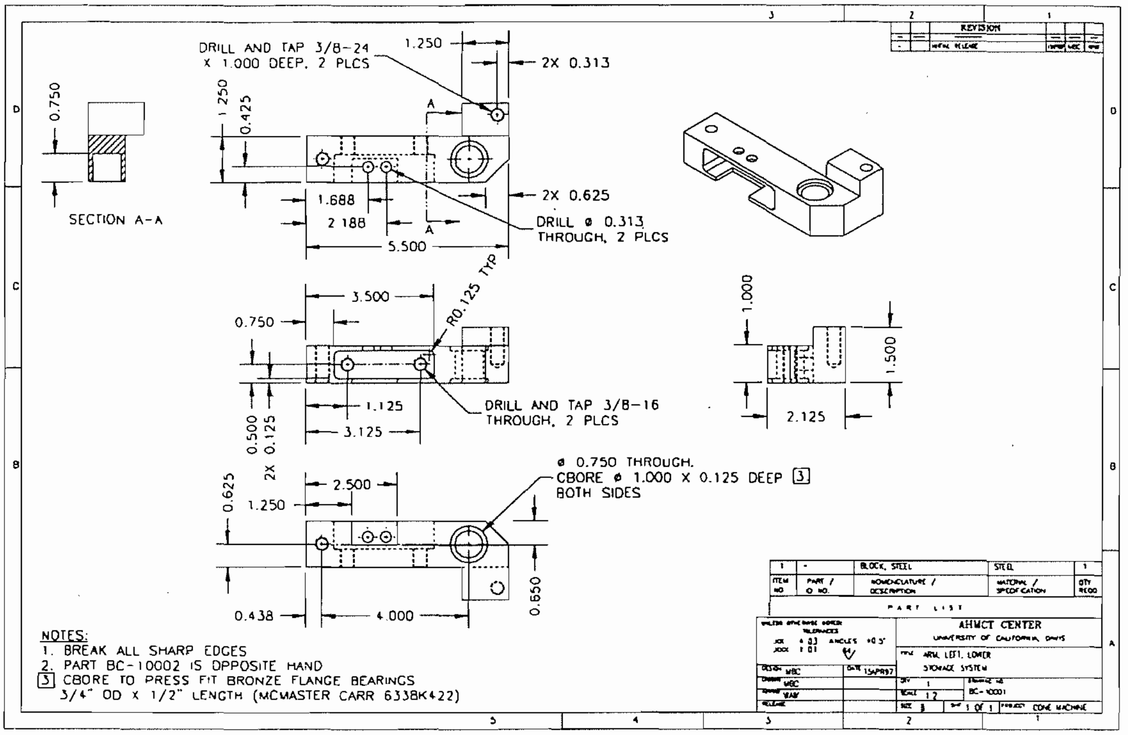
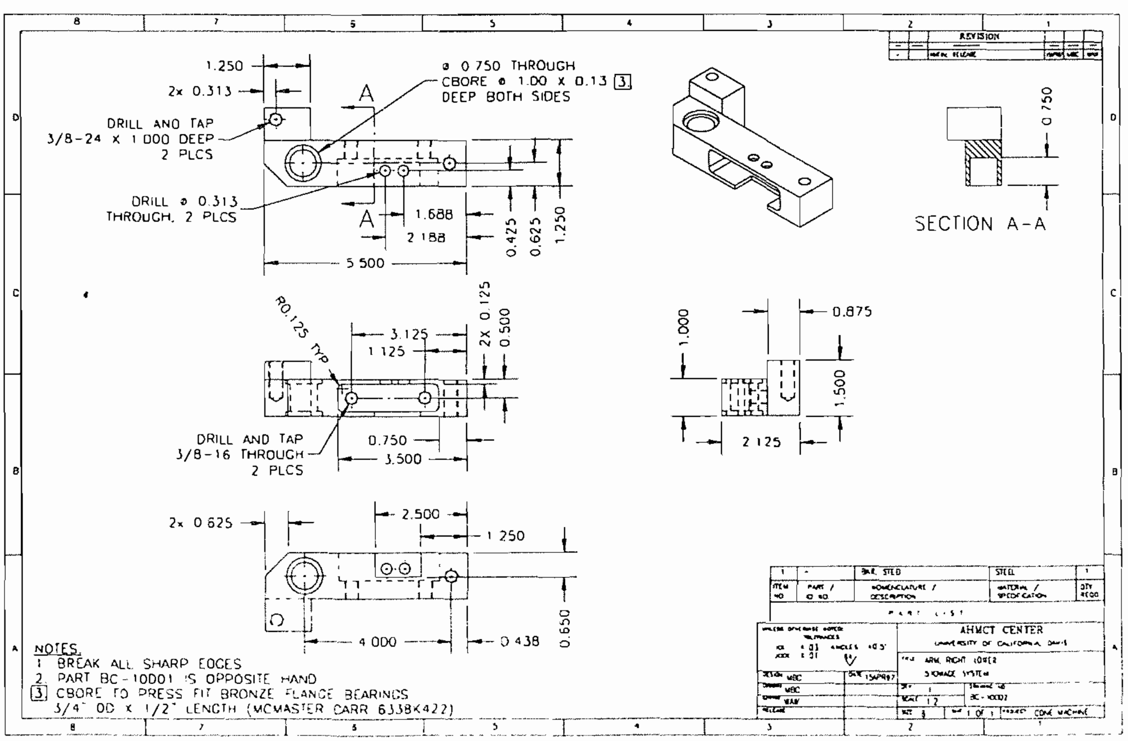
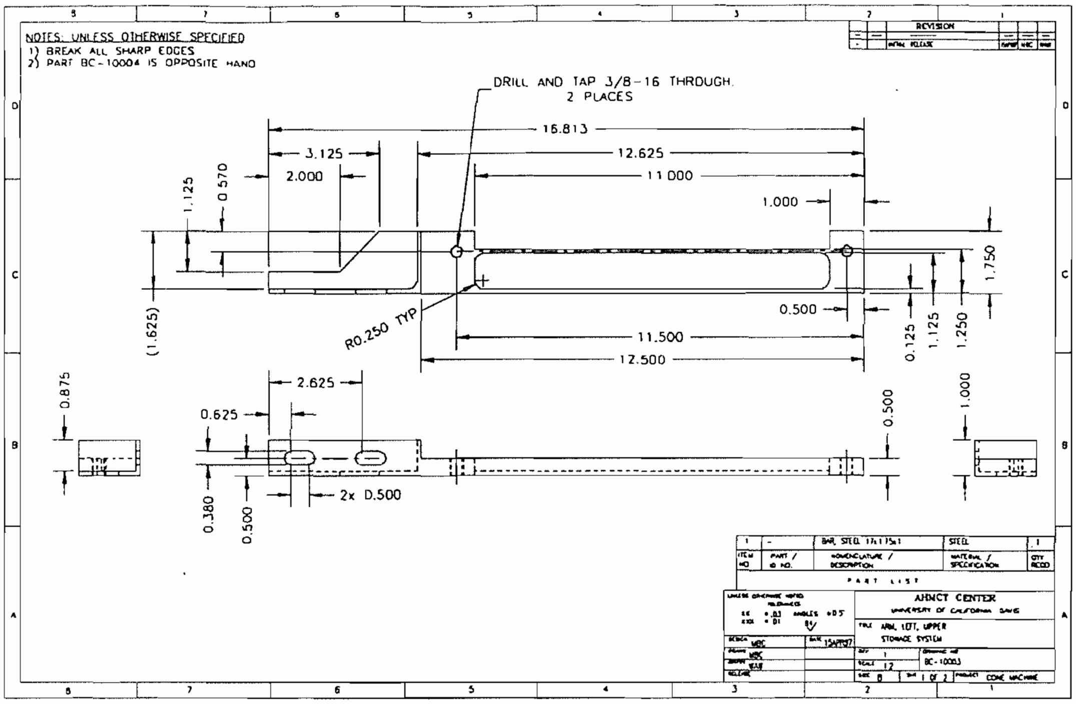


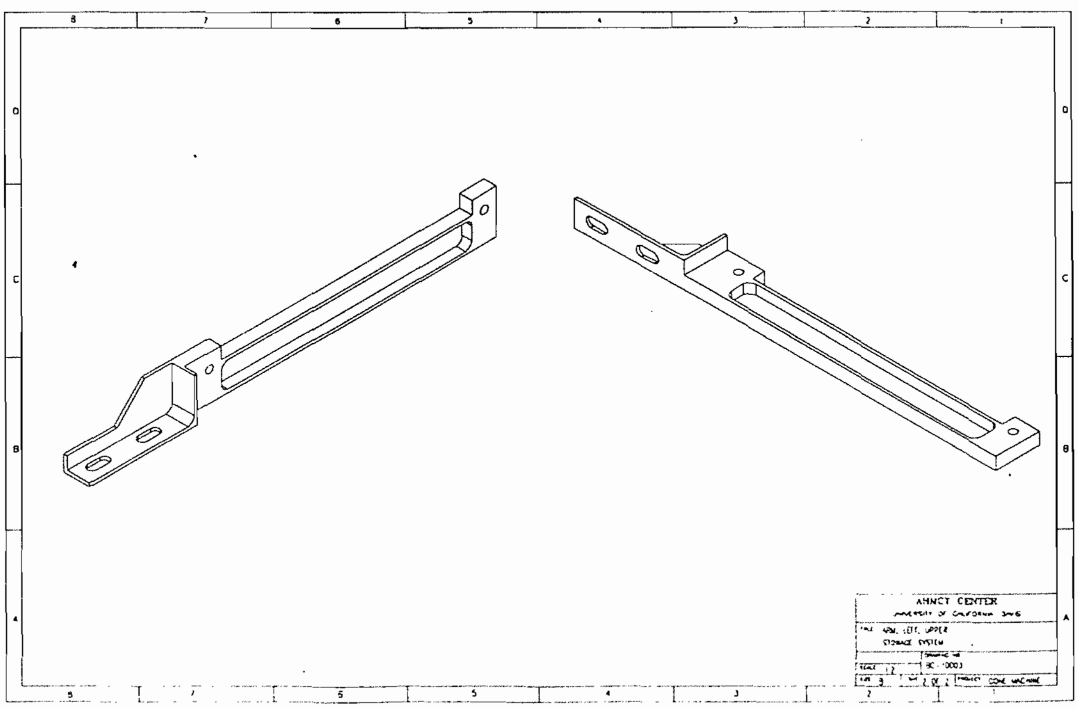
Figure A.2 *Reference Drawing for Calculation 5.2*

Appendix B


DRILL AND TAP 3/8-24 X 1.000 DEEP, 2 PLCS
1.250
2X 0.313
2X 0.625
DRILL ø 0.313 THROUGH, 2 PLCS
1.688
2.188
5.500
SECTION A-A
0.750
1.250
0.425
3.500
0.750
R0.125 TYP
1.125
3.125
DRILL AND TAP 3/8-16 THROUGH, 2 PLCS
0.500
2X 0.125
1.000
1.500
2.125
ø 0.750 THROUGH,
CBORE ø 1.000 X 0.125 DEEP 3
BOTH SIDES
2.500
1.250
0.625
0.438
4.000
0.650
NOTES:
1. BREAK ALL SHARP EDGES
2. PART BC-10002 IS OPPOSITE HAND
3 CBORE TO PRESS FIT BRONZE FLANGE BEARINGS 3/4" OD X 1/2" LENGTH (MCMASTER CARR 6338K422)
REVISION
BLOCK, STEEL
STEEL
PART LIST
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
ARM, LEFT, LOWER
STORAGE SYSTEM
BC-10001
1 OF 1
CONE MACHINE


1.250
2x 0.313
DRILL AND TAP 3/8-24 X 1.000 DEEP 2 PLCS
ø 0.750 THROUGH
CBORE ø 1.00 X 0.13 3
DEEP BOTH SIDES
A
DRILL ø 0.313 THROUGH, 2 PLCS
1.688
2.188
5.500
0.425
0.625
1.250
SECTION A-A
0.750
R0.125 TYP
3.125
1.125
2X 0.125
0.500
DRILL AND TAP 3/8-16 THROUGH 2 PLCS
0.750
3.500
1.000
0.875
1.500
2.125
2x 0.625
2.500
1.250
4.000
0.438
0.650
NOTES:
1. BREAK ALL SHARP EDGES
2. PART BC-10001 IS OPPOSITE HAND
3 CBORE TO PRESS FIT BRONZE FLANGE BEARINGS 3/4" OD X 1/2" LENGTH (MCMASTER CARR 6338K422)
REVISION
BAR, STEEL
STEEL
PART LIST
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
ARM, RIGHT, LOWER
STORAGE SYSTEM
BC-10002
1 OF 1
CONE MACHINE


NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
2) PART BC-10004 IS OPPOSITE HAND
DRILL AND TAP 3/8-16 THROUGH.
2 PLACES
16.813
3.125
12.625
2.000
11.000
1.000
R0.250 TYP
0.500
11.500
12.500
2.625
0.625
2x 0.500
AHMCT CENTER
ARM, LEFT, UPPER
STORAGE SYSTEM
BC-10003
CONE MACHINE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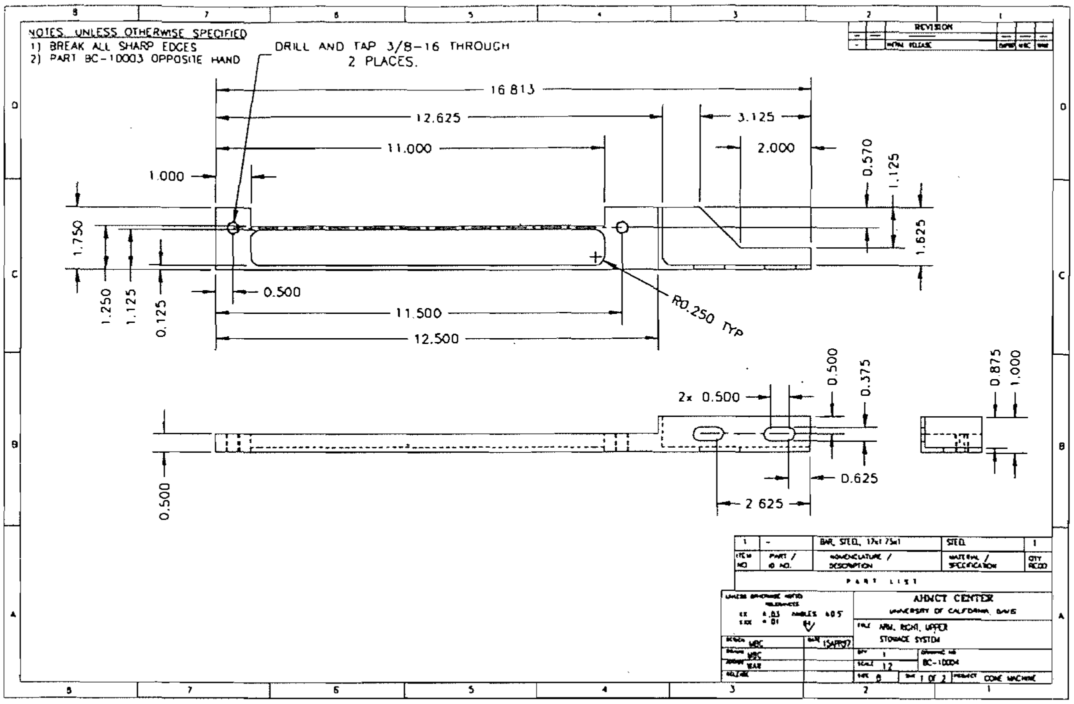
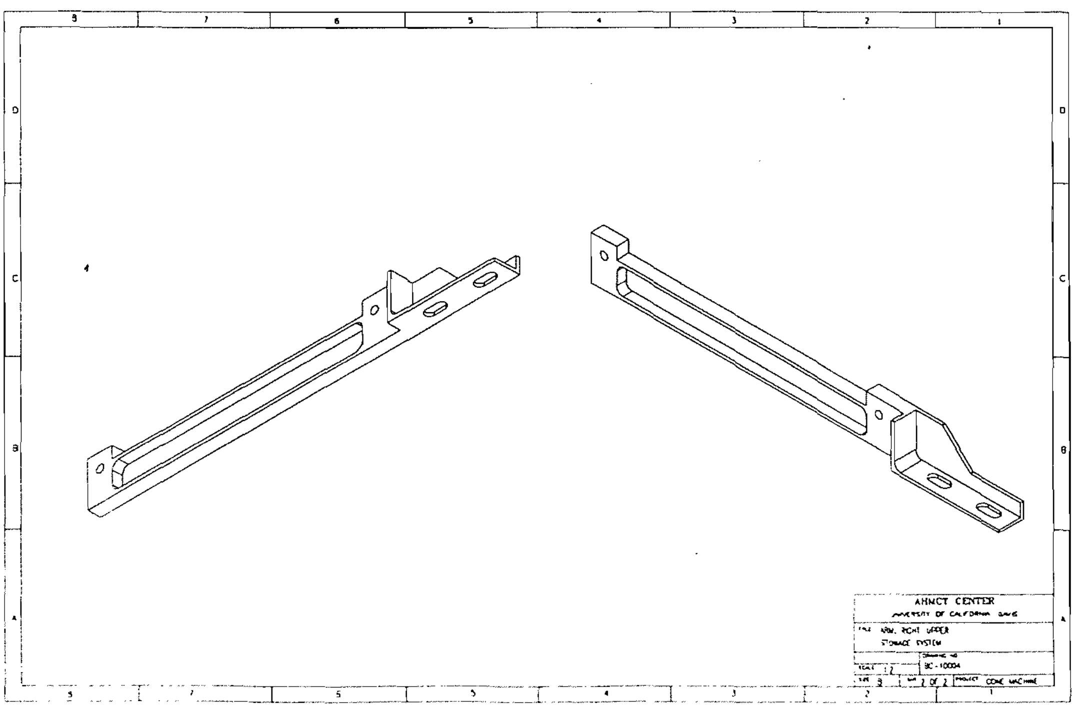
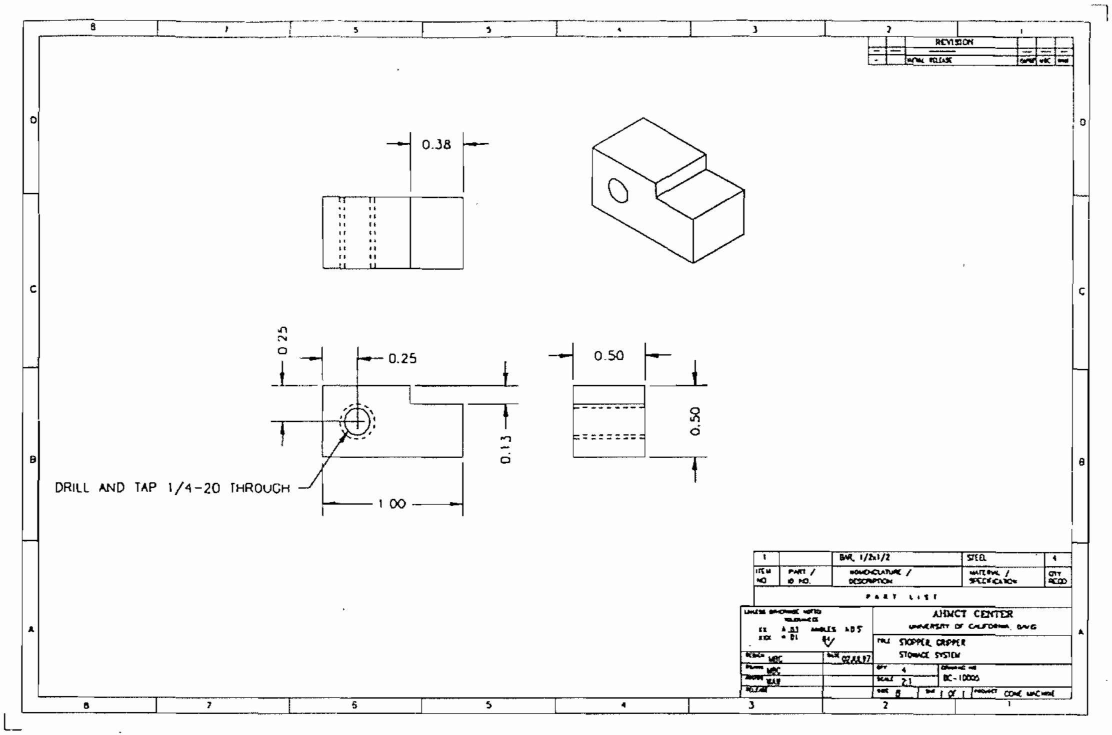
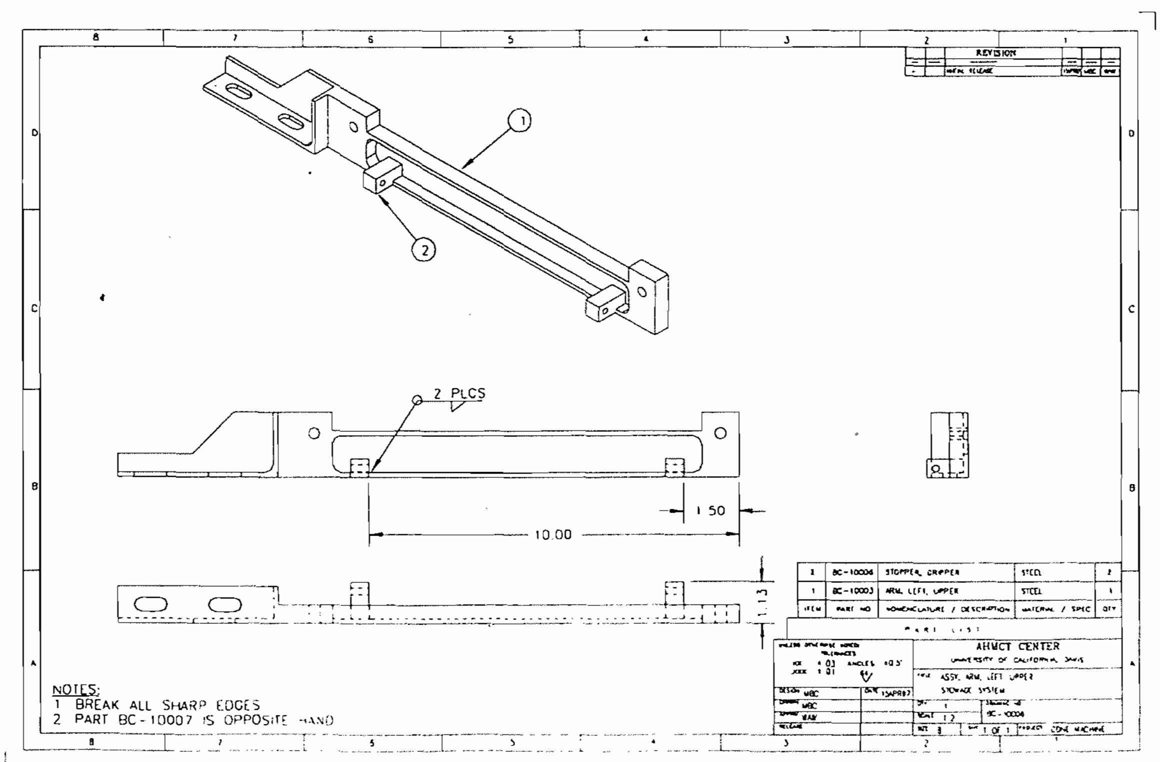
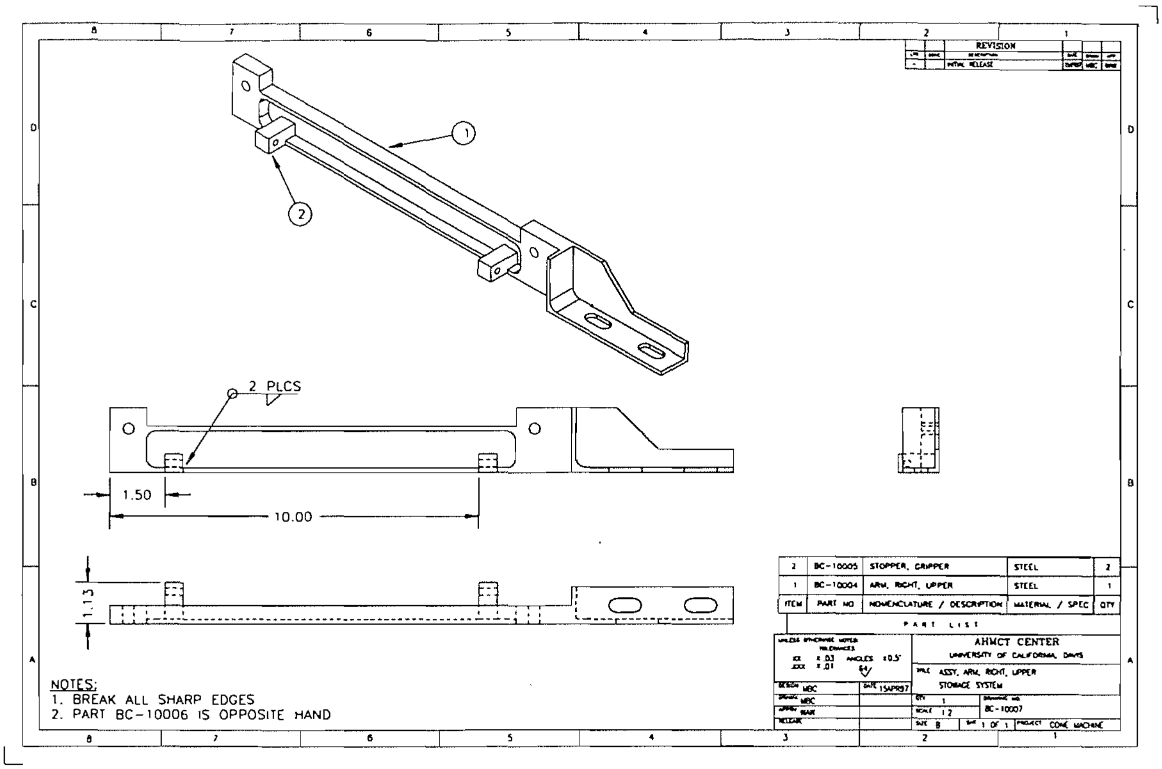
ARM, LEFT, UPPER
STORAGE SYSTEM
CONE MACHINE

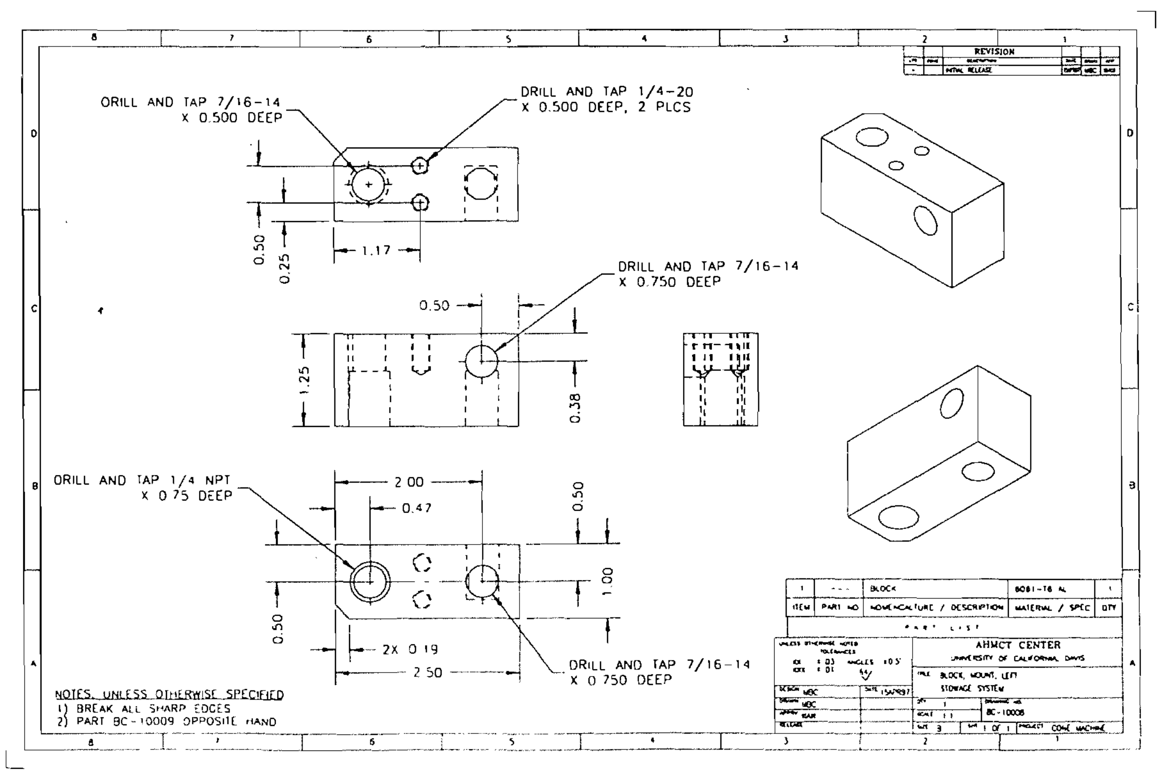

NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
2) PART BC-10003 OPPOSITE HAND
DRILL AND TAP 3/8-16 THROUGH 2 PLACES.
16.813
12.625
3.125
11.000
2.000
0.570
1.125
1.000
1.750
1.625
1.250
1.125
0.125
0.500
11.500
12.500
R0.250 TYP
2x 0.500
0.500
0.375
0.875
1.000
0.500
0.625
2.625
REVISION
AHMCT CENTER
ARM, RIGHT, UPPER
STORAGE SYSTEM
BC-10004
CONE MACHINE

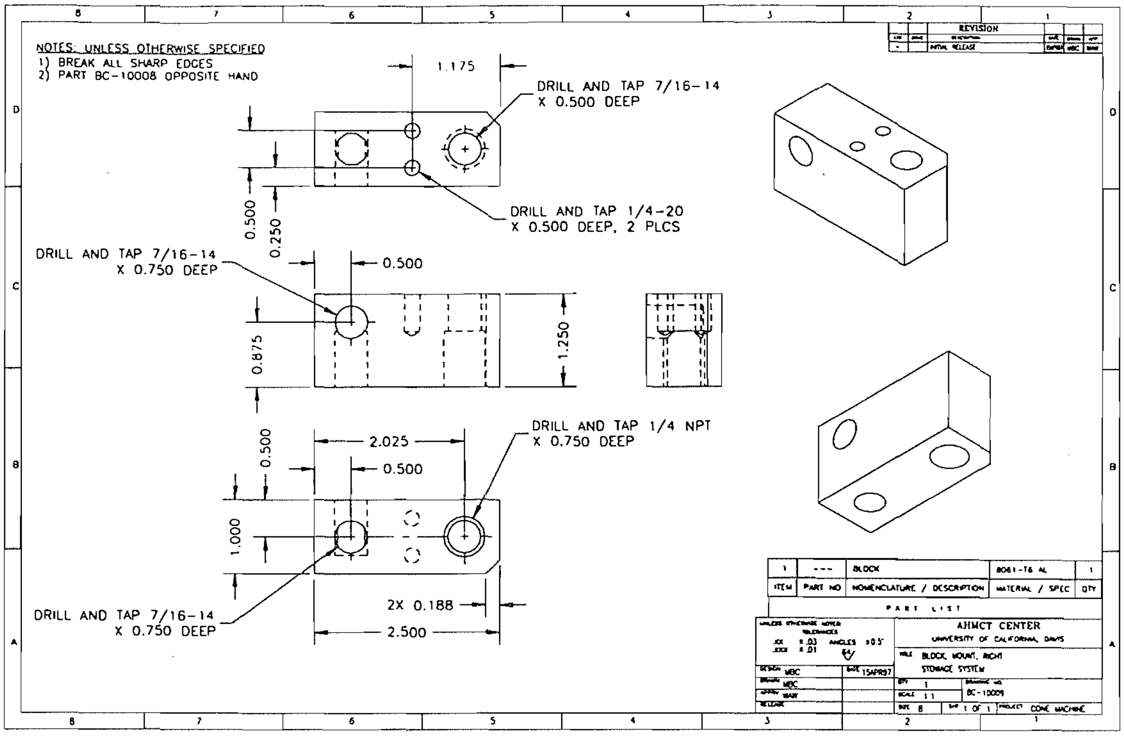

AHMCT CENTER
ARM, RIGHT UPPER
STORAGE SYSTEM
BC-10004
CONE MACHINE

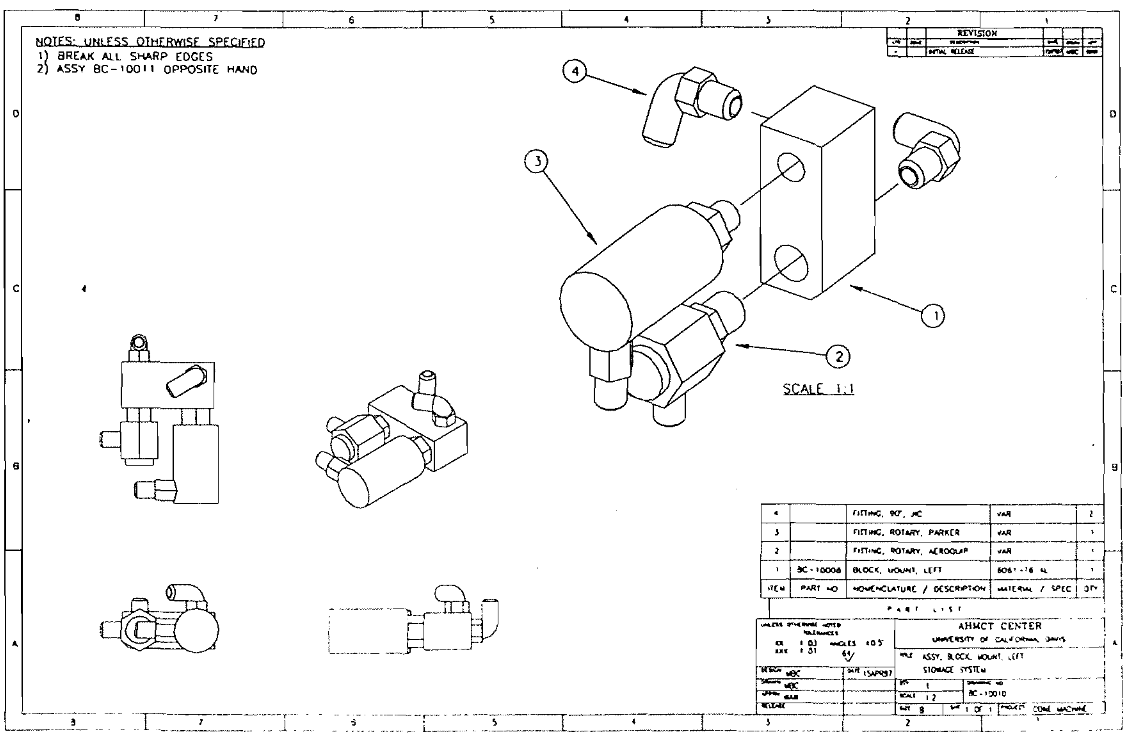

0.38
0.25
0.25
0.50
0.13
0.50
DRILL AND TAP 1/4-20 THROUGH
1.00
AHMCT CENTER
STOPPER, GRIPPER
STOWAGE SYSTEM
BC-10006

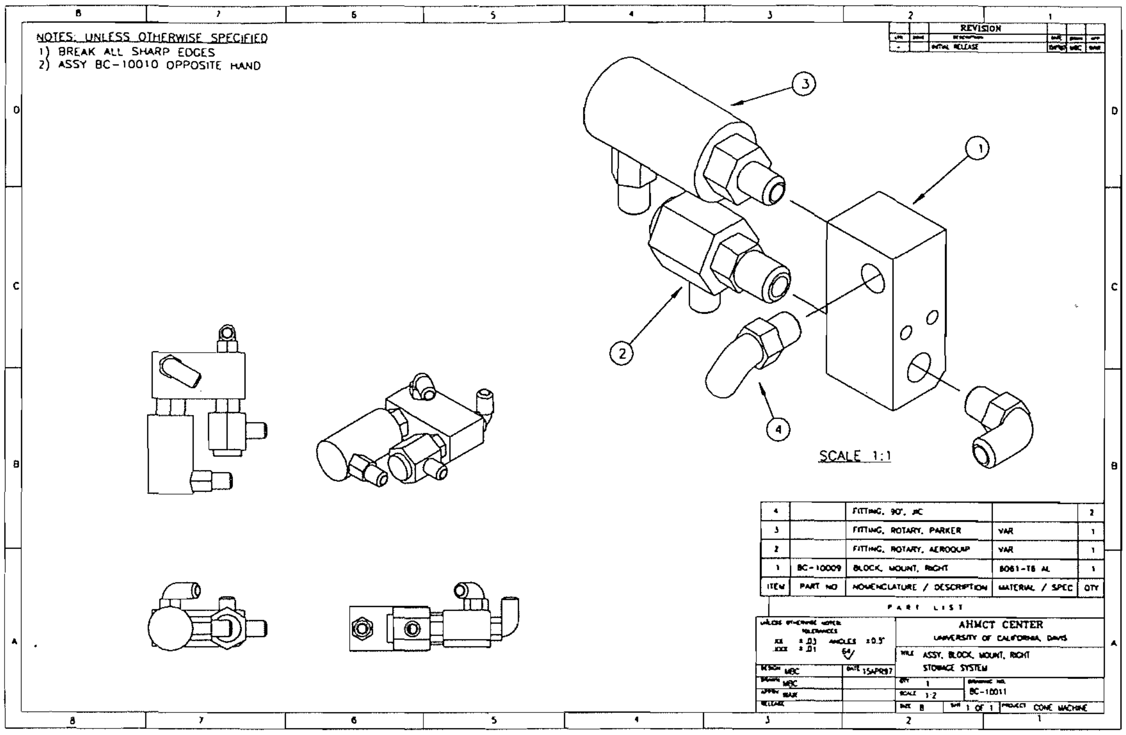

1
2
2 PLCS
1.50
10.00
1.13
NOTES:
1 BREAK ALL SHARP EDGES
2 PART BC-10007 IS OPPOSITE HAND
AHMCT CENTER

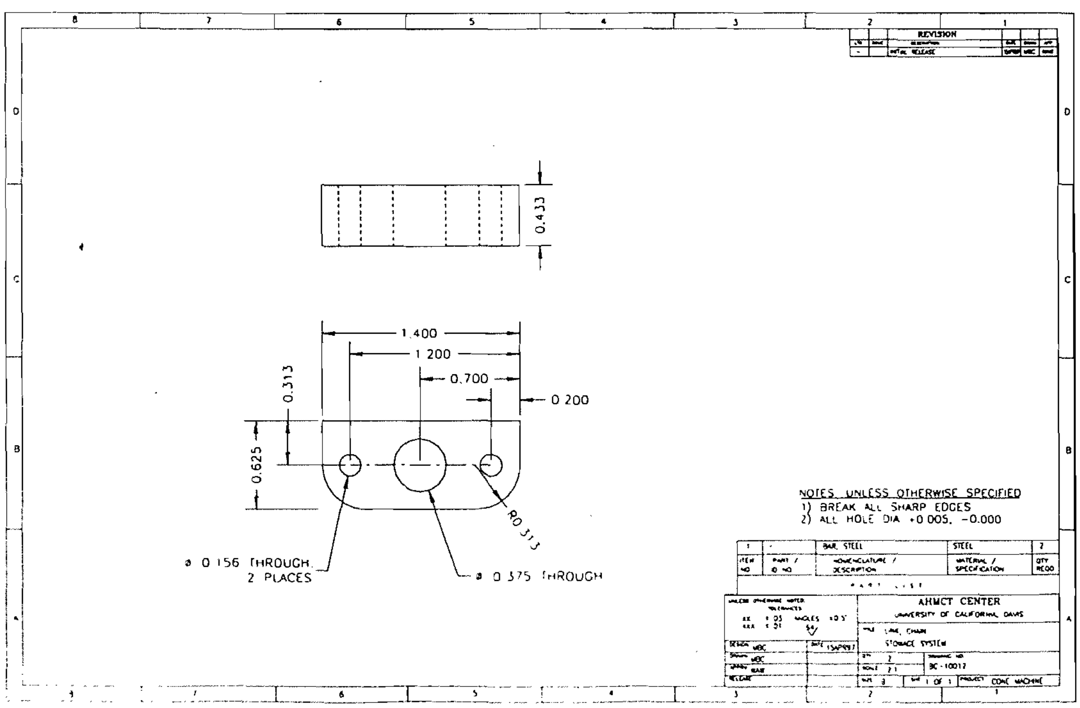

REVISION
INITIAL RELEASE
2 PLCS
1.50
10.00
1.13
2 | BC-10005 | STOPPER, GRIPPER | STEEL | 2
1 | BC-10004 | ARM, RIGHT, UPPER | STEEL | 1
ITEM | PART NO | NOMENCLATURE / DESCRIPTION | MATERIAL / SPEC | QTY
PART LIST
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
ASSY, ARM, RIGHT, UPPER
STOWAGE SYSTEM
.XX ±.03 ANGLES ±0.5°
.XXX ±.01
DESIGN MBC
DATE 15APR97
DRAWN MBC
QTY 1
DRAWING NO BC-10007
SCALE 1 2
SIZE B
SHT 1 OF 1
PROJECT CONE MACHINE
NOTES:
1. BREAK ALL SHARP EDGES
2. PART BC-10006 IS OPPOSITE HAND

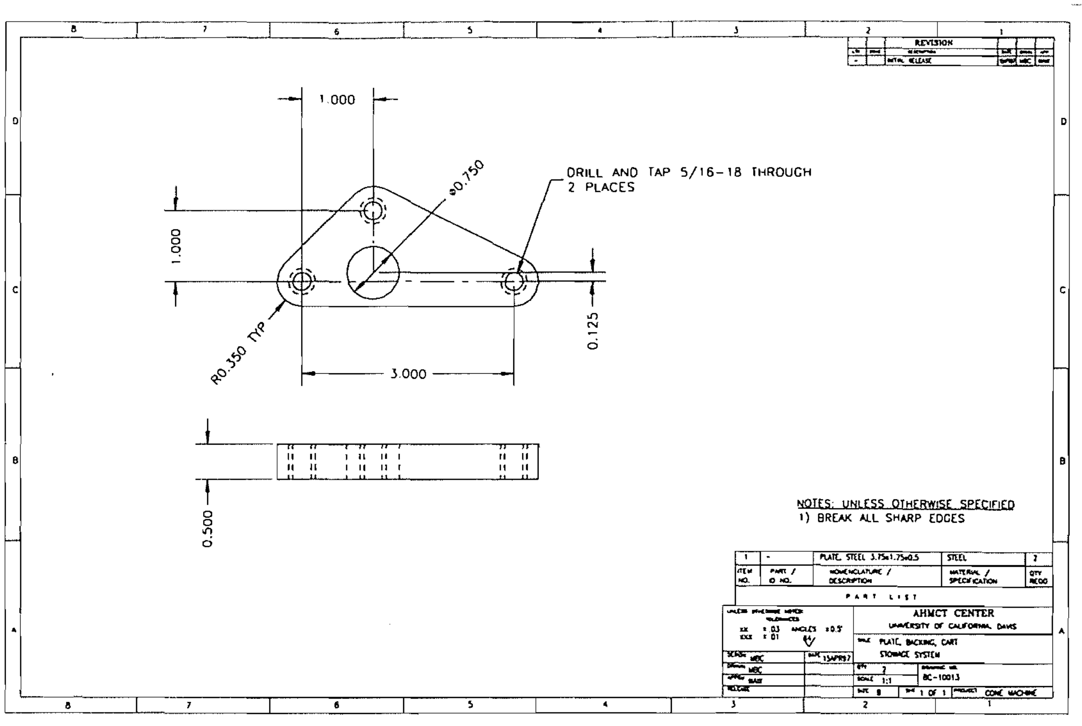

REVISION
INITIAL RELEASE
DRILL AND TAP 7/16-14
X 0.500 DEEP
DRILL AND TAP 1/4-20
X 0.500 DEEP, 2 PLCS
0.50
0.25
1.17
DRILL AND TAP 7/16-14
X 0.750 DEEP
0.50
1.25
0.38
DRILL AND TAP 1/4 NPT
X 0.75 DEEP
2.00
0.47
0.50
1.00
0.50
2X 0.19
2.50
DRILL AND TAP 7/16-14
X 0.750 DEEP
1 | --- | BLOCK | 6061-T6 AL | 1
ITEM | PART NO | NOMENCLATURE / DESCRIPTION | MATERIAL / SPEC | QTY
PART LIST
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
BLOCK, MOUNT, LEFT
STOWAGE SYSTEM
DESIGN MBC
DATE 15APR97
DRAWN MBC
QTY 1
DRAWING NO BC-10008
SCALE 1 1
SIZE B
SHT 1 OF 1
PROJECT CONE MACHINE
NOTES, UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
2) PART BC-10009 OPPOSITE HAND

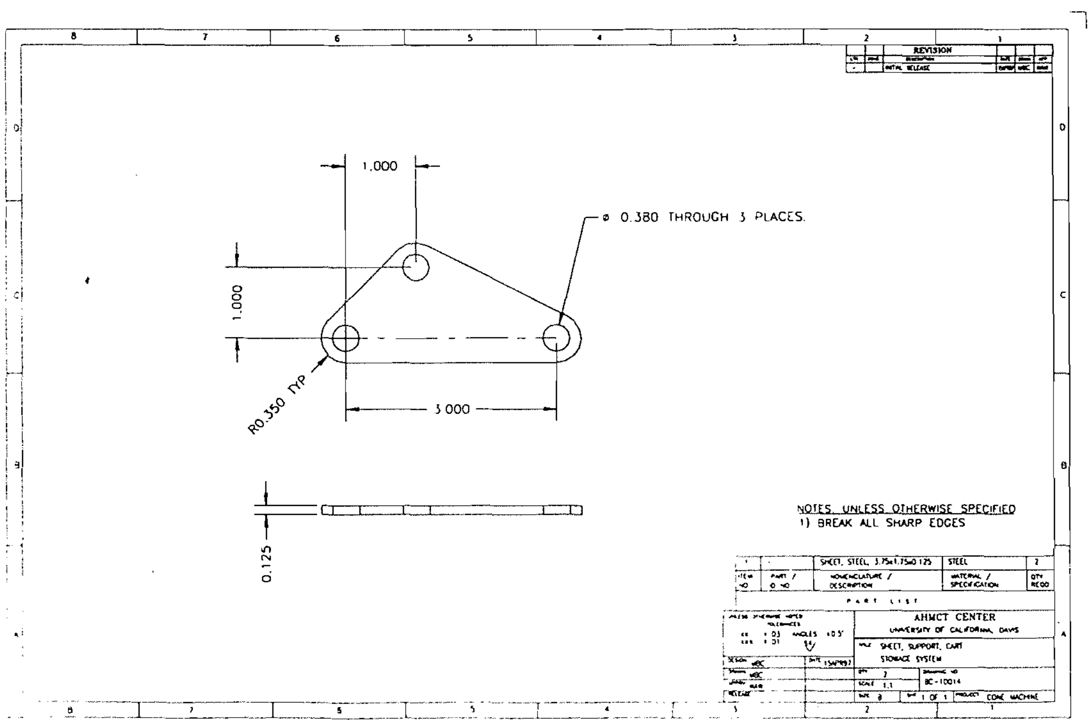

NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
2) PART BC-10008 OPPOSITE HAND
1.175
DRILL AND TAP 7/16-14
X 0.500 DEEP
0.500
0.250
DRILL AND TAP 1/4-20
X 0.500 DEEP, 2 PLCS
DRILL AND TAP 7/16-14
X 0.750 DEEP
0.500
0.875
1.250
DRILL AND TAP 1/4 NPT
X 0.750 DEEP
0.500
2.025
0.500
1.000
DRILL AND TAP 7/16-14
X 0.750 DEEP
2X 0.188
2.500
REVISION
INITIAL RELEASE
BLOCK
6061-T6 AL
ITEM
PART NO
NOMENCLATURE / DESCRIPTION
MATERIAL / SPEC
QTY
PART LIST
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
BLOCK, MOUNT, RIGHT
STOWAGE SYSTEM
BC-10009
CONE MACHINE

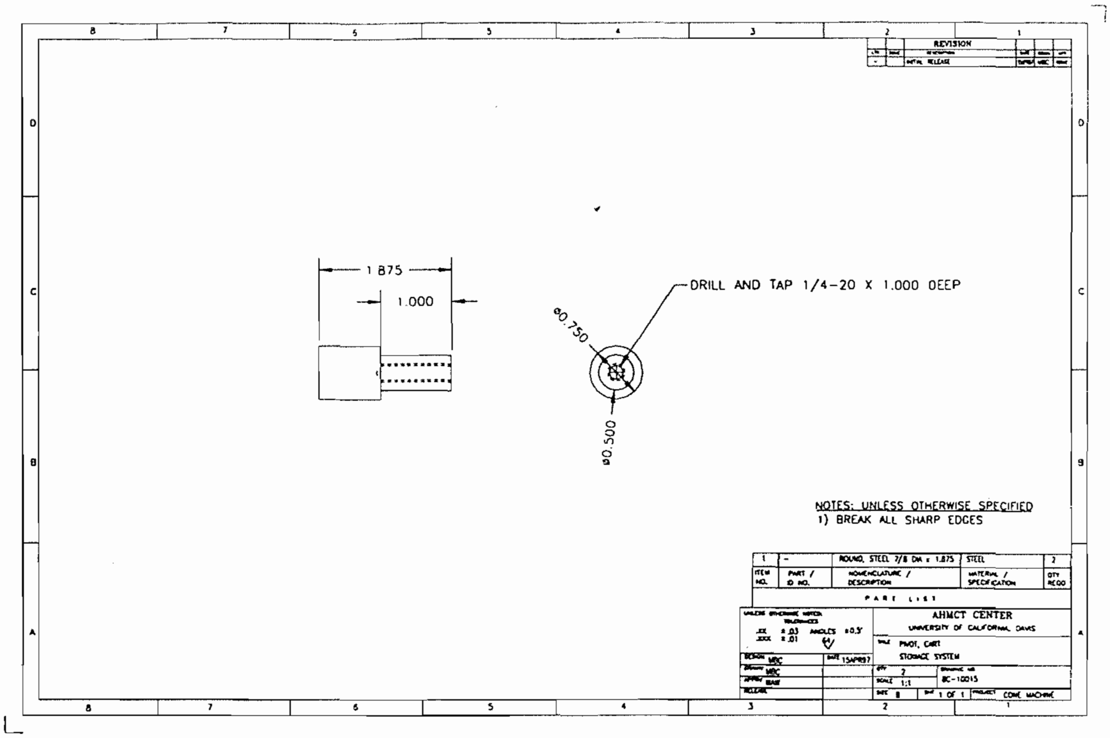

NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
2) ASSY BC-10011 OPPOSITE HAND
4
3
1
2
SCALE 1:1
REVISION
INITIAL RELEASE
FITTING, 90°, JIC
FITTING, ROTARY, PARKER
FITTING, ROTARY, AEROQUIP
BC-10008
BLOCK, MOUNT, LEFT
6061-T6 AL
ITEM
PART NO
NOMENCLATURE / DESCRIPTION
MATERIAL / SPEC
QTY
PART LIST
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
ASSY, BLOCK, MOUNT, LEFT
STOWAGE SYSTEM
BC-10010
CONE MACHINE

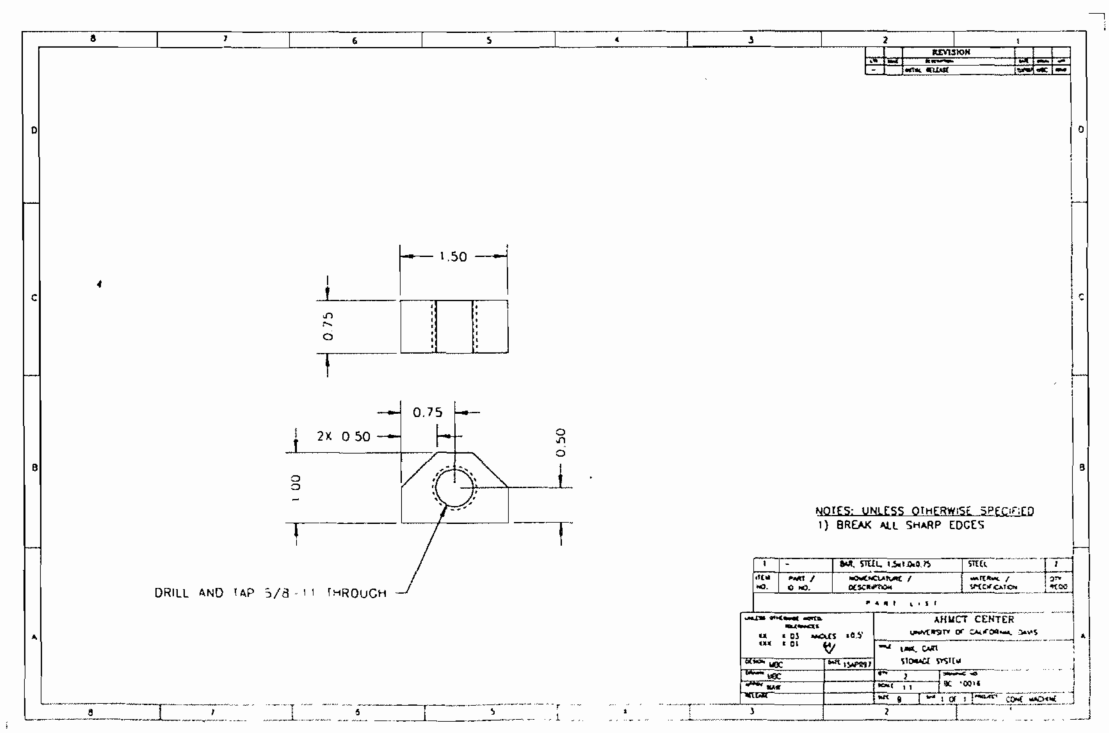

NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
2) ASSY BC-10010 OPPOSITE HAND
REVISION
INITIAL RELEASE
SCALE 1:1
FITTING, 90°, JIC
FITTING, ROTARY, PARKER
FITTING, ROTARY, AEROQUIP
BC-10009 BLOCK, MOUNT, RIGHT
6061-T6 AL
ITEM PART NO NOMENCLATURE / DESCRIPTION MATERIAL / SPEC QTY
PART LIST
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
ASSY, BLOCK, MOUNT, RIGHT
STOWAGE SYSTEM
15APR97
BC-10011
CONE MACHINE

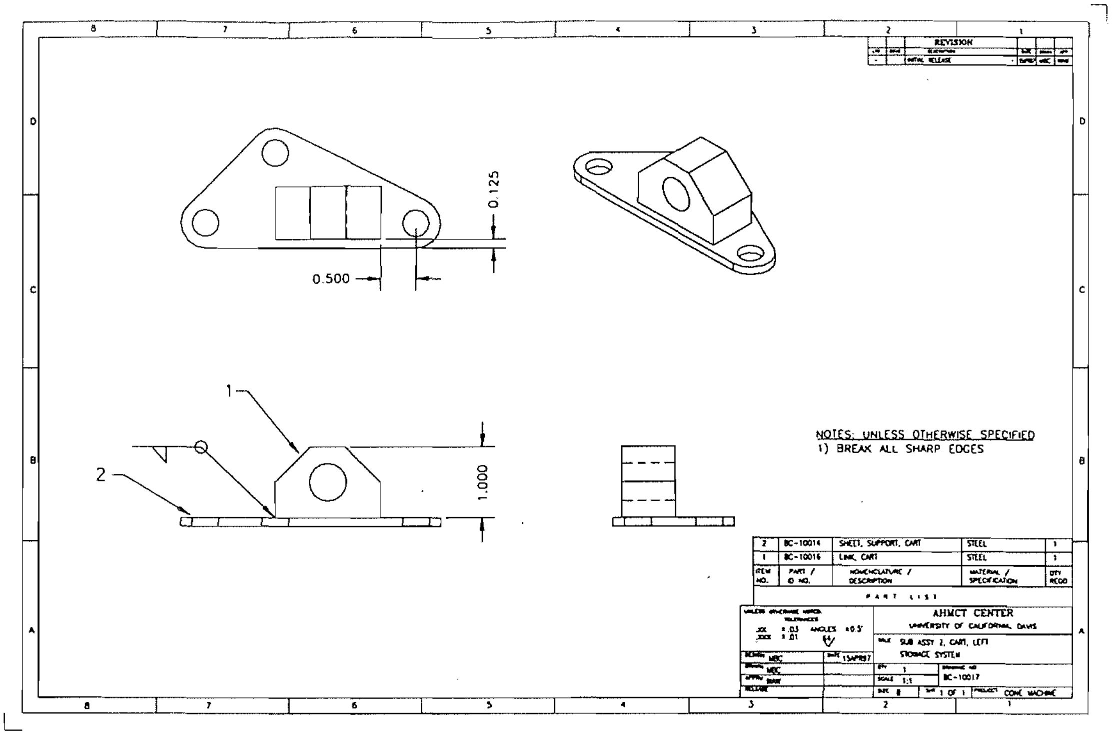

REVISION
INITIAL RELEASE
0.433
1.400
1.200
0.700
0.200
0.313
0.625
R0.313
⌀ 0.156 THROUGH, 2 PLACES
⌀ 0.375 THROUGH
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
2) ALL HOLE DIA +0.005, -0.000
BAR, STEEL
STEEL
PART LIST
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
STOWAGE SYSTEM
15APR97
BC-10012
CONE MACHINE

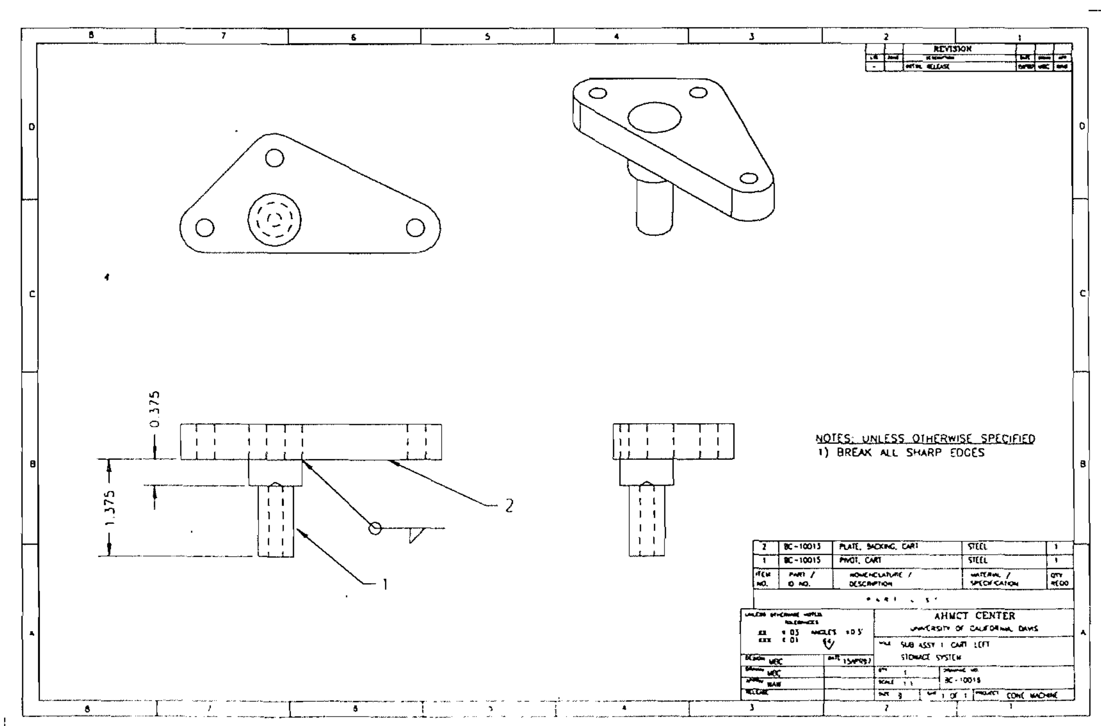

1.000
DRILL AND TAP 5/16-18 THROUGH
2 PLACES
⌀0.750
1.000
0.125
R0.350 TYP
3.000
0.500
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
PLATE, STEEL 3.75x1.75x0.5
STEEL
PART LIST
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
PLATE, BACKING, CART
STOWAGE SYSTEM
BC-10013
CONE MACHINE

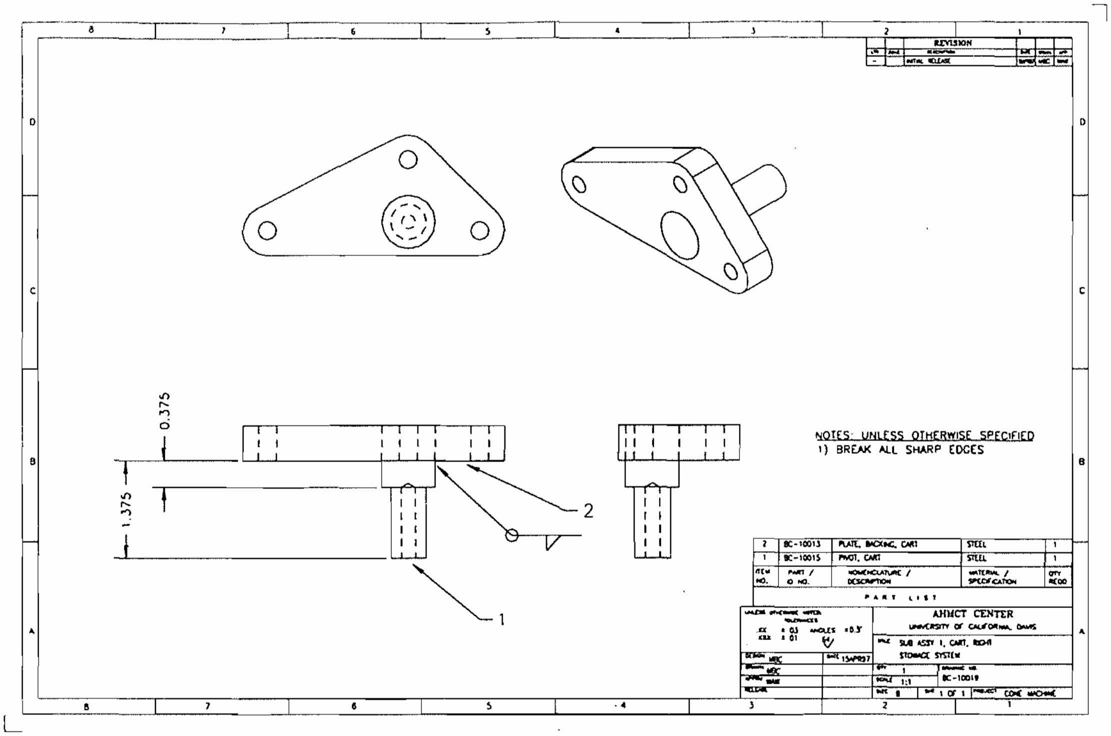

1.000
⌀ 0.380 THROUGH 3 PLACES.
1.000
R0.350 TYP
3.000
0.125
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
SHEET, STEEL 3.75x1.75x0.125
STEEL
PART LIST
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
SHEET, SUPPORT, CART
STOWAGE SYSTEM
BC-10014
CONE MACHINE

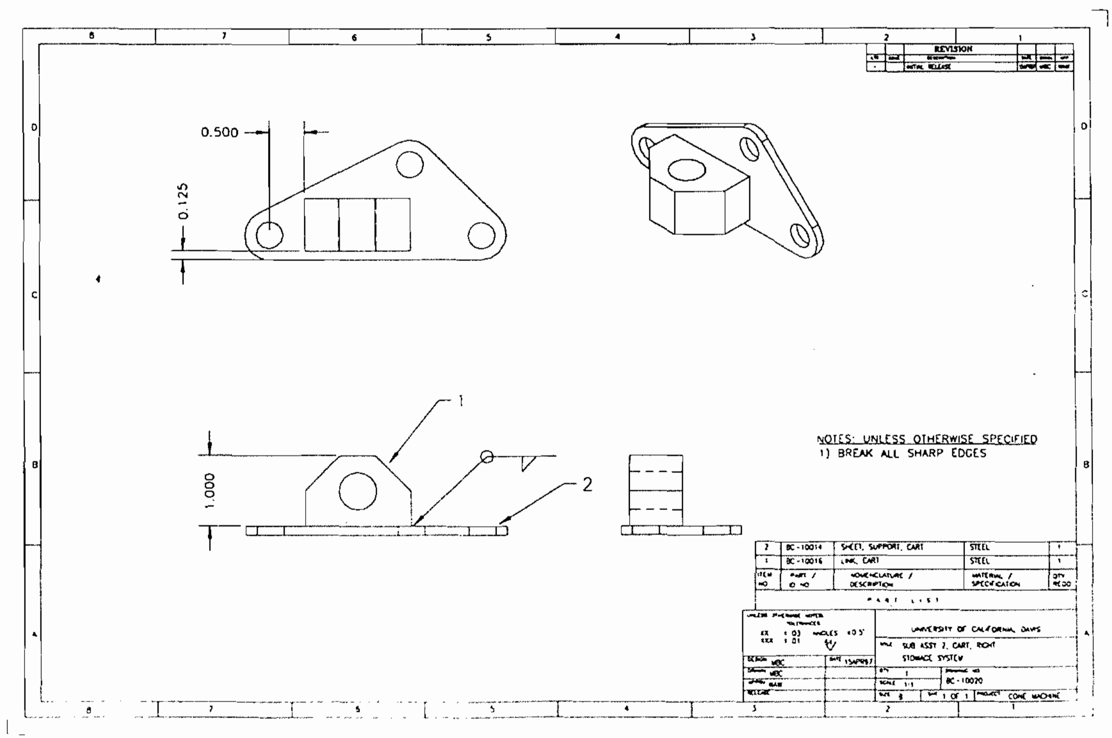

1.875
1.000
DRILL AND TAP 1/4-20 X 1.000 DEEP
ø0.750
ø0.500
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
ROUND, STEEL 7/8 DIA x 1.875
STEEL
PART LIST
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
PIVOT, CART
STORAGE SYSTEM
15APR97
1:1
1 OF 1
CONE MACHINE

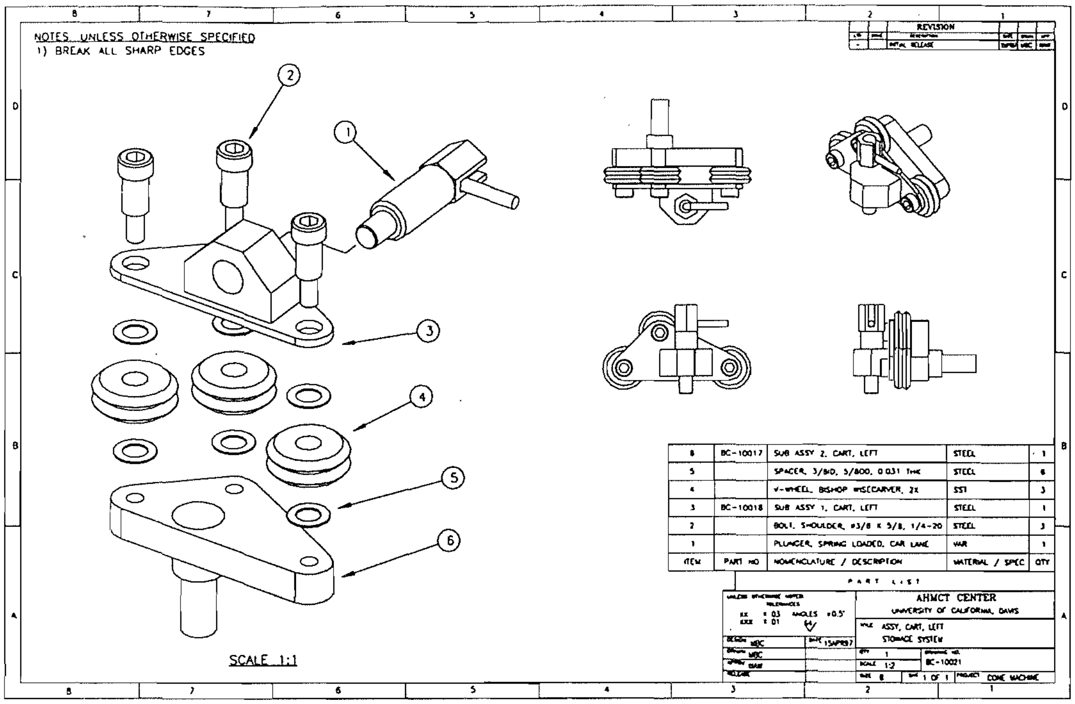

1.50
0.75
0.75
2X 0.50
1.00
0.50
DRILL AND TAP 5/8-11 THROUGH
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
STEEL
PART LIST
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
STORAGE SYSTEM
15APR97
1 OF 1
CONE MACHINE

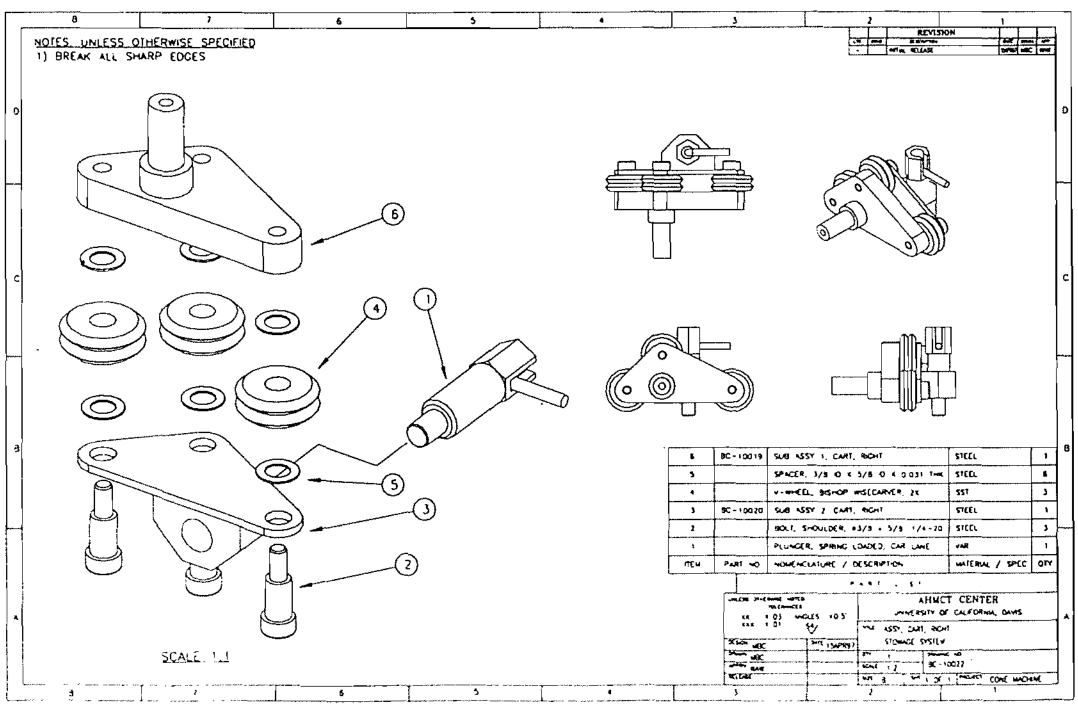

REVISION
INITIAL RELEASE
0.125
0.500
1
2
1.000
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
2 BC-10014 SHEET, SUPPORT, CART STEEL 1
1 BC-10016 LINK, CART STEEL 1
ITEM NO. PART / ID NO. NOMENCLATURE / DESCRIPTION MATERIAL / SPECIFICATION QTY REQD
PART LIST
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
SUB ASSY 2, CART, LEFT
STORAGE SYSTEM
BC-10017
SCALE 1:1
1 OF 1
CONC MACHINE

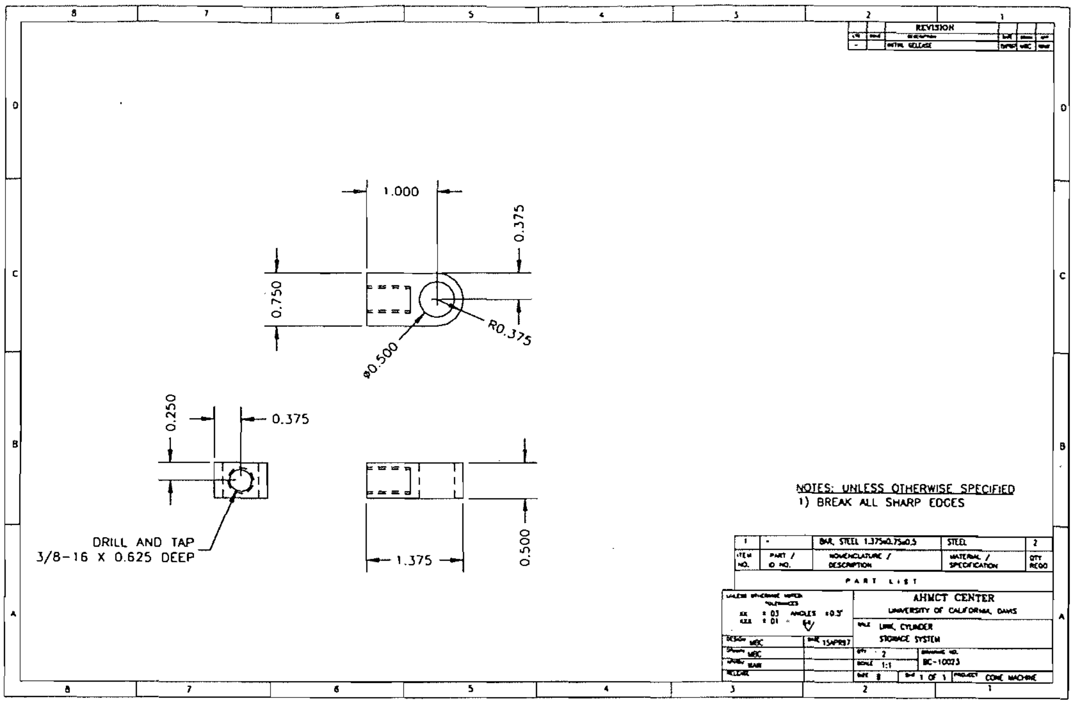

REVISION
INITIAL RELEASE
0.375
1.375
2
1
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
2 BC-10013 PLATE, BACKING, CART STEEL 1
1 BC-10015 PIVOT, CART STEEL 1
ITEM NO. PART / ID NO. NOMENCLATURE / DESCRIPTION MATERIAL / SPECIFICATION QTY REQD
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
SUB ASSY 1 CART LEFT
STORAGE SYSTEM
BC-10015
1 OF 1
CONC MACHINE

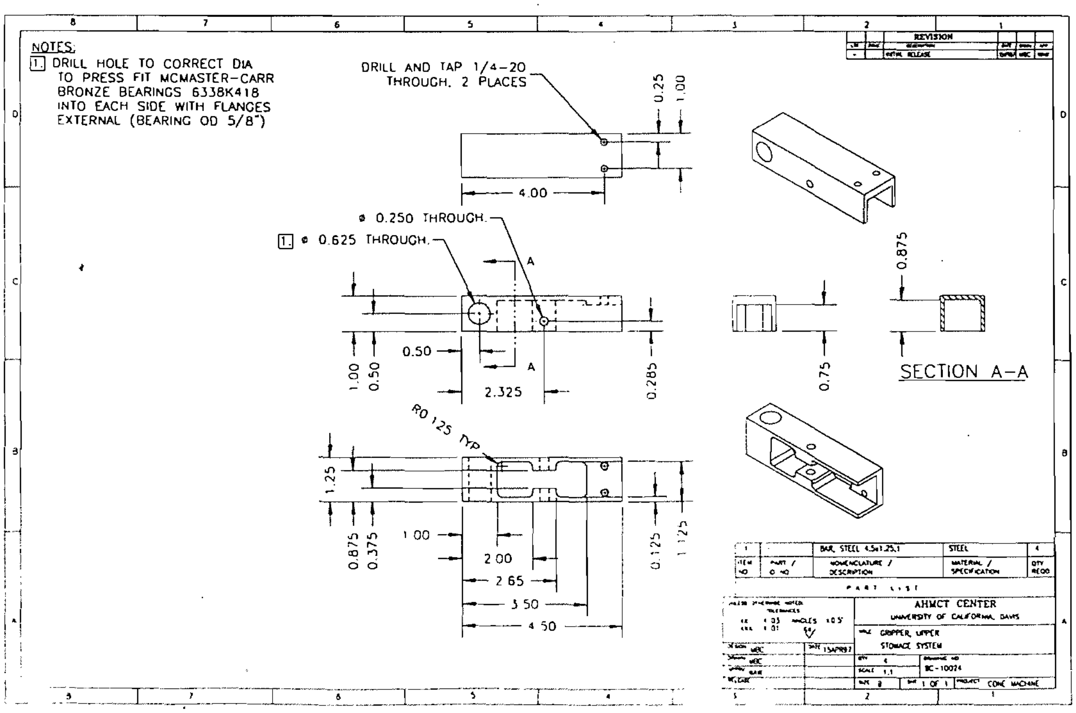

0.375
1.375
2
1
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
2 BC-10013 PLATE, BACKING, CART STEEL 1
1 BC-10015 PIVOT, CART STEEL 1
ITEM NO. PART / ID NO. NOMENCLATURE / DESCRIPTION MATERIAL / SPECIFICATION QTY REQD
PART LIST
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
SUB ASSY 1, CART, RIGHT
STORAGE SYSTEM
15APR97
1:1
BC-10019
1 OF 1
CONE MACHINE

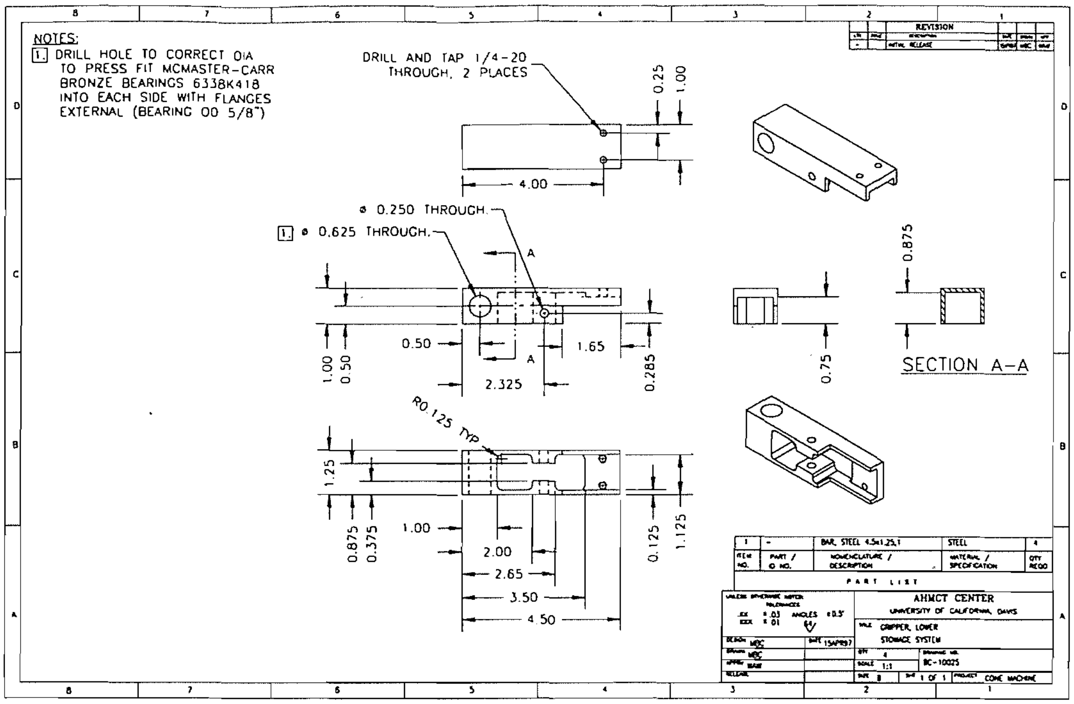

0.500
0.125
1.000
1
2
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
2 BC-10014 SHEET, SUPPORT, CART STEEL 1
1 BC-10016 LINK, CART STEEL 1
ITEM NO. PART / ID NO. NOMENCLATURE / DESCRIPTION MATERIAL / SPECIFICATION QTY REQD
PART LIST
UNIVERSITY OF CALIFORNIA, DAVIS
SUB ASSY 2, CART, RIGHT
STORAGE SYSTEM
1:1
BC-10020
1 OF 1
CONE MACHINE

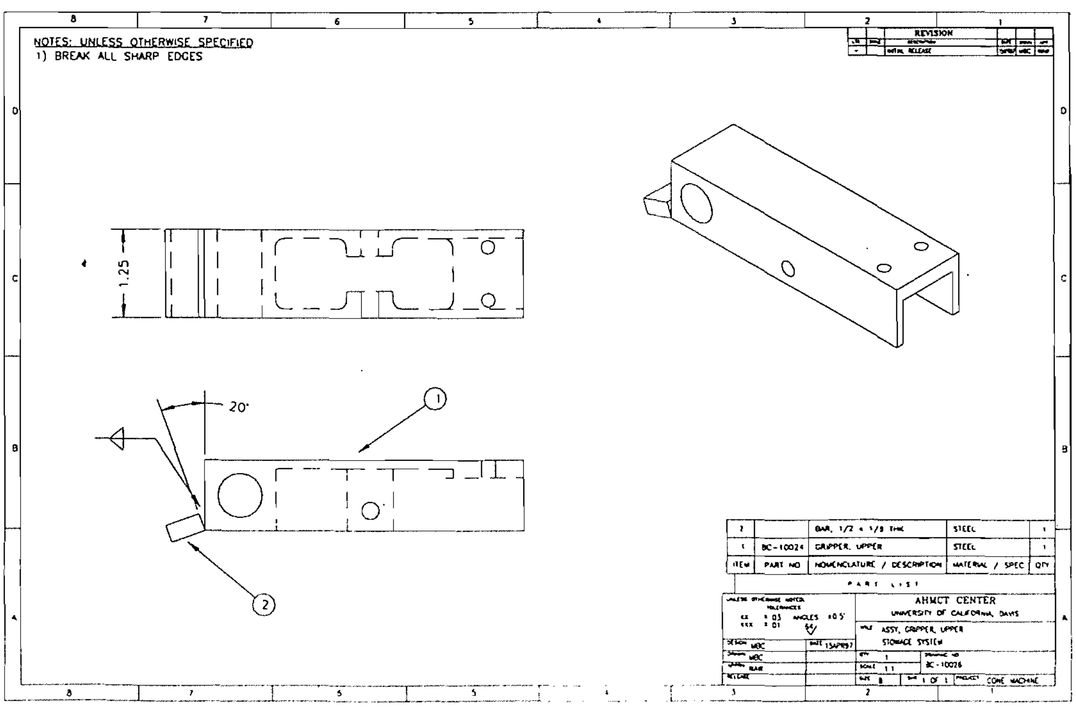

NOTES UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
REVISION
INITIAL RELEASE
6 | BC-10017 | SUB ASSY 2, CART, LEFT | STEEL | 1
5 | | SPACER, 3/8ID, 5/8OD, 0.031 THK | STEEL | 6
4 | | V-WHEEL, BISHOP WISECARVER, 2X | SST | 3
3 | BC-10018 | SUB ASSY 1, CART, LEFT | STEEL | 1
2 | | BOLT, SHOULDER, #3/8 X 5/8, 1/4-20 | STEEL | 3
1 | | PLUNGER, SPRING LOADED, CAR LANE | VAR | 1
ITEM | PART NO | NOMENCLATURE / DESCRIPTION | MATERIAL / SPEC | QTY
PART LIST
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
ASSY, CART, LEFT
STORAGE SYSTEM
15APR97
1
1:2
BC-10021
1 OF 1
CONE MACHINE
SCALE 1:1

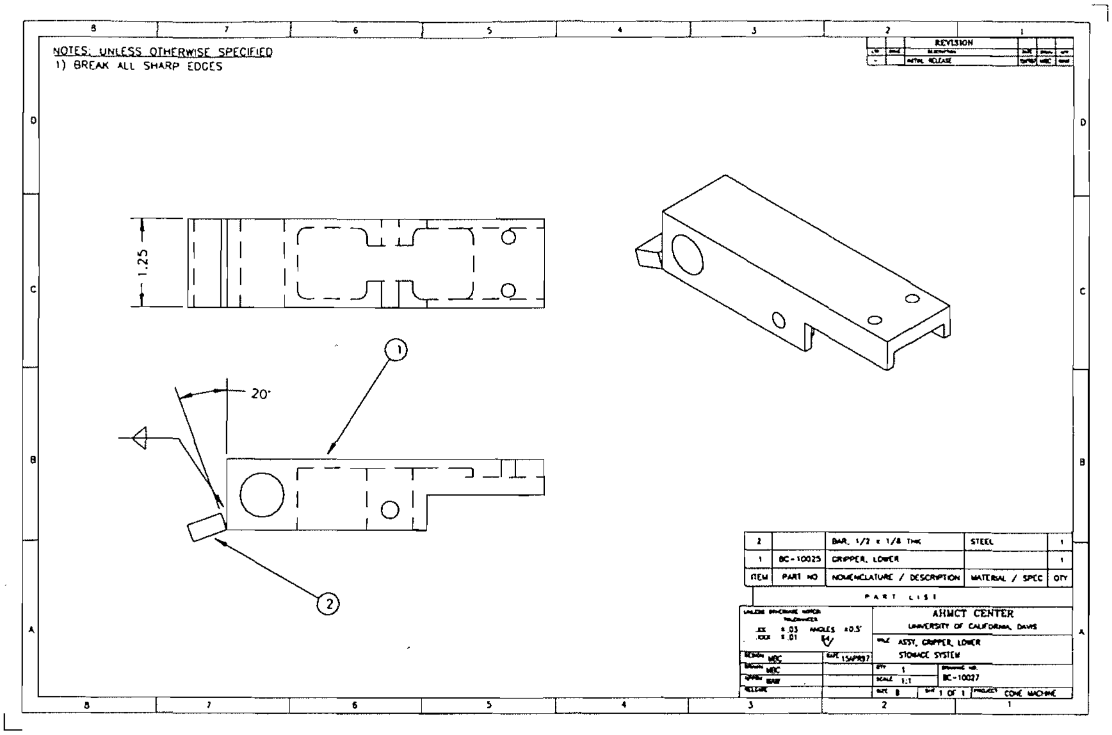

NOTES UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
REVISION
INITIAL RELEASE
6 | BC-10019 | SUB ASSY 1, CART, RIGHT | STEEL | 1
5 | | SPACER, 3/8 ID X 5/8 OD X 0.031 THK | STEEL | 6
4 | | V-WHEEL, BISHOP WISECARVER, 2X | SST | 3
3 | BC-10020 | SUB ASSY 2 CART, RIGHT | STEEL | 1
2 | | BOLT, SHOULDER, #3/8 X 5/8 1/4-20 | STEEL | 3
1 | | PLUNGER, SPRING LOADED, CAR LANE | VAR | 1
ITEM | PART NO | NOMENCLATURE / DESCRIPTION | MATERIAL / SPEC | QTY
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
ASSY, CART, RIGHT
STORAGE SYSTEM
15APR97
CONE MACHINE
SCALE 1:1

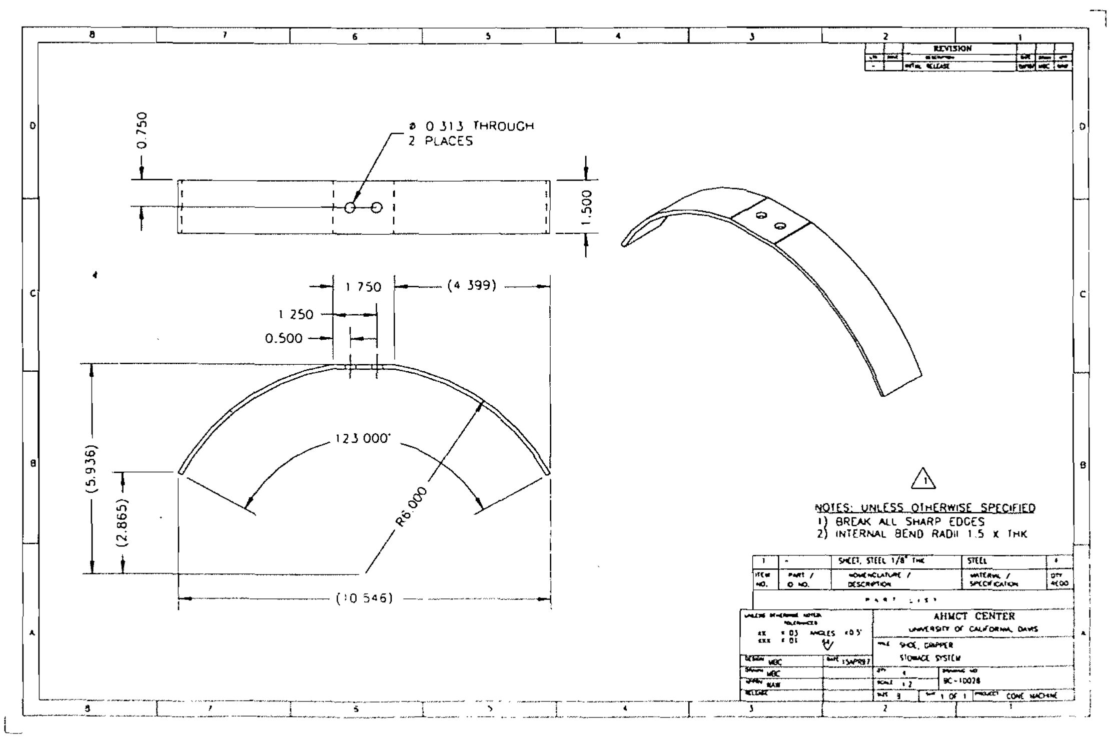

1.000
0.375
0.750
R0.375
Φ0.500
0.250
0.375
DRILL AND TAP
3/8-16 X 0.625 DEEP
1.375
0.500
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
PART LIST
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
LINK, CYLINDER
STORAGE SYSTEM
BC-10023
SCALE 1:1
1 OF 1
CONE MACHINE

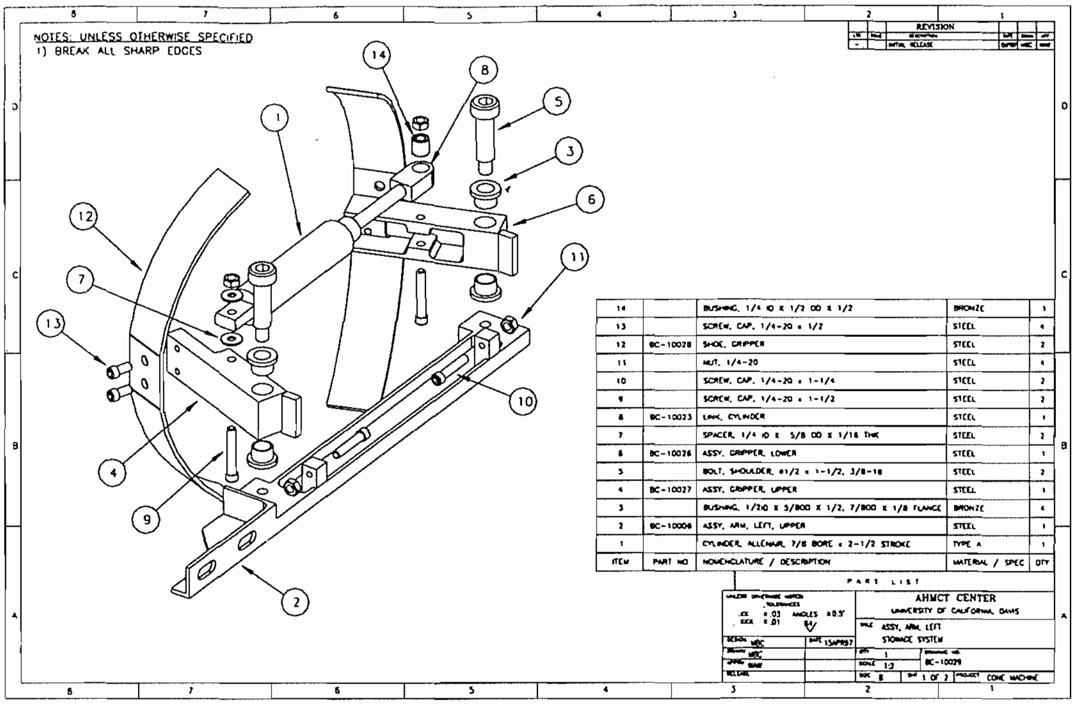

NOTES:
1. DRILL HOLE TO CORRECT DIA TO PRESS FIT MCMASTER-CARR BRONZE BEARINGS 6338K418 INTO EACH SIDE WITH FLANGES EXTERNAL (BEARING OD 5/8")
DRILL AND TAP 1/4-20 THROUGH, 2 PLACES
0.25
1.00
4.00
ø 0.250 THROUGH
1. ø 0.625 THROUGH
0.50
1.00
0.50
2.325
0.285
0.875
0.75
SECTION A-A
R0.125 TYP
1.25
0.875
0.375
1.00
2.00
2.65
3.50
4.50
0.125
1.125
PART LIST
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
GRIPPER, UPPER
STORAGE SYSTEM
BC-10024
1 OF 1
CONE MACHINE


NOTES:
1. DRILL HOLE TO CORRECT DIA TO PRESS FIT MCMASTER-CARR BRONZE BEARINGS 6338K418 INTO EACH SIDE WITH FLANGES EXTERNAL (BEARING OD 5/8")
DRILL AND TAP 1/4-20 THROUGH, 2 PLACES
0.25
1.00
4.00
ø 0.250 THROUGH
1. ø 0.625 THROUGH
0.875
0.50
1.65
1.00
0.50
2.325
0.285
0.75
SECTION A-A
R0.125 TYP
1.25
0.875
0.375
1.00
2.00
2.65
3.50
4.50
0.125
1.125
BAR, STEEL 4.5x1.25.1
STEEL
PART LIST
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
GRIPPER, LOWER
STORAGE SYSTEM
BC-10025
1:1
CONE MACHINE

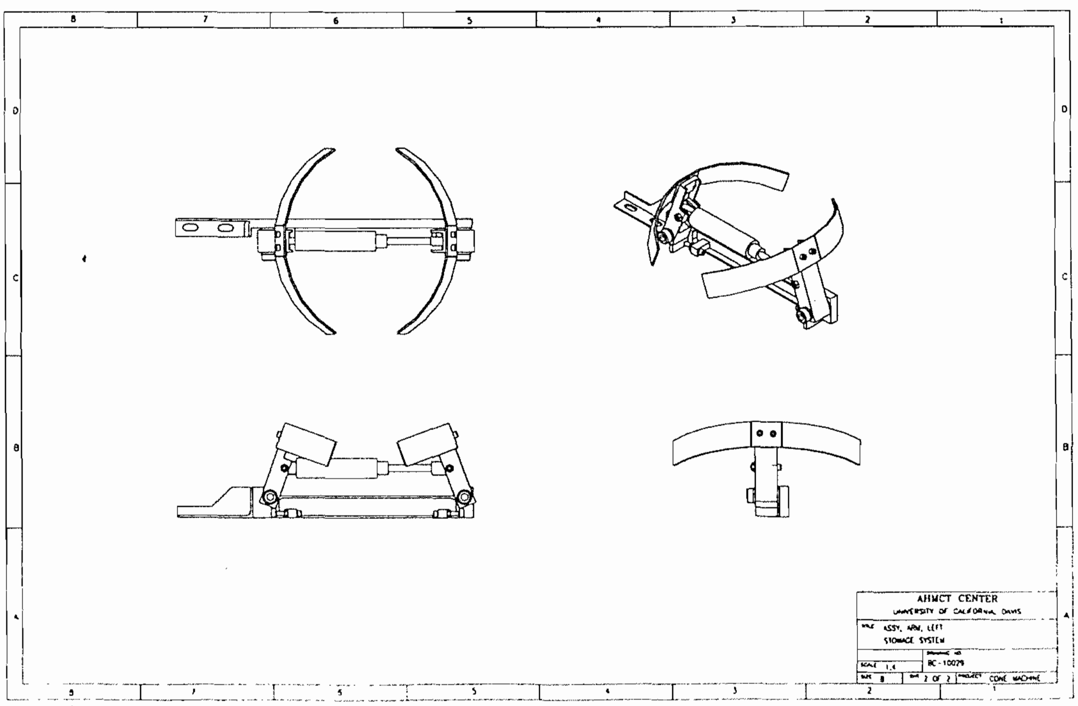

NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
1.25
20°
1
2
BAR, 1/2 x 1/8 THK
STEEL
BC-10024
GRIPPER, UPPER
STEEL
ITEM
PART NO
NOMENCLATURE / DESCRIPTION
MATERIAL / SPEC
QTY
PART LIST
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
ASSY, GRIPPER, UPPER
STORAGE SYSTEM
BC-10026
CONE MACHINE


NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
1.25
20°
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS

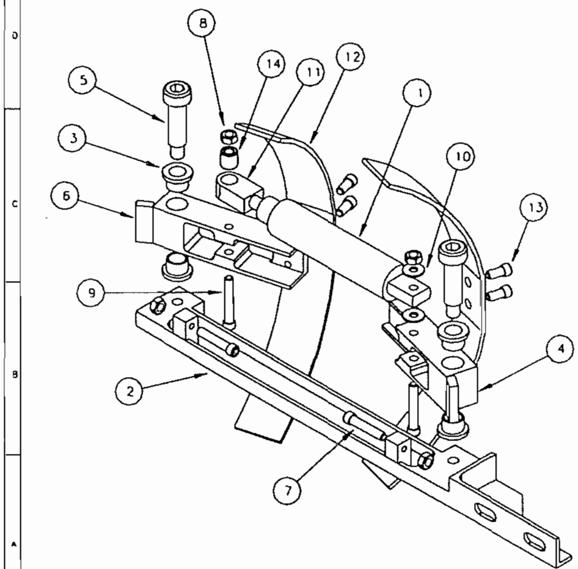

0.750
ø 0.313 THROUGH
2 PLACES
1.500
1.750
(4.399)
1.250
0.500
123.000°
R6.000
(5.936)
(2.865)
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
2) INTERNAL BEND RADII 1.5 X THK
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS



ITEM	PART NO	NOMENCLATURE / DESCRIPTION	MATERIAL / SPEC	QTY
14		BUSHING, 1/4 ID X 1/2 OD X 1/2	BRONZE	1
13		SCREW, CAP, 1/4-20 x 1/2	STEEL	4
12	BC-10028	SHOE, GRIPPER	STEEL	2
11		NUT, 1/4-20	STEEL	4
10		SCREW, CAP, 1/4-20 x 1-1/4	STEEL	2
9		SCREW, CAP, 1/4-20 x 1-1/2	STEEL	2
8	BC-10023	LINK, CYLINDER	STEEL	1
7		SPACER, 1/4 ID X 5/8 OD X 1/16 THK	STEEL	2
6	BC-10026	ASSY, GRIPPER, LOWER	STEEL	1
5		BOLT, SHOULDER, ø1/2 x 1-1/2, 3/8-16	STEEL	2
4	BC-10027	ASSY, GRIPPER, UPPER	STEEL	1
3		BUSHING, 1/2ID X 3/8OD X 1/2, 7/8OD X 1/8 FLANGE	BRONZE	4
2	BC-10006	ASSY, ARM, LEFT, UPPER	STEEL	1
1		CYLINDER, ALLENAIR, 7/8 BORE x 2-1/2 STROKE	TYPE A	1



NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES



ITEM	PART NO	NOMENCLATURE / DESCRIPTION	MATERIAL / SPEC	QTY
14		BUSHING, 1/4 ID X 1/2 OD X 1/2	BRONZE	1
13		SCREW, CAP, 1/4-20 X 1/2	STEEL	4
12	BC-10028	SHOE, GRIPPER	STEEL	2
11	BC-10023	LINK, CYLINDER	STEEL	1
10		SPACER, 1/4 ID X 5/8 OD X 1/16 THK	STEEL	2
9		SCREW, CAP, 1/4-20 X 1-1/2	STEEL	2
8		NUT, 1/4-20	STEEL	4
7		SCREW, CAP, 1/4-20 X 1-1/4	STEEL	2
6	BC-10026	ASSY, GRIPPER, LOWER	STEEL	1
5		BOLT, SHOULDER, Ø1/2 X 1-1/2, 3/8-16	STEEL	2
4	BC-10027	ASSY, GRIPPER, UPPER	STEEL	1
3		BUSHING, 1/2ID X 5/8OD X 1/2, 7/8OD X 1/8 FLANGE	BRONZE	4
2	BC-10007	ASSY, ARM, RIGHT, UPPER	STEEL	1
1		CYLINDER, ALLENAIR, 7/8 BORE X 2-1/2 STROKE	TYPE A	1

PART LIST

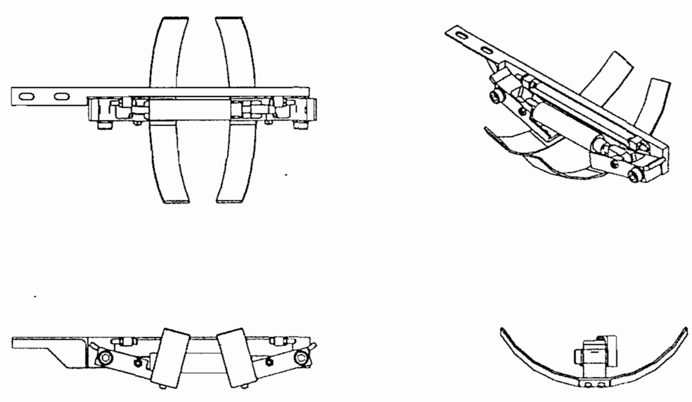
UNLESS OTHERWISE NOTED TOLERANCES .XX ±.03 .XXX ±.01 ANGLES ±0.5°

DESIGN MBC DATE 15APR97
DRAWN MBC
APPROV WAW
RELEASE

AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS

TITLE ASSY, ARM, RIGHT STOWAGE SYSTEM

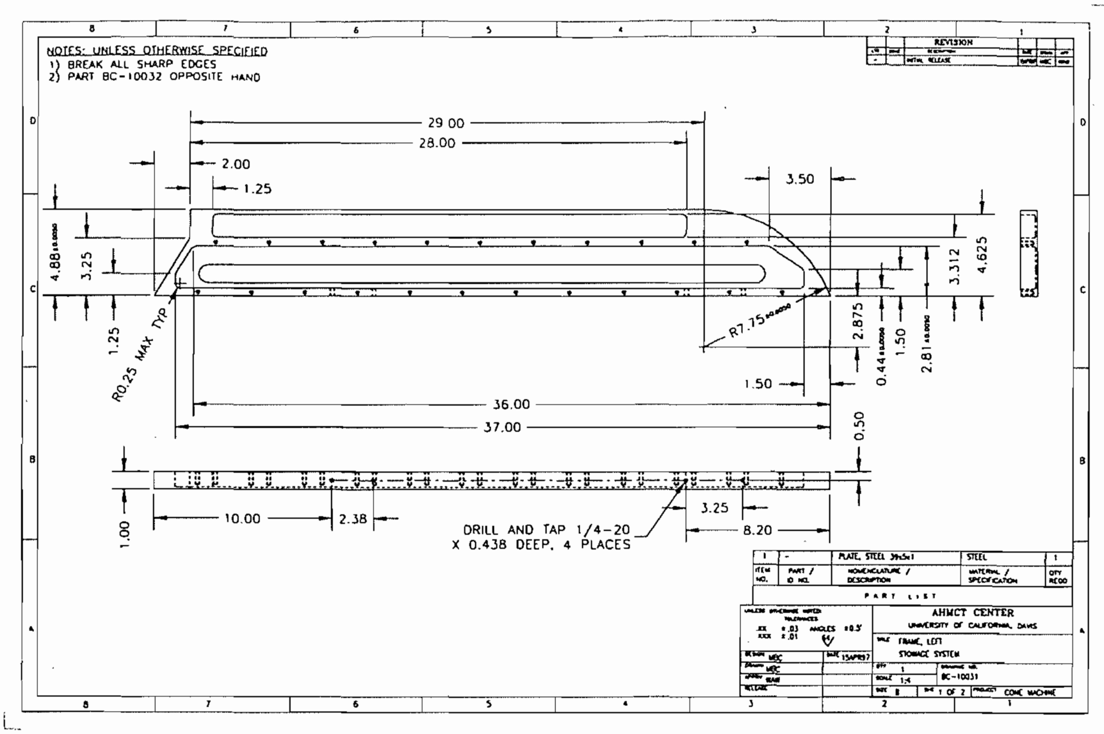
QTY 1 SCALE 1:2 DRAWING NO. BC-10030
SIZE B SHT 1 OF 2 PROJECT CONE MACHINE

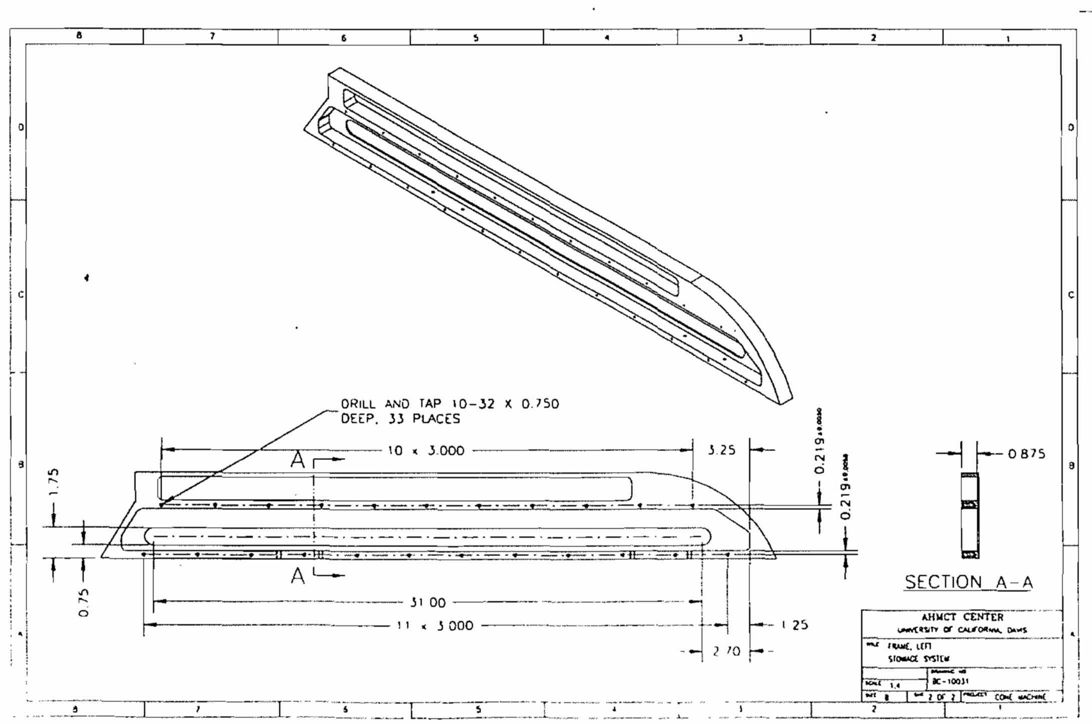


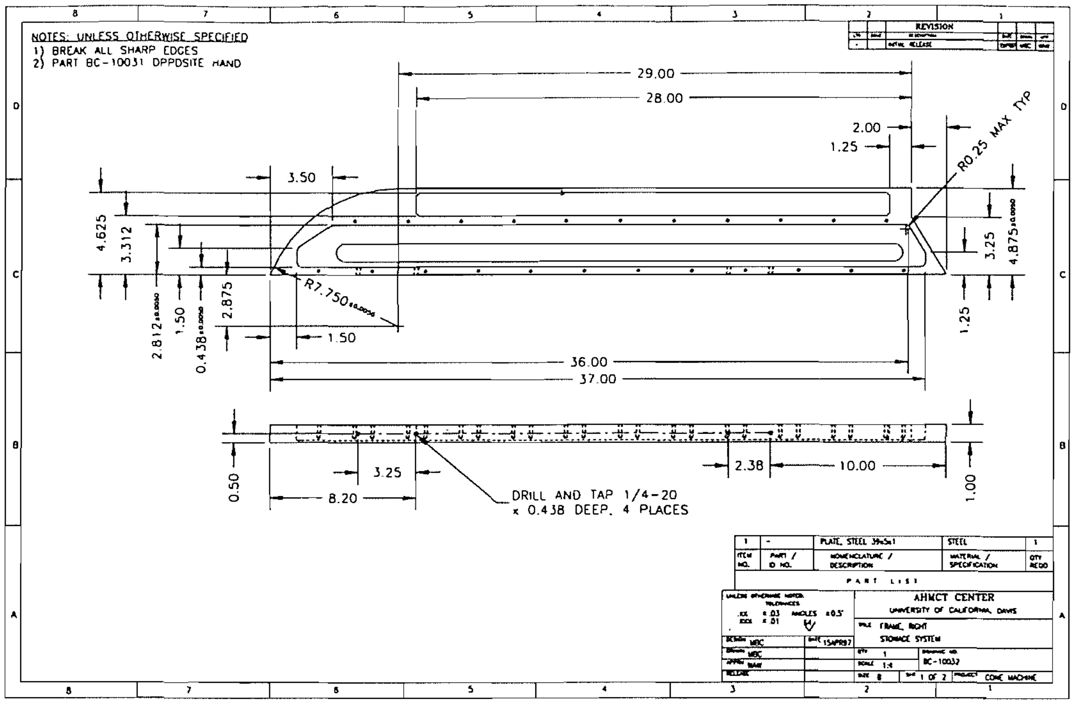
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS

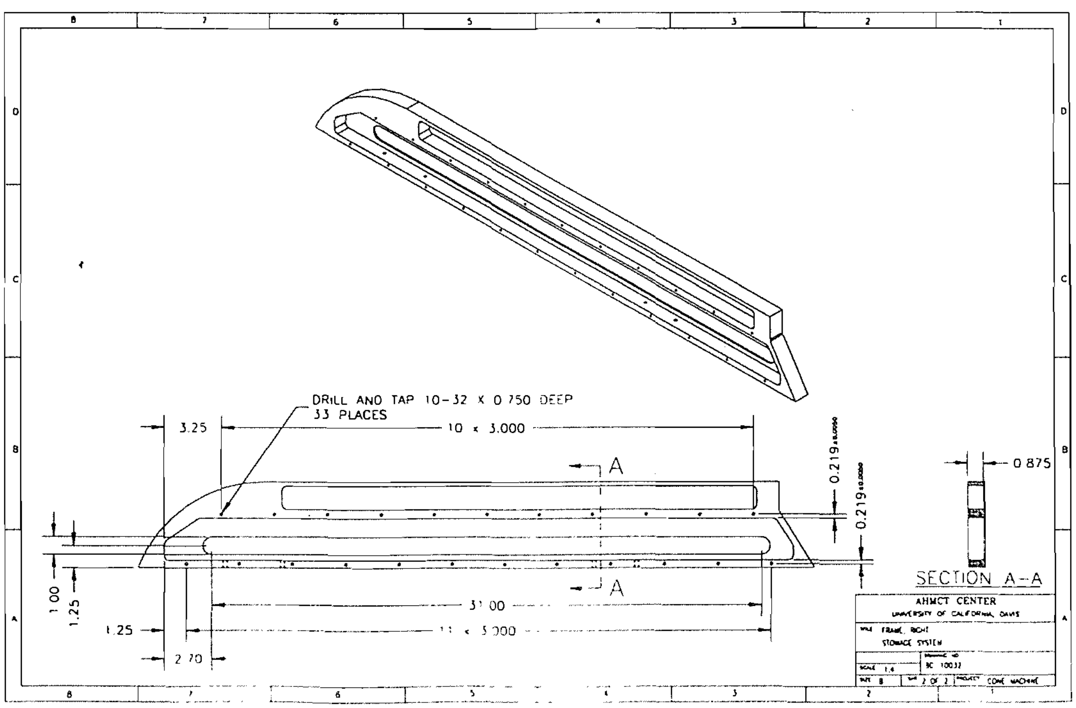
TITLE ASSY, ARM, RIGHT STOWAGE SYSTEM

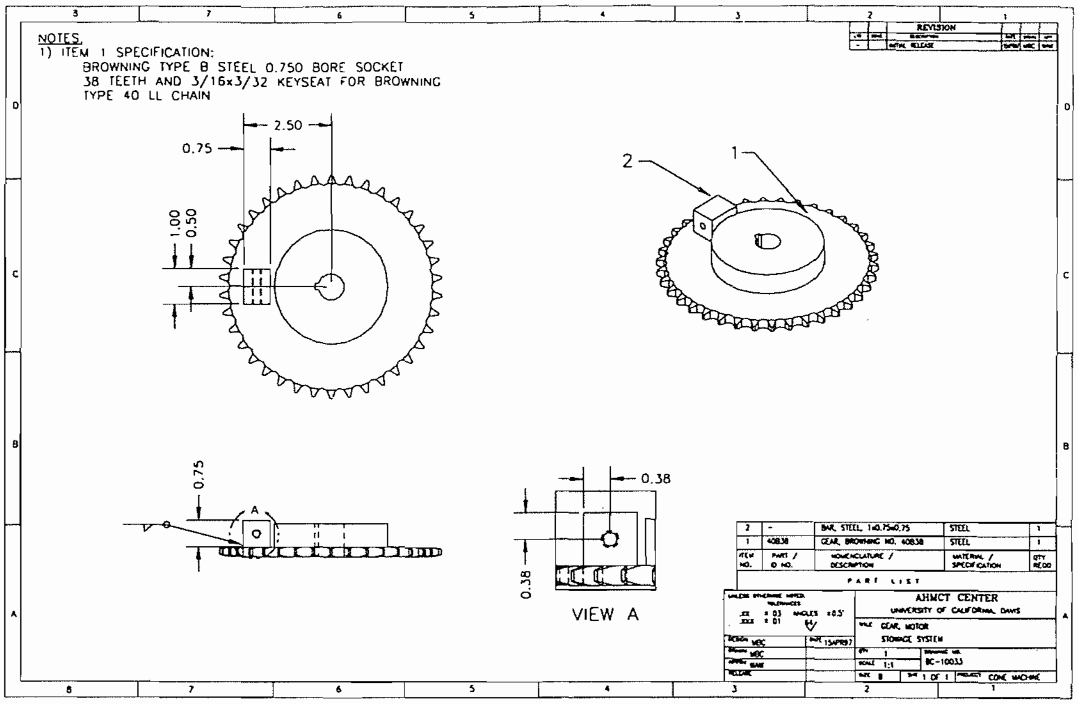
SCALE 1:4 DRAWING NO BC-10030
SIZE B SHT 2 OF 2 PROJECT CONE MACHINE


NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
2) PART BC-10032 OPPOSITE HAND
29.00
28.00
2.00
1.25
3.50
4.88
3.25
1.25
R0.25 MAX TYP
R7.75
2.875
0.44
1.50
2.81
3.312
4.625
1.50
36.00
37.00
0.50
1.00
10.00
2.38
3.25
8.20
DRILL AND TAP 1/4-20
X 0.438 DEEP, 4 PLACES
PART LIST
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
FRAME, LEFT
STOWAGE SYSTEM
BC-10031
1 OF 2
CONE MACHINE

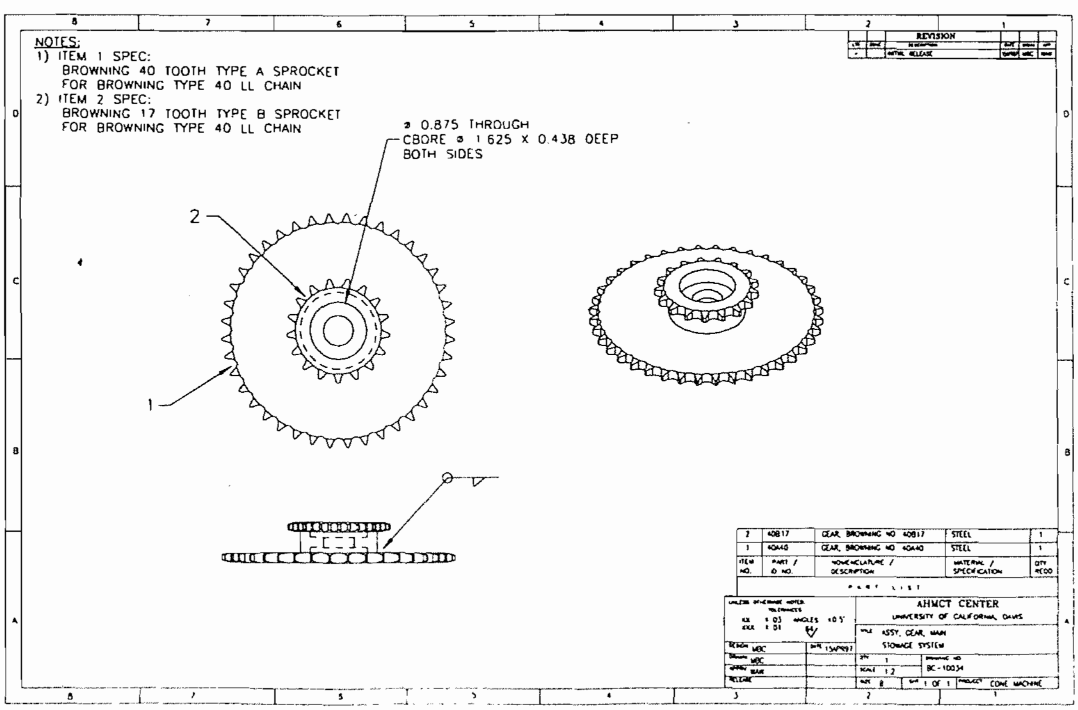

DRILL AND TAP 10-32 X 0.750
DEEP, 33 PLACES
10 x 3.000
3.25
A
1.75
0.75
0.219
0.219
0.875
SECTION A-A
31.00
11 x 3.000
1.25
2.70
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
FRAME, LEFT
STOWAGE SYSTEM
BC-10031
2 OF 2
CONE MACHINE


NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
2) PART BC-10031 OPPOSITE HAND
29.00
28.00
2.00
1.25
R0.25 MAX TYP
3.50
4.625
3.312
2.875
1.50
1.50
36.00
37.00
3.25
1.25
3.25
8.20
2.38
10.00
0.50
1.00
DRILL AND TAP 1/4-20
x 0.438 DEEP, 4 PLACES
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
FRAME, RIGHT
STOWAGE SYSTEM
BC-10032
CONE MACHINE

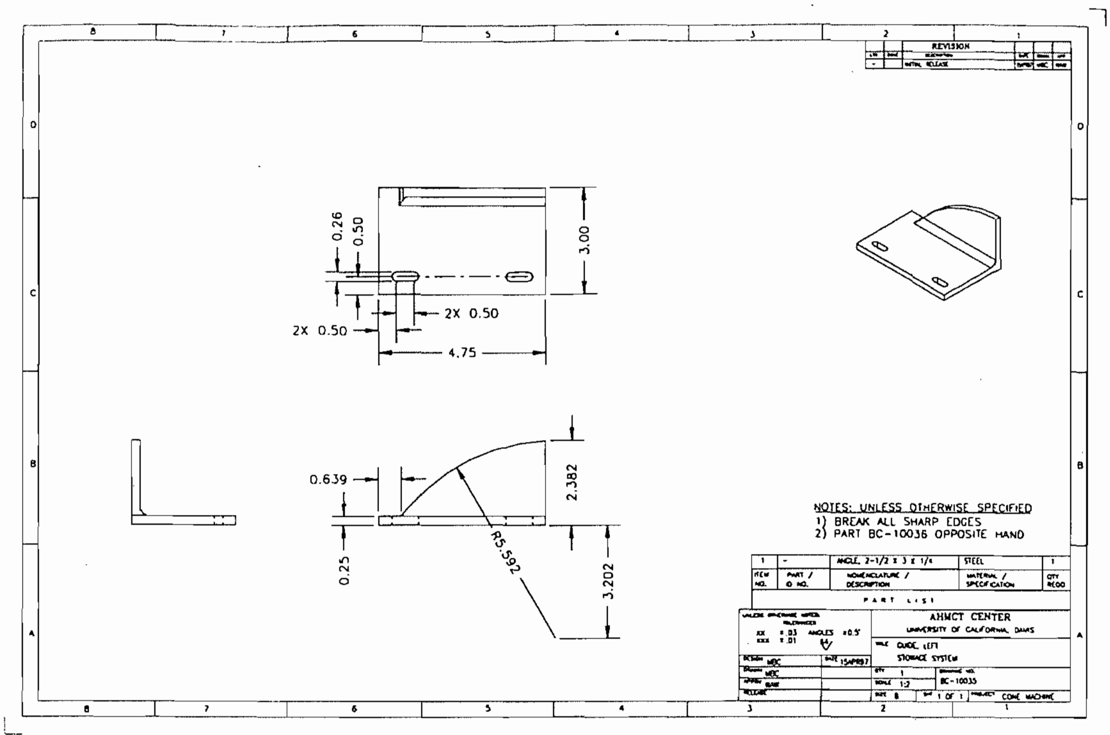

DRILL AND TAP 10-32 X 0.750 DEEP
33 PLACES
3.25
10 x 3.000
A
A
0.875
SECTION A-A
1.00
1.25
1.25
2.70
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
FRAME, RIGHT
STOWAGE SYSTEM
CONE MACHINE

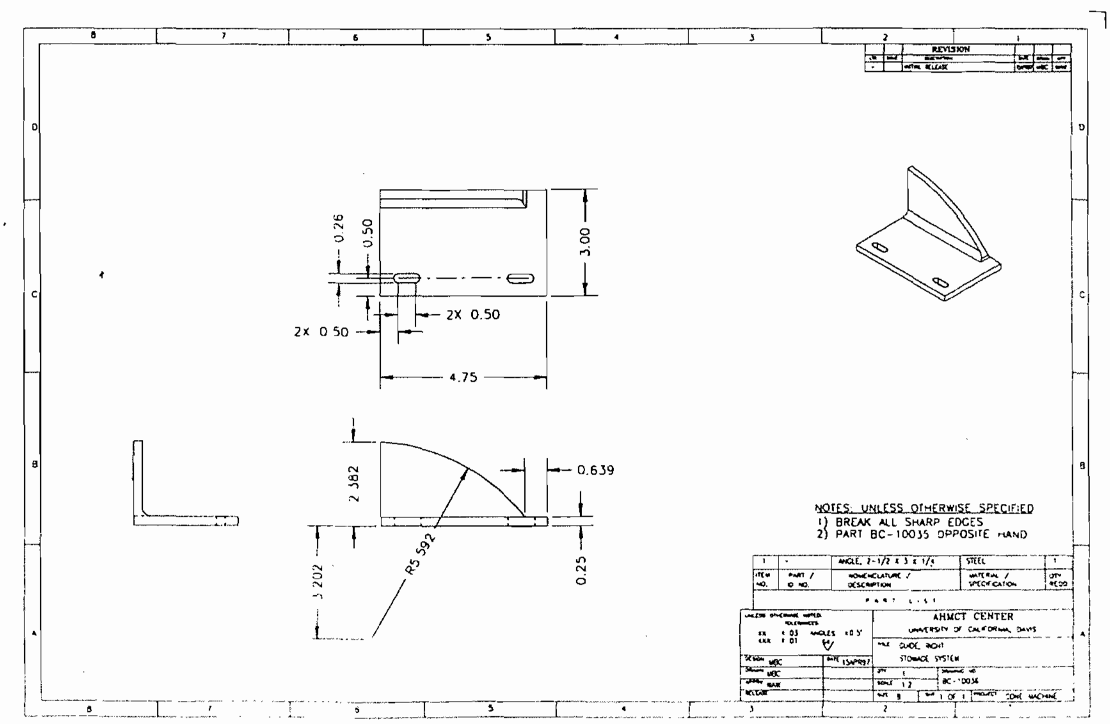


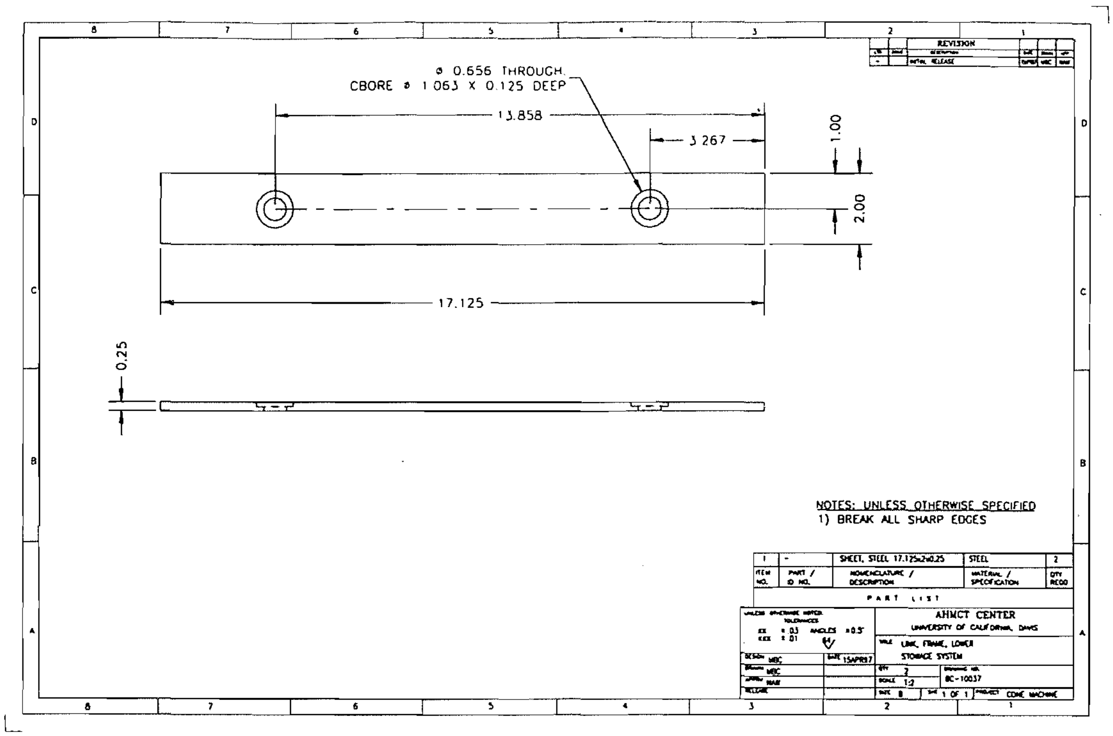
NOTES:
1) ITEM 1 SPECIFICATION:
BROWNING TYPE B STEEL 0.750 BORE SOCKET
38 TEETH AND 3/16x3/32 KEYSEAT FOR BROWNING
TYPE 40 LL CHAIN
2.50
0.75
1.00
0.50
2
1
0.75
A
0.38
0.38
VIEW A
REVISION
2 - BAR, STEEL, 1x0.75x0.75 STEEL 1
1 40B38 GEAR, BROWNING NO. 40B38 STEEL 1
ITEM NO. PART / ID NO. NOMENCLATURE / DESCRIPTION MATERIAL / SPECIFICATION QTY REQD
PART LIST
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
GEAR, MOTOR
STORAGE SYSTEM
1:1
BC-10033
1 OF 1
CONE MACHINE



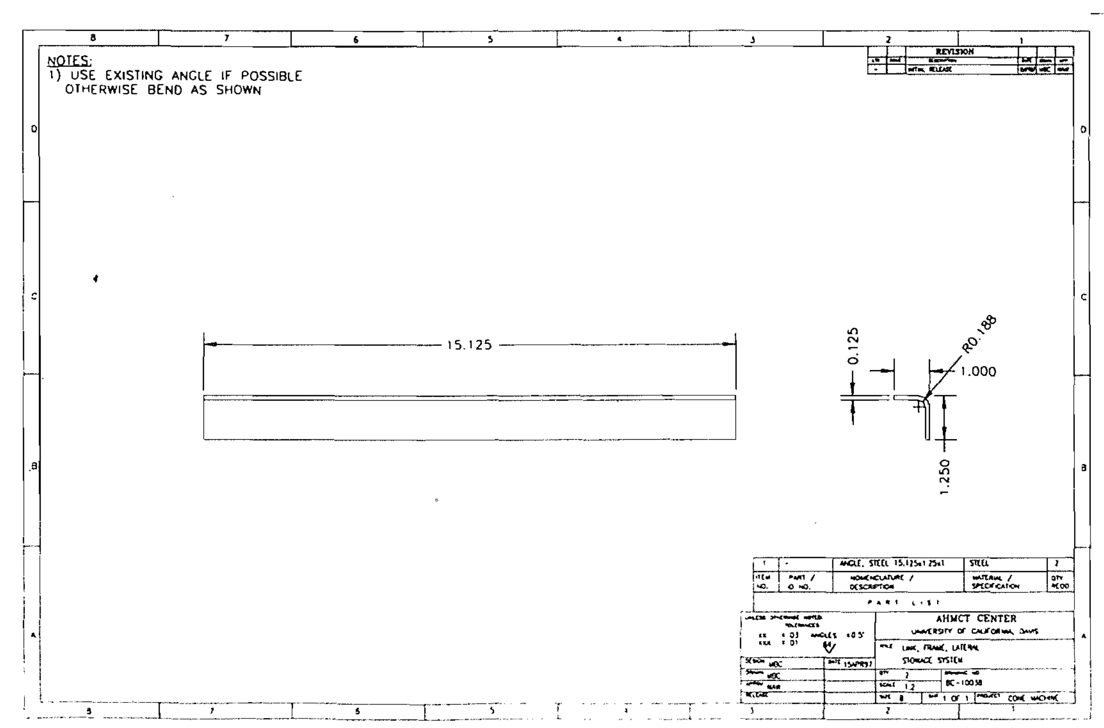
NOTES:
1) ITEM 1 SPEC:
BROWNING 40 TOOTH TYPE A SPROCKET
FOR BROWNING TYPE 40 LL CHAIN
2) ITEM 2 SPEC:
BROWNING 17 TOOTH TYPE B SPROCKET
FOR BROWNING TYPE 40 LL CHAIN
⌀ 0.875 THROUGH
CBORE ⌀ 1.625 X 0.438 DEEP
BOTH SIDES
2
1
REVISION
2 40B17 GEAR, BROWNING NO 40B17 STEEL 1
1 40A40 GEAR, BROWNING NO 40A40 STEEL 1
ITEM NO. PART / ID NO. NOMENCLATURE / DESCRIPTION MATERIAL / SPECIFICATION QTY REQD
PART LIST
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
ASSY, GEAR, MAIN
STORAGE SYSTEM
1:2
BC-10034
1 OF 1
CONE MACHINE


NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
2) PART BC-10036 OPPOSITE HAND
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
BC-10035

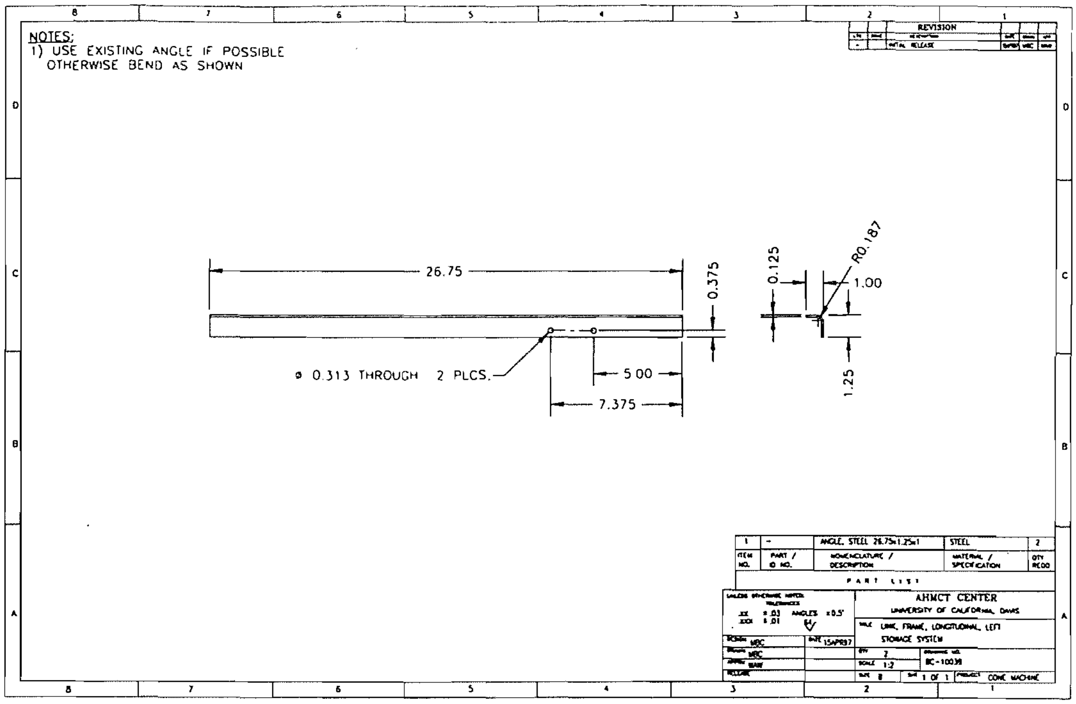

NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
2) PART BC-10035 OPPOSITE HAND
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
BC-10036

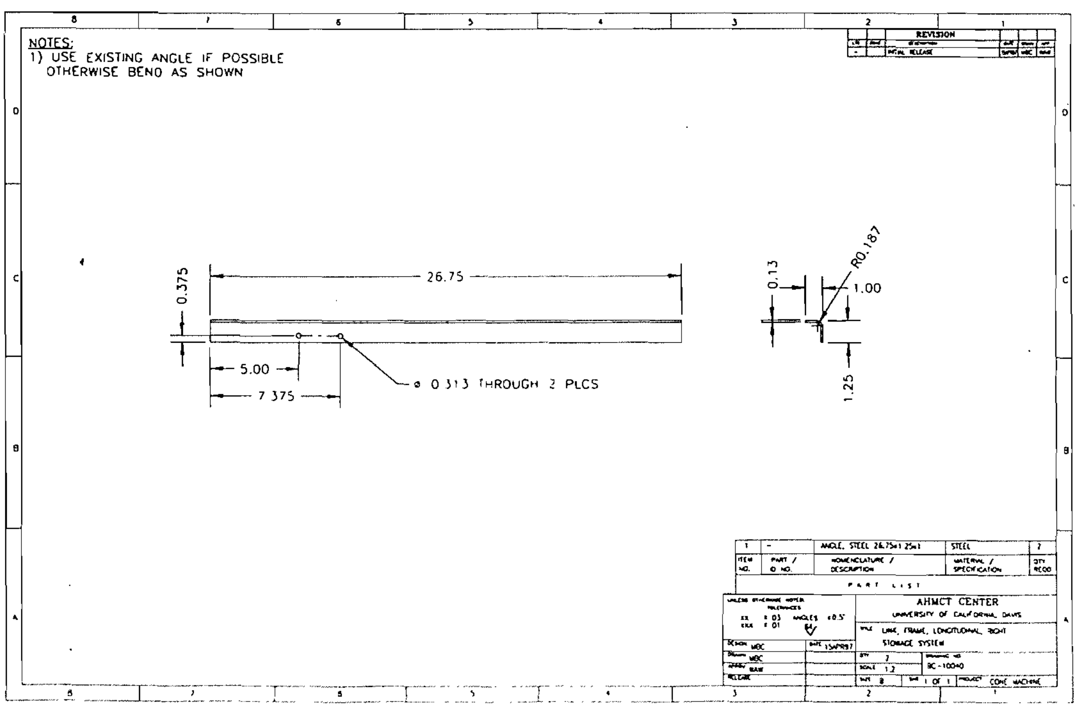


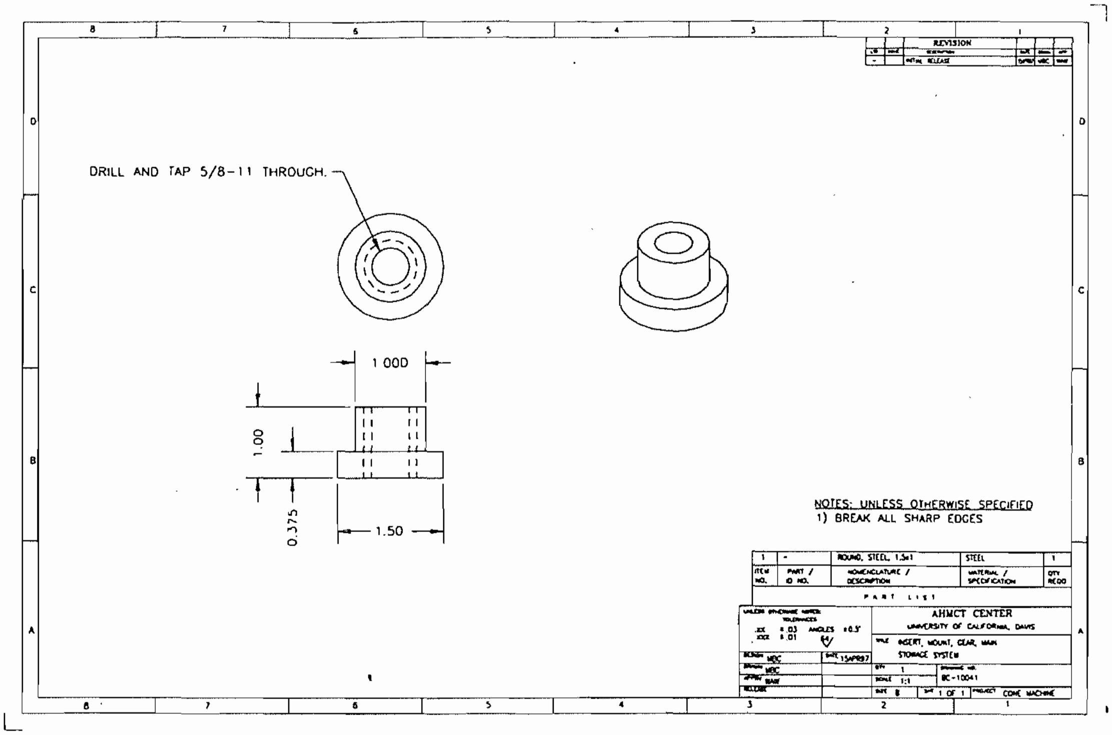
ø 0.656 THROUGH
CBORE ø 1.063 X 0.125 DEEP
13.858
3.267
1.00
2.00
17.125
0.25
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
SHEET, STEEL 17.125x2x0.25
STEEL
PART LIST
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
LINK, FRAME, LOWER
STORAGE SYSTEM
15APR97
BC-10037
CONE MACHINE

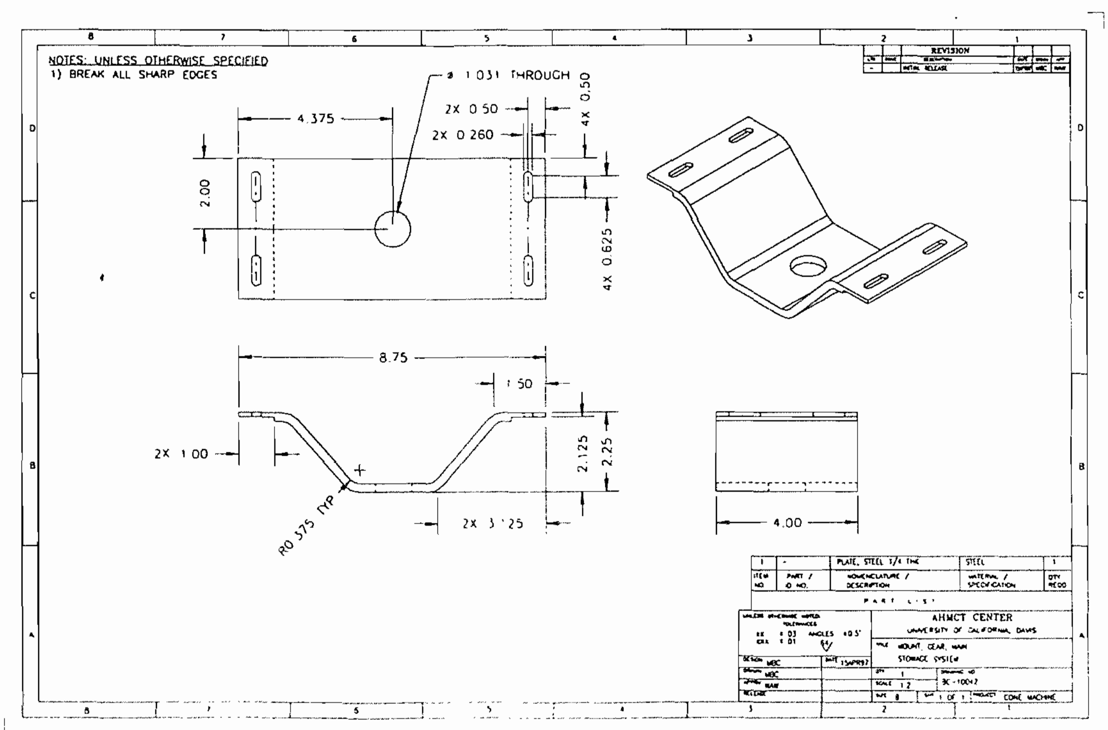


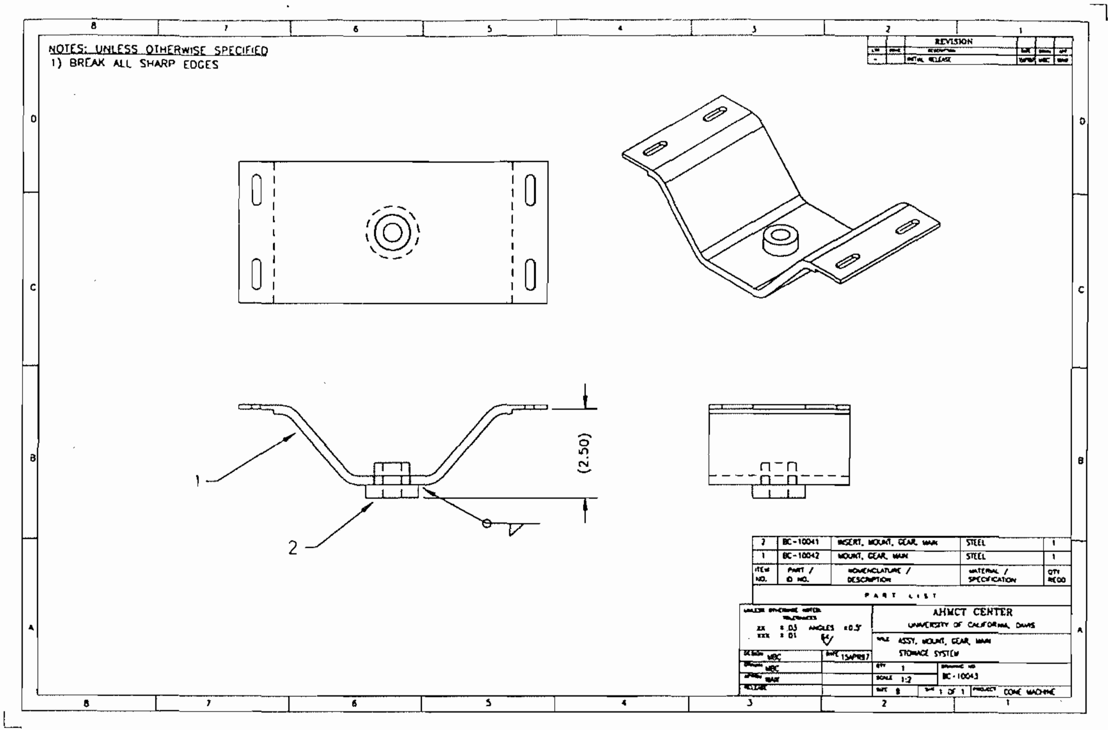
NOTES:
1) USE EXISTING ANGLE IF POSSIBLE
OTHERWISE BEND AS SHOWN
15.125
0.125
R0.188
1.000
1.250
ANGLE, STEEL 15.125x1.25x1
STEEL
PART LIST
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
LINK, FRAME, LATERAL
STORAGE SYSTEM
15APR97
BC-10038
CONE MACHINE

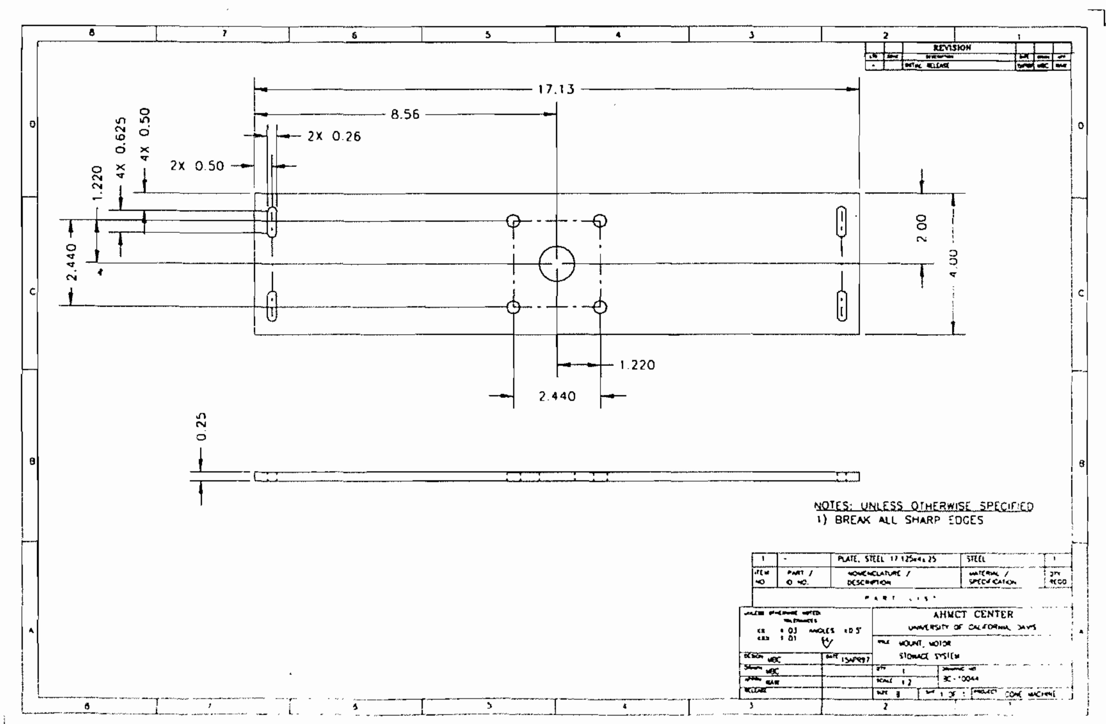

NOTES:
1) USE EXISTING ANGLE IF POSSIBLE
OTHERWISE BEND AS SHOWN
REVISION
26.75
0.375
0.125
R0.187
1.00
ø 0.313 THROUGH 2 PLCS.
5.00
7.375
1.25
ANGLE, STEEL 26.75x1.25x1
STEEL
PART LIST
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
LINK, FRAME, LONGITUDINAL, LEFT
STORAGE SYSTEM
15APR97
SCALE 1:2
1 OF 1
CONE MACHINE

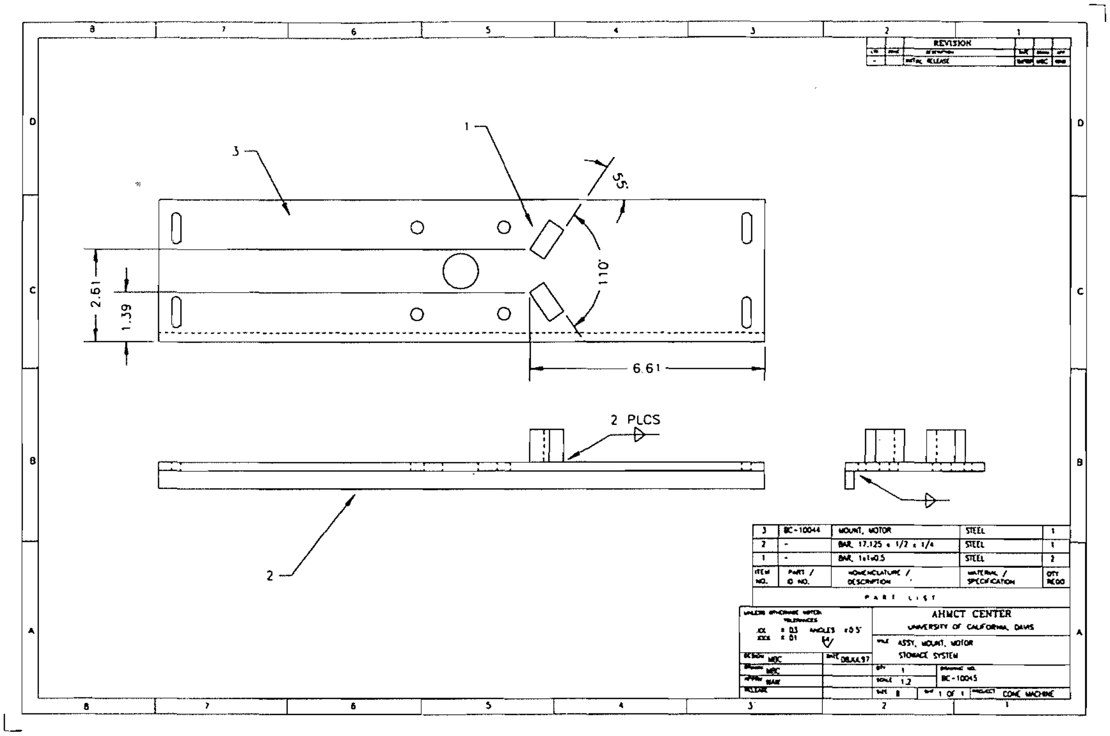

NOTES:
1) USE EXISTING ANGLE IF POSSIBLE
OTHERWISE BEND AS SHOWN
REVISION
0.375
26.75
0.13
R0.187
1.00
5.00
7.375
ø 0.313 THROUGH 2 PLCS
1.25
ANGLE, STEEL 26.75x1.25x1
STEEL
PART LIST
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
LINK, FRAME, LONGITUDINAL, RIGHT
STORAGE SYSTEM
15APR97
SCALE 1:2
1 OF 1
CONE MACHINE


DRILL AND TAP 5/8-11 THROUGH.
1.000
1.00
0.375
1.50
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
ROUND, STEEL, 1.5x1
STEEL
PART LIST
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
INSERT, MOUNT, CEAR, MAIN
STORAGE SYSTEM
BC-10041
CONE MACHINE
REVISION
INITIAL RELEASE

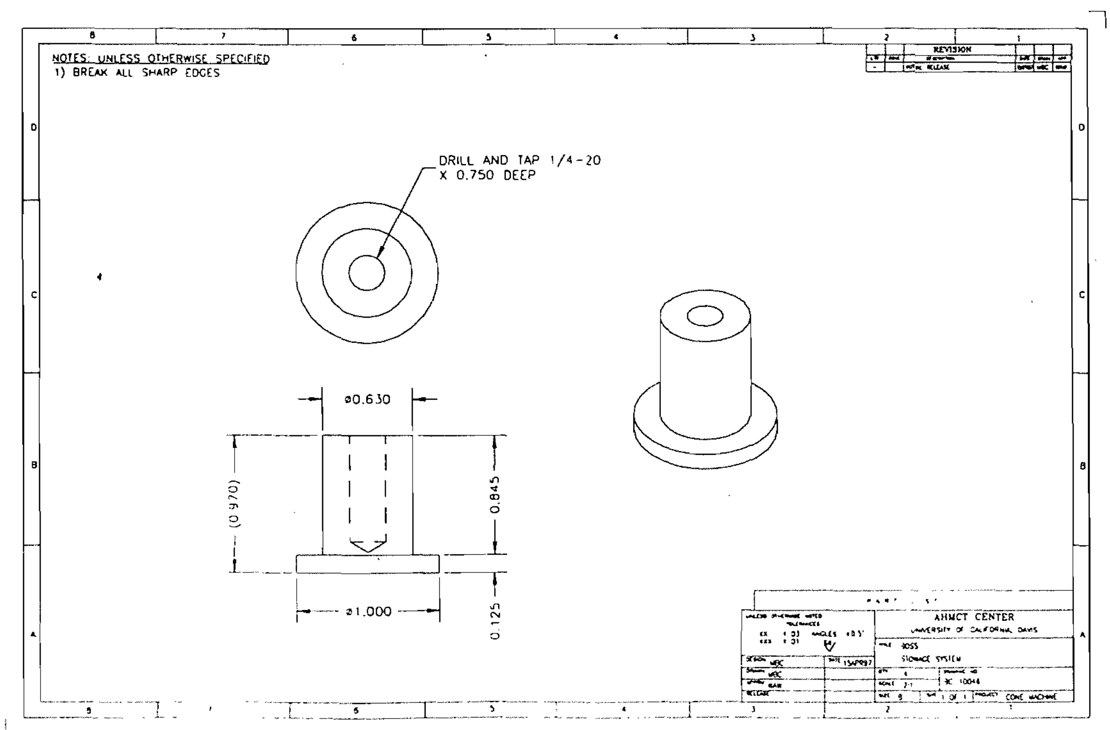

NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
ø 1.031 THROUGH
4.375
2X 0.50
2X 0.260
4X 0.50
2.00
4X 0.625
8.75
1.50
2X 1.00
2.125
2.25
R0.375 TYP
2X 3.125
4.00
PLATE, STEEL 3/4 THK
STEEL
PART LIST
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
MOUNT, CEAR, MAIN
STORAGE SYSTEM
BC-10042
CONE MACHINE
REVISION
INITIAL RELEASE


NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
REVISION
(2.50)
1
2
2 BC-10041 INSERT, MOUNT, GEAR, MAIN STEEL 1
1 BC-10042 MOUNT, GEAR, MAIN STEEL 1
PART LIST
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
ASSY, MOUNT, GEAR, MAIN
STORAGE SYSTEM
BC-10043
CONE MACHINE

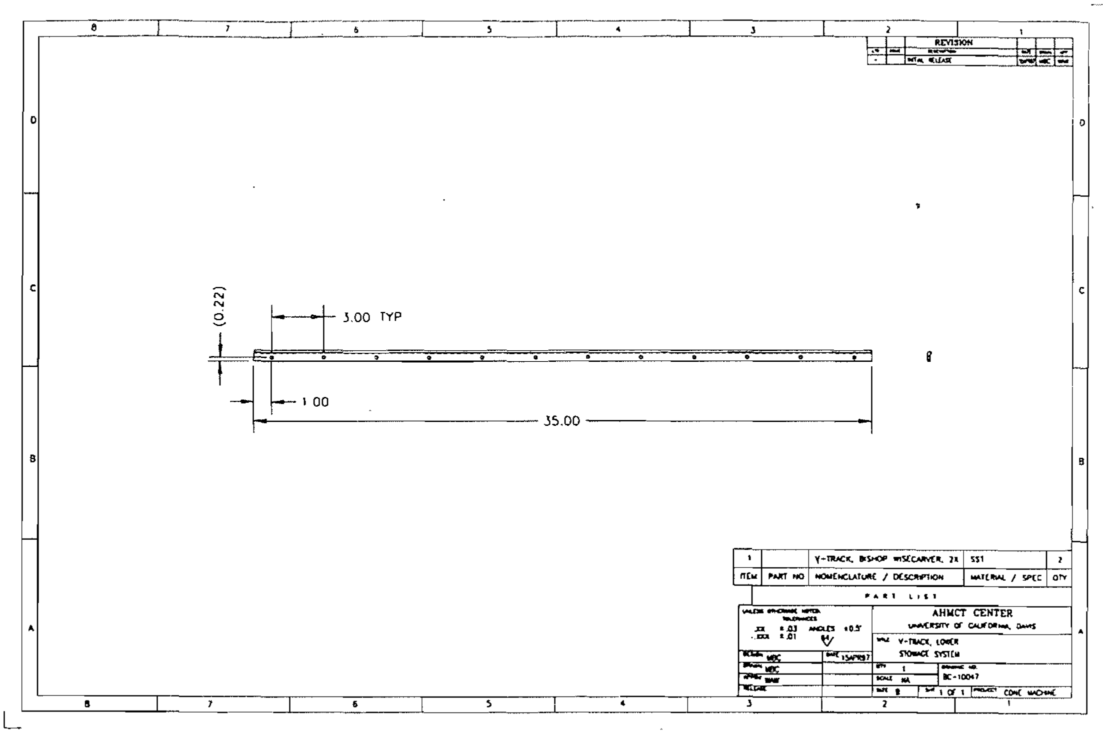

REVISION
17.13
8.56
2X 0.26
2X 0.50
4X 0.625
4X 0.50
1.220
2.440
2.00
4.00
1.220
2.440
0.25
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
1 - PLATE, STEEL 17.125x4x.25 STEEL 1
PART LIST
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
MOUNT, MOTOR
STORAGE SYSTEM
BC-10044
CONE MACHINE

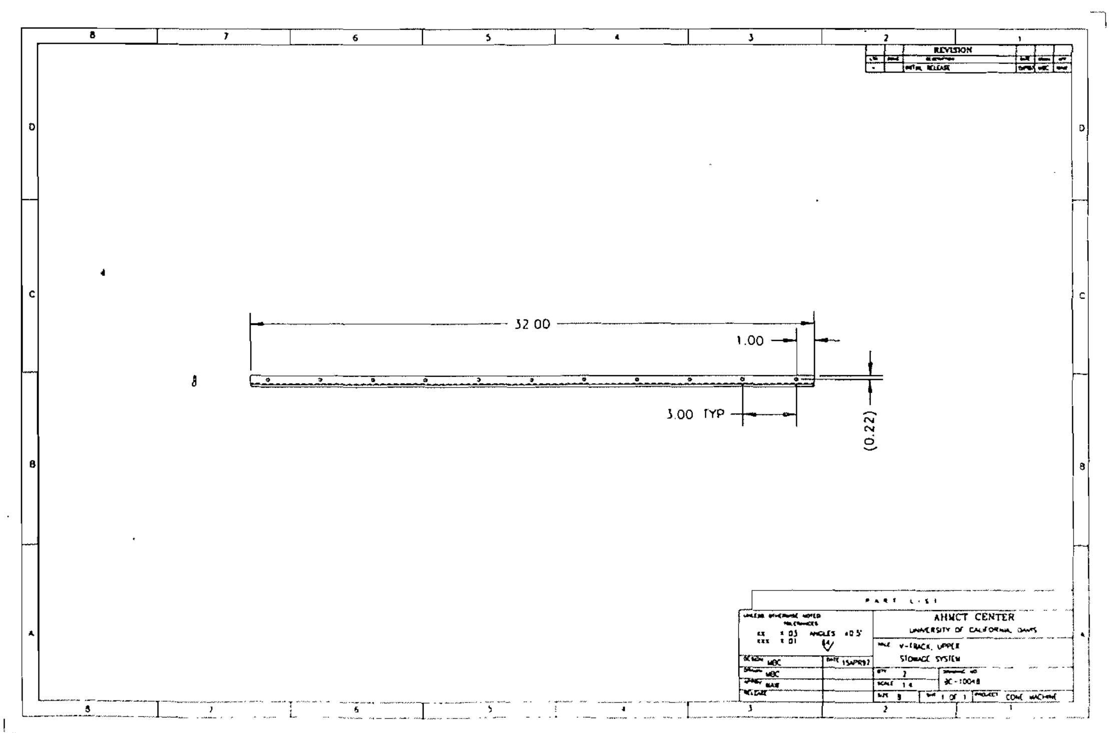


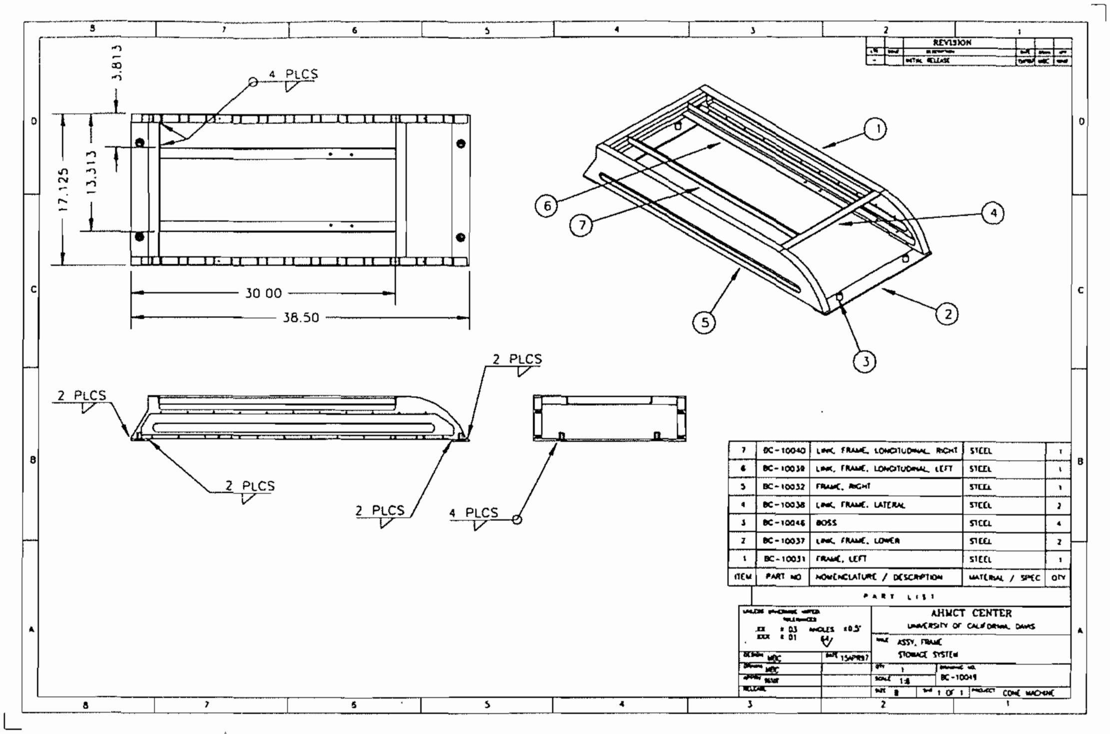
REVISION
INITIAL RELEASE
3
1
55°
110°
2.61
1.39
6.61
2 PLCS
2
3 | BC-10044 | MOUNT, MOTOR | STEEL | 1
2 | - | BAR, 17.125 x 1/2 x 1/4 | STEEL | 1
1 | - | BAR, 1x1x0.5 | STEEL | 2
ITEM NO. | PART / ID NO. | NOMENCLATURE / DESCRIPTION | MATERIAL / SPECIFICATION | QTY REQD
PARTS LIST
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
ASSY, MOUNT, MOTOR
STOWAGE SYSTEM
BC-10045
CONE MACHINE



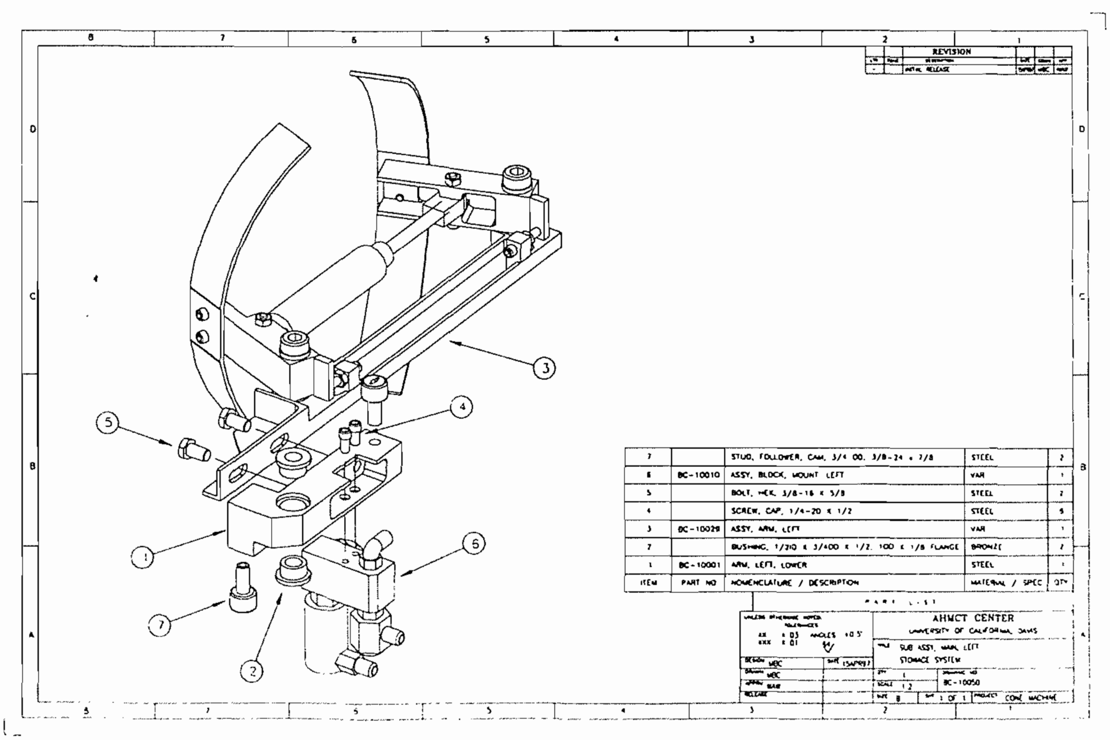
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
REVISION
INITIAL RELEASE
DRILL AND TAP 1/4-20
X 0.750 DEEP
ø0.630
(0.970)
0.845
ø1.000
0.125
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
BOSS
STOWAGE SYSTEM
BC-10044
CONE MACHINE


(0.22)
3.00 TYP
1.00
35.00
Y-TRACK, BISHOP WISECARVER, 2X
AHMCT CENTER
V-TRACK, LOWER STOWAGE SYSTEM
BC-10047
CONE MACHINE

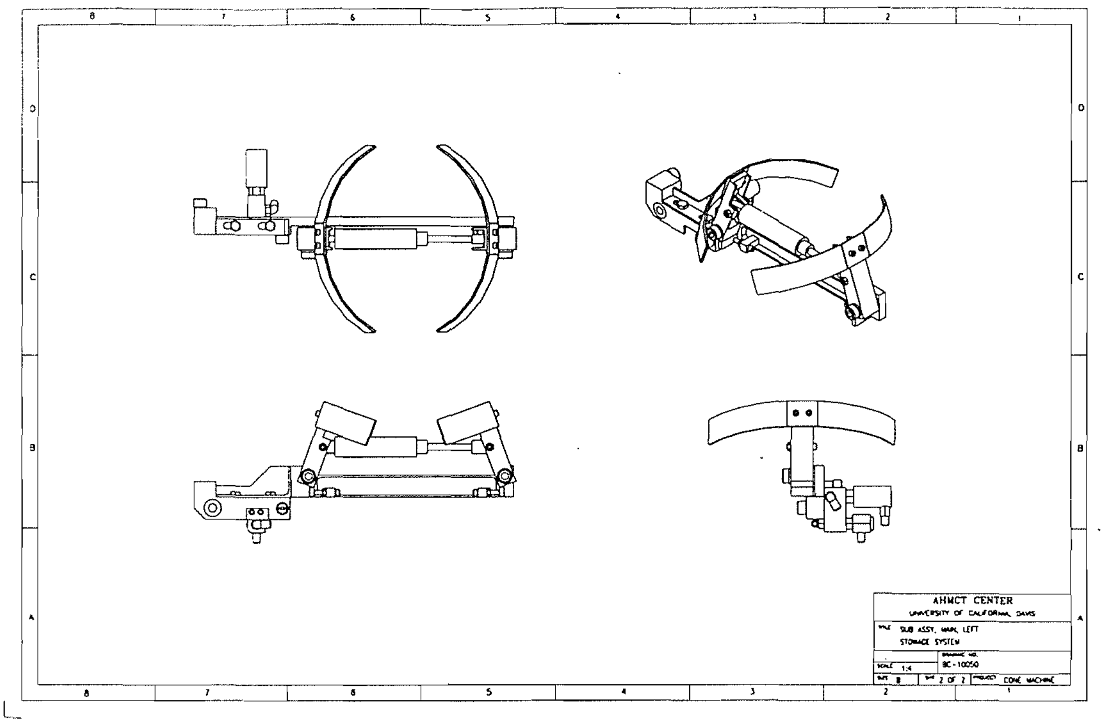

32.00
1.00
3.00 TYP
(0.22)
AHMCT CENTER
V-TRACK, UPPER STOWAGE SYSTEM
BC-10048
CONE MACHINE

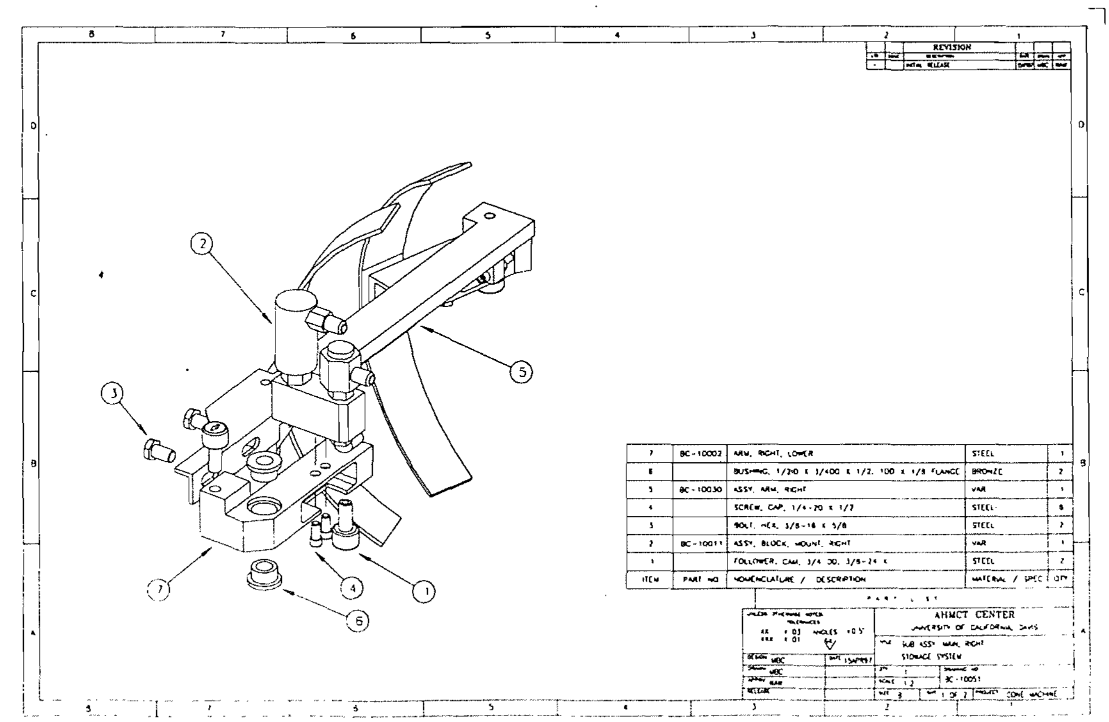


3.813
4 PLCS
17.125
13.313
30.00
38.50
2 PLCS
2 PLCS
2 PLCS
2 PLCS
2 PLCS
4 PLCS
4 PLCS
REVISION
INITIAL RELEASE
7 | BC-10040 | LINK, FRAME, LONGITUDINAL, RIGHT | STEEL | 1
6 | BC-10039 | LINK, FRAME, LONGITUDINAL, LEFT | STEEL | 1
5 | BC-10032 | FRAME, RIGHT | STEEL | 1
4 | BC-10038 | LINK, FRAME, LATERAL | STEEL | 2
3 | BC-10046 | BOSS | STEEL | 4
2 | BC-10037 | LINK, FRAME, LOWER | STEEL | 2
1 | BC-10031 | FRAME, LEFT | STEEL | 1
ITEM | PART NO | NOMENCLATURE / DESCRIPTION | MATERIAL / SPEC | QTY
PART LIST
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
ASSY, FRAME
STORAGE SYSTEM
.XX ± .03 ANGLES ±0.5°
.XXX ± .01
15APR97
1:8
BC-10049
1 OF 1
CONE MACHINE



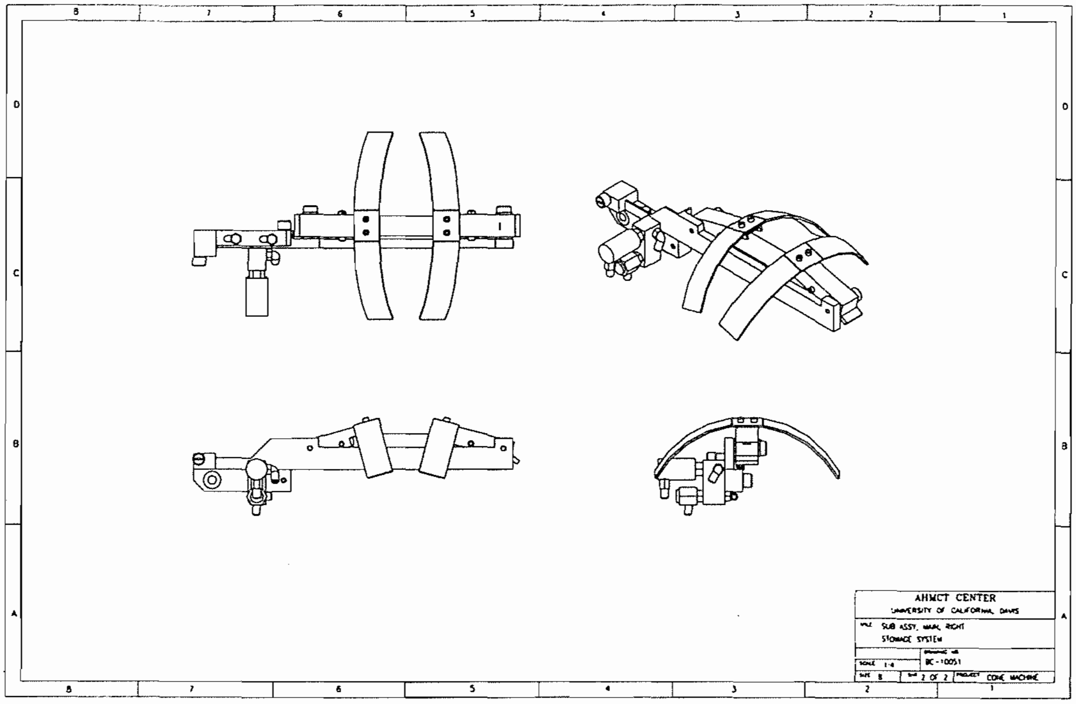
REVISION
INITIAL RELEASE
7 | | STUD, FOLLOWER, CAM, 3/4 OD, 3/8-24 x 7/8 | STEEL | 2
6 | BC-10010 | ASSY, BLOCK, MOUNT LEFT | VAR | 1
5 | | BOLT, HEX, 3/8-16 x 5/8 | STEEL | 2
4 | | SCREW, CAP, 1/4-20 x 1/2 | STEEL | 5
3 | BC-10029 | ASSY, ARM, LEFT | VAR | 1
2 | | BUSHING, 1/2ID x 3/4OD x 1/2, 1OD x 1/8 FLANGE | BRONZE | 2
1 | BC-10001 | ARM, LEFT, LOWER | STEEL | 1
ITEM | PART NO | NOMENCLATURE / DESCRIPTION | MATERIAL / SPEC | QTY
PART LIST
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
SUB ASSY, ARM, LEFT
STORAGE SYSTEM
.XX ± .03 ANGLES ±0.5°
.XXX ± .01
15APR97
1:2
BC-10050
1 OF 1
CONE MACHINE

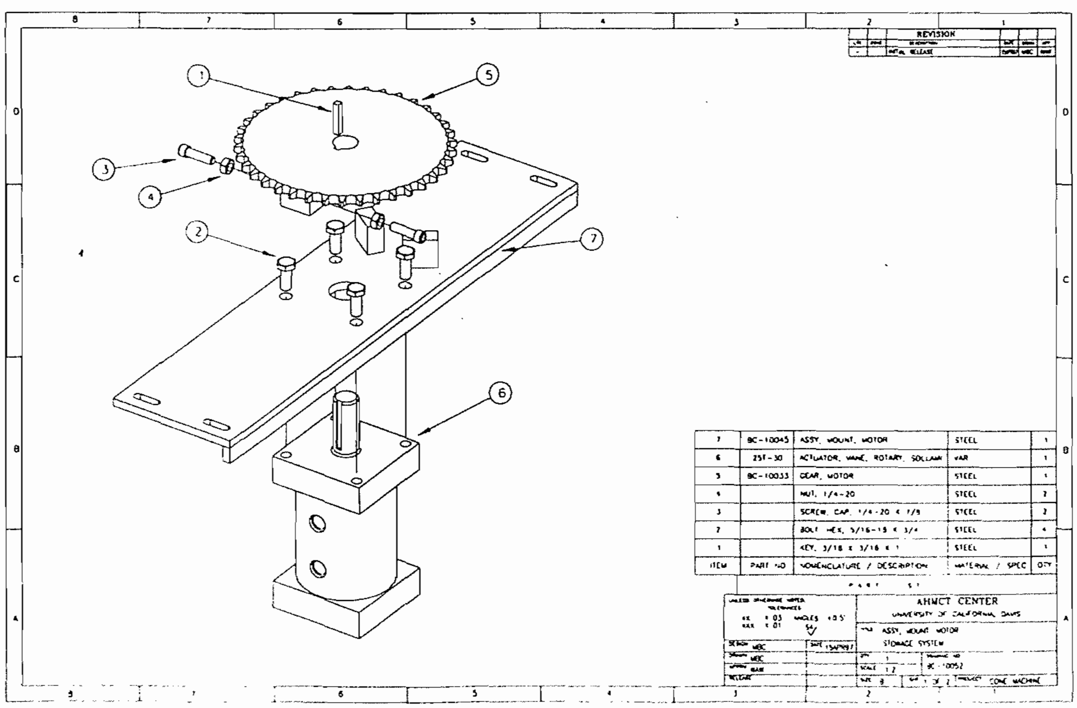


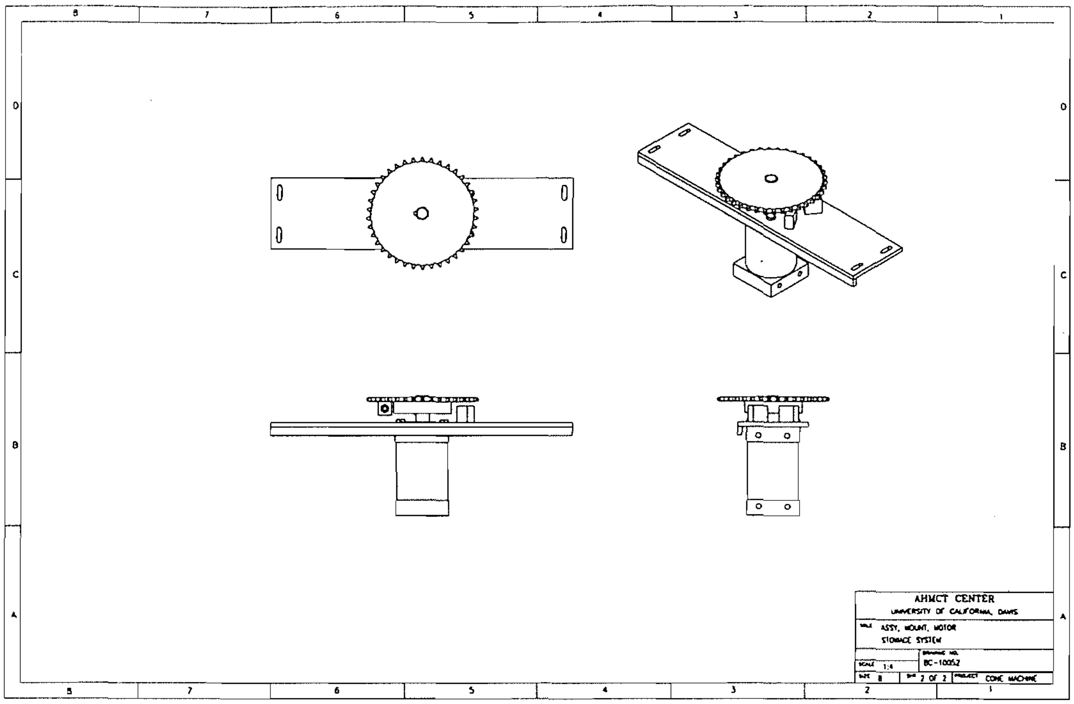


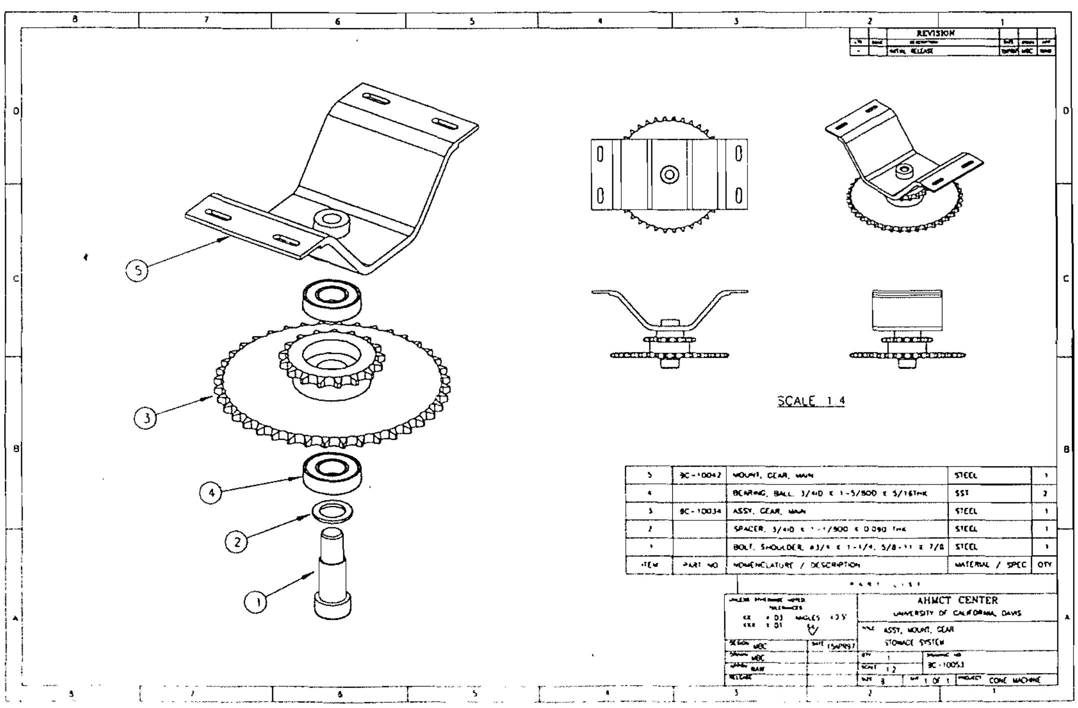
ITEM	PART NO	NOMENCLATURE / DESCRIPTION	MATERIAL / SPEC	QTY
7	BC-10002	ARM, RIGHT, LOWER	STEEL	1
6		BUSHING, 1/2ID x 3/4OD x 1/2, 1OD x 1/8 FLANGE	BRONZE	2
5	BC-10030	ASSY, ARM, RIGHT	VAR	1
4		SCREW, CAP, 1/4-20 x 1/2	STEEL	8
3		BOLT, HEX, 3/8-16 x 5/8	STEEL	2
2	BC-10011	ASSY, BLOCK, MOUNT, RIGHT	VAR	1
1		FOLLOWER, CAM, 3/4 OD, 3/8-24 x	STEEL	2

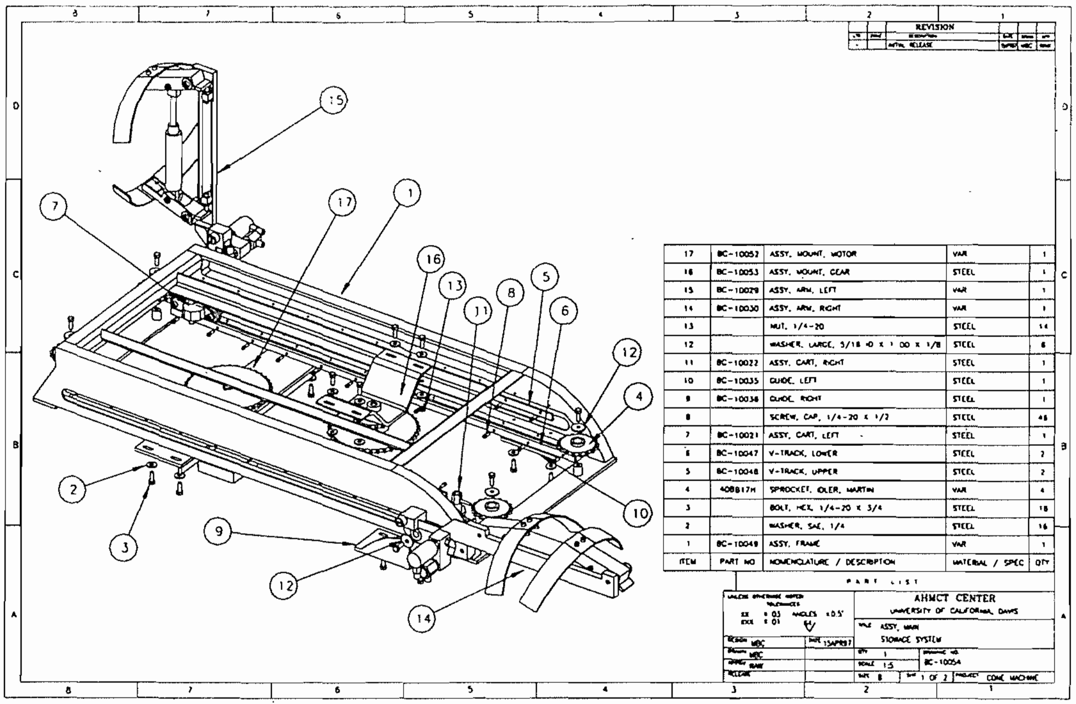
PARTS LIST


AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
SUB ASSY, MAIN, RIGHT
STORAGE SYSTEM
BC-10051
2 OF 2
CONE MACHINE


REVISION
INITIAL RELEASE
7 BC-10045 ASSY, MOUNT, MOTOR STEEL 1
6 25T-30 ACTUATOR, VANE, ROTARY, SOLLAMI VAR 1
5 BC-10033 GEAR, MOTOR STEEL 1
4 NUT, 1/4-20 STEEL 2
3 SCREW, CAP, 1/4-20 X 7/8 STEEL 2
7 BOLT HEX, 5/16-18 X 3/4 STEEL 4
1 KEY, 3/16 X 3/16 X 1 STEEL 1
ITEM PART NO NOMENCLATURE / DESCRIPTION MATERIAL / SPEC QTY
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
ASSY, MOUNT, MOTOR
STORAGE SYSTEM
MBC
MBC
BC-10052
CONE MACHINE


AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
ASSY, MOUNT, MOTOR
STORAGE SYSTEM
BC-10052
1:4
B
2 OF 2
CONE MACHINE


REVISION
5
3
4
2
1
SCALE 1:4
5 BC-10042 MOUNT, GEAR, MAIN STEEL 1
4 BEARING, BALL, 3/4ID X 1-5/8OD X 5/16THK SST 2
3 BC-10034 ASSY, GEAR, MAIN STEEL 1
2 SPACER, 3/4ID X 1-1/8OD X 0.090 THK STEEL 1
1 BOLT, SHOULDER, ø3/4 X 1-1/4, 5/8-11 X 7/8 STEEL 1
ITEM PART NO NOMENCLATURE / DESCRIPTION MATERIAL / SPEC QTY
AHMCT CENTER
UNIVERSITY OF CALIFORNIA, DAVIS
ASSY, MOUNT, GEAR
STORAGE SYSTEM
BC-10053
CONE MACHINE



ITEM	PART NO	NOMENCLATURE / DESCRIPTION	MATERIAL / SPEC	QTY
17	BC-10052	ASSY, MOUNT, MOTOR	VAR	1
16	BC-10053	ASSY, MOUNT, GEAR	STEEL	1
15	BC-10029	ASSY, ARM, LEFT	VAR	1
14	BC-10030	ASSY, ARM, RIGHT	VAR	1
13		NUT, 1/4-20	STEEL	14
12		WASHER, LARGE, 5/16 ID X 1.00 X 1/8	STEEL	8
11	BC-10022	ASSY, CART, RIGHT	STEEL	1
10	BC-10035	GUIDE, LEFT	STEEL	1
9	BC-10036	GUIDE, RIGHT	STEEL	1
8		SCREW, CAP, 1/4-20 X 1/2	STEEL	48
7	BC-10021	ASSY, CART, LEFT	STEEL	1
6	BC-10047	V-TRACK, LOWER	STEEL	2
5	BC-10048	V-TRACK, UPPER	STEEL	2
4	40BB17H	SPROCKET, IDLER, MARTIN	VAR	4
3		BOLT, HEX, 1/4-20 X 3/4	STEEL	18
2		WASHER, SAE, 1/4	STEEL	16
1	BC-10049	ASSY, FRAME	VAR	1