Draft for Review
Not for Publication

FABRICATION AND TESTING OF MAINTENANCE EQUIPMENT USED FOR PAVEMENT SURFACE REPAIRS

Final Report of Phase II - Part I

SHRP H-107A

UCD-ARR-92-04-15-01

Participating Organizations
University of California, Davis
California Department of Transportation
Bechtel, Inc.
ERES Consultants, Inc.

Steven A. Velinsky, Principal Investigator
Department of Mechanical Engineering
University of California, Davis

April 15, 1992

Strategic Highway Research Program
National Research Council
Washington, D.C.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1.0 - FABRICATION OF FIRST GENERATION COMPONENT PROTOTYPES

1.1 - Introduction

The ultimate goal of the SHRP H-107A project is to develop prototype automated machinery that will sense, prepare, and seal (or fill) cracks and joints on pavement. As such, the primary objectives of this project are to design machinery for the sealing and filling of joints and cracks in pavement in order to:

- Increase the cost-effectiveness of these operations,
- Increase the quality, consistency, and life of the resultant seals and fills,
- Increase the safety of workers and highway users, and
- Increase the use of remote operation and control of equipment to attain the above.

Machinery that satisfies these objectives will additionally reduce lane and highway closures and thus, will play a significant role in reducing traffic congestion, an area of considerable concern in the major urban regions around the world. The cost effectiveness of such machinery is due to a combination of the increased speed of sealing and reduced manpower needs, in addition to the higher quality seal which will reduce the frequency of major highway rehabilitations.

In order to have the greatest impact, such machinery should satisfactorily perform the following functions automatically:

- Sense the occurrence and location of cracks in pavement.
- Adequately prepare the pavement surface for sealing/filling with the appropriate methods; for example, any operation that is deemed necessary such as removing entrapped moisture and debris, preheating the road to ensure maximum sealant adhesion, refacing of reservoirs, etc.
- Prepare the sealant/filler for application; i.e., heat and mix the material, etc.
- Dispense the sealant/filler.
- Form the sealer/filler into the desired configuration.
- Finish the sealer/filler.

Additionally, as overall functional specifications, this machinery should be:

- Reasonable in cost,
- Easy to use,
- Reliable and fast,

- Rugged,
- Safe,
- Capable of being driven on the highway under its own power,
- Self-contained (contain all of the components necessary to perform task),
- Primarily powered by an internal combustion engine,
- Provided with a heavy duty electrical system with sufficient capacity for safe operation of all components,
- Compatible with repair materials to be identified under SHRP H-106,
- Fabricated in such a manner that the eventual addition of safety lighting & appurtenances (arrow boards, etc.) is possible, and
- Compliant with any applicable OSHA standards.

Phase I of this project involved a feasibility study on the possible development of the automated pavement repair machinery discussed above, the design of first generation machine components, and the conceptual design of the integrated prototype machinery. Phase I work was performed during the period December 1, 1990 through May 31, 1991. A detailed report discussing these items was delivered at the end of Phase I, the Phase I Final Report, at which time continuation through Phase II was approved.

Phase II of the H-107A project included two specific tasks; TASK 3) the fabrication of first generation component prototypes, and TASK 4) the testing of these components and the development of component modifications based on this testing. More globally, the goal of this phase was to make satisfactory progress concerning machine components such that the development of the integrated machinery in the last phase can be accomplished. Phase II work was performed during the period from June 1, 1991 through March 31, 1992.

1.2 - Purpose

The purpose of this document, Part I of the Phase II Final Report, is to report on the completion of TASK 3 of SHRP H-107A, Fabrication of First Generation Prototypes. This task involved the fabrication of first generation components, the development of required software, the purchase of numerous commercially available components, and the issuance of subcontracts to expedite machine fabrication and development. The work has been based on the approval by SHRP of the plans, specifications and shop drawings from the Phase I final report. Part II of the Phase II Final Report, published separately, discusses TASK 4 of SHRP H107A, Conduct a Laboratory Test Program Using Prototype Components & Prepare an Interim Report of Phase II.

In the sections that follow, detail component descriptions and a discussions on the principles of operation of each of the machine components and subsystems are presented. When appropriate, engineering drawings of the various components have been included along with photos of the manufactured components. Appendices have also been included which contain the vendor specifications for much of the equipment purchased.

The Integration and Control Unit (ICU) is discussed first, in Section 2, followed by the Vision Sensing and Local Sensing Systems (VSS and LSS) in Sections 3 and 4. The remaining three sections cover the Robot Positioning System (RPS), Applicator and Peripherals Systems (APS), and Vehicle Orientation and Control System (VOC).

The remainder of the H-107A project involves the development of the prototype integrated machinery, its field testing, and the reporting of results and documentation. These activities are comprised in Phases III and IV which are divided into four tasks. Since SHRP's sunset is March 31, 1993, the H-107A project must be entirely completed by that date. Accordingly, Phases III and IV encompass 12 months.

2.0 - INTEGRATION AND CONTROL UNIT (ICU)

2.1 - Introduction

The development of an Automated Crack Sealing machine (ACSM) includes the integration of a variety of sensing, command and actuating systems, many of which will synchronously perform tasks in real-time. A control architecture has been developed to assure that these systems act in a coordinated manner to achieve the overall goal of sealing pavement cracks at an acceptable performance level. It is important to note that control system architectures have the definitive purpose of ensuring that a task is achieved and correcting for any deviations affecting the execution of this plan. From a technical standpoint, the control architecture requires a modular configuration in order to profoundly affect the versatility and maintainability of the resulting product. There is also a direct connection between the control architecture and design time, integration and overall functionality of the product. Furthermore, from an industrial standpoint, architecture choices are commercially important in the production costs and marketing appeal considerations. In short, the choice of the control architecture for a particular product can have a profound affect on the development as well as the commercialization of that product.

During the Phase I feasibility study, it was determined that the Integrated Control Unit (ICU) of the Automated Crack Sealing Machine oversee all operations from start to finish. This control unit needs to coordinate and initiate information and control flow between the separate systems of the machine. The ICU, therefore, acts as a liaison between the otherwise disassociated systems. In addition, the control system must perform efficiently to sustain ACSM operation at the required speeds.

Specifically, the ICU must take crack location information from the Vision Sensing System (VSS) and use Vehicle Orientation information to translate that information into a path configuration usable by the Robot Positioning System and valid for the current reference frame. Thus, the ICU will accommodate path planning and updating algorithms necessary for accurate crack/joint sealing/filling. The ICU will also interact with the Applicator and Peripherals Sytem (APS) in order to synchronize applicator positioning and usage.

In review of the machine requirements, it is apparently necessary for the ICU to meet the following criteria:

- fast and efficient computation
- able to recognize and process prioritized interrupts
- process concurrent information rapidly (multi-tasking)
- retain sufficient spare capacity and flexibility to expand
- support multiple processors
- expandable backplane

In addition to these necessary requirements, other development requirements were recommended as follows:

- modular in both hardware and software design
- application software should be developed in a user-friendly environment that is common to many programmers
- system software should be ROMable to enable an embedded application
- vehicle mounted ICU needs to be rugged to operate in a hostile environment (the environment as described in the Phase I report)
- compatible with other CalTrans/UCD in-house development efforts and expertise

Considering the responsibilities of task monitoring as well as the development requirements, the ICU team assessed, recommended and purchased a "mother system" for the crack sealing machine and acquired a development system. Based on compatibility with other subsystems, ruggedness, bus transfer rate, multi-processing capability, and compatibility with other highway maintenance automation projects, the Single Board, Smart I/O, STD Bus, PC/AT, and MultiBus options were eliminated. The VME system bus architecture utilizing an OS-9 real-time operating system was selected as the most desirable based on all considerations and requirements. The VME bus provides the highest bus transfer rate, is rugged enough to perform in the maintenance vehicle environment and is a truly flexible system. The VME bus provides the flexibility, compatibility, modularity, and multi-processing necessary for the efficient operation of the ACSM. OS-9 was recommended as the operating system for the VME bus because it is increasingly accepted as a standard and complies with the requirement to be compatible with other ACSM subsystems and other CalTrans and UC-Davis automated highway maintenance projects.

2.2 - The Development Environment

The development system described in the Phase I report as the Apollo workstation has been replaced by a Sun SPARC II workstation. The Sun workstation was more readily available and provided the user-friendly programming environment required of a development system. This workstation has been loaned to the project by CalTrans and is used only for ICU development; the final ICU will not employ this workstation, only the VME hardware. The Sun workstation is connected to the VME system (target system) via Ethernet backbone. The Sun workstation combined with the VME system is referred to as the 'development environment' and serves as the programming environment when connected via the 'telnet' command. Using the VME system terminal, only one process, such as editing a program or executing code, can be run at once. In using the Sun workstation development system, however, multiple windows and multiple tasks are accommodated. Thus, several windows and processes can be open and running on the workstation. In this manner, the programmers can edit a program in one window while another program is compiling in another window and, perhaps, even executing through another window. Therefore, many processes can be executed at once, allowing for quicker program development and accurate testing of the multitasking capability of the VME system. Since it is connected to the VME system via Ethernet, the Sun workstation also serves to simulate the Vision Sensing System (VSS).

In order to provide a user-friendly graphical interface, the RAVE (Real-time Audio Visual Environment) system was added to the system recommended in the Phase I report. The RAVE system, software developed by Microware, Inc. and hardware developed by Vigra Corporation, is designed to allow development of a graphical user interface. The RAVE software provides a library of graphics, representing dials, meters, buttons, etc., and allows the programmer to create an interactive operator screen. RAVE generates the resulting code for the graphics portion of the interface, while the programmer adds the code to be executed upon user interaction. For example, the programmer can specify that a red and black vertical meter be placed on the interactive screen in a certain position; RAVE will generate the code to recreate this graphic image; the programmer can then add code to cause the vertical meter to move according to certain input. In this manner, a complete user interface screen to serve as the "Crack Sealing Machine Control Panel" is easily defined and developed. In this manner, an Input/Output simulation program has been developed.

2.3 - Detailed Components Description

The components of the ICU are of two types - hardware and software. During Phase II some hardware components were added and several software components were developed. These components were developed individually and then integrated to form the ICU. Following is a current list of ICU components with detailed descriptions of each. Appendix A contains manufacturer's specifications for many of the items discussed below.

2.3.1 - Hardware Components

Backplane (HSE/17R-12V-W60-F3-S150-Ethernet Cables)

The backplane integrates all the cards of the ICU. It includes a 17.5 inch (height) rack mount enclosure with 12-slot VME card cage, 500 Watt power supply, 60 MB Embedded SCSI hard disk drive, 2 MB 3.5" (38W7 format type) floppy disk drive, 150 MB 1/4" Archive Streamer Tape Drive and Ethernet Cable Package which includes an Ethernet Transceiver, Transceiver cable, 10ft. Thin Net Cable, T-connector (Thin-Net) and 2-Terminators (Thin-Net).

CPU Card (HK68H/V3E-4 MB)

Includes a 50 MHz 68030 CPU with 4 MB DRAM, 128 bytes non-volatile RAM, 4 RS-232 ports, single parallel port, VSB compatible bus interface, SCSI interface, time of day clock and full interface to VME bus with four level system controller functions.

Analog I/O Card (XVME540)

Analog I/O card. 12-bit A/D and D/A conversion. 16 channel, 4 channel output. Inputs configurable to bipolar or unipolar with 12-bit conversion resolution.

Digital I/O Card (XVME201)

Digital I/O card. VME bus interface, two 68230 Parallel Interface Timer (PI/T) chips, and TTL buffers to provide 48-bits of digital I/O. 4 bi-directional 8-bit ports and two 16-bit ports.

Communications Card (CMC ENP-10)

Ethernet communications card. Interface between VME bus host system and Ethernet. Processes network protocols, manages the local bus and performs DMA transfers across the bus.

Multi Media Graphics Card (MMI250)

Hardware component of the Real Time Audio Visual Environment (RAVE). A high performance graphics board for the VME bus that combines graphics frame store, keyboard, RS-232C, and sound output functions to provide an effective man-machine interface. It is a standard 6U board with both VME bus and VSB bus interfaces, and provides a bit-mapped color graphics controller, an IBM/PC compatible keyboard interface, two RS-232C compatible serial ports, and 4 MB of multi-ported frame store RAM. The MMI250 provides the hardware necessary to run the user interface screen, keyboard, speaker and the graphical processing required for real time display of information.

Test Box

A Test Box was designed and developed to provide and take digital and analog signals. These signals were used to simulate input and output information coming into and going out of the ICU. Functions of the test box were displayed on the user interface and control of the test box hardware was accomplished using the user interface.

2.3.2 - Software Components-Basic System

Software modules developed by the team are typically generic. This simplifies the task of interfacing with other subsystems of the crack sealing machine. Integration will require only minor modifications to software modules.

Operating System (OS-9 Professional)

Real time, multi-user, multi-tasking operating system with a system state debugger and a source level debugger.

Software Drivers (ENP-10 and VXME982)

Software drivers for Ethernet and I/O cards with all requisite libraries.

Real Time Audio Visual Environment (RAVE)

A graphical user interface development package which can be customized for a specific application. This has the capability to provide real time machine control and to provide real time user feedback.

2.3.3 - Software Components-System Test Modules

The following modules were developed to test the I/O cards and to develop multi-tasking capabilities:

analogio.c	initializes the analog I/O board(XVME540) and reads analog input signals from input channels.
anrave.c	a modified version of analogio.c to work with RAVE.
diotimer.c	tests the functionality and initializes the digital I/O board.
demo540.c	tests the interrupt generating capability of the analog I/O board (XVME201).
proc1.c	tests the multi-tasking capabilities of OS-9 operating system. In particular, tests the signal and pipe mechanism while running concurrent processes.

2.3.4 - Software Components-Data Modules

icu.data	disk based crack configurations generated by the Vision Sensing System (VSS).

2.3.5 - Software Components-Communication Modules

The following modules were developed to test the communication cards and to develop data transfer capabilities on the Ethernet network:

comdraw.c	receives crack information from the Vision Sensing System (VSS) and displays it on the user interface.
drawarray.c	displays crack information obtained from magnetic media(disk)
hold.c	a network driven interrupt handler to facilitate processing of information exchange on the Ethernet.
send.c	a module to send data from icu.data to comdraw.c over the Ethernet network.

2.3.6 - Software Components-Main Module

icudemo.c	main module of the demonstration program which integrates the above mentioned Test, Data and Communication modules. This demonstration will give a representation of the graphics and user interface capabilities of the ICU. Various submodules are utilized by icudemo.c which include graphics generators, mouse and keyboard facilitators, sound generators and communication subroutines.

2.4 - Description of Tasks

Four distinct ICU tasks are as follows:

1. System diagnosis and initialization
2. Data communications with other ACSM subsystems
3. Input/output with machine hardware

4. Operator machine control and monitoring via user interface

The task of system diagnosis and initialization would be conducted at the beginning of a crack sealing run. Initialization clears any control lines and resets them to an initial setting. ICU input/output boards are reset to accept and place information on the 'correct' lines using an expected format. Other dependent systems are also reset and prepared for communication. Any system and/or subsystem problems are identified and corrected, if possible, in this stage. The initialization routine for the ICU is executed by several independent routines: analogio.c or anrave.c, diotimer.c, demo540.c, proc1.c, and system.c. These routines specifically initialize and diagnose the XVME540 (Analog I/O), XVME201 (Digital I/O), and HK68H/V3E-4 MB (CPU) boards of the ICU. In the future, the initialization and diagnosis processes will be incorporated into one independent routine.

The task of communicating with ACSM subsystem refers to Ethernet communications through the ENP10 Ethernet board and backbone. Ethernet communication will be used with subsystems such as the Vision Sensing System (VSS) and the Robot Positioning System (RPS). At this point in the project, the vision system information passing is performed through the Sun workstation. Communication from the workstation to the ICU is via Ethernet. Data from the VSS is sent over the Ethernet network to the ICU. The ICU waits for the data and displays it on the user interface whenever it is transmitted. The ICU displays a window once a data transmission begins and closes it after data transmission is complete. The socket.c, comdraw.c, drawarray.c, hold.c, and send.c routines facilitate the task of communication over the CMC ENP-10 (Ethernet) board.

Subsystem input/output includes information passing through the analog and digital boards. This task handles the subsystem control and/or monitoring not handled through the Ethernet link. An example is the control of various subsysterms of the Applicator and Peripherals System (APS). The sealant temperature would be controlled by the user through an analog channel. The user specified temperature is translated to the pre-determined analog channel, which directly connects to the sealant temperature adjuster. These I/O tasks are handled by some routines within the icudata.c module accessing the XVME201 (Digital I/O) and XVME540 (Analog I/O) cards.

The user interface allows control of the machine and displays the status of the ACSM in real-time. Interactive slide bars and buttons on the user interface can provide controls such as switching the heater on and off and setting and changing temperature and level parameters on the heater and dispenser. The user screen displays status and emergency indicators, also with the use of graphical meters and buttons. The icudemo.c module, developed in part by the RAVE software, uses the MMI250 (Audio/Graphics) card to affect a friendly user screen.

2.5 - Component Interaction

The following diagram, Figure 2.1, provides some insight into the current ICU architecture and information flow from other subsystems. This information is based on integration discussions between the ICU and various subsystem groups.

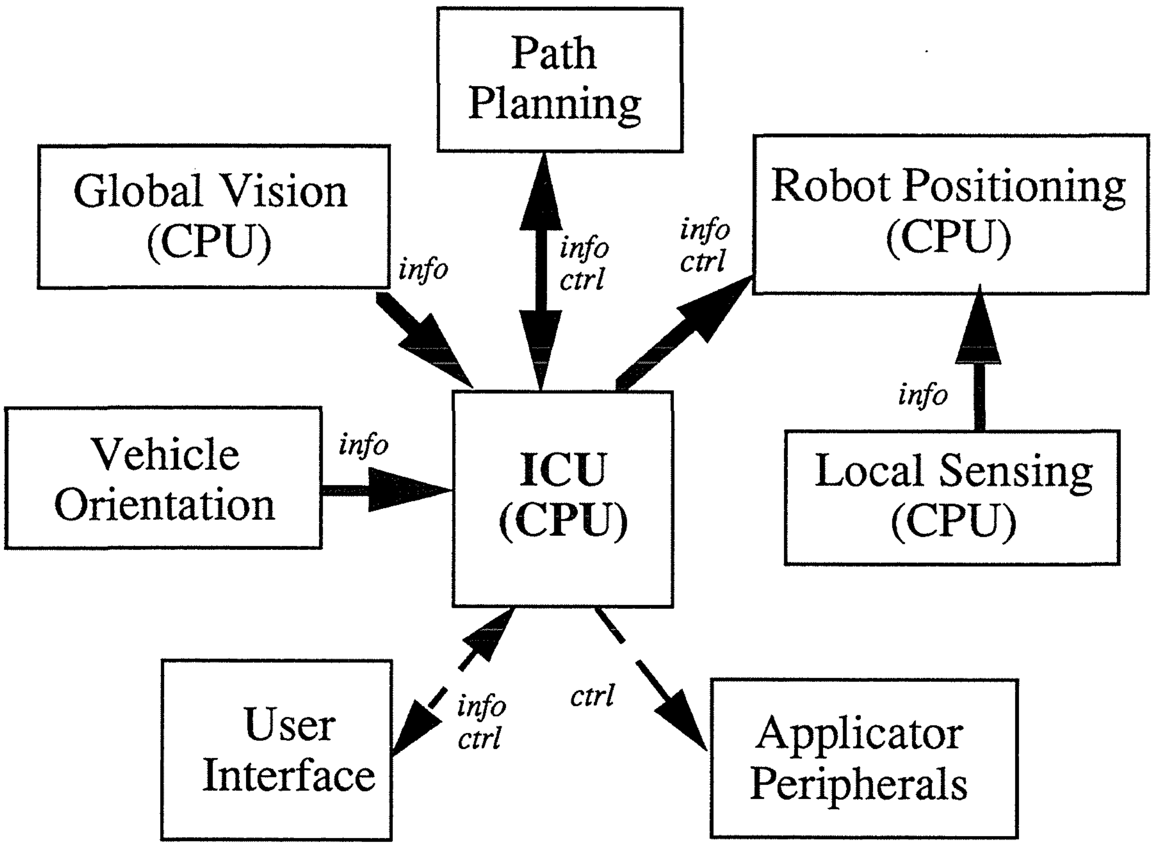


Figure 2.1 - *ICU functional architecture, minor links are not shown.*

3.0 - VISION SENSING SYSTEM (VSS)

3.1 - System Description

The purpose of the Vision Sensing System (VSS) is to locate pavement crack positions using machine vision. This section describes the functional aspects of the VSS, which is followed by a physical description of the system, its components, and a description of how it relates to other parts of the automated crack sealing machine (ACSM).

The VSS processes information from a gray scale image of the top view of a section of pavement, approximately 12 feet wide (one lane width). Acquisition of the image is coordinated with the rotation of the ACSM wheels in order to maintain a proper aspect ratio of the pavement image. *Hence, the image is created by the forward movement of the vehicle.* As the computer acquires sufficient blocks of image data, a ten inch long by 12 foot wide block of video data is built in increments of two inch square tiles. For each of the tiles the determination is made as to whether a crack exists, and if so, in which of eight directions is it headed. This data is immediately transferred to a remote storage area for path planning and updating from the ICU and Vehicle Orientation and Control System (VOC) as the vehicle continues to move forward. No attempt is made by the VSS to connect indications of crack presence among tiles. This is left for the path planning function. Functional components of the VSS can be seen in Figure 3.1. The actual operational steps (single camera shown for convenience only) are shown in Figure 3.2, Principles of Operation.

3.2 - Principles of Operation

The most fundamental portion of the Vision Sensing System is the algorithm that determines crack presence. This algorithm consists basically of four steps:

1. Divide the pavement image into a *grid* for which the mesh (tile size) depends on speed requirements, desired resolution, and acceptability of falsely recognized cracks.
2. Build a *histogram* representing each tile.
3. Compute a *statistical moment* of each histogram.
4. *Compare local values* of moments to identify cracks.

We make note that the algorithm makes no attempt at obtaining a binary image in order to determine more specific qualities of crack segments through chain coding or other means. To follow is a more detailed description of these four steps.

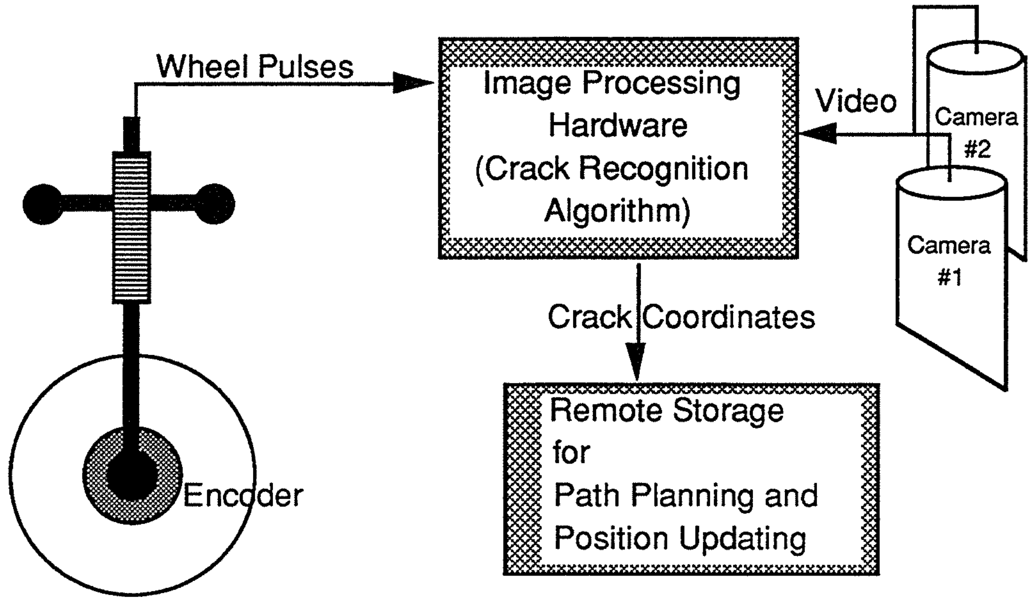
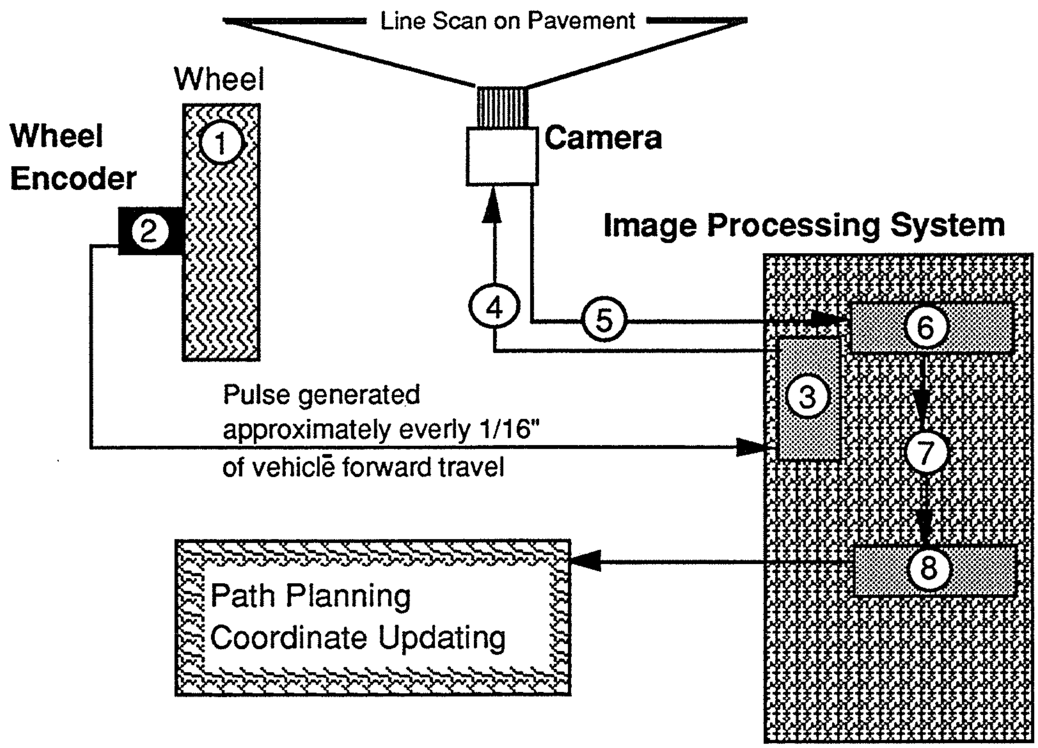


Figure 3.1 *- Vision Sensing System Functional Layout.*

A video image is first created of the pavement with a pixel resolution sufficient to resolve an 1/8 inch feature. In order to satisfy the Nyquist sampling frequency this requires a pixel for every 1/16 inch of highway pavement. A grid is then created to carry information about pavement features contained within tiles (see Figure 3.3). Each tile within the grid is represented by 32x32 (1024) pixels. Through the building of a histogram for each tile and a moment computation, the data representing each tile can be reduced from 1024 counts of 8 bit data (8192 bits) to one integer (moment) consisting of 32 bits. This allows quick manipulation of data in order to determine the presence of a crack. The manipulation of the reduced data is further described below.

The tile size of 32x32 pixels allows for a minimal variance in local modes by reducing the effects of intensity changes within a tile due to differing shades of aggregate and surface defects without significantly affecting the accuracy required to perform the sealing operation. The small variance in modes allows for a comparable measure of darker grey level values among adjacent tiles. *This characteristic of local modes is what specifically allows for the recognition of cracks based on moments about local modes.* Local is defined as a 5x5 grouping of tiles. This is the minimum



① Wheel rotates an incremental amount
② Encoder produces a pulse resulting from incremental vehicle travel
③ Image processing hardware reads pulse from encoder
④ Sends control signals for camera to acquire video line
⑤ Return a video signal representing one line of pavement to the
⑥ Image Processing Hardware
(......*this procedure iterates until enough lines are gathered to determine crack presence at which time* ....)
⑦ An Algorithm determines crack presence in image (in local areas called tiles) and transmits crack information to
⑧ A communications device which communicates the crack information to a path planning function (external to the Vision Sensing System).

***Figure 3.2** - Principles of Operation.*

number of tiles required to identify eight directions we have chosen to recognize.

Next, histograms are created for each tile. A histogram is an ordering of pixel values based on intensities. The number of pixel values that occur in a given area are represented by 256 vertical bars, one for each image grey level (see Figure 3.4).

Following the creation of a histogram, a statistical moment is taken about the mode of the histogram for each tile. The mode is the highest bar in the distribution. The moment is taken by multiplying the cubed distance from the mode by the height of the bar for a given intensity value. This is shown in Figure 3.5.

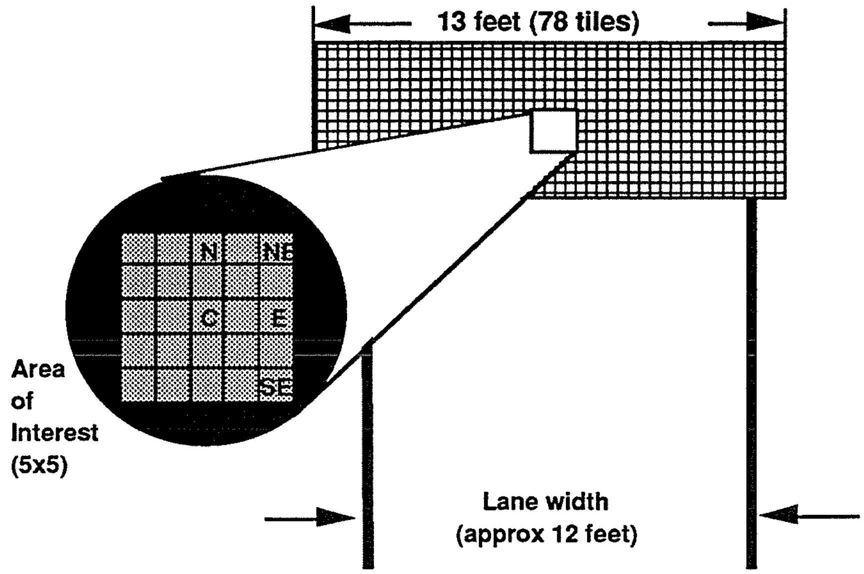


Figure 3.3 - *Crack directions within 5x5 area of interest.*

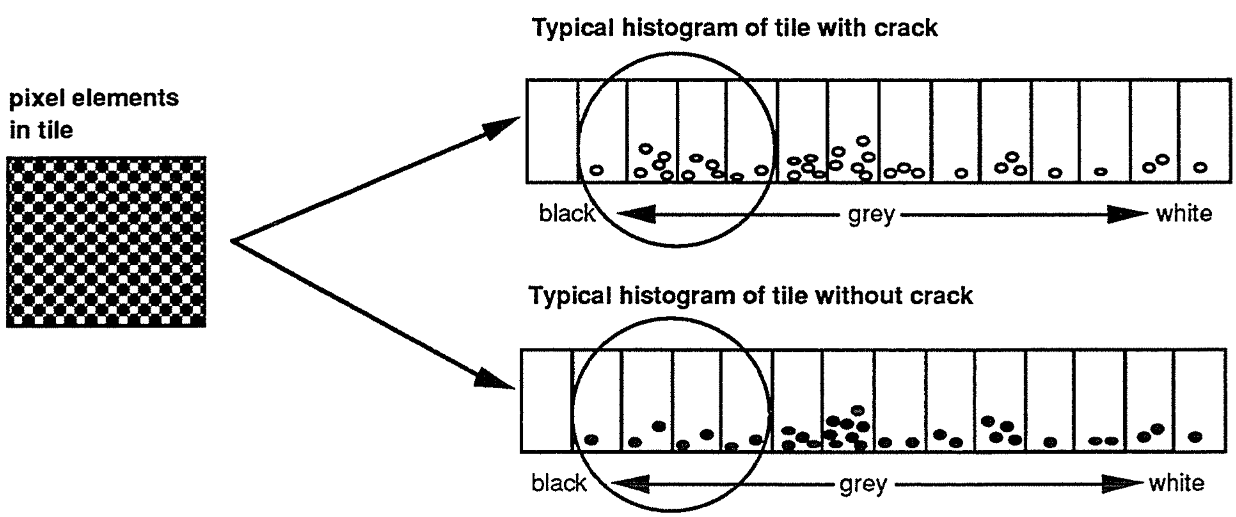
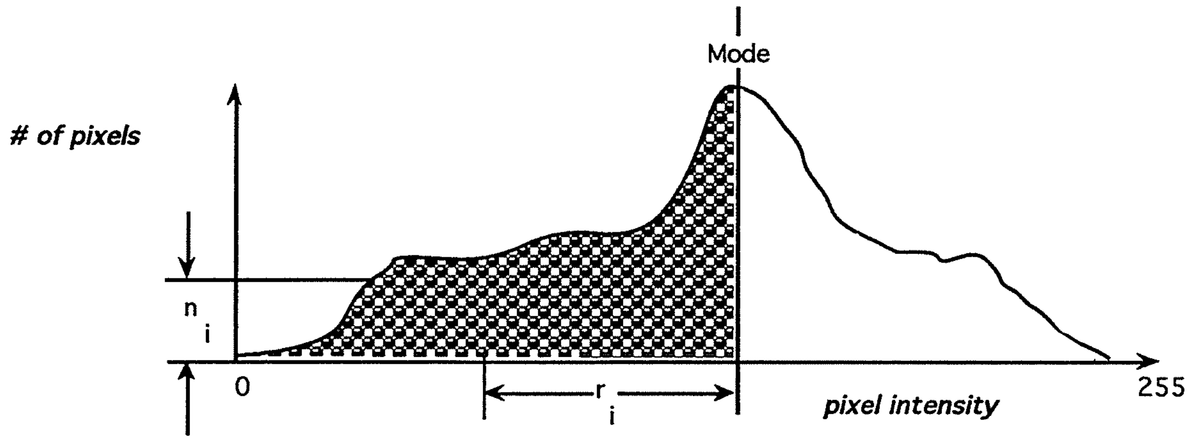


Figure 3.4 - *Histogram of cracked and non-cracked tile.*



moment = $\sum (r_i^e * n_i)$

r_i=grey level distance from mode

n_i=number of pixels at r_i

e=exponent

Figure 3.5 - *Moment Computation.*

Once the moments are computed for each tile, the moment values are compared within independent 5x5 tile grids. See Figure 3.3 for four of the eight directions which can occur in this grid. Every tile in the grid (except two tiles on each end) takes its turn as the center tile in the 5x5 area of interest. The comparisons are based on two parameters, the continuity level and the uniformity level. These two parameters determine the extent and what type of comparisons are made within the 5x5 area of interest in order to determine the presence of a crack and its direction.

There are three selectable crack lengths for a crack to exist. These selectable levels are called continuity levels. Figure 3.6 shows North East bound crack segments and the required continuity levels which will accept or reject a crack based on its length. From Figure 3.6 it can be seen that a continuity level of 1 requires a crack to occupy only one tile, a continuity level of 2 requires a crack to occupy three tiles, and a continuity level of 3 requires a crack to occupy five tiles. Most of the test results to date have been using the continuity level of 3.

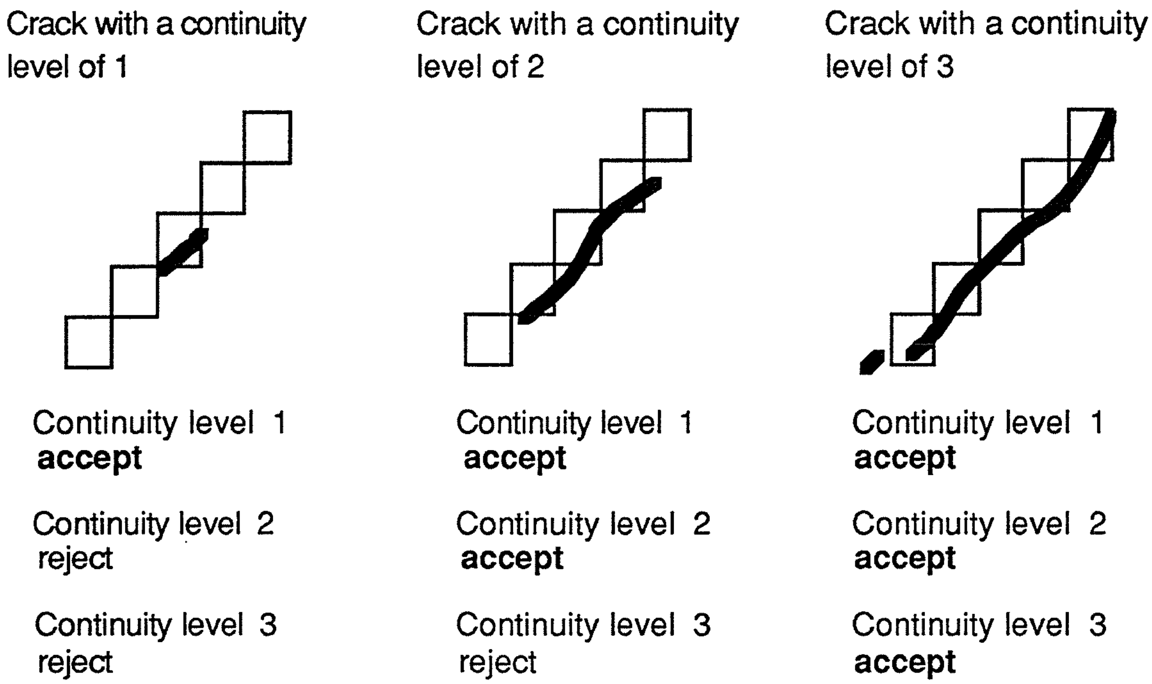
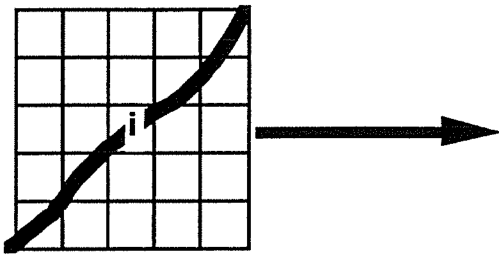


Figure 3.6 *- Continuity Levels.*

The number of neighboring tiles that are used for comparisons in a 5x5 area of interest is called the uniformity level. Figure 3.7 shows how these comparisons are made for a continuity level of 2 with a North East bound crack segment within an area of interest. As the uniformity level increases, each tile associated with a given continuity level must be compared to a greater number of neighboring tiles. That is to say; for a greater uniformity level, the moment values called "cracks" must be so relative to a larger sample of neighboring tiles. Note that a crack is recognized at the center tile marked by "i" only if all of the uniformity level comparisons are true. If any condition is false, it is determined that no crack exists for a given direction. The test results to date have been based on using the maximum number of continuity levels for each direction. These comparisons could be optimized with further testing. The continuity and uniformity levels for all directions are shown in Figure 3.8.

For a more in depth discussion of the VSS, the interested reader is referred to the Phase I Final Report and Appendix B of this report which contains company literature describing the wheel encoder, vision system and cameras purchased.



3l	2lb	4lb		iiir
2la	1l		iir	
4la		i		4rb
	iil		1r	2rb
iiil		4ra	2ra	3r

Example of comparisons:

Continuity level=2 (**i&ii**)

Uniformity level=3 (**1-3**)

Uniformity level 1 check

i> 1l &1r
iil> 1l &1r
iir> 1l & r

Uniformity level 2 check

i> 2la &2lb & 2ra & 2rb
iil> 2la &2lb &2ra &2rb
iir> 2la &2lb &2ra &2rb

Uniformity level 3 check

i> 3l &3r
iil> 3l &3r
iir> 3l &3r

Figure 3.7 - *Example of comparisons.*

3		iii		3
2		ii		2
1		i		1
2		ii		2
3		iii		3

N Comparisons

3	2		iii	
2	1	ii		5
4		i		4
5		ii	1	2
	iii		2	3

N_NE Comparisons

3	2	4		iii
2	1		ii	
4		i		4
	ii		1	2
iii		4	2	3

NE Comparisons

3	2	4	5	
2	1			iii
	ii	i	ii	
iii			1	2
	5	4	2	3

NE_E Comparisons

3	2	1	2	3
iii	ii	i	ii	iii
3	2	1	2	3

E Comparisons

	5	4	2	3
iii			1	2
	ii	i	ii	
2	1			iii
3	2	4	5	

E_SE Comparisons

iii		4	2	3
	ii		1	2
4		i		4
2	1		ii	
3	2	4		iii

SE Comparisons

	iii		2	3
5		ii	1	2
4		i		4
2	1	ii		5
3	2		iii	

SE_N Comparisons

Figure 3.8 - *Comparisons for eight directions.*

4.0 - LOCAL SENSING SYSTEM (LSS)

4.1 - Component Description

The purpose of the Local Sensing System is to locate crack position and measure crack width to a degree of precision such that the crack preparation, sealant application and shaping of the seal can be performed in an automated fashion.

On the general crack sealing machine, the LSS will work in conjunction with the VSS to confirm the presence of a crack within a given area. The VSS will locate the approximate position of a possible crack using a video camera. This camera uses a line scan charged coupled device (CCD) as its sensing element. As the vehicle moves, lines across the lane width will be gathered to form an area view of the road surface. Through measuring the intensity of gray levels which the camera senses, it is possible to determine the position of possible cracks. However, since the line scan camera only has two-dimensional measuring capabilities, it may mistake an oil spot, shadow, or previously filled crack for an actual crack. The purpose of the LSS on the general machine is to scan the area near the potential crack location identified by the VSS to confirm or reject the presence of a crack. Furthermore, there are inherent inaccuracies in the VSS crack identification algorithm which gives it a resolution of approximately +/-1". There are also errors associated with the motion of the vehicle that will result in errors in the crack location identified by the VSS. Therefore, the LSS will also provide more precise position information to the general Robot Positioning System (RPS). Local sensing will provide range information that can accurately sense the presence and position of a crack. However, local sensing alone would not be adequate because the local sensor requires a planned path to scan for random cracks. Given the operating speed of the vehicle, the update rate and field of view of the local sensor are not adequate to track random cracks without prior knowledge of crack direction.

On the longitudinal crack sealing machine, the local sensor will provide all sensing information to the longitudinal RPS. Because the longitudinal cracks do not randomly vary in direction, it is possible to design a sensing system in which the local sensing system provides an error feedback signal to the longitudinal RPS. The start of the crack must initially be placed within the local sensor field of view, and then through real time controls and feedback provided by the local sensor, it will be possible for the longitudinal RPS to follow the longitudinal crack.

A variety of sensors technologies have been researched in order to select a sensing system which best meets the sensing requirements. The Local Sensing System which has been selected is the most cost effective, off-the-shelf component which meets all the requirements. The system selected is a laser vision sensor which measures range information using triangulation. Using triangulation, distance measurements are determined by transmitting a laser light source, then focusing the diffusely reflected light source on a photosensitive device. This method of detection has proved to be reliable and is commercially available and widely used for seam detection during automated welding.

Sensing systems based on triangulation are impervious to color variations. Therefore, a laser range finding sensor will work well on all pavements. Also, laser sensors are not sensitive to a dusty environment. Furthermore, laser triangulation is insensitive to lighting conditions because the sensor provides its own lighting via the laser. Overall, laser triangulation is a proven reliable technique for extracting three-dimensional surface characteristics.

To achieve optimal field of view and update rate from the sensor, a laser vision system using structured light was chosen. Laser vision systems based on structured light offer reliability, design simplicity, compactness, while maintaining cost effectiveness. Structured light extracts a three dimensional surface profile by projecting a laser pattern in a plane perpendicular to the surface being measures. The line of light is then observed by a CCD camera at an angle allowing the surface features to be found.

Because the goal was to use off-the-shelf components, five companies which manufacture laser vision systems were found and considered. Modular Vision Systems (MVS) was the only manufacturer who produced a commercially available sensor which met the requirements. The MVS LaserVision system provides off-the-shelf reliability and its image processing board is completely IBM compatible. It was specifically designed for tracking and inspection in robotics applications. Furthermore, this sensor is simple to use and rugged in harsh environments. The sensor has a built-in heat exchanger for cooling and a cleaning mechanism which prevents dust from settling on the lens which would distort the image. These attributes are attractive given the harsh environment associated with automated crack sealing. The MVS LaserVision system consists of the hardware and software listed in Table 4.1. Figure 4.1 contains a photo of the unit mounted in a test stand.

The sensor itself is a small package weighing 9 ounces and measuring 4" x 3" x 1.6". This package contains a laser light source, a CCD camera, and appropriate

One Laser Vision Sensor
One 30mW laser source
One sensor and laser power supply
One Laser Vision Image Processor
One co-processor board
One Microsoft compatible C5.1 library of driver routines
Menu Driven Program - Profile capture, store, segment, recall - Adjust laser intensity
Segmentation Program
IBM compatible 386-25 MHz - VGA color monitor and graphics card - Four empty full sized slots - Two serial ports - 40 MB hard drive - 4 MB RAM

Table 4.1 - *Local Sensing System (LSS) software and hardware.*

optics. The sensor will be mounted to the robot with a provided precision machined camera bracket. A vibration isolator will be placed between this bracket and the robot arm to protect the sensor from harsh vibrations and to prevent the image from being distorted. It should be noted that moderate vibration will not destroy the reliability of the camera data because the camera captures a "blur" and the image is placed optimally within this blur to compensate for the vibration. Mounting will provide flexibility of vertical and lateral adjustment for initial calibration procedures.

Power for both the laser and the camera is provided by a standard rack mounted power supply. Cabling will run between the sensor and this power supply as shown in Figure 4.2. Output from the camera will be input to the laser vision profile processing board, which will be placed in a standard IBM-AT compatible slot, where the camera data will be processed and the profile will be extracted. For increased performance, the profile data will be transferred to a co-processor board, which also plugs into a standard IBM-AT compatible slot.

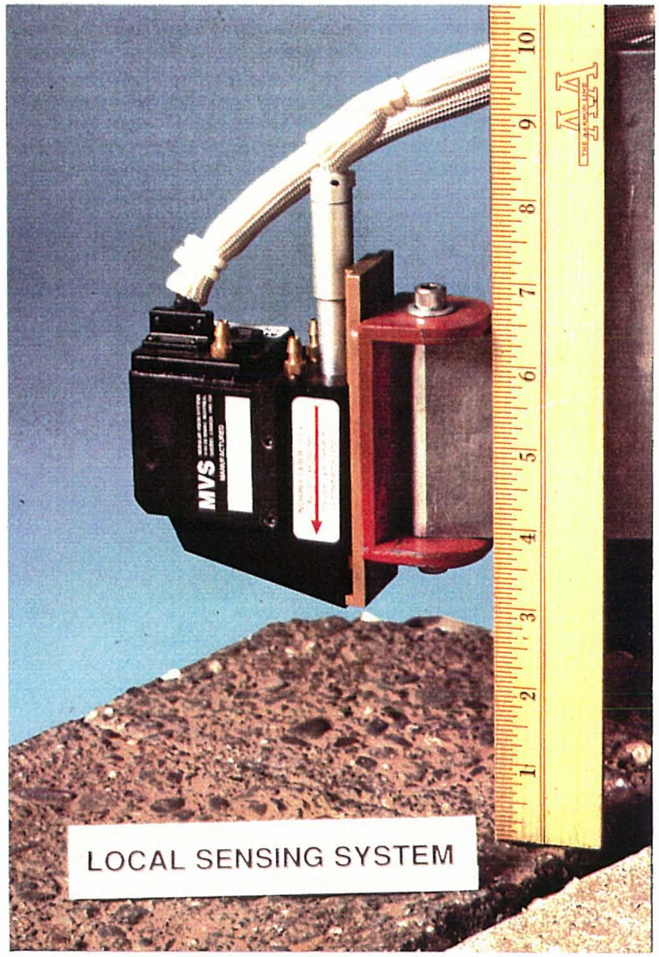


Figure 4.1 - *Photo of local sensor mounted in test stand.*

A summary of the pertinent specifications for the LSS is shown in Table 4.2. For detailed specifications, see the manufacturer's specifications in Appendix C.

4.2 - Principles of Operation

As previously discussed, a laser vision system using triangulation was chosen to locally locate a crack in pavement. Figure 4.3 illustrates the principle of triangulation. Distance measurements are determined by transmitting a focused laser light source onto an object and then imaging the diffusely reflected light onto a photosensitive device. The photosensitive device (PSD) is an analog light sensor that is sensitive to the intensity and position of a light spot in its field of view. Knowing the position of the image on the PSD, the distance between the detector lens and light source and the

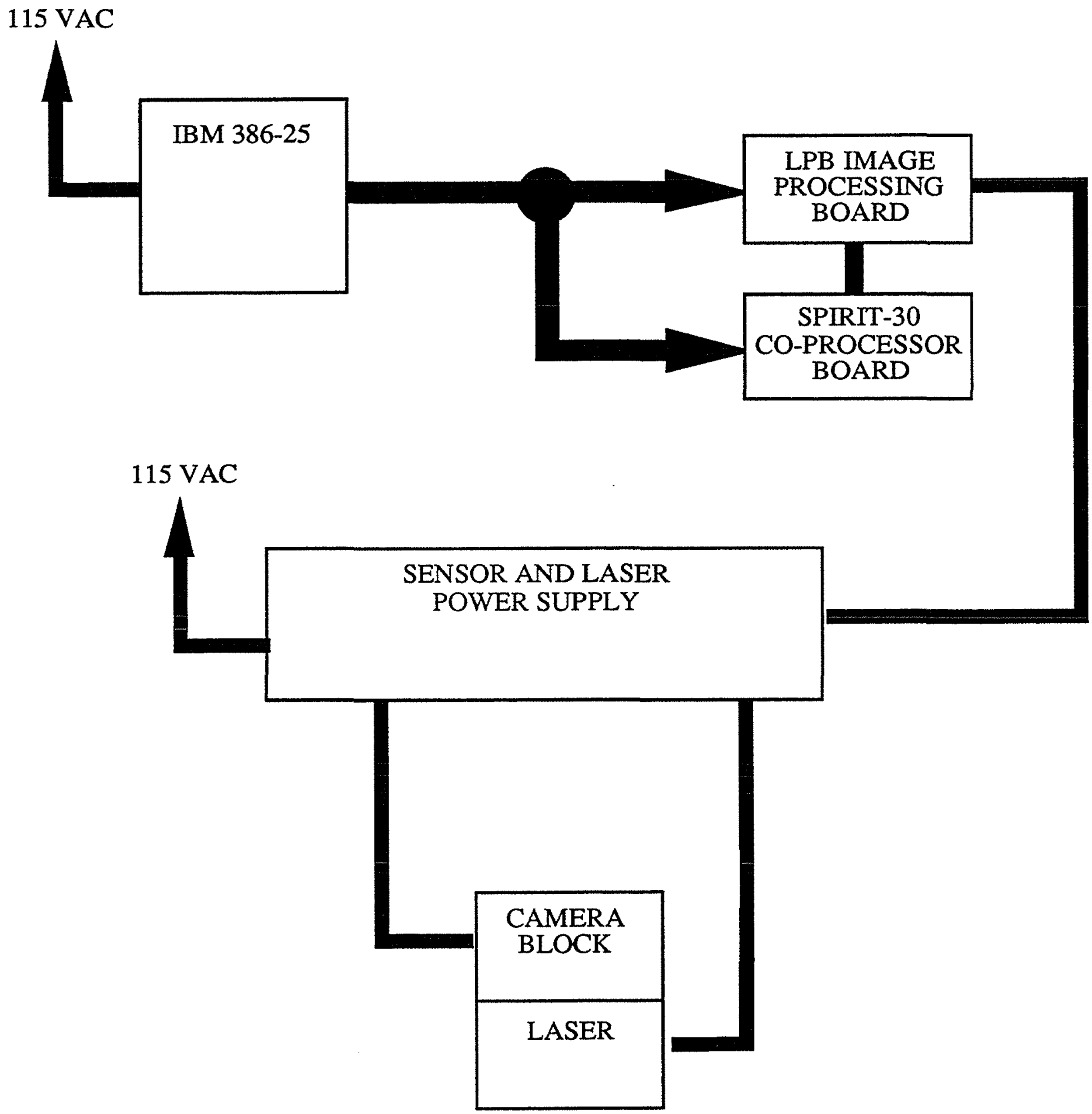


Figure 4.2 - *LSS interconnect diagram.*

projection angle of the source, the distance measurement can be geometrically determined.

Figure 4.4 illustrates a laser vision system using structured light to develop three dimensional surface profiles. A laser light source is projected approximately perpendicular to the direction of the crack. The bright line produced by this laser source on the surface is then observed by a CCD camera at an angle (20°-30°). The

	Horizontal		Vertical
Speed images/sec	60	30	
Resolution*	0.005"	0.0025"	0.006"
Accuracy position*	0.006"	0.003"	0.008"
Accuracy mismatch*			0.002"
Accuracy gap*	0.012"	0.006"	
Mounting distance to road	6.5" max.		
Field of View	4.34" max.		
Moisture	to 85%		
Vibration	typical vehicle vibration		
Temperature	-20 to 160^{o}F		
Service Life	10 years.		
Speed	60 images per second - RS170 50 images per second - CCir standard		
Water cooling	0.25 gallon per minute		
Air cooling	0.11 CFM		
Weight	9 oz (250 g)		
Processor	IBM-AT compatible, up to 8 MHz bus speed, requires 64K memory mapped space		

Table 4.2 - *Laser vision system specifications. *Accuracy and resolution specifications are based on operating the sensor in the optimum area. The sensor will be operated outside this area to achieve a larger field of view. However, the manufacturer has guaranteed that the sensor will still meet the system requirements with a 4" field of view.*

analog camera data is then digitized, filtered, and processed using triangulation to determine depth information.

The MVS LaserVision sensor projects a laser light source approximately perpendicular to the direction of the crack. The bright line produced by this laser source on the surface is then observed by a CCD camera at an angle (20°-30°). At this angle the line will appear to be broken.

The camera output of the laser sensor is then input to the MVS LaserVision Profile Board (LPB-200). The LPB-200 is an image processing board designed to extract the three dimensional profile from the surface of an object. The broken laser line of data

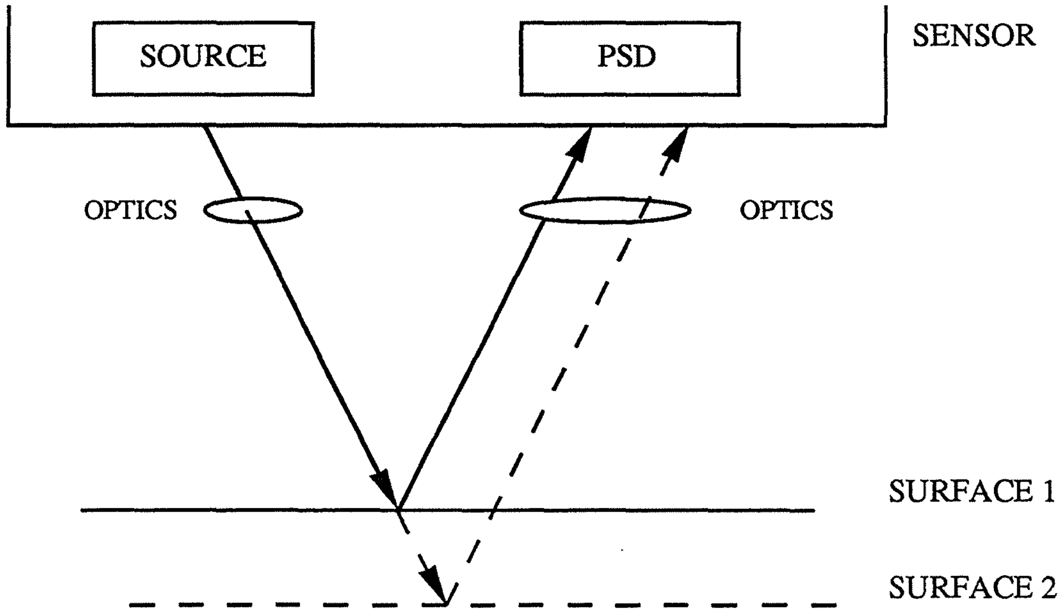


Figure 4.3 - *Principle of triangulation.*

acquired by the CCD camera is input to the LPB-200 and the surface profile is extracted at 60 times per second. The LPB can be used in a stand alone configuration, or with an additional co-processor board for increased performance. For the crack detecting application, a Spirit-30 co-processor board will be used. The profile data will be transferred to the co-processor board via a separate output port which is internal to the computer.

Among many features, the LPB-200 contains a histogram circuit which can operate on either an entire frame captured by the camera, or a selected window area of interest. Eight Area of Interest windows are user selectable and may be easily moved around the picture area using software routines. Performing the histogram function in hardware rather than software decreases required processor time.

The Area of Interest window can also be set to work on the extracted profile data. The profile extractor on the LPB stores x, y coordinates and light intensities of the most probable line. The data is digitally filtered in real time for accurate profile data.

The LPB board also contains an output which can control the laser intensity. This value is set in software using the provided software functions.

For more detailed feature descriptions, see the MVS LaserVision specifications in Appendix C.

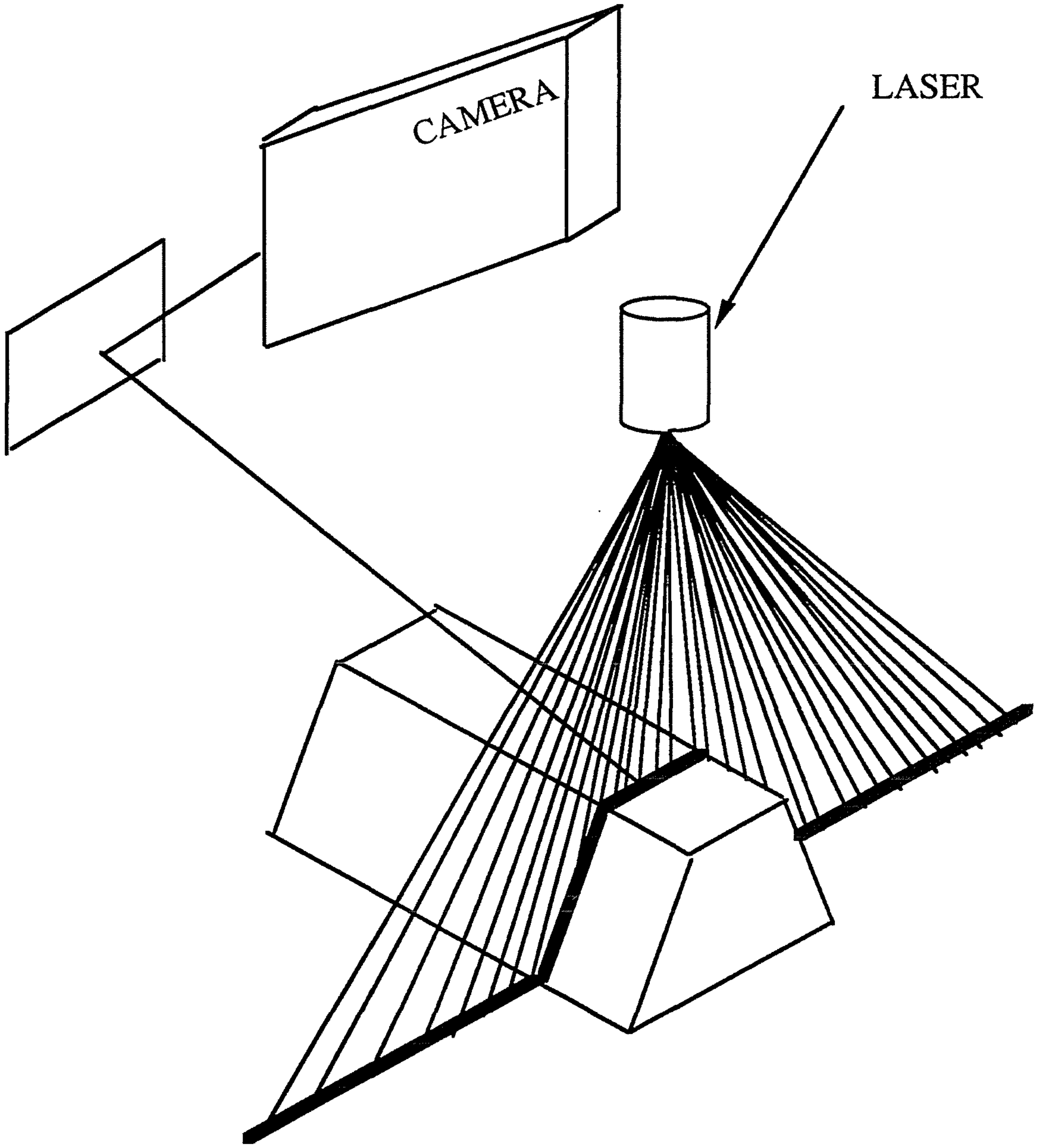


Figure 4.4 - *Structured Light*

In order to acquire and interpret the depth information gathered by the sensor, a customized software program was developed. This program acquires data, interprets the data and extracts information relating to the position of the crack, and communicates this information to the appropriate systems.

The calling program will operate in real-time on an IBM compatible 386-25 Mhz computer. The program will be compiled using Microsoft QuickC, which is compatible with the Microsoft compiler which has compiled the functions provided with the MVS sensor. The supplied functions are contained in a library which will be linked to the calling program during compilation.

The program consists of an initialization procedure followed by the main body of the program which senses the presence of cracks in pavement. In the main body, first a profile of the road surface is captured. Next, each individual data point along the profile is analyzed to determine if a crack has been found. If a crack has been located, the program sends position information to the Robot Positioning System and then loops back to the start of the main body and captures the next profile. If the entire profile is analyzed and no crack has been located, a signal is sent to the ICU and then the program loops back the start of the main body and captures the next profile. Details of each task performed by the crack sensing program are described in the following sections.

Before the main body of the program can begin acquiring data and detecting crack location, an initialization procedure in software must be performed. During the initialization procedure, the LSS hardware is initialized. This is done through calls to initialization procedures which were provided with the MVS system software. The laser intensity is also set to maximum intensity by calling a procedure provided with the system software. Maximum intensity has reliably given optimal results on pavement surfaces during testing. Serial communication is also initialized. Two serial ports are used for communications (COM1 and COM2). The baud rate, number of stop bits, and parity (odd, even, or none) must be set for each serial port before communication can be successfully established. Using C function calls to the DOS operating system, the serial ports are initialized. Also, a profile is extracted using MVS system software and the typical roughness of the pavement surface being measured is determined. This measurement is necessary in order to determine typical depth variations from the sensor to the pavement surface. From the typical variance, an acceptable tolerance is set. Depth measurements exceeding the tolerance are therefore considered a crack. Lastly, the average depth of the pavement at the beginning of the profile is determined. This is accomplished by averaging the first twenty-five extracted data points over a typical section of pavement not containing a crack. This average is used to initialize the digital filter.

To compensate for varying surface profiles and normal height deviations in pavement, a digital low pass filter is used on the extracted data. A low pass filter was chosen to filter out normal high frequency variations in the depth measurements since the measurements of concern are low frequency components in the depth measurements - due to the presence of a crack. The digital filter was modeled after a low pass second order filter. The filter constants were determined using a Digital Fourier Transform (DFT) analysis. Figure 4.5 shows the profile of a crack measured by the local sensor before filtering, while Figure 4.6 shows the crack profile after filtering.

Before the program continues, it waits for a start signal from the ICU via the COM2 serial port. Once the signal to begin is received, the first task performed by the calling program is to determine if the sensor has located a crack. If the sensor is located over a crack, location is determined and sent to the RPS. If no crack is found, an indicating signal is sent to the ICU. This is performed by making a software function call to extract a profile and calibrate the data. The result is x, y coordinates in millimeters, where x is the direction along the line of light, and y is the depth measurement from the sensor to the surface. The zero coordinate along the x direction is located in the center of the scan. The result is stored in an array accessible to the program. Each element in this array is consecutively filtered and then compared to the previous value to determine if the starting edge of a crack has been located. If the current measurement varies by more than the accepted tolerance determined in the initialization procedure, then the program assumes that the leading edge of the crack has been located.

A simpler routine would be to compare the current data to a set point value. However, this approach was not taken because the road surface profile may vary gradually within the sensor field of view by more than the accepted tolerance without a crack being present. By comparing the current value to the previous value, gradual changes in profile are allowed for, and erroneous indications of the presence of cracks are avoided.

A problem arises in requiring that a previous value be set for both the filtering routine and the crack detection routine. Without an initial value, it would be impossible to detect a crack if it was located at the first data point. To solve this problem, the average value determined during the initialization routine is used.

Once the program has determined that the sensor has detected the leading edge of a crack, a flag is set, and the x coordinate of the leading edge of the crack is stored. This flag will remain set until the trailing edge of the crack is located. The trailing edge of the crack is located by again comparing the current depth measurement to the last measurement taken. When the depth variance exceeds the tolerance, the trailing edge of the crack has been located. The x coordinate of the trailing edge of the crack is then stored.

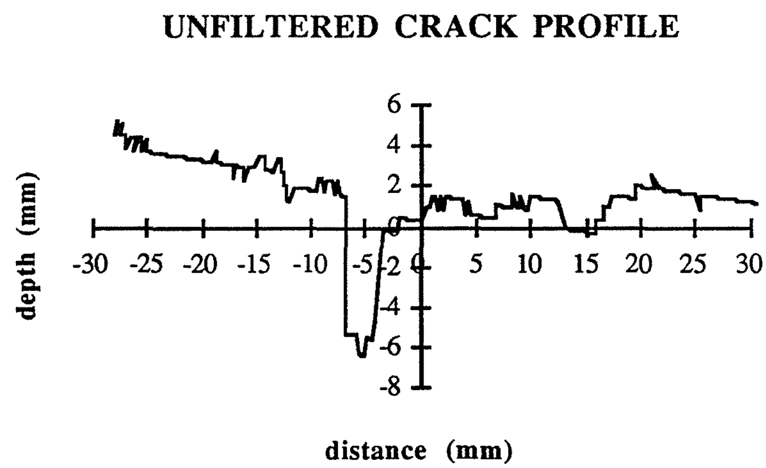


Figure 4.5 - *Crack profile before filtering.*

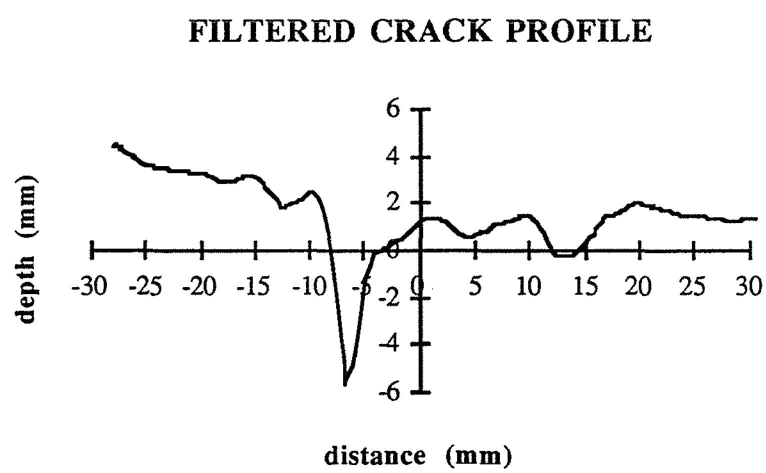


Figure 4.6 - *Crack profile after filtering.*

The next software task is to determine the width of the crack. This is simply determined by subtracting the leading edge coordinate from the trailing edge coordinate. Cracks less than 1/8" in width are not sealed (same as no crack located). This effectively serves as a threshold filter which ignores unwanted spikes due to noise in the data. In the case where a crack less than 1/8" wide is located, the program continues to analyze the remainder of data points in the scan line for a crack in the same manner as described above.

Once the crack has been located and the width has been determined to be greater than 1/8", the midpoint of the crack is calculated by averaging the leading edge and trailing edge coordinates. This location constitutes the error feedback signal required by the RPS to follow the crack.

Once the error signal is determined, it is sent to the RPS directly via an RS-232 port. Using C function calls to the DOS operating system, data is sent one byte at a time per the RS-232 standard protocol.

The program then loops back to the beginning, where a profile is once again extracted and analyzed. The remainder of data points extracted during the last measurement are not further analyzed because the current machine operation does not address situations when two cracks have been located within the local sensor field of view. Because the other subsystems do not currently support the situation of multiple cracks, it would be counter productive to further analyze the data. However, only minor modifications to the program are necessary to alter the operation such that error signals can be sent to the RPS each time the sensor locates a crack, regardless of the number of cracks which have been located.

If each element of the extracted profile is analyzed and no crack location is found, an indicating signal is sent to the ICU. This signal is also sent over a second serial port (COM2). Under normal conditions, the sensor will be located over a crack and no signal will be sent to the ICU. Therefore, the ICU must constantly be polling this port to see if a signal has been sent. After the indicating signal is sent to the ICU, the program loops back to the starting point, where once again a profile is extracted and analyzed.

5.0 - ROBOT POSITIONING SYSTEM (RPS)

5.1 - General Positioning System

5.1.1 - Introduction

The following describes the GMF A-510 SCARA manipulator and the Karel controller which have been purchased for the AHMT crack-sealing project. The purpose of the manipulator is to guide process carts over pavement cracks as part of the general crack sealing machine. The A-510 manipulator will be inverted and mounted on a linear slide on the back of the crack sealing truck. The Karel controller is a fully integrated robot motion controller which will be responsible for all motion of the manipulator. The controller will receive input from the LSS and the ICU which will provide it with necessary information to control the manipulator which in turn guides the process carts over cracks in the pavement. The slide-mounted A-510 and the Karel controller are currently schedule to be shipped to the UCD campus from GMF in Auburn Hills, Michigan on May 20, 1992.

5.1.2 - Component Description and Principles of Operation

5.1.2.1 - A-510 manipulator:

The GMF A-510 is a SCARA type four degree-of-freedom manipulator (see Figure 5.1). Manipulators such as these are commonly used for assembly operations, food packing, and palletizing. Each joint shown is driven by a servo motor and the relative position of the joint is recorded by encoders. The servo motors and encoders are interfaced with the Karel controller. The Karel controller is able to use information from the encoders to move the end effector to locations within the workspace of manipulator. Pre-programmed information on the manipulator kinematics allows the controller to move the manipulator to points in Cartesian space with respect to the base of the manipulator.

5.1.2.2 - Karel controller:

The Karel controller is capable of making calculations and running programs similar to many high level programming languages. These programs allow the robot motion to be controlled to execute a variety of complex tasks. In addition, the Karel controller can interface with other systems through digital I/O ports and serial lines. This allows the controller to operate with information from sensors and also to send motion information to other systems. As an additional feature, the Karel controller is

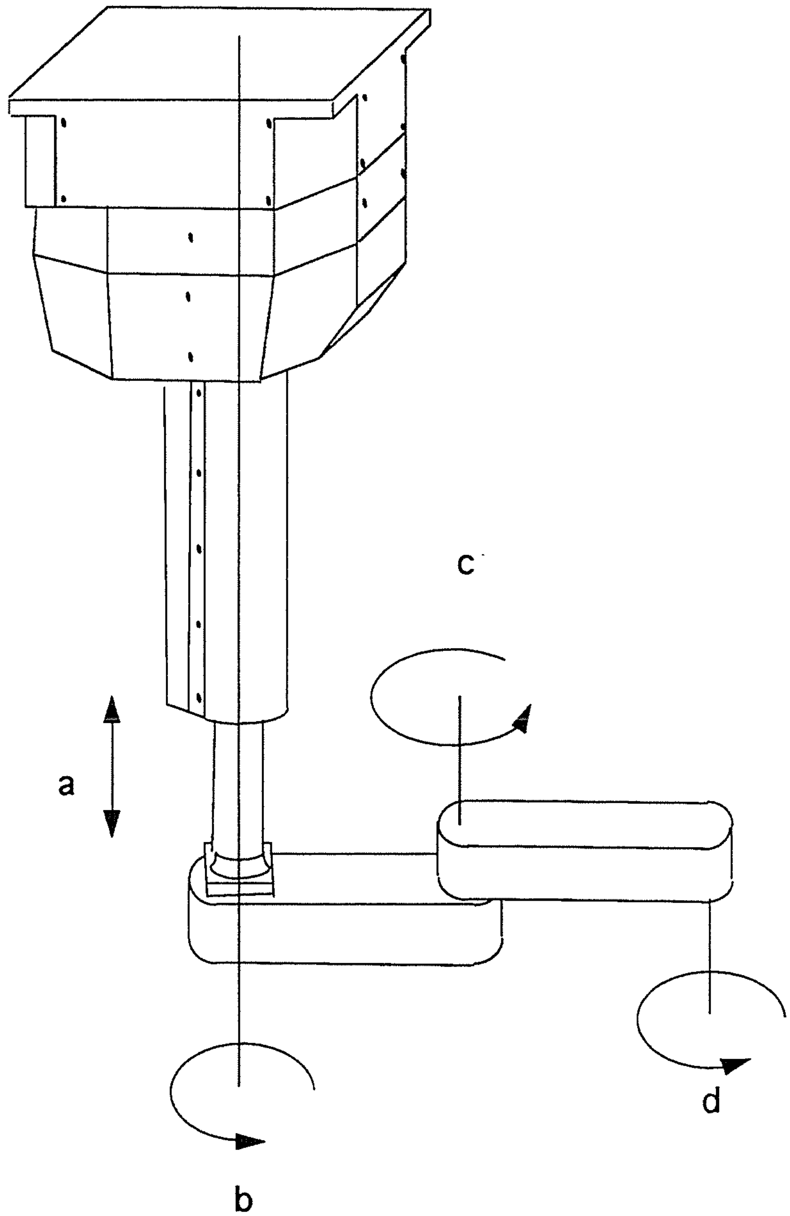


Figure 5.1 - *GMF A-510 inverted configuration, a) joint 1 - translation, b) joint 2 - rotation, c) joint 3 - rotation, d) joint 4 - end effector flange rotation.*

capable of controlling machinery other than the manipulator. As an example, in an assembly environment the controller could be used to operate conveyors, parts feeders and linear actuators. Integration with other machinery can include custom hardware integration such as the integration of the A-510 and the linear slide or it can

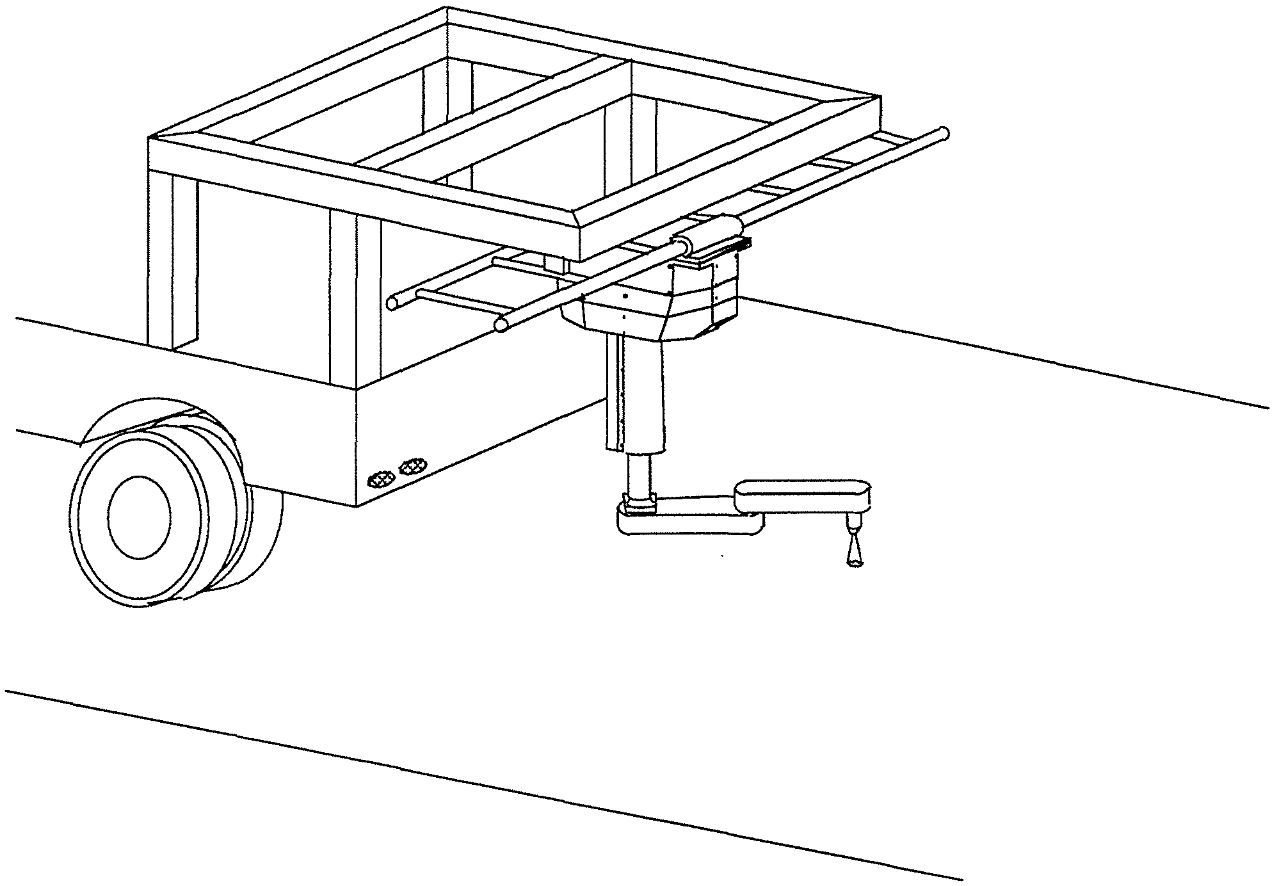


Figure 5.2 - *The GMF A-510 mounted on a linear slide on the back of a truck.*

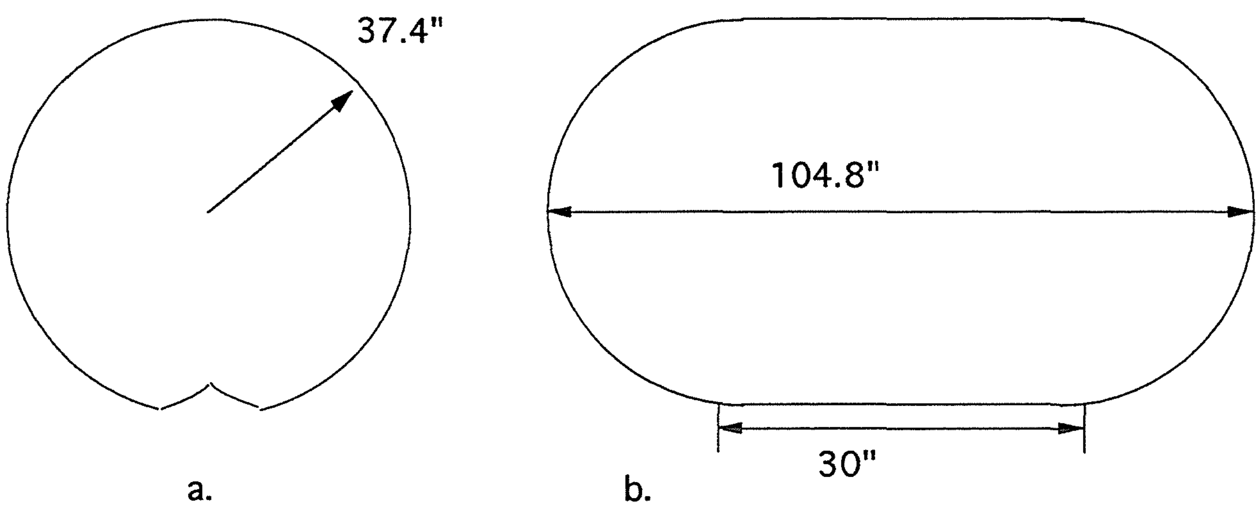


Figure 5.3 - *Workspace of the A-510 manipulator, a) without the linear slide and b) with the linear slide.*

Maximum reach		37.4 in.	
Payload		22 lb.	
Weight		330 lb.	
Maximum overall height		55.3"	
Joint 1	Stroke		11.8 in.
	Speed		27.6 in/sec
Joint 2	Rotation		300°
	Speed		300°/sec
Joint 3	Rotation		300°
	Speed		300°/sec
Joint 4	Rotation		540°
	Speed		540°/sec

Table 5.1 - *General specifications for the GMF A-510 manipulator.*

take place through any of the I/O devices that were previously mentioned. The flexibility of the Karel controller and its ability to integrate with other systems make it an ideal component for use in a research environment.

Additional degrees-of-freedom can be incorporated into the manipulator motion using the Karel controller. This will allow the manipulator to be mounted on a linear slide with the slide and manipulator operating as a single unit in the eyes of the user.

5.1.2.3 - Linear slide:

The manipulator will be mounted on a custom built, servo controlled linear slide which will be integrated to the Karel controller. The slide will have an overall width of 8 feet to fit on the back of the crack sealing truck. The slide will have 2.5 feet of horizontal travel (see Figure 5.2). Note that the travel of the slide is restricted by such factors as the width of the manipulator base. A custom built slide manipulator unit may be desirable during the commercialization stage. The addition of the linear slide will increase the reachable workspace of the manipulator and enhance its dexterity in certain areas near the edge of the workspace. A normal SCARA configuration manipulator can not necessarily move along a given path within its workspace. In addition to extending the workspace, the addition of the linear slide provides a redundant degree of freedom which will allow the manipulator to move in any direction

Operator interface through Karel programming language
Simultaneous control of up to 9 motion axes
Capable of remote or local operation
2 MB RAM
Serial communication capability
Analog to Digital module
8 Channel Digital I/O
4 Channel Analog Input
2 Channel Analog Output
Real time I/O monitoring
Complete programming control structures
Full Cartesian level transformation capability
Continuous path motions
Basic and advanced arithmetic functions
Flexible operator interface

Table 5.2 - *Features of the Karel controller.*

and along any path (e.g. following a crack) within its workspace. The workspace of the manipulator with and without the linear slide is shown in Figure 5.3.

The A-510 manipulator was selected from a field of commercial manipulators on the basis of workspace, payload, and controllability. Important specifications of the GMF A-510 are listed in the Table 5.1. Important features of the Karel controller are shown in Table 5.2.

5.2 - Longitudinal Positioning System

5.2.1 - Component Description

Due to the nature of the tasks involved, the development and fabrication of the longitudinal RPS design has occurred in two stages. The first stage included the design and fabrication of the mechanical structure, the longitudinal machine, which includes the cart, linear slide table, and the connecting links. The second stage consisted of the selection, purchase, and integration of the actuator and control system. The first stage has been completed but the purchasing process is pacing the receipt of the actuator and control system in the second stage. Completion is pending the receipt of the actuator and control system and integration which can be completed once the hardware is available.

5.2.1.1 - Longitudinal Machine

The longitudinal machine was designed to serve as the test vehicle for the APS components and a prototype to the longitudinal RPS. Important design criteria identified during development follow:

1) The actuator control system is simple. To accommodate this, the linkage allows the cart to translate laterally with the movement of the actuator.
2) The linkage design is such that motion of the cart due to the changes in elevation and angle of the road surface result in the least possible lateral translation - which would are compensated for by the actuator.
3) Stowage is simple.
4) A cart length of 5 feet is provided to allow installation of APS components in the worst case configuration. Lateral movement of the cart is limited to 12 inches total, representative of driver's abilities when crack sealing.
5) Simplification of the design is important to prove the concept and have a working prototype to support the APS component testing. Development for commercialization should address issues such as optimum cart configuration and stowage design.
6) Designed for ease of application to any size support vehicle. The particular prototype built is dimensioned around the 40 inch high bed of the test vehicle made available to the project by CalTrans.

Figure 5.4 depicts the basic components of the longitudinal machine which are described in the following paragraphs. It should be noted that the item numbers discussed correspond with those of the figure *and* those of the detail assembly drawing, SHRP(LPS)LM-A100 in Appendix D.2.2.

1) Linear slide table (item 2) - The base of the table (item 1) is bolted to the truck bed and can be adjusted to set the slide table parallel to the road, allowing for an adjustment of 0.75 inches. A linear actuator (item 11) with a 12 inch stroke drives the slide table which is mounted on two linear bearings (item 12), 39 inches in length.
2) Upper link (item 3) - During operation of the machine, this link serves as a structural member rigidly attached to the slide table and extending down to the lower link attached to the cart. The linear movement of the table on top of the truck is transferred by this link down to the cart (item 5) near the road. It is hinged to the table at one end and can be unlocked to allow it to

rotate upward lifting the cart up for stowage. The length of the link between the attachment point on the table to the lower link would be sized for the vehicle to which it is attached, and this is the only part that would need to be adjusted in mounting the unit to another vehicle.

3) Lower link (item 4) - The link is hinged at the upper link and the center of the cart. The hinge points allow the cart to translate vertically and rotate about its longitudinal axis as it follows the road. Lateral translation of the linear table is transferred to the cart across this link. At nominal dimensions on a flat road the axes of both hinge points line in a plane parallel to the road. The bend in the arms of the link provide clearance to allow the casters (item 10) on the cart to rotate 360°.

4) Cart (item 5) - The cart is a simple rectangular frame usually mounted on a pair of casters. The casters support the weight of the frame and components while maintaining a constant height with respect to the road surface (see Figure 5.5). When operated in a configuration that includes the router (see Figure 5.6), the casters are removed and the cart is attached to the frame of the router. Rotation of the cart about the transverse axis (pitch) is prevented by the reaction forces across the lower link. So, the cart longitudinal axis is always parallel to the longitudinal axis of the truck. Bolt holes are placed in the frame as required to attach the APS components.

During operation the links allow the cart to follow the road surface defined by the contact points at the casters. The cart is free to move vertically and rotate about the hinges on the lower link as shown in Figure 5.7. The stowage of the cart is achieved by rotating the upper link upward as shown. This is presently done by using an overhead hoist attached to the lower link. Modifications to the upper link and the use of hydraulic actuators during commercialization would allow for other stowing configurations.

5.2.1.2 - Actuator and Controller

A commercially available prepackaged electro-hydraulic linear drive was selected for the longitudinal RPS. The system, presently on order, uses a programmable digital controller to operate the servo valve on a hydraulic cylinder and operates in a closed loop with the feedback from a position transducer on the hydraulic cylinder. The controller can be programmed to accept input from the LSS across a RS-232 port. Given a value for position, the controller will then drive the actuator to the location at

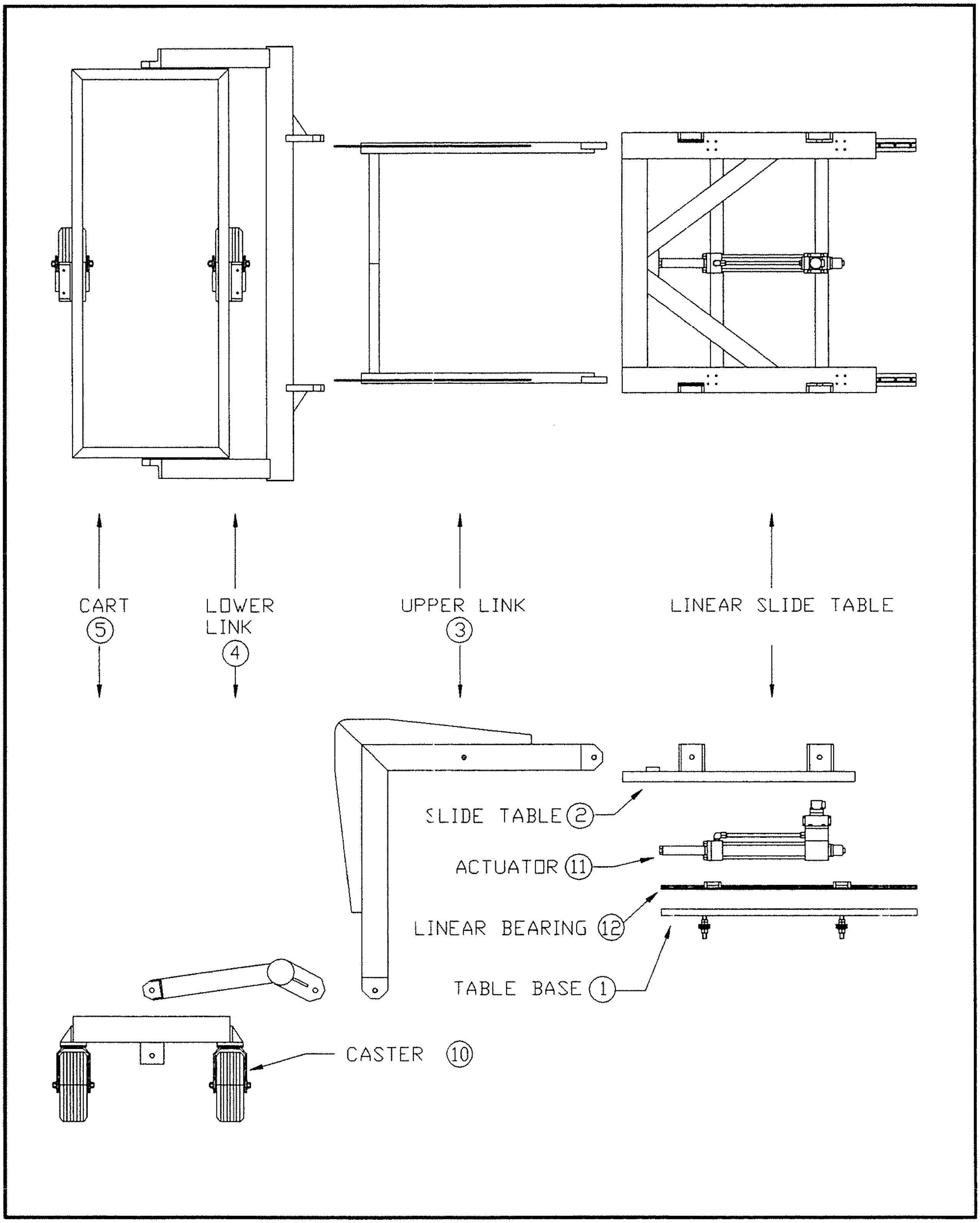


Figure 5.4 *- Longitudinal machine basic components. Item numbers correspond to assembly drawing SHRP(LPS)LM-A100 in Appendix D.2.2.*

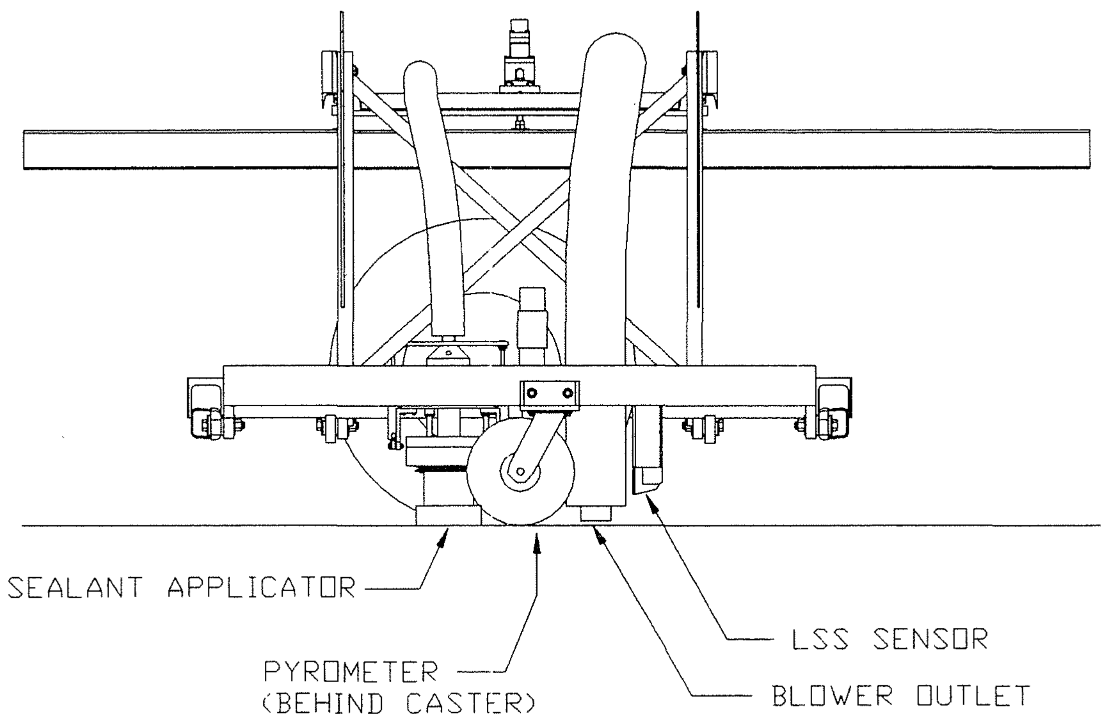


***Figure 5.5** - Longitudinal configuration without router attached. Note the pneumatic casters which support the linkage.*

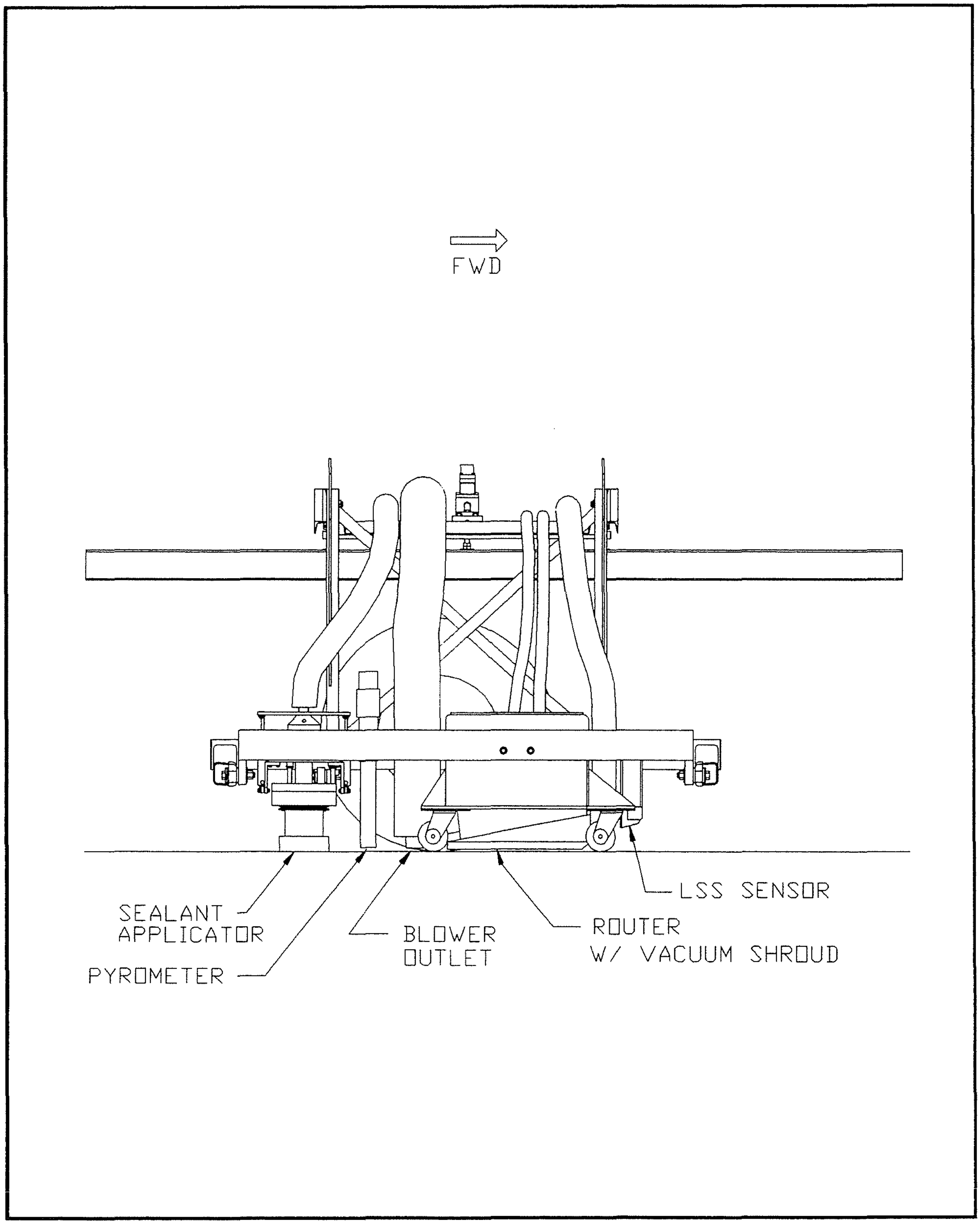


Figure 5.6 *- Longitudinal configuration with router attached. Note: the casters have been removed, the linkage is supported by the router wheels.*

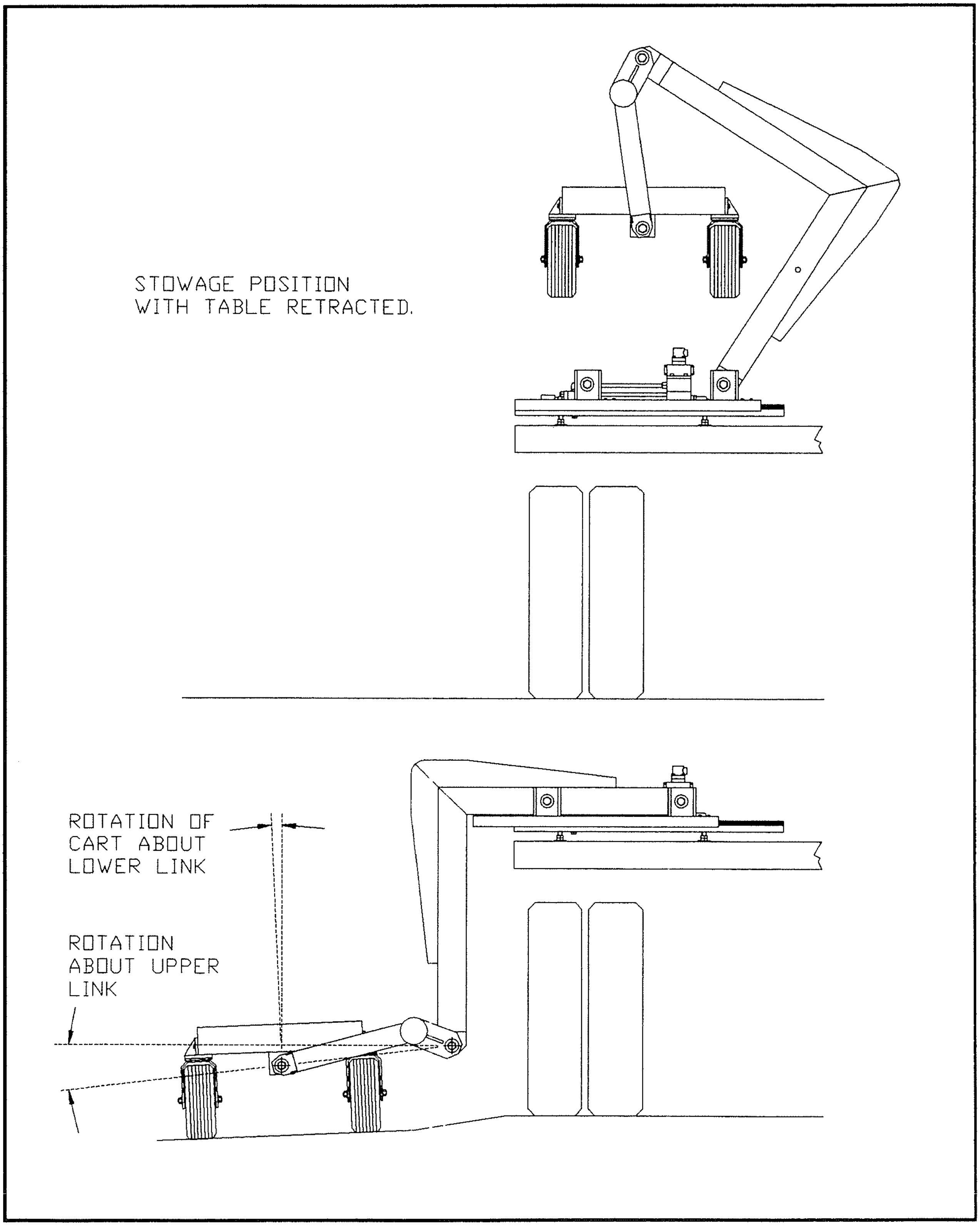


Figure 5.7 *- Motion of the longitudinal machine.*

preprogrammed acceleration and velocity values. Information will be provided by the LSS and the controller operating at 10 Hz. The chosen system has higher speed capabilities with minor hardware and software modifications, although the noted rate is expected to be more than adequate.

5.2.2 - Principles Of Operation

The longitudinal RPS is the subsystem that carries the local sensor, the router, the vacuum and heater/blower ducts and the sealant applicator unit during operations on longitudinal pavement cracks running parallel to the roadway. The system consists of a cart in which these APS components can be installed in various configurations and, an actuation and control system that guides it. Figure 5.8 shows an early photo of the longitudinal linkage described above deployed from a truck with mock-up subsystems installed.

The cart is attached to the side of the road maintenance vehicle with a mechanical linkage that allows the cart to move laterally a distance representative of crack geometry and driver capabilities as the vehicle is driven alongside the crack. The lateral movement is controlled automatically to correct for the relative position of the vehicle to the crack. The linkage also allows the cart to be retracted from the road when not in operation.

A single actuator provides the force to move the cart. It is driven by a controller that receives input from the LSS which is mounted at the centerline, forward end of the cart. As the cart is pulled forward, its lateral location is continually updated to keep the cart centerline over the crack, as measured at the local sensor.

The APS components, which are located on the centerline of the cart, prepare and fill the crack as it passes beneath them. These components are modular and can be installed in various configurations to allow for different crack sealing methods used by various DOTs. The support equipment necessary to operate the various components is located on the vehicle.

The configuration of the components installed in the cart imposes design constraints that specify the overall size of the cart, structural strength, stowing configuration options, and the limits on the system's ability to follow changes in crack path. To maintain flexibility in the development of the system and APS components, a worst case configuration was considered. This includes installation of the components in the following order beginning at the forward end of the cart (see Figure 5.6):

1) Local Sensor - Required for all configurations to provide for crack location through the LSS.

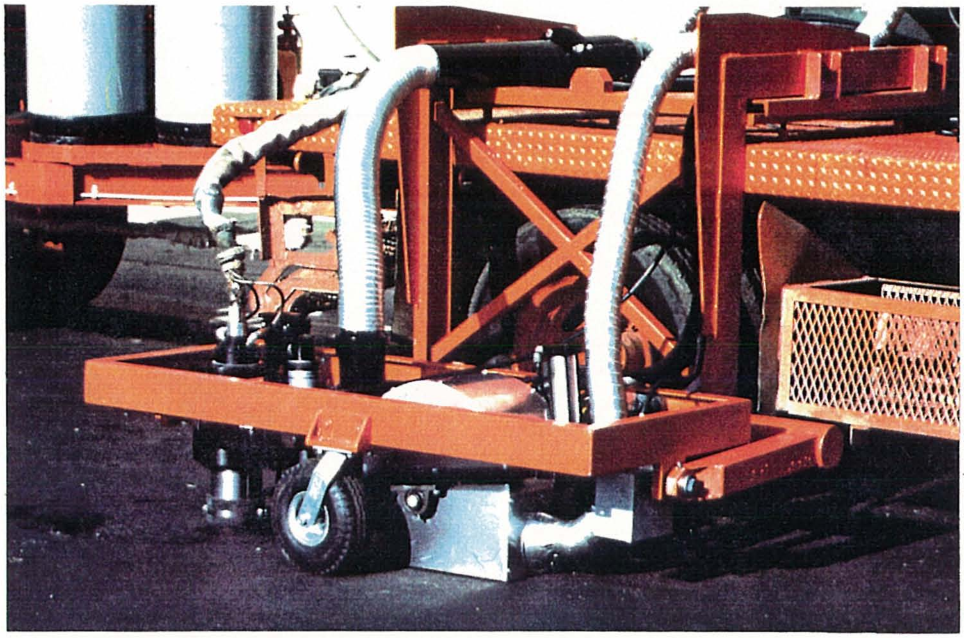


Figure 5.8 *- Longitudinal linkage with representative components.*

2) Vacuum Duct - Required for use in combination with the router to remove debris from the area around the crack and control exposure to dust created during routing. This ducting would be integrated within the body of the router.
3) Router - Required for some methods of crack preparation prior to sealing.
4) Heater/Blower Duct - Required for some methods of crack preparation. It could conceivably be used in conjunction with the router for preparation of the crack. With this configuration, a pyrometer used to sense the road surface temperature is located immediately behind the hot air duct to control the application of heat.
5) Sealant applicator - Required for sealing the crack. It places a five inch wide band over the prepared crack and will always be the last component on the cart.

When following a crack, the combination of all five components is most limiting since they are located on the centerline of the cart and define the minimum distance between the local sensor and sealant applicator. This distance then imposes a limit on the maximum rate of change in relative position between the crack and the maintenance vehicle (see Figure 5.9). Actuation of the cart is limited to translation in the direction perpendicular to the centerline of the cart, which is parallel to the

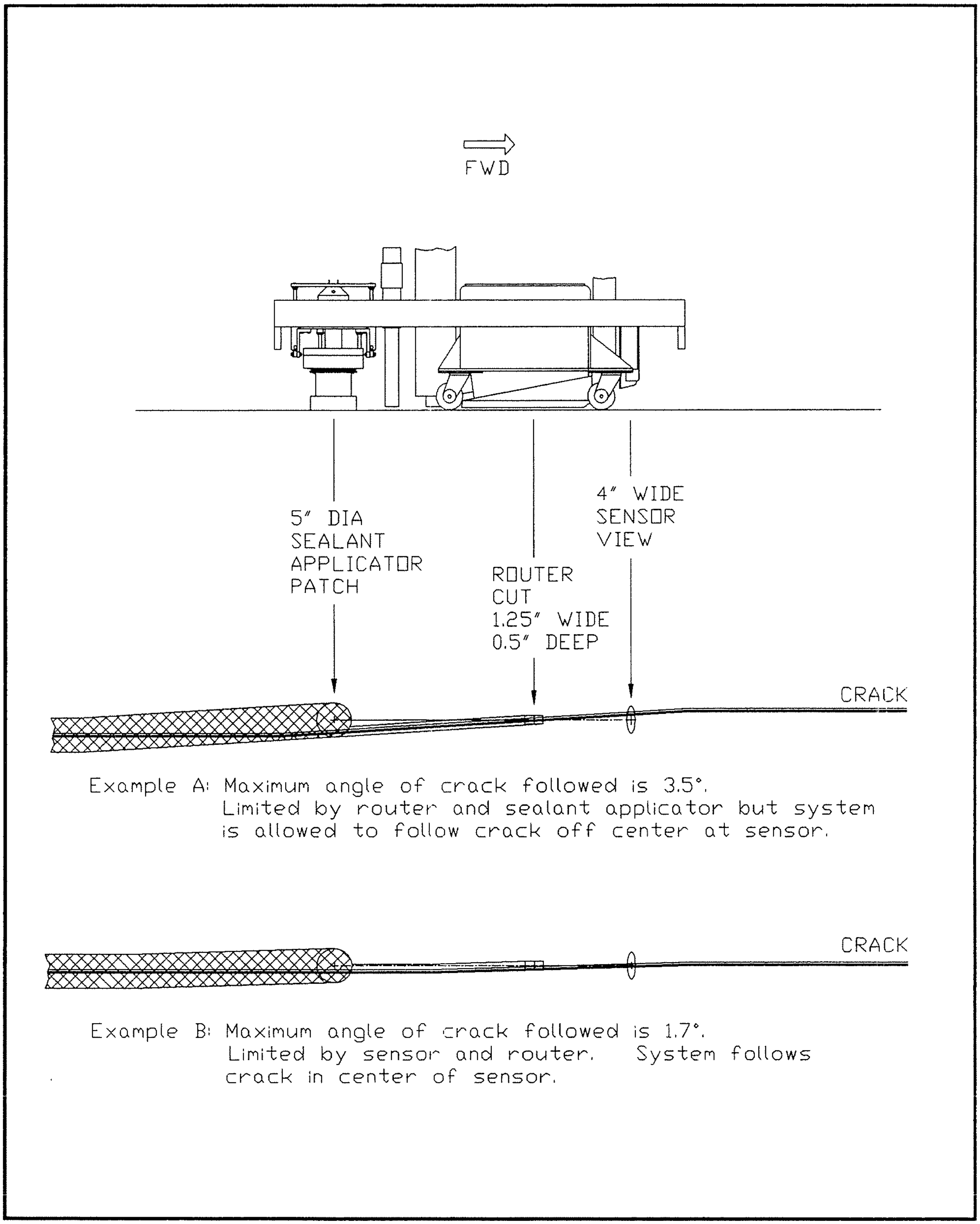


***Figure 5.9** - Physical limitations to longitudinal crack sealing linkage.*

direction of travel of the vehicle. The cart follows the crack located by the sensor at the forward end, which has a maximum four inch field of view. The applicator at the aft end lays a band of sealant five inches wide. The router cannot cut a path without a significant forward component since the cart does not have a rotational component which would allow the router to follow a circular path. These basic limitations on the crack following capability are inherent in the definition of 'parallel crack' but, as noted, are dependent on factors that include selection of crack preparation components.

The longitudinal RPS will operate as a component of the crack sealing machine controlled through the ICU, but it can be used independently as a self-contained unit with the LSS output provided directly to the controller. For initial development, testing, and evaluation, the system has been configured to operate on a test vehicle which supports only the longitudinal RPS. The capability to operate as a self-contained system, the relative simplicity of its operation, and the modularity of the APS components, support the commercial viability of the longitudinal RPS.

6.0 - APPLICATOR & PERIPHERALS SYSTEM (APS)

6.1 - Router

6.1.1 - Component Description

The routing component consists of a commercial impact cutting wheel mounted in a frame supported on casters. It is a modular unit that can be attached to the longitudinal or general crack sealing machines. The weight of the router unit is supported entirely by its wheels and the wheeled frame is designed to resist all forces that act to upset the cart during operation including forces from the RPS to which it is attached. The cutting wheel is driven by a hydraulic motor with the fluid flow lines running from the cart to the power unit on the truck bed. Detail drawings of the router are located in Appendix E.1. Figure 6.1 depicts the basic components which are described in the following paragraphs. Note that the item numbers in this figure correspond with those of the router assembly drawing SHRP(APS)RM-A100 in Appendix E.1. Photos of the actual fabricated unit can be seen in Figures 6.2 and 6.3.

The router cutting wheel (item 14) is a commercial unit removed from the manually operated router described above. The cutting wheel holds six rows of cutters and is designed to run at 2000 RPM. The cutters have a diameter of 4.75 inches and the total effective cutting diameter of the wheel is 15 inches. The maximum cutting width of this particular wheel is 2.25 inches, limited by its cutting wheel design.

The router cutting wheel and hydraulic motor (item 8) are mounted on bearings (item 12) attached to the cutter frame (item 13) which is hinged at the forward end. This allows the cutter to be extended into the road and retracted. The range of motion in the present design allows for a cutting depth of up to .85 inches and a retraction of 1 inch. An electric linear drive actuator (items 3 & 7) is used to extend and retract the cutting wheel. The cutter frame rotates about the C-channel pin (item 11) which is bolted to the inner frame (item 6). The inner frame serves as the shroud and the attachment point for the linear drive and linkage which extends and retracts the cutting wheel. This assembly is a very compact self-contained mechanism which is then bolted to the wheel support frame (item 2).

The wheel support frame is mounted on four casters (item 1) and supports the weight and cutting forces of the complete router. It also provides the interface to the RPS machines. It is designed to sit inside the longitudinal machine cart and in this

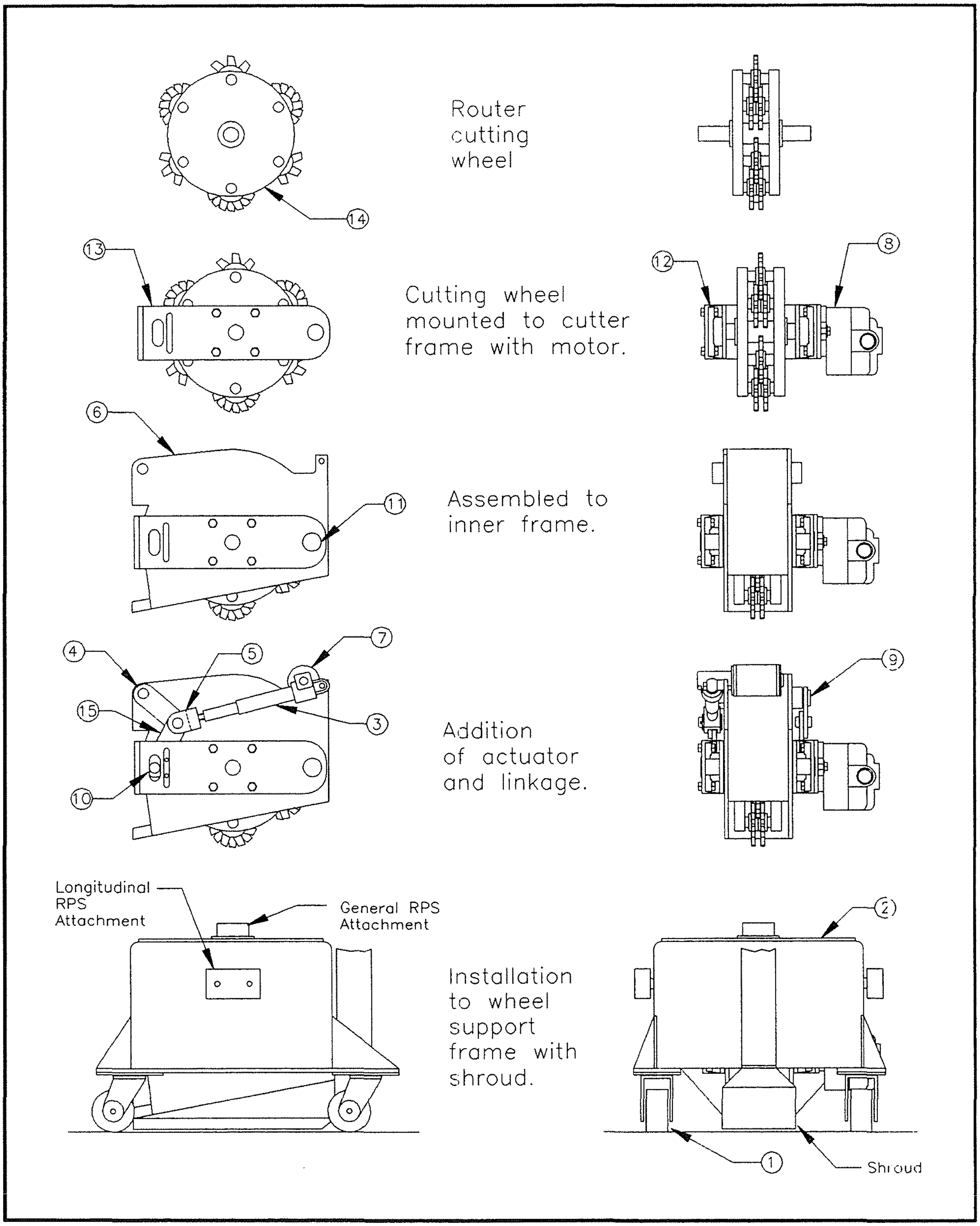


***Figure 6.1** - Description of router assembly, items numbers are circled.*

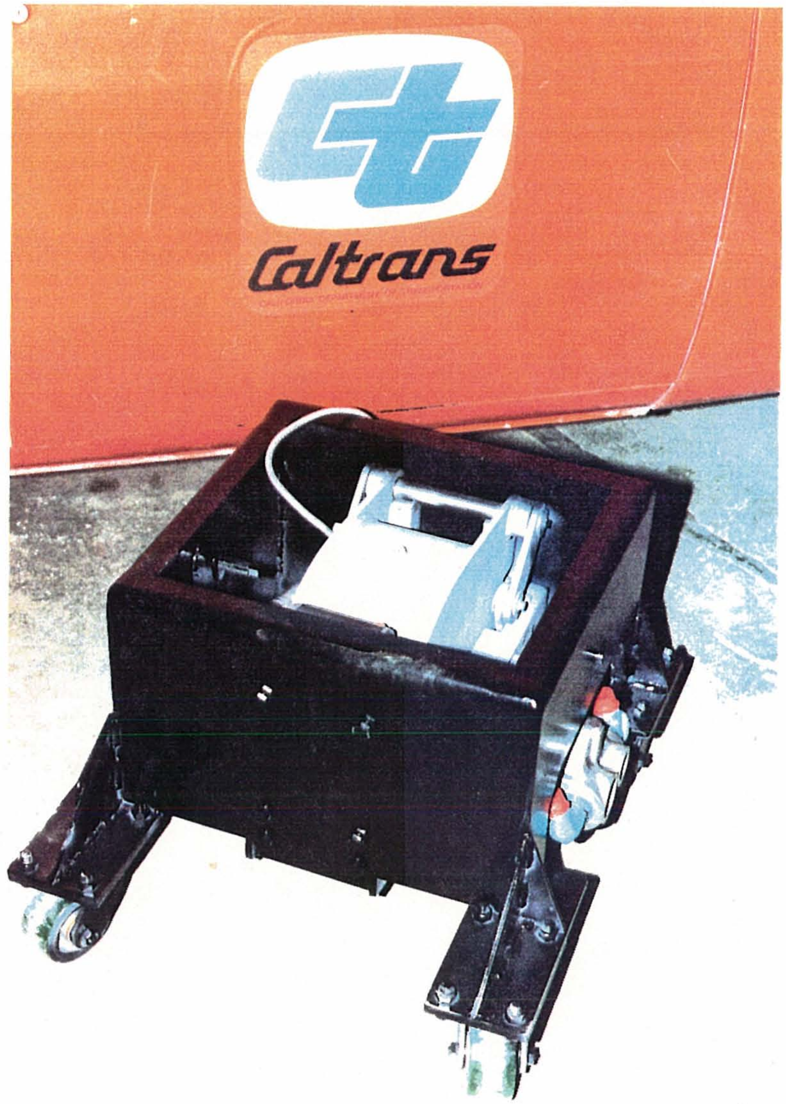


Figure 6.2 - *Photo of the fabricated router unit. For illustration purposes the top cover was removed.*

configuration, the casters of the longitudinal machine are removed and the weight of the longitudinal machine cart and the other APS components is carried by the wheel support frame of the router. An attachment point on the top of the wheel support frame provides the interface for the general machine.

The linear drive has a range of 4 inches and extends and retracts the cutting wheel by rotating two of the links as part of a four bar linkage as depicted in Figure 6.4. It acts at the upper and lower link capture (item 5) which is a clevis that shares a pin with two links on the actuator side of the assembly. The two upper links (item 4) are

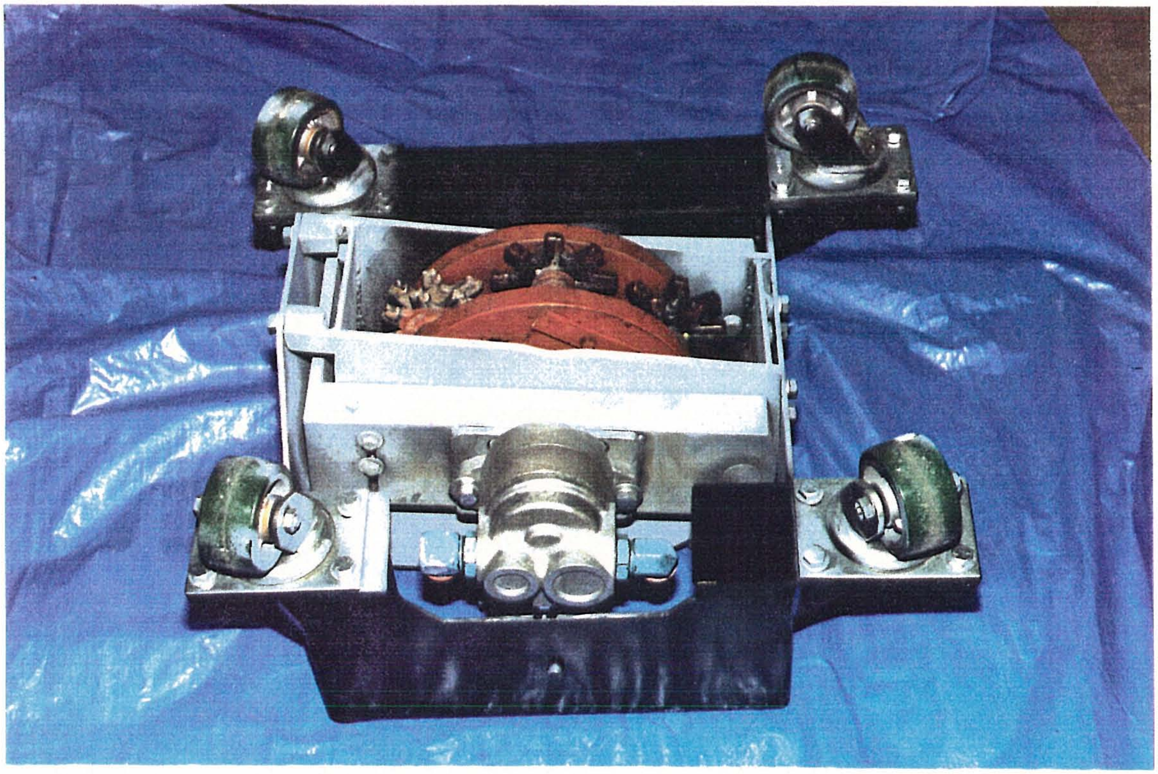
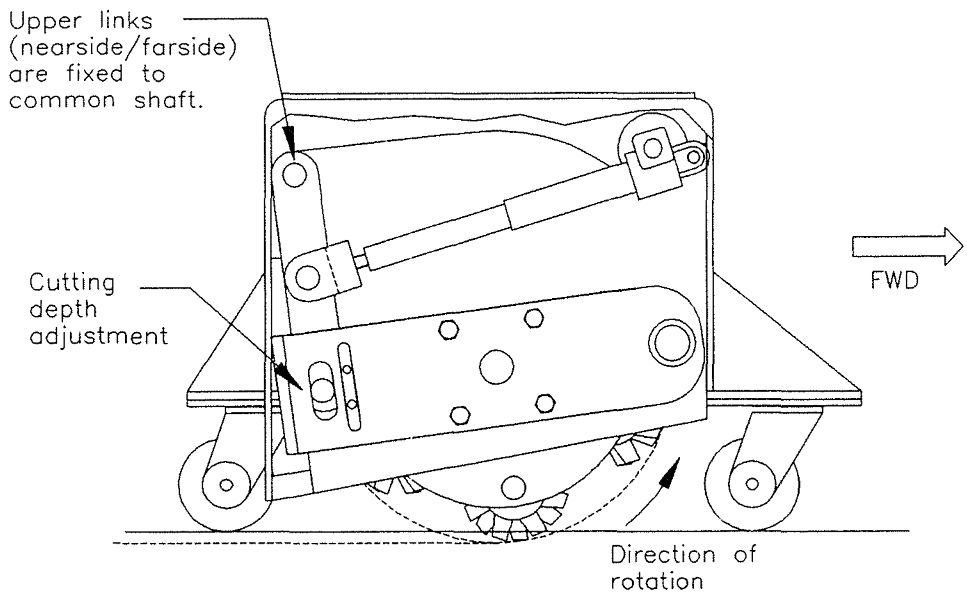


Figure 6.3 *- The router unit underside. Note the compact hydraulic motor.*

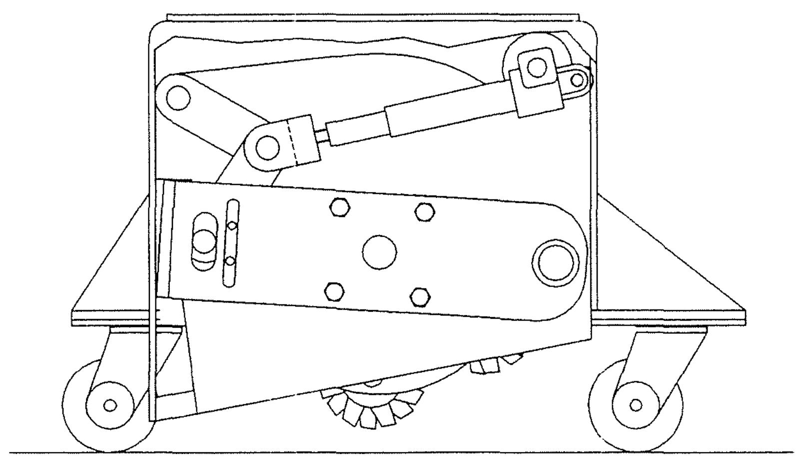
attached to a common shaft at the upper link pin (item 9) and move as a single member acting on the two separate lower links (item 15). The linkage is designed so that at full extension of the actuator, the upper and lower links are in line with each other and the loads transmitted from the router cutting wheel to the inner frame have no component in the direction of the actuator. In order to provide for cutting at different depths, the attachment of the lower link hinge point to the cutter frame is adjusted at the lower link pin block (item 10). The adjustment is set prior to operation of the router. The linkage is designed to retract the cutting wheel 1 inch above the surface of the road. Through the use of a linkage that is in effect, self-locking, the actuator will only be subjected to routing impact forces while it is extending the cutting wheel into the road. The nominal cutting depth that the router can be set for is 0.1 to 0.85 inches. This accommodates the .75 inch cut being evaluated in SHRP H-106.

A debris shroud from the debris removal system will be attached to the bottom of the router shroud that serves as the intermediate frame. It includes a deflector plate forward of the cutting wheel which directs the debris to the vertical tube attached to the vacuum line of the debris removal system. The debris shroud will provide a partial



Router cutting wheel extended for cutting. Cutting depth shown set at mid-range.

(View is cutaway of wheel support frame and does not show dust collection shroud.)



Router cutting wheel retracted.

(View is cutaway of wheel support frame and does not show dust collection shroud.)

***Figure 6.4** - Router cutting wheel extension and retraction.*

vacuum seal with the road surface and will act to retain the debris ejected by the cutting wheel. The debris is emitted in the forward direction by the action of the cutting wheel so the flow of the air will be directed by the vacuum in this same direction and exit forward through a transition from a rectangular cross section into a 3 inch diameter tube.

The hydraulic motor is keyed directly into the end of the shaft that drives the cutting wheel. The displacement of the motor is 1.95 in^3/rev which is designed to have an output of about 17 HP at 2000 RPM with an input pressure of 2000 PSI. The power for the test system is being provided by a hydraulic power supply system that was acquired with other than SHRP funds. Operation of the router is achieved by powering the motor with the router retracted, then extending the cutting wheel into the ground to full extension while stationary. Once extended the router is moved forward to cut the channel.

6.1.2 - Principles of Operation

The router, one of the APS components, is used to prepare cracks by cutting a channel along the crack in a profile that allows for increased penetration and adhesion of the sealant. The router was developed to accommodate the unique requirements imposed by the crack sealing machine. The design uses an existing impact router cutting wheel installed in a configuration that will follow random cracks with the general purpose RPS or the nearly linear cracks with the longitudinal RPS. It is hydraulically powered which allows it to be operated with a remote power supply. As a result, its size and weight are minimized to best accommodate its use with the RPS systems. In addition, the design allows for cutting at the increased speeds necessary for the automated crack sealing applications. The impact cutter design allows for variations in cutting depth and width which can be adjusted by placing the individual cutting wheels in various configurations. Adding cutters and increasing the rotational speed of the cutting wheel assembly also allows for operation at higher road speeds. The router component is a modular unit that will operate in both systems with minor modifications.

The basic principles of impact router operation have been verified on a manually operated commercial routing unit. The operator, while walking backwards and pulling the machine, guides the unit by observing the cutting wheel as it follows the crack. Debris is thrown in the direction away from the operator. This mode of cutting runs the cutter wheel in a "down-milling" cut direction (see Figure 6.5). Testing showed that the router tended to pull itself up out of the road bed when operated at higher surface

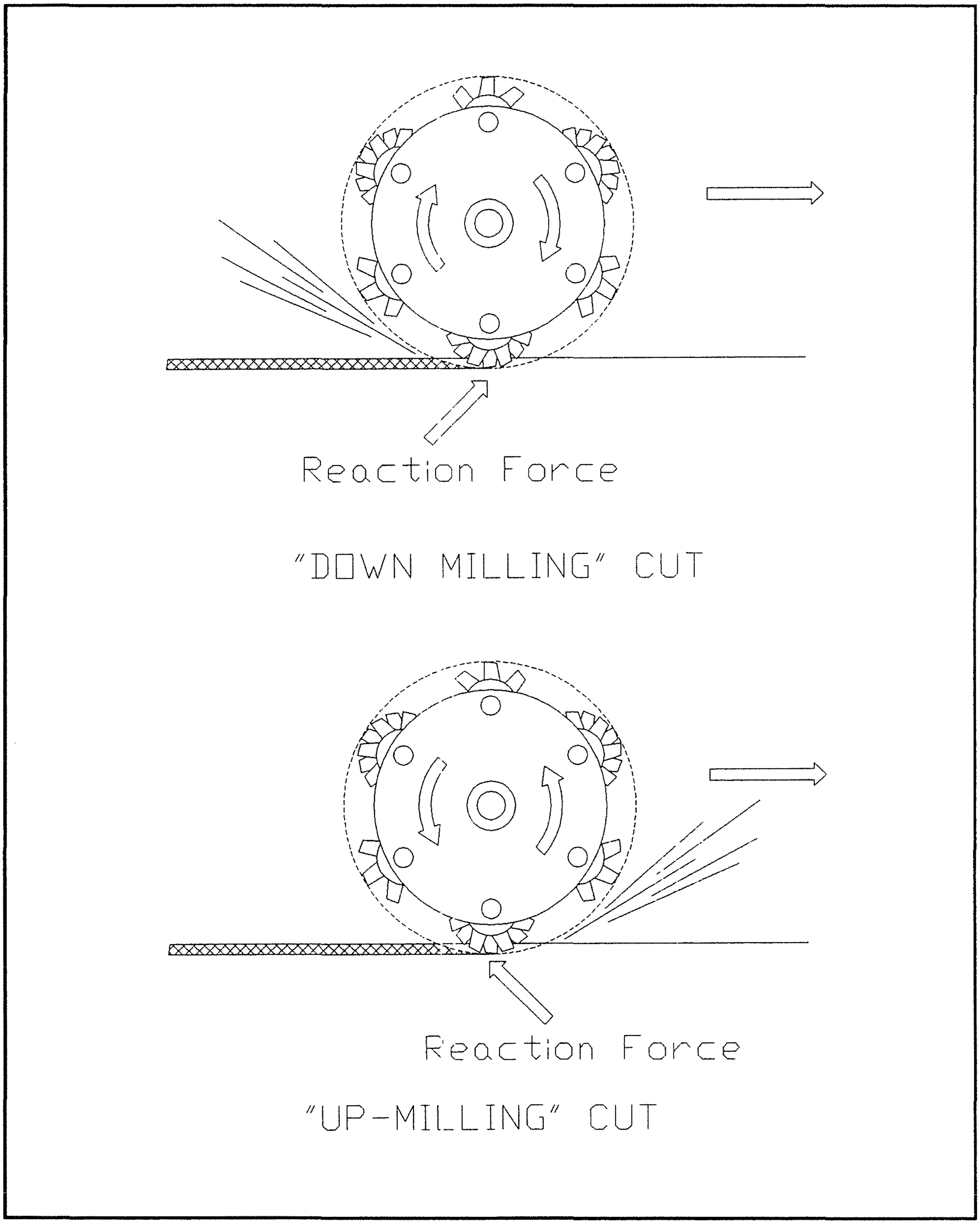


Figure 6.5 *- Description of router cutting wheel operation.*

speeds. By pushing the router, which results in a conventional "up-milling" cut (see Figure 6.5), the operation of the router is considerably smoother. Greater force is required to push the unit since the resulting cutting force acts in the direction opposite the direction of travel. However, a significant advantage is that the routing machine does not pull itself out of the roadway when "up-milling". Test results determined that operating the router in the conventional "up-milling" mode was the most efficient and would be used for the APS router component. This option is not possible with the manually guided machine since the debris would be thrown toward the operator.

6.2 - Heating/Cleaning/Debris Removal

6.2.1 - Component Selection

The main component in the heating, cleaning and debris removal (HCD) subsystem is the burner. Four liquid propane heating systems from major burner manufacturing companies were identified using the computational models developed earlier and appeared to closely meet the overall design criteria. However, two were logically concluded to best do so: the previously investigated Sur-Lite burner and the Eclipse Thermal Blast Heater. As mentioned in previous reports, Sur-Lite's modular design affords the possibility of incorporating a larger blower. However, the recently investigated Eclipse Thermal Blast Heater is limited to a maximum 400 SCFM of air flow. Yet, this burner is built for high pressure operation, up to 50 PSI, and has been designed around the operating envelope specific to this application. The Eclipse burner also ejects its hot exhaust via a 4" diameter duct as opposed to Sur-Lite's 6" exit. This means that in order to reduce the exhaust area at the nozzle to increase flow velocity, the Sur-Lite system would experience a much greater pressure drop and generally be more bulky. Also, the Thermal Blast Heater is designed specifically for remote blower placement. In the case of the Sur-Lite burner, less routine modifications would be necessary. Therefore, it seemed reasonable to conclude that if the heat output from the Eclipse burner is not significantly limited by the 400 SCFM maximum flow and the burner can heat the crack to 250°F at a relative speed of 2 MPH, then it should be selected as the preferred method. A simulation using the convective model was run and indeed, a sufficient surface temperature of 260°F was achieved (see Figure 6.6 below). Thus, the Eclipse burner was chosen for integration with the automated crack sealing vehicle. Selection of the flame safeguard and fuel train was fairly straight forward since it is made of components commonly available through most burner manufacturing companies. For convenience, a local vendor, Control Technology Specialists, was chosen to provide this portion of the HCD system and to help install and fine tune the heating system as needed.

More straight forward were the component selection choices for the blower and debris separator. The Paxton CB-87 comes as a complete package as opposed to most other hydraulic blower and therefore, best meets project goals in terms of off-the-shelf reliability. EG & G Rotron provides a debris separator that is able to be easily emptied using a standard 55 gallon drum mounted on casters. Both of these units were therefore purchased for use with the heating system outlined above.

6.2.2 - System Description

The automated pavement crack heating, cleaning, and debris removal (HCD) system designed and purchased primarily consists of an EG & G Rotron debris separator, model IVM2000PF (approximately the size of 2 - 55 gallon drums stacked vertically), a 5 PSI, 400 SCFM hydraulically powered centrifugal blower, Paxton Centrifugal Blowers model CB-87, a 692,000 BTU/hr Eclipse Thermal Blast Heater, and an infrared pyrometer, Raytek model ET3LT, which measures crack temperature and thereby modulates fuel flow to the burner. Overseeing safe operation of the burner is a standard flame safeguard control panel built by Control Technology Specialists. It features additional control panel functions for diverter valve actuation (to ensure safe idle operation), CLEAN ONLY operation (no heat), and a PID controller to interface with the pyrometer.

The debris removal portion of this system consists of a debris shroud mounted to the router casing, the EG &G Rotron debris separator unit and waste container located on the truck bed, and two (2) 3" diameter flexible hoses. The Paxton blower provides vacuum air to the debris shroud and separator unit and the waste container houses all collected debris for later disposal. Both the blower and burner units are to be located on the truck in a location which minimizes pressure and heat losses through minimal bending and plumbing distance. Proper insulation will protect subsystems and operators from danger. Hydraulic power to the blower is provided by the central hydraulic system. Perhaps in the future, a drive train power take-off unit could be used to power other subsystems. The pyrometer is located just aft of the burner exhaust nozzle on the longitudinal sealant cart and between the sealant applicator and heater nozzle exit on the general process cart. Appendix E.2.1 contains the general specifications used in evaluating available commercial equipment and Appendix E.2.2 contains manufacturer's specifications for the major equipment purchased (exclusive of the flame safeguard unit and fuel train).

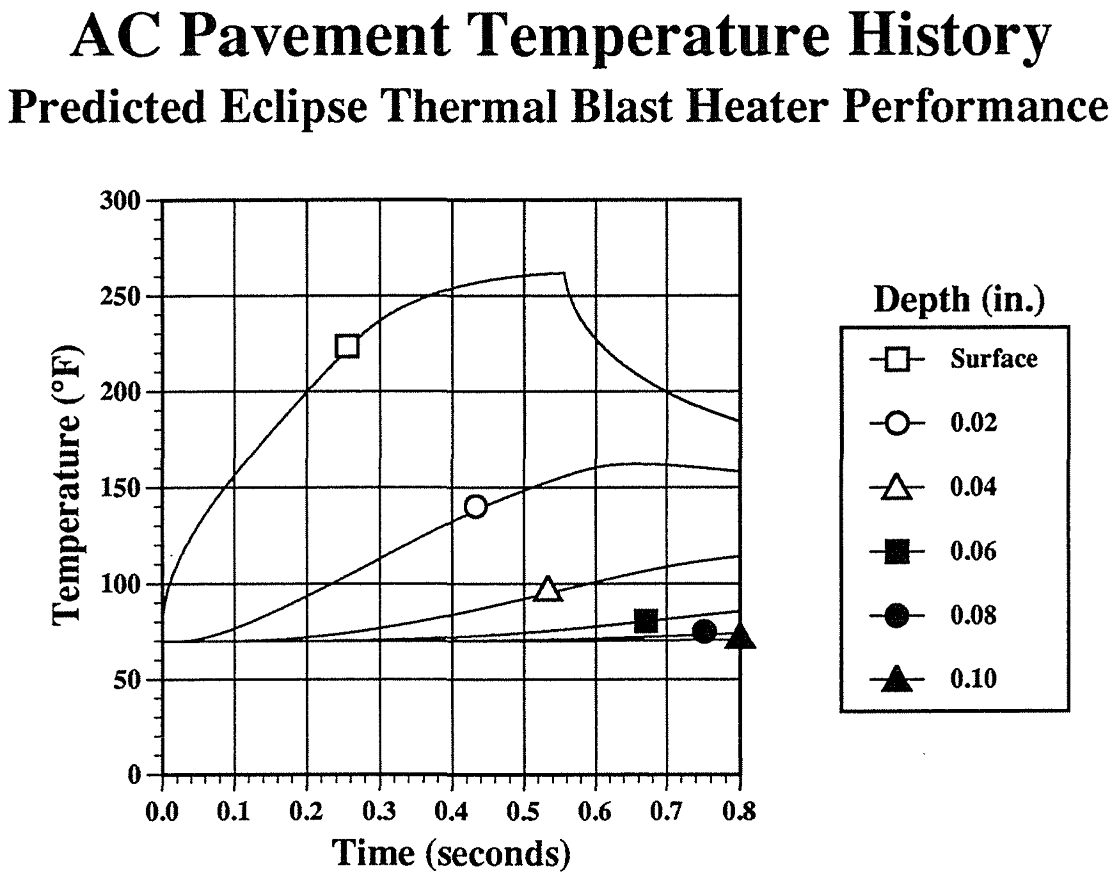


Figure 6.6 - *Predicted Eclipse Thermal Blast Heater performance. Relative speed is 2 MPH, nozzle exit diameter is necked down to 2.5", and the exit gas temperature is set at 1500°F.*

The Eclipse burner purchased, at maximum output, consumes approximately 28 LB of liquid propane (LP gas) per hour, meaning that for a normal eight hour work day, 224 LB of fuel could be consumed if run continuously. By outfitting the support vehicle with 2 additional vapor withdrawal 100 LB tanks, in addition to the 2 tanks already present for use with the melter, this consumption rate can be met.

6.2.3 - Principles of Operation

Since both the debris removal and the surface heating portions of the HCD system require high volume / low pressure air, it is obvious that combining their required air flows into one centralized system, affords the possibility of utilizing a single blower. Vacuum air from the debris removal portion is therefore cleaned of debris in the separator unit, then exhausted to a burner, and blown onto the road surface to heat it to the proper temperature. This setup provides the best solution in terms of cost and

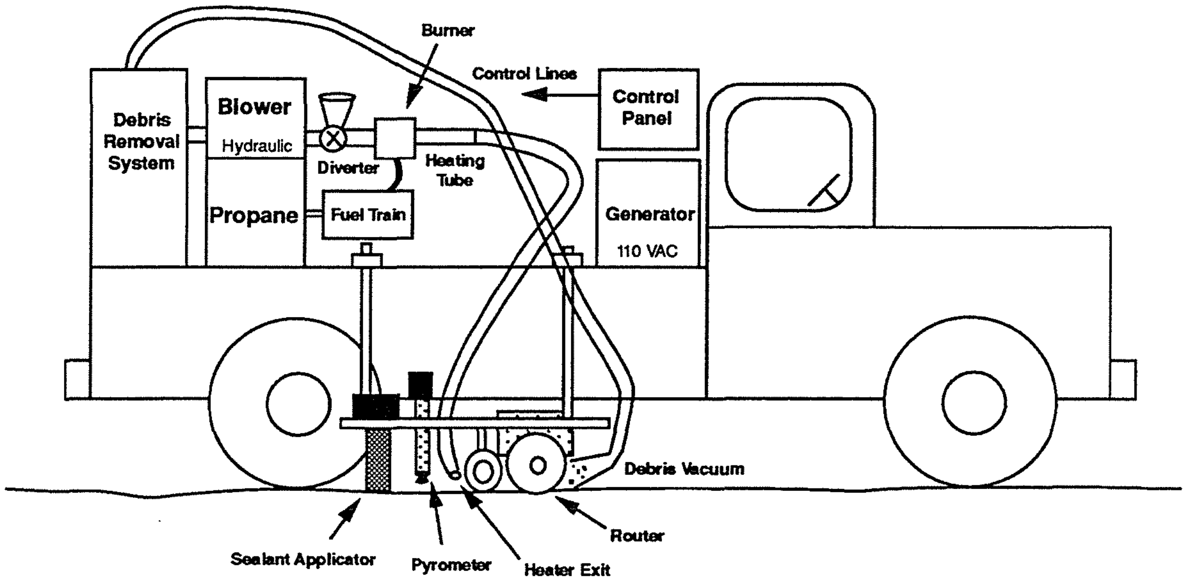


***Figure 6.7** - Sketch of HCD system deployed for longitudinal sealing.*

efficiency. Figure 6.7 shows a conceptual sketch of this set-up deployed for longitudinal sealing.

The system is also designed such that it can operate in the CLEAN ONLY or HEAT AND CLEAN mode. In the CLEAN ONLY mode, the heater is not ignited and the blower is used by itself, with or without the debris removal attachment. This is a necessary feature since many DOTs do not heat the roadway prior to sealing. The diverter valve is also necessary to adjust for the proper component pressure loads during system qualification. This will ensure maximum performance of the components while not causing damage to them.

Operation of the integrated unit takes place via a control panel to be mounted conveniently on the crack sealing vehicle. To begin operation, the unit is first configured for the type of sealing desired. (Some DOT's do not route or heat, others route and heat, while some may only route etc.) After configuration, the system is activated by first switching on the main subsystem power (assuming the ICU is in operation and power is present in the hydraulic system) then flipping solenoid switches that regulate hydraulic fluid flow to the blower. Normally the diverter should be set to divert flow from the pavement for safety reasons during start-up. After the blower reaches operating speed, the diverter valve can be released to deflect flow to the pavement enabling the burner to be ignited.

In general, the burner operates similar to most LP gas burner packages with a few exceptions. Ignition of the burner is automatically controlled by the flame safeguard system and takes place only after an air purge has been verified (1-5 seconds). Once ignited, the burner operates as a self contained unit as long as air flow is present. Should the air lines become clogged or the blower shut down, pressure switches sensing deviant air pressure would trip thereby shutting down the fuel flow. Fuel flow is normally maintained through a PID controller connected to the pyrometer - as opposed to a manually or permanently set flow rate. Based on the surface temperature of the pavement, the pyrometer returns a signal, roughly between 12 and 16 mA (200°F and 300°F), back to the PID controller which in turn sends out a 4-20 mA signal, linear over the turn down range of the fuel control valve, either increasing or decreasing fuel flow in order to approach the desired surface pre-heat temperature. The burner output is therefore automatically proportionally adjusted for the set point programmed into the PID controller.

6.3 - Sealant Applicator

The sealant applicator unit constitutes a significant advancement in crack sealing technology. It was designed to deliver hot thermoplastic sealant at an increased velocity over current crack sealing techniques, as well as shape the material to produce a variety of sealant finish configurations. A significant advantage this unit possesses over other sealing methods is that it uses a small amount of pressure to force sealant into the crack. The sealant flow rate is automatically adjusted according to the cross-sectional area of the crack and is described below.

During Phase II of this project, the design of the sealant applicator was finalized and a first generation prototype was built (see Figures 6.8 and 6.9). In the following paragraphs, the principles of operation and a description of the various subassemblies is provided (see Figures 6.10 - 6.13).

6.3.1 - Subassembly A

Figure 6.10, Subassembly A shows the sealant supply tube. The hot-pour sealant is supplied to the tube through a teflon hose from a melter unit mounted on the truck platform. During the time it takes for the sealant to flow from the melter to the pavement crack, the sealant must be kept at a high temperature in order to prevent the sealant from solidifying. To accomplish this, a continuous hot oil line is doubly wrapped around the teflon hose. The line is broken when it reaches the sealant applicator and each end is mounted to the top of the subassembly (item 10). The entering oil sees a cavity in the shape of a half-circle (item 10, Section A-A), flows

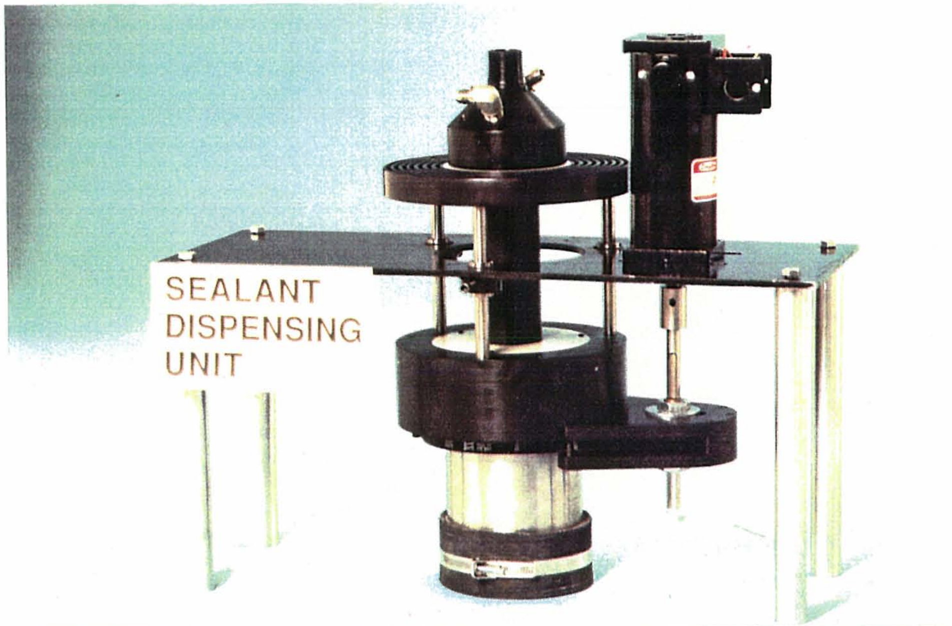


Figure6.8 - *The sealing dispensing unit mounted on the base plate for the longitudinal crack sealing machine.*

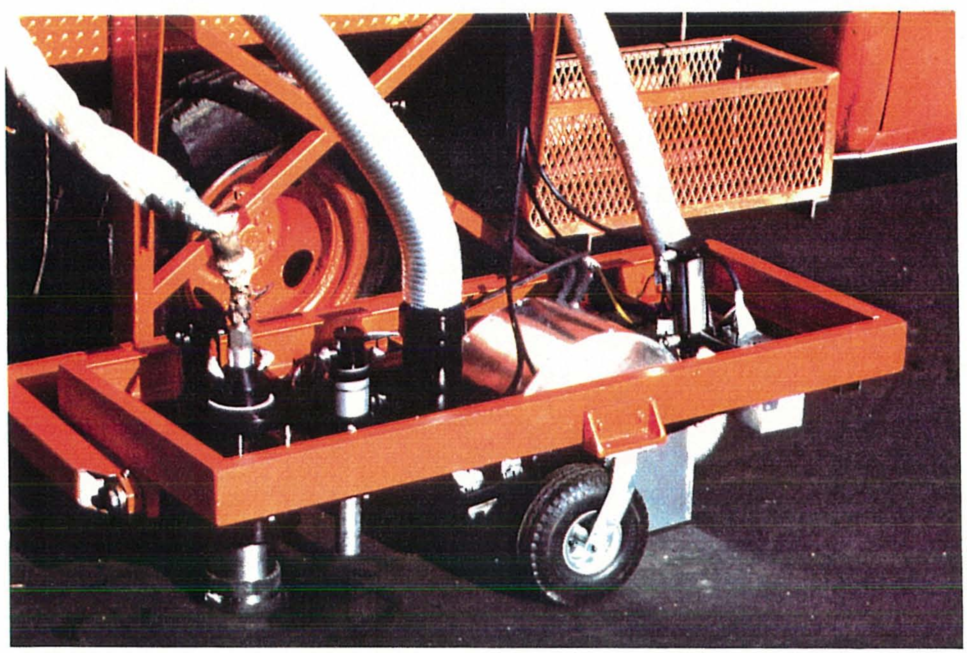


Figure6.9 - *The sealant applicator at the end of the longitudinal machine.*

through this cavity, then travels through an area between the sealant tube (item 1) and an outer wall (item 2). Two rods press-fitted between the sealant tube and the outer wall (item 32, Section B-B) force the oil to flow down the length of the sealant tube on one side and then back up on the other side where it exits. Proper sealant application temperature is maintained by this design. High-temperature O-ring seals in the design insure that both sealant and oil do not leak outside the body or into each other.

At the base of the center tube (item 1) there is a cone-valve (item 7 mounted to item 9). The cone is spring-loaded, so when there is no sealant flowing, the sealant orifice is closed off. The force of the spring is just equal to the weight of a standing column of sealant. At the time when sealant is to be applied, pressure generated by the melter pump opens the cone-valve. When the applicator reaches the end of a crack, the sealant flow is stopped and the cone-valve closes, preventing extra sealant from flowing out of the tube.

6.3.2 - Subassembly B

During design it was necessary to address protection of temperature-sensitive parts of the applicator from the very high temperatures necessary to retain sealant fluidity. It is apparent that over a period of time, the entire Subassembly A will reach 350-400°F. This problem was solved in three ways: insulating material was used between Subassembly A and the rest of the applicator (Figure 6.11, items 4, 5 and 13), contact points were minimized (item 10), and heat fins were provided for maximum heat dissipation (item 6).

Another design issue concerned the manner in which the applicator would follow the contour of a road. All roads are not perfectly flat; i.e., surface irregularities are always present in pavement. The manner in which this problem is addressed is apparent by considering the drawing of Subassembly B. Three hardened Thompson shafts (item 3) are mounted between the upper and lower sections of the applicator (items 6 and 14). The shafts pass through three linear bearings captured in the frame. The result is that the entire sealant applicator assembly has the ability to move vertically over a range of 5.5" yet still be rigid in the horizontal plane. Overall, the modular design of the sealant applicator allows it to be mounted to the longitudinal machine, the general crack sealing machine, or any other compatible device.

The last design feature described using the Subassembly B drawing is the method by which the applicator controls the flow of sealant over a given crack. Consider the flow of sealant through the sealant tube (item 1). At the base of the tube, the sealant both fills up a crack and pushes a float (item 30) upwards (Circle A). The volume of

Figure 6.10 - Sealant applicator unit, Subassembly A.

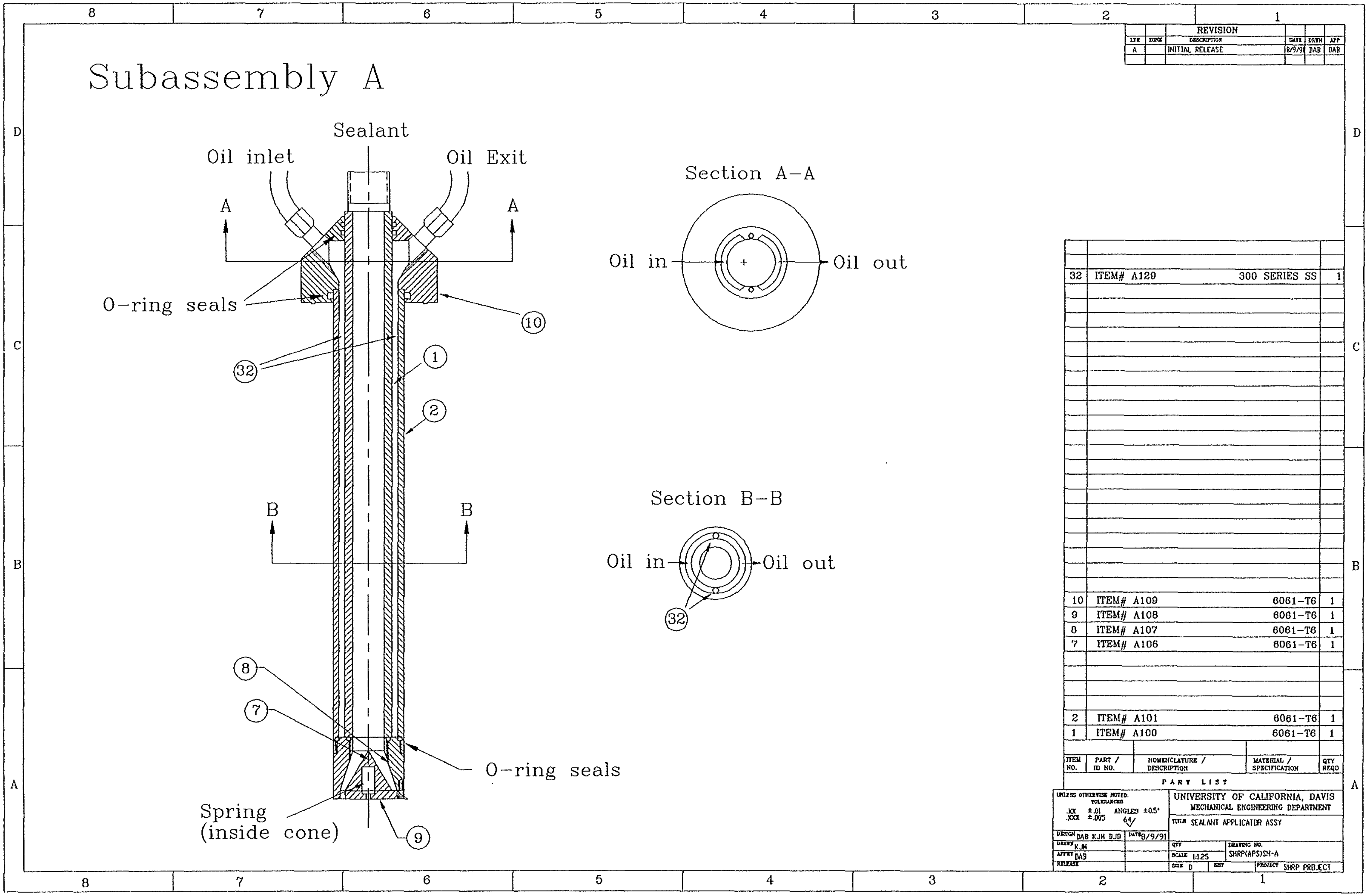
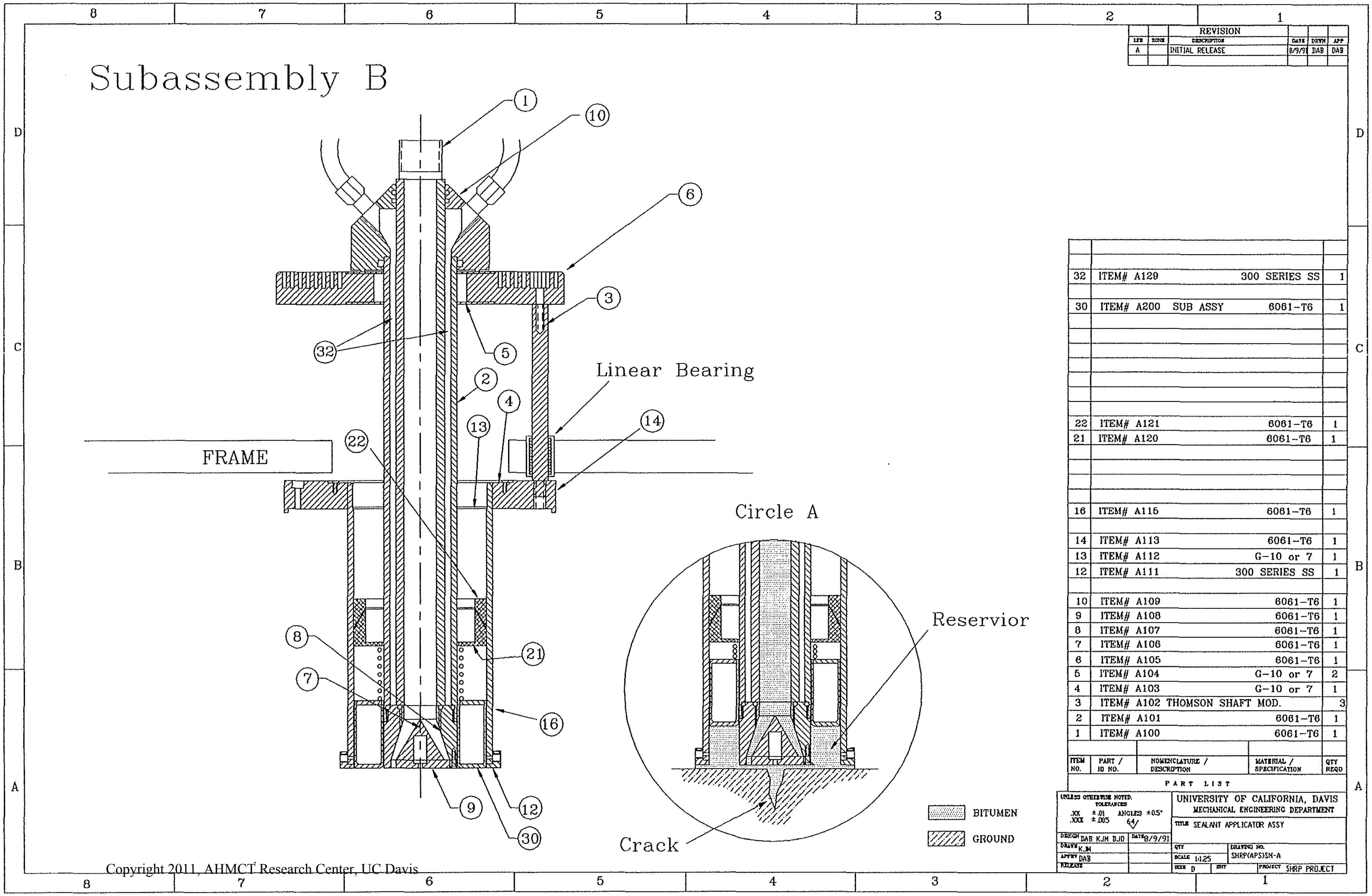


Figure 6.11 - Sealant applicator unit, Subassembly B.



sealant underneath the float is referred to as the reservoir. The float in turn compresses a spring (between items 21 and 30) which deflects a circular plate (item 21) on which four strain gages are mounted. The output of the strain gage circuit is conditioned and transformed into a voltage representing the amount of sealant in the reservoir. The circuit controls a proportional valve which adjusts the rate of sealant flow.

As the applicator travels along a crack, a varying amount of sealant (dependent on crack width and depth) is pushed into the crack from the reservoir (Circle A). Note that the spring pushes against the float, forcing sealant into the crack. The internal sealant pressure in the reservoir is maintained between 2 and 8 PSI. As the float lowers due to sealant dispensing, the strain gage circuit signals for an increase in sealant flow into the reservoir. Once the reservoir fills, the sealant flow is again decreased, etc. The closed loop nature of the applicator provides continuous and complete filling of cracks independent of crack size and applicator surface speed.

6.3.3 - Subassembly C

As mentioned in the Phase I final report the sealant applicator is a combination sealant dispenser and shaper (squeegee). To provide for a wide variety of crack seal configurations, the rubber ring/squeegee at the base of the applicator was selected to have a 5" inside diameter (ID). During development, a problem concerning the contact between the rubber ring and the ground was identified. The rubber has to withstand frictional forces due to vehicle movement as well as high temperature sealant. As such, as is shown in Figure 6.12, Subassembly C, a ring of mesh-reinforced high-temperature Hypalon industrial tubing (item 31) is used. This ring will flex on the road surface and can provide for a flush sealant configuration over the crack. It is easily replaceable as it slips on and off an outer wall (item 17) and it is held in place by an adjustable clamp.

Proper operation of traditional squeegees requires a downward force of 10 - 20 LB. The weight of the sealant applicator is approximately 35 LB. Accordingly, this weight is counterbalanced by two compressed air cylinders (not shown) so as to provide proper down force.

Angular contact ball bearings permit the rotation of the tubing ring providing for other sealant configurations (e.g., overband) as mentioned in the Phase I final report. This rotation additionally provides for more uniform wear of the tubing ring and reduces the possibility of sealant buildup on the ring (item 31). The bearings are mounted within the applicator body, away from the base to protect them from the

Figure 6.12 - Sealant applicator unit, Subassembly C.

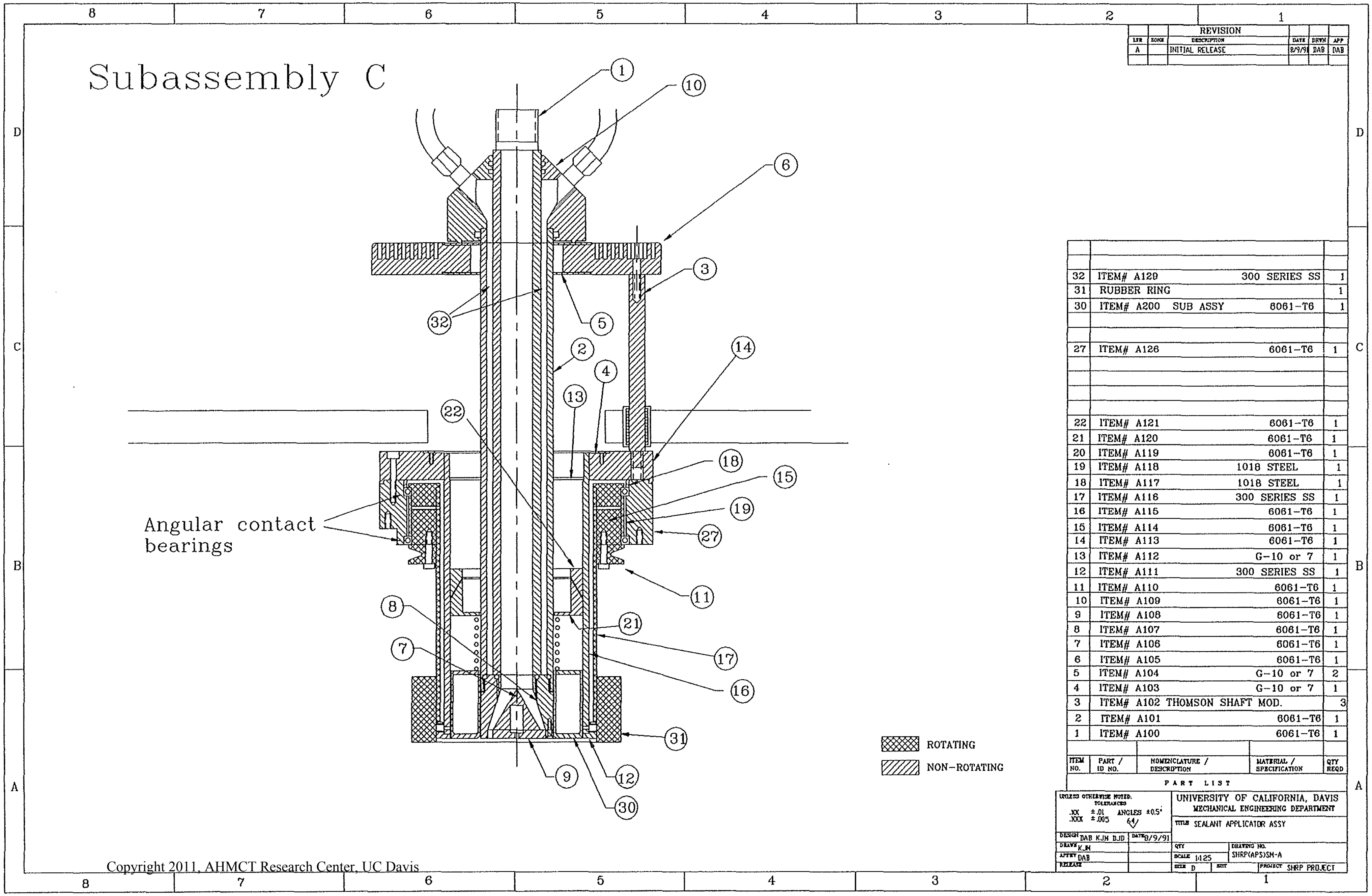
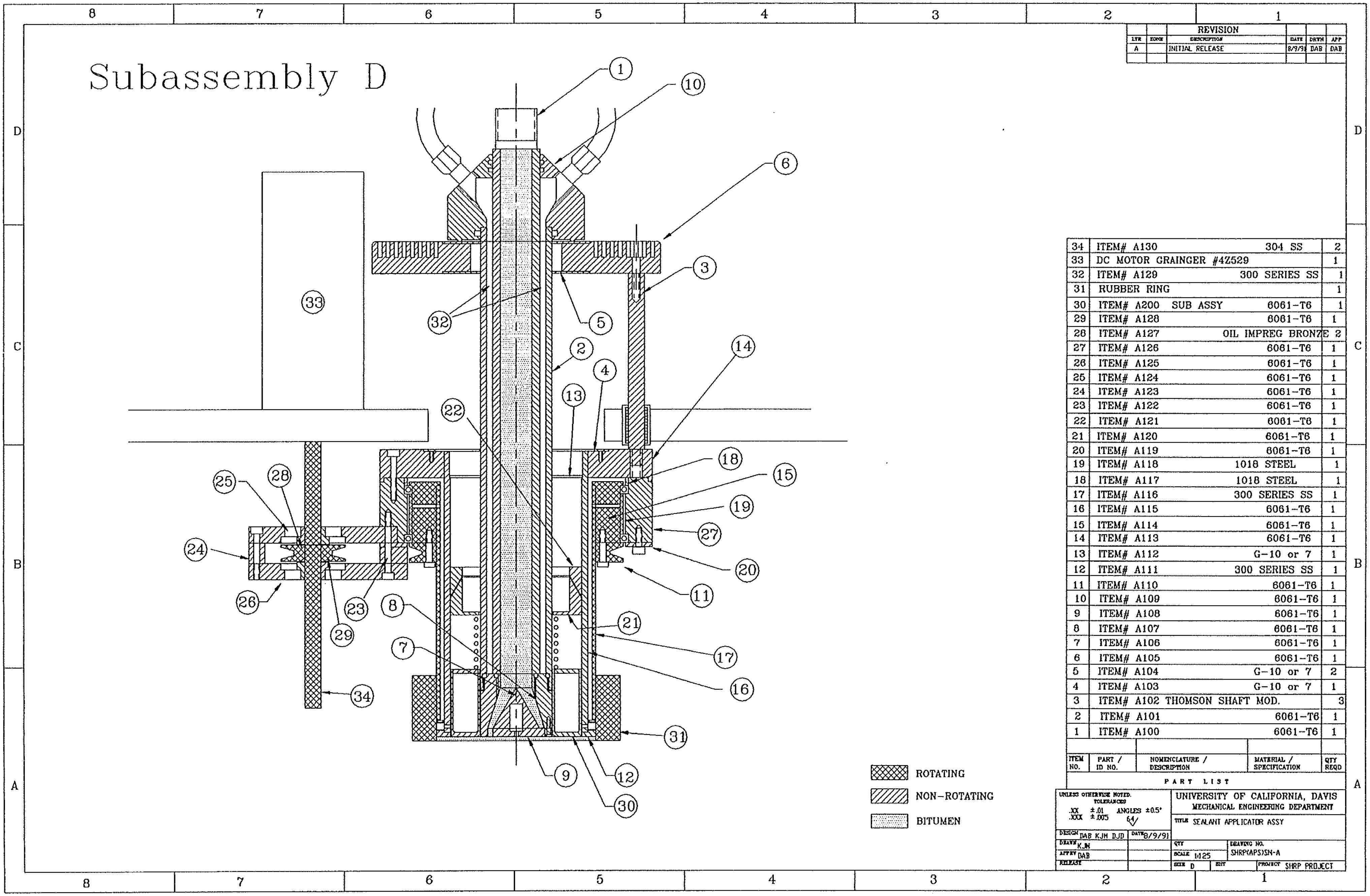


Figure 6.13 - Sealant applicator unit, Subassembly D.



environment (items 15, 18, 19 and 27). A V-belt drives all the various rotating components through a pulley (item 11) mounted to the outer wall (item 17).

6.3.4 - Subassembly D

Figure 6.13, Subassembly D shows a half-view of the entire sealant applicator assembly. On the left, a variable speed DC motor (item 33) drives a shaft (item 34). The shaft has a raceway for a ball bearing which is mounted to a smaller pulley (item 28). The bearing acts in two ways: 1) it allows the pulley to move up and down with the main body of the applicator as it travels down the road and, 2) it allows the pulley to spin due to the rotation of the shaft. The shaft assembly can also be moved back and forth in guiding groves (items 25 and 26) in order to adjust tension and change the belt that rotates the tube assembly. As noted above, this rotation provides for more uniform tubing ring wear and less sealant build-up.

7.0 - VEHICLE ORIENTATION AND CONTROL SYSTEM (VOC)

7.1 - System Description

The Vehicle Orientation and Control (VOC) system tracks the position of cracks on the road surface with respect to a fixed point (e.g. the robot base) located on the truck. This system is required so that the position of road cracks identified by the Vision Sensing System (VSS) at the front of the crack sealing truck can be tracked continuously as the truck moves forward moving the cracks into the work space of the robot arms at the rear of the truck. At that point, the crack position data will be sent to the controllers on the robot arms (RPS) via the ICU. The robot controllers will then send signals to position the end effectors of the robot arms over the cracks. Once positioned, the end effectors will rout, clean, heat, and finally seal the cracks. It is our intent that ultimately the entire process of identifying the cracks, tracking their positions, positioning the robot end effectors, and performing the crack repair operation will be done in a continuous fashion with the truck moving ahead at a slow forward speed. A schematic illustration of the crack sealing truck and the integrated VOC, VSS, RPS, and ICU is given in Figure 7.1.

The task of tracking points on a crack would be simple if the truck were moving straight ahead or if it were turning a corner of constant radius. However, this is usually not the case. To illustrate this point, it is noted here that after a particular point on a crack is identified by the VSS, the truck must move ahead approximately 35 feet before that same point on the crack moves into the work space of a robot arm. Throughout this distance it is unlikely that the truck will maintain a straight heading or even a turn of constant radius. Instead it is very likely that the truck will be moving with many combinations of left and right turns (of various radii) and straight ahead motion. The heading variations may be small but they will be significant enough to have a large impact on the accurate positioning of the robot end effectors.

7.2 - Principles of Operation

The entire VOC system will use digital communication. Two (2) optical, rotary, incremental encoders will each be mounted on separate "fifth wheel" assemblies. The fifth wheel assemblies will be mounted on either side of the truck outside of the rear wheels and midway between the two rear axles of the truck so that the center line of

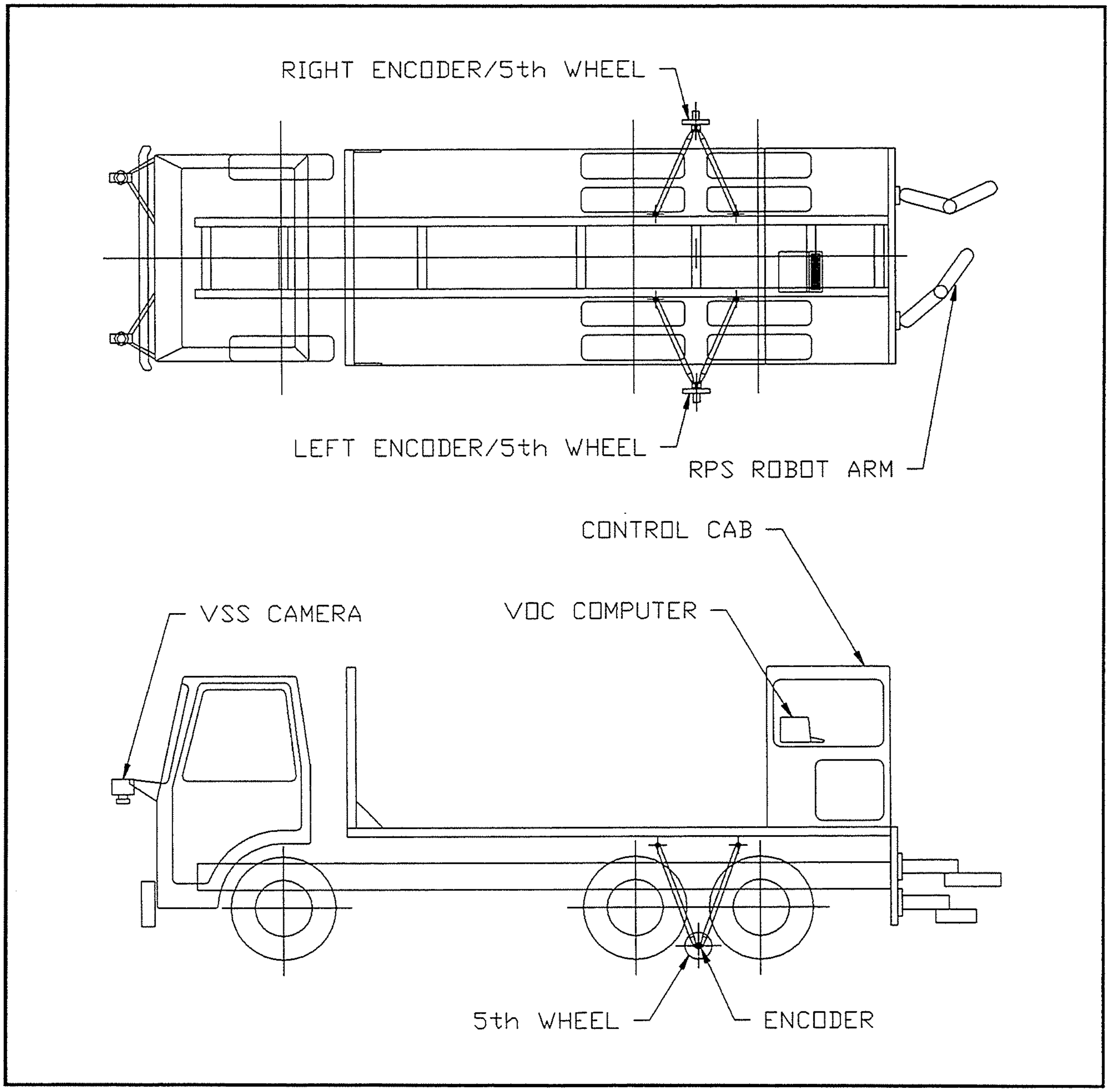


***Figure 7.1** - Crack sealing truck showing integrated VOC, VSS, RPS, and ICU (conceptual illustration only).*

the encoders passes through the center of rotation of the truck (see Figure 7.2). The fifth wheel assemblies will be located approximately 10 feet apart. The fifth wheel assemblies will continuously monitor the change in position of each side of the truck. From position data obtained from the encoders, the translation of the truck (laterally

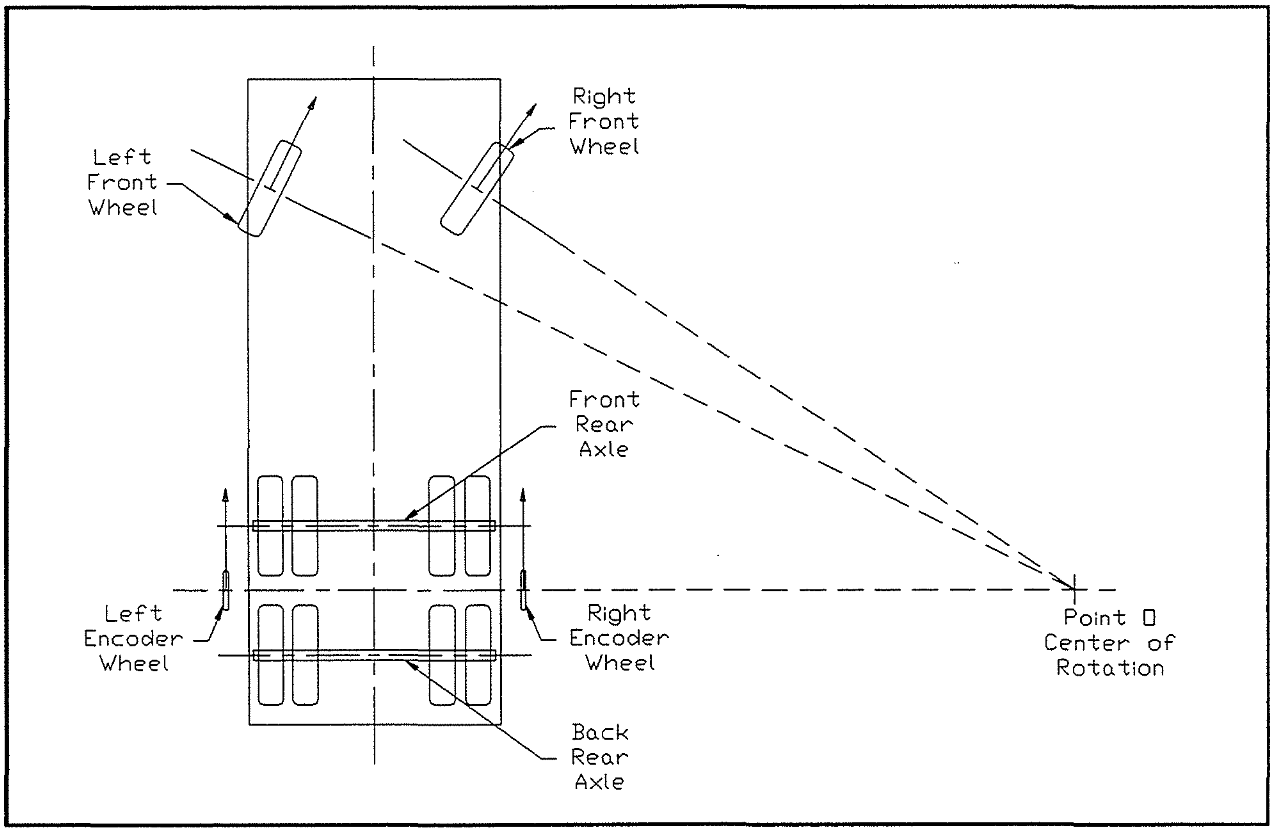


Figure 7.2 *- Placement of encoders on crack sealing truck.*

with respect to the road surface) and rotation of the truck (yaw - about a vertical axis with respect to the road surface) can be continuously calculated.

An on-board computer will also be a part of the VOC. This computer will serve several functions. In general, crack position data will be sent to the VOC computer from the VSS and truck position data will gathered from the encoders on the fifth wheels. Calculations of truck position and orientation and crack position (with respect to the truck) will be performed by the VOC computer. This information will be shared with the ICU. The VOC computer will also update the path planning module in the ICU. Finally, the VOC computer will send current crack position data to the RPS for immediate crack sealing.

More specifically, the VOC computer will perform as follows. The Cartesian reference frame used by the computer program will be fixed on the truck near the center of the rear bumper. This reference frame will move (in position and orientation with respect to the road surface) as the truck moves. The VOC computer will receive (from the VSS) the position, perpendicular to the direction of travel of the truck (with respect to the truck), of points on cracks as they are identified by the VSS camera at the front of the truck. The VOC computer will note the time instant when this data was received. Then the VOC will begin tracking the change in position and orientation of the truck with respect to the time instant when the data was received from the VSS by sampling data (at a set time frequency) from the right and left encoders. When the crack moves into the work space of the RPS and is immediately ready to be sealed, the VSS will perform a final calculation of points on the crack with respect to the truck. This information will be sent immediately to the RPS so that the RPS end effectors can clean, heat, and seal the crack. Once the crack repair operation is completed on that particular portion of crack, that crack portion will no longer be tracked by the VOC computer. Refer to Figure 7.8 for a flow chart of the integration of the VOC with the VSS, RPS, and ICU.

7.3 - The Use of Fifth Wheels

One design consideration that merits some discussion is the decision to mount the position encoders on fifth wheels rather than attaching them directly to the tires of the crack sealing truck. There are several advantages to the fifth wheel design. These advantages follow.

- All drive train noise that is transmitted through the truck wheels is not transmitted to the encoders.
- The wheel base distance can be increased (if necessary) to allow greater accuracy in computing the vehicle position and orientation.
- Noise coming from the truck and various systems can be dampened through the fifth wheel connection (to the truck) so that the noise is minimized by the time it reaches the encoders.
- The truck tires are subject to fluctuations in radius caused by tires of low stiffness and changes in tire pressure, vehicle weight, consumable materials fluctuations, number and weights of persons riding the truck, vibrations, etc. Nearly all problems caused by changes in tire diameter can be eliminated through the use of a relatively high stiffness wheel attached to a fifth wheel assembly. This would allow for greater accuracy in the encoder data since fluctuations in wheel radius will be minimized.
- For a tandem axle truck that is turning any sort of corner, the tires of one of the rear axles must always "scrub" sideways slightly. If more of the vehicle weight is resting on the front rear axle, the back rear axle tires will do the majority of scrubbing. Conversely, if more of the vehicle weight is resting on

the back rear axle, the front rear axle tires will do the majority of scrubbing. This phenomenon effectively changes the distance between the front of the truck (where the VSS cameras are located) and the rear axle that is in contact with the road surface. This change causes a slight error in the results of the kinematics equations used for the VOC system. This error can be minimized by centering the encoders midway between the rear axles of the truck. As an added benefit, the scrub on the encoder wheels is minimized. The fifth wheel is an effective design feature for mounting the encoders midway between the rear axles of the truck.

- The fifth wheels can be designed to be more sensitive to the road surface than truck tires by optimizing design characteristics such as damping, wheel stiffness, road/wheel contact force, natural frequencies of fifth wheel components, etc.

7.4 - Position and Orientation Kinematics

7.4.1 - Introduction

The task of tracking points on a crack would be simple if the truck were moving straight ahead or if it were turning a corner of constant radius. However, this will probably not be the case. To illustrate this point, it is noted here that after a particular point on a crack is identified by the VSS, the truck must move ahead approximately 35 feet before that same point on the crack moves into the work space of a robot arm. Throughout this distance it is unlikely that the truck will maintain a straight heading or even a turn of constant radius. Instead it is very likely that the truck will be moving with many combinations of left and right turns (of various radii) and straight ahead motion. The heading variations may be small, but they will be significant enough to have a large impact on the accurate positioning of the robot end effectors.

To accomplish the complicated task of tracking road cracks with respect to the crack sealing truck, it is necessary to develop the proper kinematics of the problem and incorporate them into the VOC computer program. The kinematics of the crack tracking problem are developed in the sections that follow. It is noted here that since the maximum speed of the truck during the crack sealing operation likely to be not more that 2 MPH, dynamic effects of the truck and the various ACSM subsystems have a negligible effect on the crack tracking problem. Therefore, it is possible to get a very accurate solution to this problem by including only the kinematic equations of the systems involved.

7.4.2 - Definitions

7.4.2.1 - Subscripts

[#/#] - Any subscript of the form [#/#] identifies the variable to which it is attached as having its particular value between step "[#/" and step "/#]" of the truck. An example is [4,5]. The variable to which this subscript is attached has its particular value between step 4 and step 5 of the truck. A general example is "[n-1/n]". The variable to which this subscript is attached has its particular value between step "n-1" and step "n" of the truck.

- Any subscript not contained within "[ ]" identifies the coordinate frame from which the value of the variable to which the subscript is attached is measured with respect to. For the example of "4" the variable to which this subscript is attached is measured with respect to the 4th moving coordinate frame (4th step of the truck). For the example of "n-1", the variable to which this subscript is attached is measured with respect to the "n-1" moving coordinate frame. For the example of "0", the variable to which this subscript is attached is measured with respect to the "0" or fixed coordinate frame.

[#] - Any subscript of the form [#] identifies the variable to which the subscript is attached as having the particular value for step "#" of the truck. An example is "[3]". The variable to which this subscript is attached has the particular value for step "3" of the truck. A general example is "[n]". The variable to which this subscript is attached has its particular value for step "n" of the truck.

7.4.2.2 - Constants

D - The lateral distance (in the "y" direction) between the left encoder wheel and the right encoder wheel. Refer to Figure 7.3.

Ne - The total number of encoder pulses per revolution of the encoder wheel (fifth wheel). Refer to Figure 7.10.

Re - The radius of the encoder wheel. Refer to Figure 7.10.

W - The lateral distance (in the "y" direction) between the right encoder wheel and the point "B" located on the truck. Refer to Figure 7.3.

7.4.2.3 - Variables

7.4.2.3.1 - Angles

$\beta_{[\#]0}$ - The angle, about a vertical axis, from a line drawn through point "$B_{[n]}$" and parallel to the x-axis of the "0" (fixed) reference frame to a line drawn through point "$B_{[n]}$" and point "A". The subscript "[#]" denotes the step of the truck motion to which this value belongs. Refer to Section 7.4.2.1 and Figure 7.4. This angle is defined and used only for intermediate manipulation of the kinematics formulas. In the final equations it is eliminated through reverse substitution. This variable makes sense only when referring to the "$_0$" reference frame.

$\phi_{[\#]}$ - The angle, about a vertical axis, from a line drawn through point "$B_{[n]}$" and parallel to the x-axis of the "#-1" reference frame to a line drawn through point "$B_{[n]}$" and point "A". The subscript "[#]" denotes the step of the truck motion to which this value belongs. Refer to Section 7.4.2.1 and Figure 7.4. This angle is defined and used only for intermediate manipulation of the kinematics formulas. In the final equations it is eliminated through reverse substitution.

$\psi_{[\#-1/\#]}$ - The angle, about a vertical axis, from a line drawn through point "$B_{[\#-1]}$" and point "$B_{[\#]}$" to the x-axis of the "#-1" reference frame. The subscript "[#-1/" refers to point "$B_{[\#-1]}$". The subscript "/#]" refers to point "$B_{[\#]}$". Refer to Section 7.4.2.1 and Figure 7.4. The value of this angle is independent of the reference frame with respect to which it is measured. This angle is defined and used only for intermediate manipulation of the kinematics formulas. In the final equations it is eliminated through reverse substitution.

$\theta_{[\#]}$ - The angle, about a vertical axis, through which the truck rotates. The subscript "[#]" denotes the step of the truck motion at which this rotation occurred. This angle is commonly referred to as the "yaw angle". The value of this angle is independent of the reference frame with respect to which it is measured. Refer to Section 7.4.2.1 and Figure 7.4.

θTotal - The sum of all "$\theta_{[\#]}$" values up to and including the present step of truck motion.

7.4.2.3.2 - Points

A - The point, located on the road surface, that is being tracked. Refer to Figure 7.3.

$B_{[\#]}$ - The point (on the truck), located on the center line of the right and left encoders, at a distance "W" to the left of the right encoder. The subscript identifies the variable to which it is attached as belonging to the [#] step. Refer to Figure 7.3.

7.4.2.3.3 - Miscellaneous Variables

$A_{[\#]}$ - The distance between a point "A" and the point "$B_{[\#]}$". Refer to Section 7.4.2.1 and Figure 7.7.

$Ax_{[\#]\#}$ - The "x" distance, measured with respect to a particular reference frame (denoted by the subscript "#"), between a point "A" and the origin of the [#] reference frame. The subscript [#] denotes the step of the truck to which this value belongs. Refer to Section 7.4.2.1 and Figure 7.6.

$Ay_{[\#]\#}$ - The "y" distance, measured with respect to a particular reference frame (denoted by the subscript "#"), between a point "A" and the origin of the [#] reference frame. The subscript [#] denotes the step of the truck to which this value belongs. Refer to Section 7.4.2.1 and Figure 7.6.

$ARCl_{[\#/\#]}$ - The length of the arc traversed by the left encoder from step "[#/" to step "/#]". Refer to Section 7.4.2.1 and Figure 7.3.

$ARCr_{[\#/\#]}$ - The length of the arc traversed by the right encoder from step "[#/" to step "/#]". Refer to Section 7.4.2.1 and Figure 7.3.

$B_{[\#/\#]}$ - The distance between one point "B" (denoted by the subscript "[#/") and another point B (denoted by the subscript "/#]. Refer to Section 7.4.2.1 and Figure 7.7.

$Bx_{[\#/\#]\#}$ - The "x" distance, measured with respect to a particular reference frame (denoted by the subscript "#"), between one point "B" (denoted by the subscript "[#/") and another point B (denoted by the subscript "/#]. Refer to Section 7.4.2.1 and Figure 7.5.

$Bx(cum)_0$ - The cumulative sum of all "$Bx_{[\#/\#]0}$" values up to and including the value for the last step of the truck. This variable makes sense only when referring to the "$_0$" reference frame.

$By_{[\#/\#]\#}$ - The "y" distance, measured with respect to a particular reference frame (denoted by the subscript "#"), between one point "B" (denoted by the subscript "[#/") and another point B (denoted by the subscript "/#]. Refer to Section 7.4.2.1 and Figure 7.5.

$By(cum)_0$ - The cumulative sum of all "$By_{[\#/\#]\,0}$" values up to and including the value for the last step of the truck. This variable makes sense only when referring to the "$_0$" reference frame.

n - The variable "n" refers to either the current step of the truck or the current moving coordinate frame depending on the context in which it is used. Additionally, "n-1" refers to the previous step or moving coordinate frame, "n-2" refers to the step or moving coordinate frame previous to the "n-1" step or moving coordinate frame, etc.

$Nl_{[\#/\#]}$ - The number of encoder pulses counted by the left encoder from step "[#/" to step "/#]".

$Nr_{[\#/\#]}$ - The number of encoder pulses counted by the right encoder from step "[#/" to step "/#]".

$Rb_{[\#/\#]}$ - The length of the radius between step "[#/," and step "/#]" of the truck drawn from the center of rotation of the truck and the arc traced by the point "B" (on the truck). Refer to Section 7.4.2.1 and Figure 7.3.

$Rl_{[\#/\#]}$ - The length of the radius between step "[#/," and step "/#]" of the truck drawn from the center of rotation of the truck and the arc traced by the left encoder wheel. Refer to Section 7.4.2.1 and Figure 7.3.

$Rr_{[\#/\#]}$ - The length of the radius between step "[#/," and step "/#]" of the truck drawn from the center of rotation of the truck and the arc traced by the right encoder wheel. Refer to Section 7.4.2.1 and Figure 7.3.

7.4.3 - The Kinematics of The Problem

7.4.3.1 - General Kinematics

First equations for several of the basic variables are derived. From Figure 7.3, it can be easily shown that:

$$ARCl_{[n-1/n]} = 2 \times \pi \times Re\left(\frac{Nl_{[n-1/n]}}{Ne_{[n-1/n]}}\right) \qquad (7.1)$$

and

$$ARCr_{[n-1/n]} = 2 \times \pi \times Re\left(\frac{Nr_{[n-1/n]}}{Ne_{[n-1/n]}}\right). \tag{7.2}$$

Next, a formula for $Rr_{[n-1/n]}$ is derived. From Figure 7.3, it can be seen that:

$$\frac{ARCr_{[n-1/n]}}{Rr_{[n-1/n]}} = \frac{ARCl_{[n-1/n]}}{Rl_{[n-1/n]}} \tag{7.3}$$

and

$$Rl_{[n-1/n]} = Rr_{[n-1/n]} + D. \tag{7.4}$$

Substituting Eqns. 7.4 into 7.3 and rearranging,

$$Rr_{[n-1/n]} = \left(\frac{(ARCr_{[n-1/n]})\ D}{ARCl_{[n-1/n]} - ARCr_{[n-1/n]}}\right). \tag{7.5}$$

Also, from Figure 7.3,

$$Rb_{[n-1/n]} = Rr_{[n-1/n]} + W, \tag{7.6}$$

$$\theta_{[n]} = \left(\frac{ARCr_{[n-1/n]}}{Rr_{[n-1/n]}}\right), \tag{7.7}$$

and

$$\theta_{[n]} = \left(\frac{ARCl_{[n-1/n]} - ARCr_{[n-1/n]}}{D}\right). \tag{7.8}$$

From Figure 7.4,

$$\phi_{[n]} = \tan^{-1}\left(\frac{Ay_{[n-1]\,n-1} - By_{[n-1/n]\,n-1}}{Ax_{[n-1]\,n-1} - Bx_{[n-1/n]\,n-1}}\right) \tag{7.9}$$

7.4.3.2 - Kinematics w/Respect to Local Reference Frame

Now, from Figure 7.5 it can be seen that:

$$\Delta Bx_{[n-1/n]\,n-1} = Rb_{[n-1/n]} \sin(\theta_{[n]}) \tag{7.10}$$

and

$$\Delta By_{[n-1/n]\,n-1} = Rb_{[n-1/n]}\left(1 - \cos(\theta_{[n]})\right). \tag{7.11}$$

Now substitute Eqn. 7.5 into Eqn. 7.6. Then substitute Eqns. 7.6 and 7.8 into Eqns. 7.10 and 7.11,

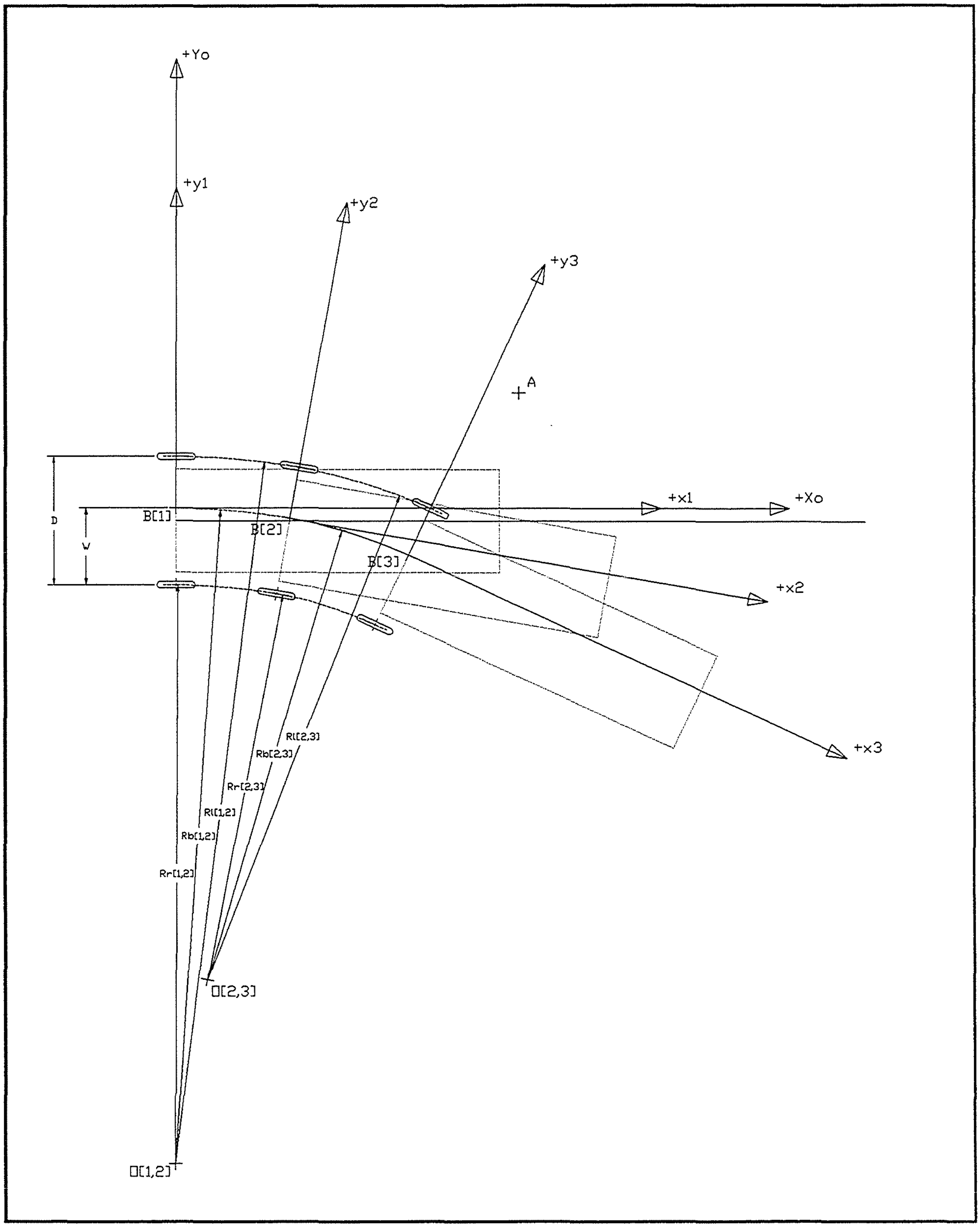


***Figure 7.3** - VOC system kinematics.*

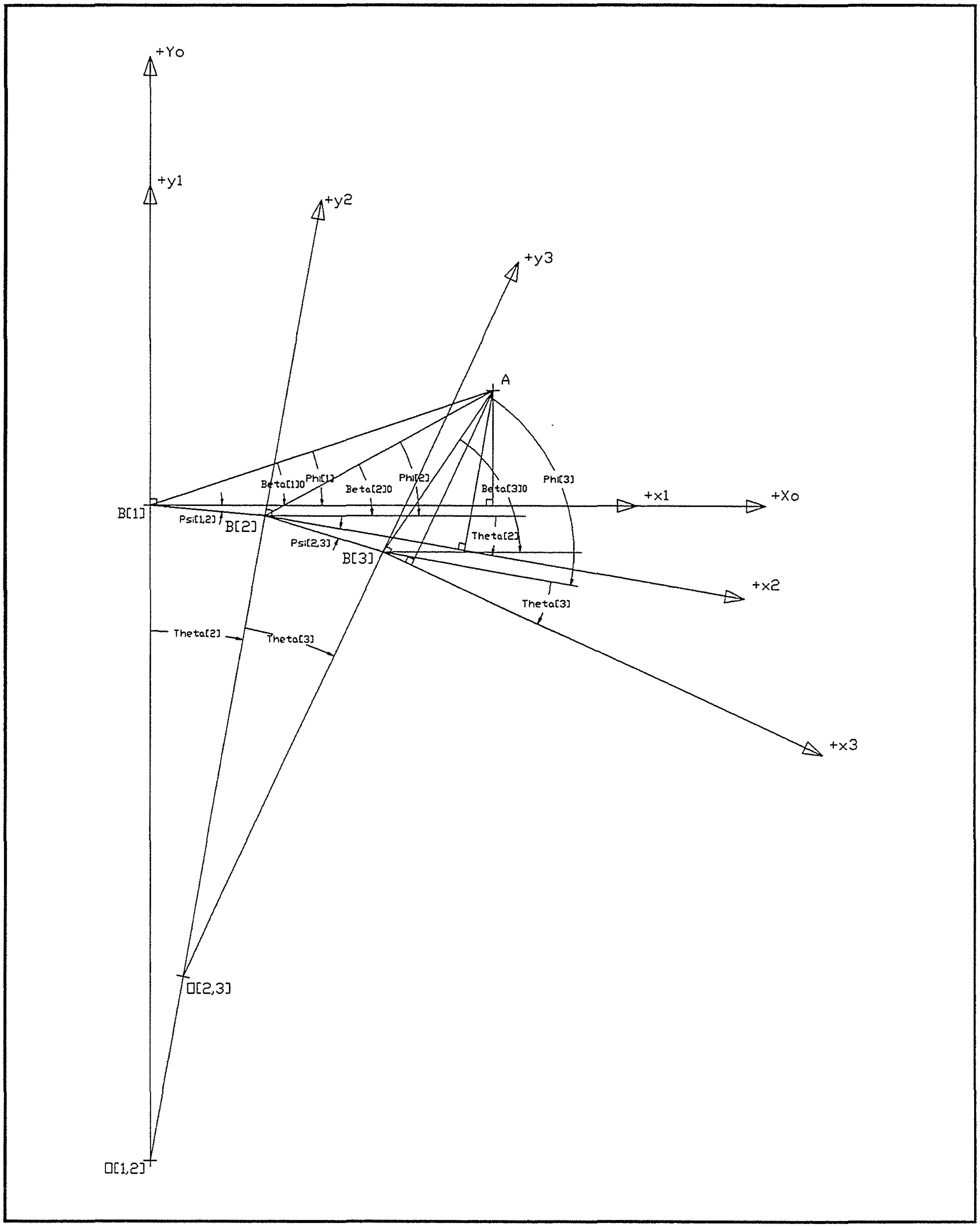


Figure 7.4 *- VOC system kinematics.*

$$\Delta Bx_{[n-1/n]\,n-1} = \left(\frac{(ARCr_{[n-1/n]})\ D}{ARCl_{[n-1/n]} - ARCr_{[n-1/n]}} + W\right)\sin\left(\frac{ARCl_{[n-1/n]} - ARCr_{[n-1/n]}}{D}\right) \tag{7.12}$$

$\boxed{\text{refer to Figure 7.5}}$

and

$$\Delta By_{[n-1/n]\,n-1} = \left(\frac{(ARCr_{[n-1/n]})\ D}{ARCl_{[n-1/n]} - ARCr_{[n-1/n]}} + W\right)\left(1 - \cos\left(\frac{ARCl_{[n-1/n]} - ARCr_{[n-1/n]}}{D}\right)\right). \tag{7.13}$$

$\boxed{\text{refer to Figure 7.5}}$

Now develop equations for point A. Referring to Figure 7.6,

$$Ax_{[n]\,n} = \left(\sqrt{(Ax_{[n-1]\,n-1} - \Delta Bx_{[n-1/n]\,n-1})^2 + (Ay_{[n-1]\,n-1} - \Delta By_{[n-1/n]\,n-1})^2}\right)\cos(\phi_{[n]} + \theta_{[n]}) \tag{7.14}$$

and

$$Ay_{[n]\,n} = \left(\sqrt{(Ax_{[n-1]\,n-1} - \Delta Bx_{[n-1/n]\,n-1})^2 + (Ay_{[n-1]\,n-1} - \Delta By_{[n-1/n]\,n-1})^2}\right)\sin(\phi_{[n]} + \theta_{[n]}). \tag{7.15}$$

Substituting Eqns. 7.8 and 7.9 into Eqns. 7.14 and 7.15,

$$Ax_{[n]\,n} = \left(\sqrt{(Ax_{[n-1]\,n-1} - \Delta Bx_{[n-1/n]\,n-1})^2 + (Ay_{[n-1]\,n-1} - \Delta By_{[n-1/n]\,n-1})^2}\right) \times \tag{7.16}$$

$$\cos\left(\tan^{-1}\left(\frac{Ay_{[n-1]\,n-1} - \Delta By_{[n-1/n]\,n-1}}{Ax_{[n-1]\,n-1} - \Delta Bx_{[n-1/n]\,n-1}}\right) + \left(\frac{ARCl_{[n-1/n]} - ARCr_{[n-1/n]}}{D}\right)\right)$$

$\boxed{\text{refer to Figure 7.6}}$

and

$$Ay_{[n]\,n} = \left(\sqrt{(Ax_{[n-1]\,n-1} - \Delta Bx_{[n-1/n]\,n-1})^2 + (Ay_{[n-1]\,n-1} - \Delta By_{[n-1/n]\,n-1})^2}\right) \times \tag{7.17}$$

$$\sin\left(\tan^{-1}\left(\frac{Ay_{[n-1]\,n-1} - \Delta By_{[n-1/n]\,n-1}}{Ax_{[n-1]\,n-1} - \Delta Bx_{[n-1/n]\,n-1}}\right) + \left(\frac{ARCl_{[n-1/n]} - ARCr_{[n-1/n]}}{D}\right)\right).$$

$\boxed{\text{refer to Figure 7.6}}$

<u>7.4.3.3 - Kinematics w/Respect to Global Reference Frame</u>

Referring to Figure 7.4, it can be seen that:

$$\psi_{[n-1/n]} = \tan^{-1}\left(\frac{-\Delta By_{[n-1/n]\,n-1}}{\Delta Bx_{[n-1/n]\,n-1}}\right) \tag{7.18}$$

and

$$\theta Total = \theta_{[1]\,0} + \ldots + \theta_{[n-1]\,n-2} + \theta_{[n]\,n-1}. \tag{7.19}$$

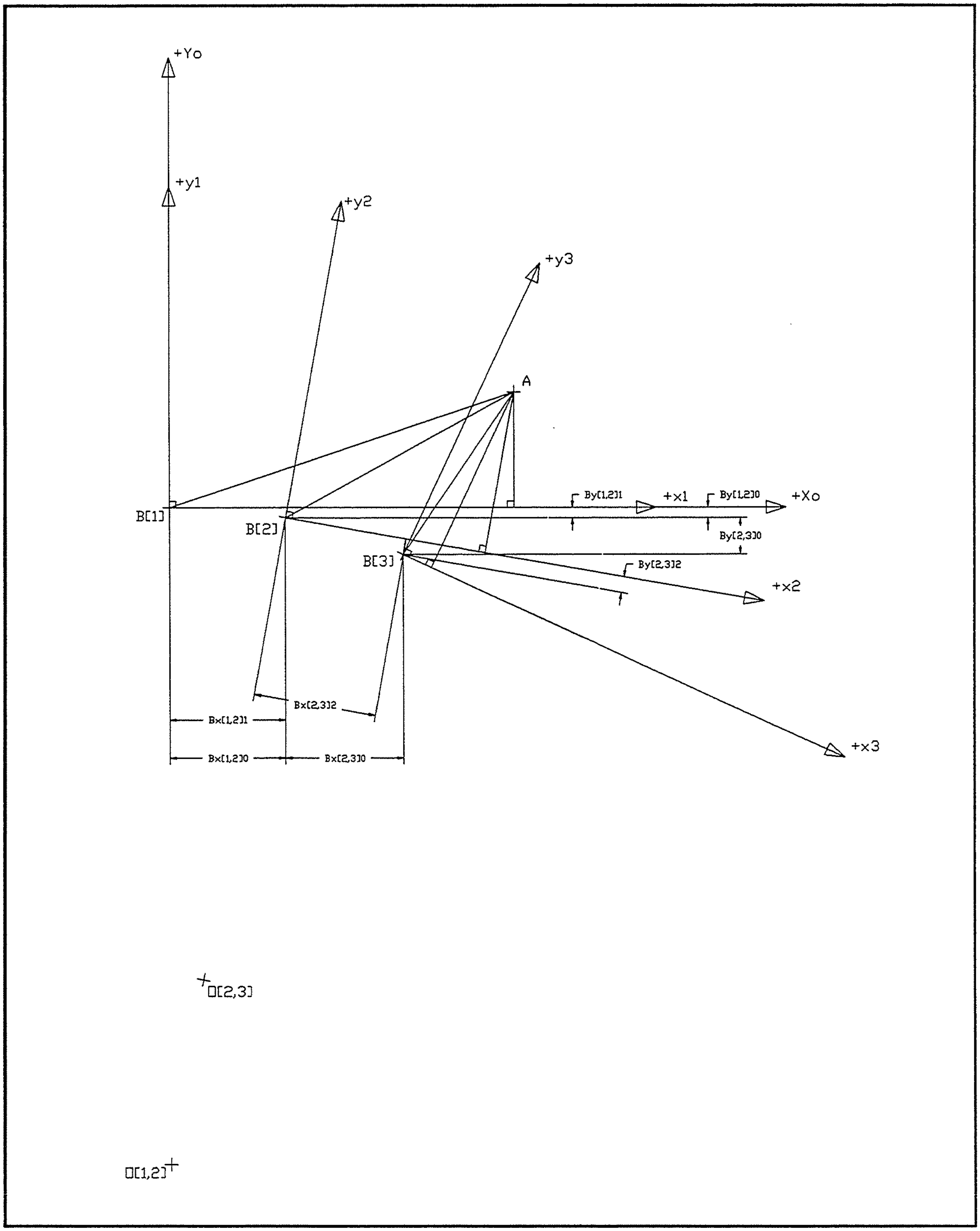


***Figure 7.5** - VOC system kinematics.*

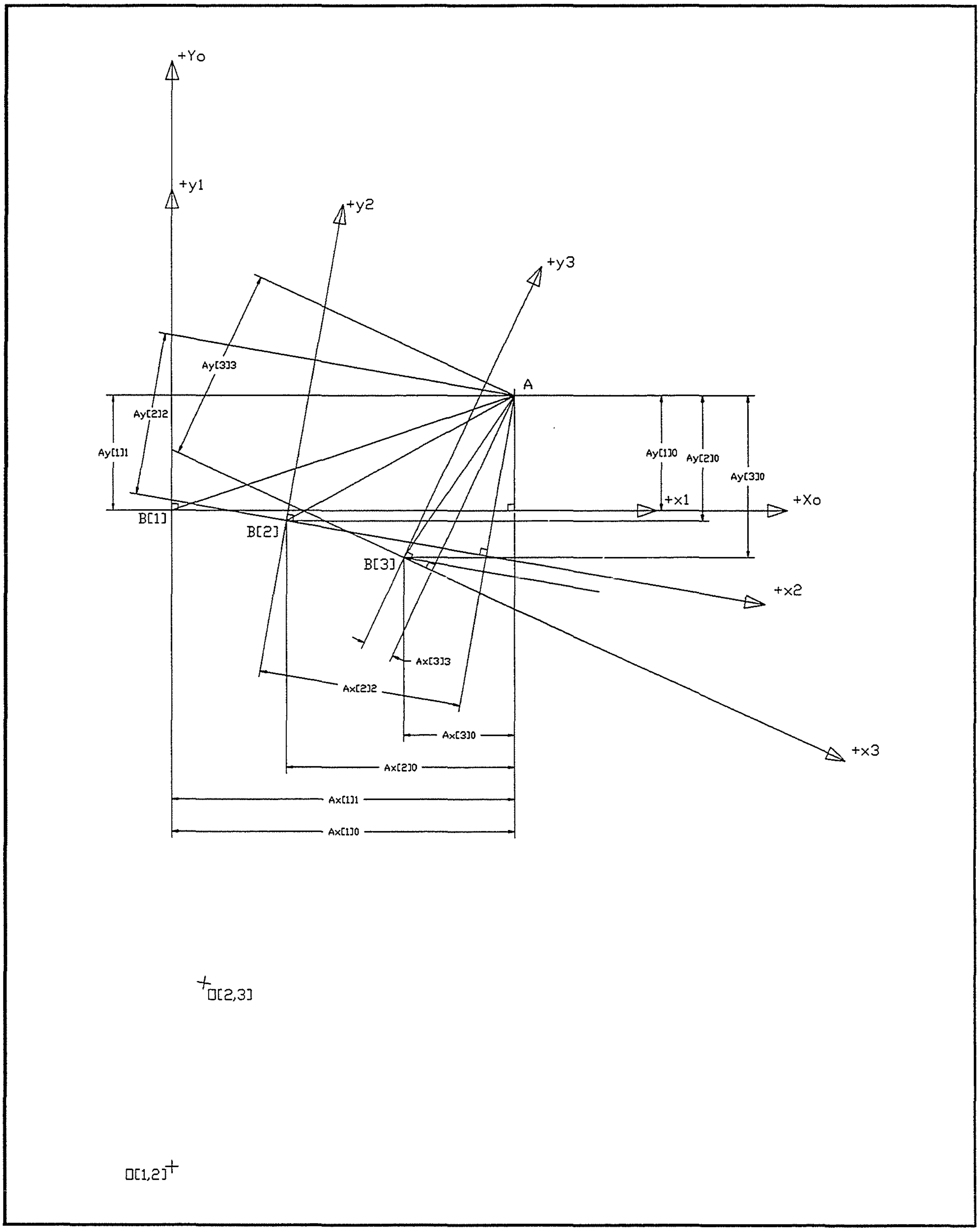


***Figure 7.6** - VOC system kinematics.*

From Figure 7.7:

$$B_{[n-1/n]} = \sqrt{(\Delta Bx_{[n-1/n]\ n-1})^2 + (\Delta By_{[n-1/n]\ n-1})^2}. \tag{7.20}$$

Now, referring to Figure 7.5,

$$\Delta Bx_{[n-1/n]\ 0} = B_{[n-1/n]} \cos(\psi_{[n]\ n-1} + \theta Total + \theta_{[n]\ n-1}) \tag{7.21}$$

and

$$\Delta By_{[n-1/n]\ 0} = B_{[n-1/n]} \sin(\psi_{[n]\ n-1} + \theta Total + \theta_{[n]\ n-1}). \tag{7.22}$$

Note that the correct signs (+/-) of $\Delta Bx_{[n-1/n]\ 0}$ and $\Delta By_{[n-1/n]\ 0}$ in Eqns. 7.21 and 7.22 may not be preserved since $B_{[n-1/n]}$ (which was calculated in Eqn. 7.20) was calculated by squaring $\Delta Bx_{[n-1/n]\ n-1}$ and $\Delta By_{[n-1/n]\ n-1}$, adding them, and taking their square root. This must be taken into account in any computer program.

Substituting Eqns. 7.8, 7.18, 7.19, and 7.20 into Eqn. 7.21,

$$\Delta Bx_{[n-1/n]\ 0} = \left(\sqrt{(\Delta Bx_{[n-1/n]\ n-1})^2 + (\Delta By_{[n-1/n]\ n-1})^2}\right) \times \tag{7.23}$$

$$\cos\left(\tan^{-1}\left(\frac{-\Delta By_{[n-1/n]\ n-1}}{\Delta Bx_{[n-1/n]\ n-1}}\right) + \left(\frac{ARCl_{[1/2]} - ARCr_{[1/2]}}{D}\right) + \ldots + \underbrace{\left(\frac{ARCl_{[n-2/n-1]} - ARCr_{[n-2/n-1]}}{D}\right)}_{\boxed{\text{refer to Figure 7.5}}}\right).$$

Similarly, substituting Eqns. 7.8, 7.18, 7.19, and 7.20 into Eqn. 7.22,

$$\Delta By_{[n-1/n]\ 0} = \left(\sqrt{(\Delta Bx_{[n-1/n]\ n-1})^2 + (\Delta By_{[n-1/n]\ n-1})^2}\right) \times \tag{7.24}$$

$$\sin\left(\tan^{-1}\left(\frac{-\Delta By_{[n-1/n]\ n-1}}{\Delta Bx_{[n-1/n]\ n-1}}\right) + \left(\frac{ARCl_{[1/2]} - ARCr_{[1/2]}}{D}\right) + \ldots + \underbrace{\left(\frac{ARCl_{[n-2/n-1]} - ARCr_{[n-2/n-1]}}{D}\right)}_{\boxed{\text{refer to Figure 7.5}}}\right).$$

Now for develop equations for point "A". First,

$$\Delta Bx(cum)_0 = \Delta Bx_{[1/2]\ 0} + \ldots + \Delta Bx_{[n-2/n-1]\ 0} + \Delta Bx_{[n-1/n]\ 0} \tag{7.25}$$

and

$$\Delta By(cum)_0 = \Delta By_{[1/2]\ 0} + \ldots + \Delta By_{[n-2/n-1]\ 0} + \Delta By_{[n-1/n]\ 0}. \tag{7.26}$$

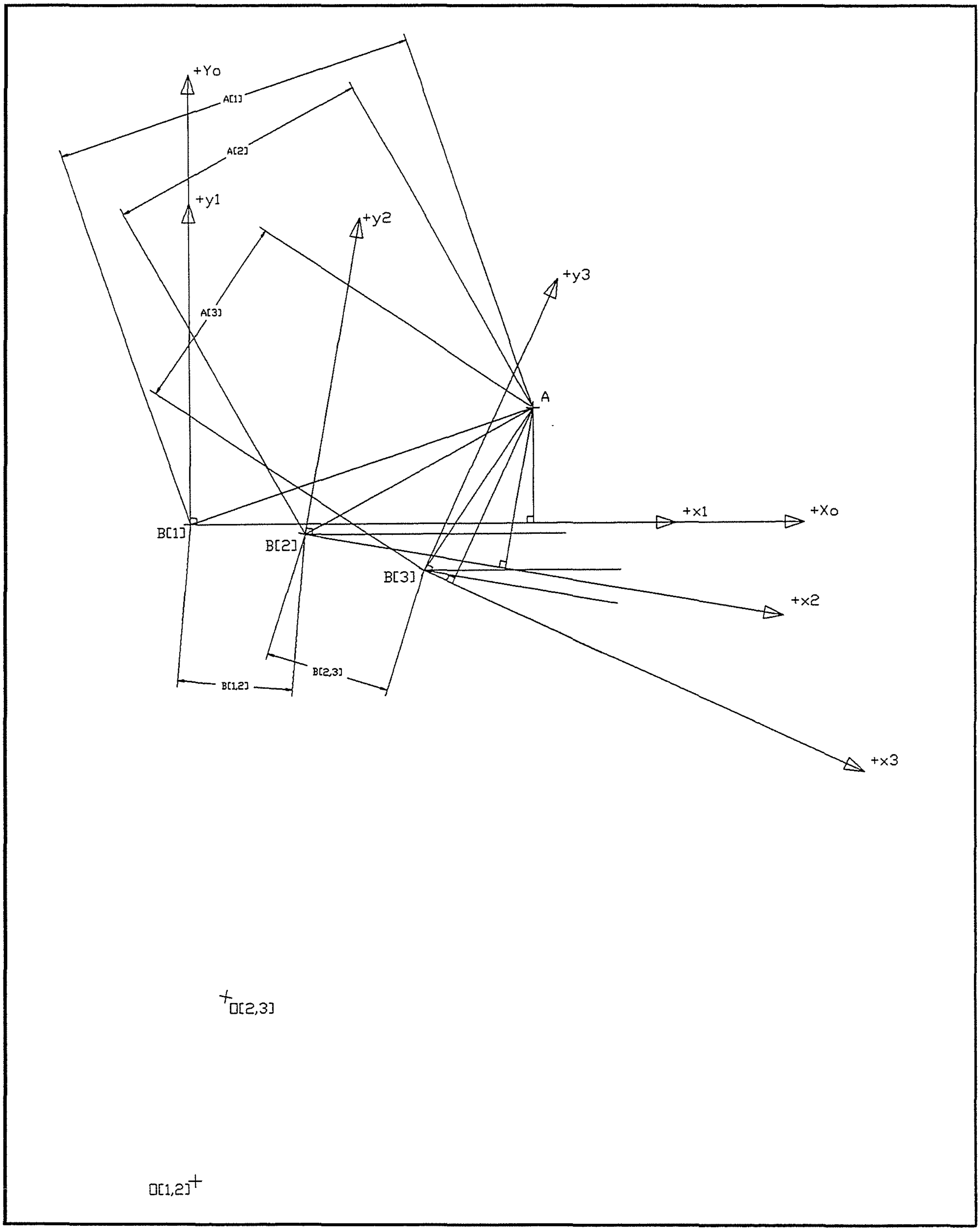


Figure 7.7 *- VOC system kinematics.*

From Figure 7.4, it is seen that:

$$\beta_{[n]\,0} = \left(\frac{Ay_{[1]\,0} - \Delta By(cum)_{\,0}}{Ax_{[1]\,0} - \Delta Bx(cum)_{\,0}}\right). \tag{7.27}$$

Now, referring to Figure 7.6:

$$Ax_{[n]\,0} = \left(\sqrt{(Ax_{[1]\,0} - \Delta Bx(cum)_{\,0})^2 + (Ay_{[1]\,0} - \Delta By(cum)_{\,0})^2}\right) \cos(\beta_{[n]\,0}) \tag{7.28}$$

and

$$Ay_{[n]\,0} = \left(\sqrt{(Ax_{[1]\,0} - \Delta Bx(cum)_{\,0})^2 + (Ay_{[1]\,0} - \Delta By(cum)_{\,0})^2}\right) \sin(\beta_{[n]\,0}). \tag{7.29}$$

Substituting Eqn. 7.27 into Eqns. 7.28 and 7.29,

$$Ax_{[n]\,0} = \left(\sqrt{(Ax_{[1]\,0} - \Delta Bx(cum)_{\,0})^2 + (Ay_{[1]\,0} - \Delta By(cum)_{\,0})^2}\right) \times \tag{7.30}$$

$$\cos\left(\frac{Ay_{[1]\,0} - \Delta By(cum)_{\,0}}{Ax_{[1]\,0} - \Delta Bx(cum)_{\,0}}\right).$$

refer to Figure 7.6

Similarly,

$$Ay_{[n]\,0} = \left(\sqrt{(Ax_{[1]\,0} - \Delta Bx(cum)_{\,0})^2 + (Ay_{[1]\,0} - \Delta By(cum)_{\,0})^2}\right) \times \tag{7.31}$$

$$\sin\left(\frac{Ay_{[1]\,0} - \Delta By(cum)_{\,0}}{Ax_{[1]\,0} - \Delta Bx(cum)_{\,0}}\right).$$

refer to Figure 7.6

7.5 - VOC Computer Program and System Interface

The VOC system consists of two optical encoders, a computer interface card, and software. The encoders output a square wave pulse as the vehicle moves, and the computer interface card records the number of pulses.

The software performs does three functions: 1) reads the number of recorded pulses on the computer interface card, 2) calculates the vehicle's new position and heading based on the number of recorded pulses, and 3) provides the RPS crack locations upon request. The new position and heading are calculated in the program using kinematics schemes similar to the ones previously described. When the RPS requests new crack locations, the program does a matrix transformation routine that provides an updated crack location based on the current vehicle location and the old crack locations provided by the VSS.

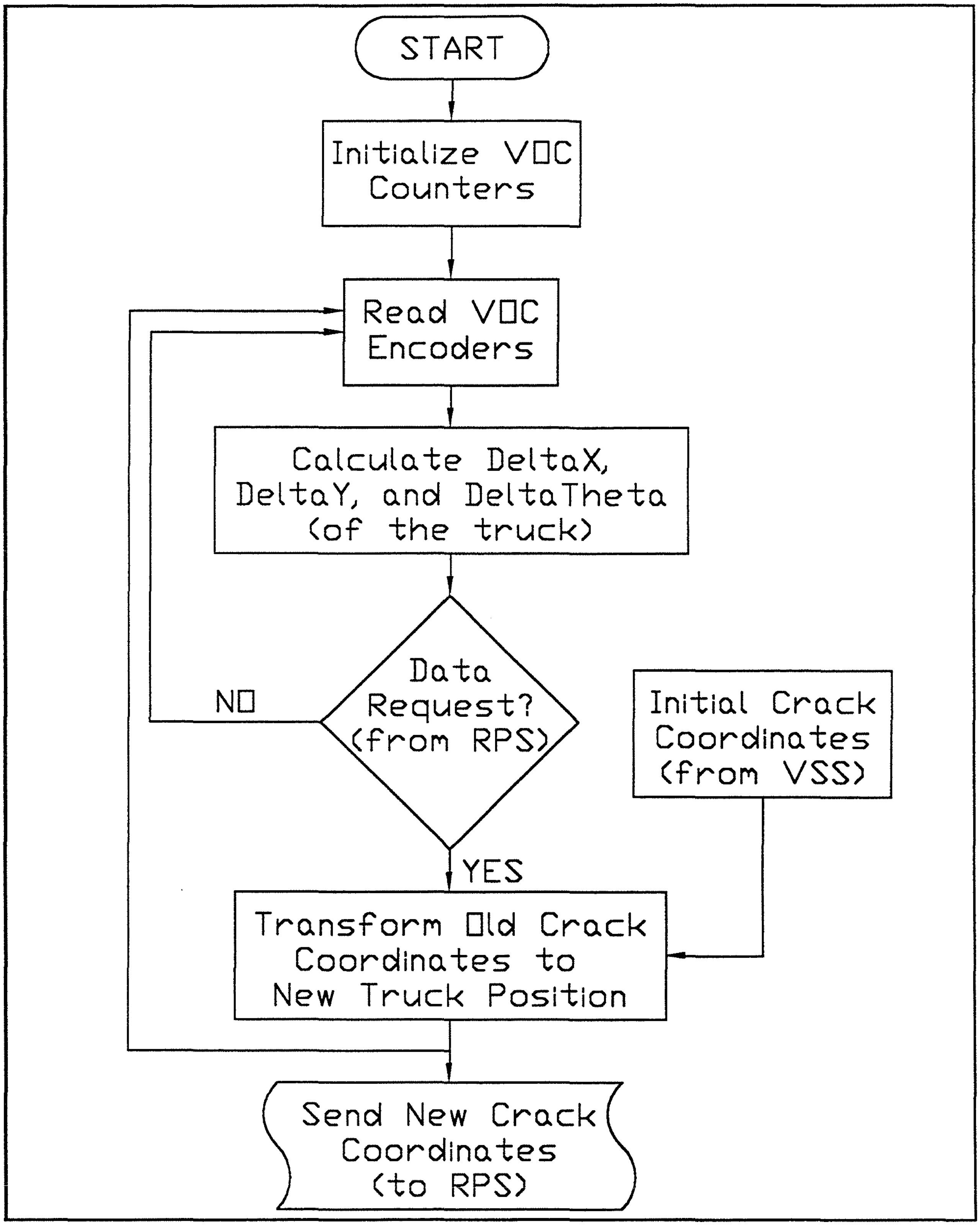


***Figure 7.8** - Flow chart of VOC system and interface.*

7.6 - Cart Test of Integrated First Generation Prototype

The integrated first generation prototype of the VOC system was recently tested and debugged on a specially designed test cart (see Figure 7.9). The test cart was used as the VOC system platform for the first generation prototype in place of the crack sealing truck. The test cart provided a convenient, scaled-down test platform on which the VOC system could be easily tested and debugged. In Phase III, the second generation prototype will be developed and manufactured as well as integrated with the ACSM. It will essentially be identical to the first generation prototype except for refinements in the design and modifications (fifth wheels) what will allow the second generation prototype to be mounted directly to the crack sealing truck.

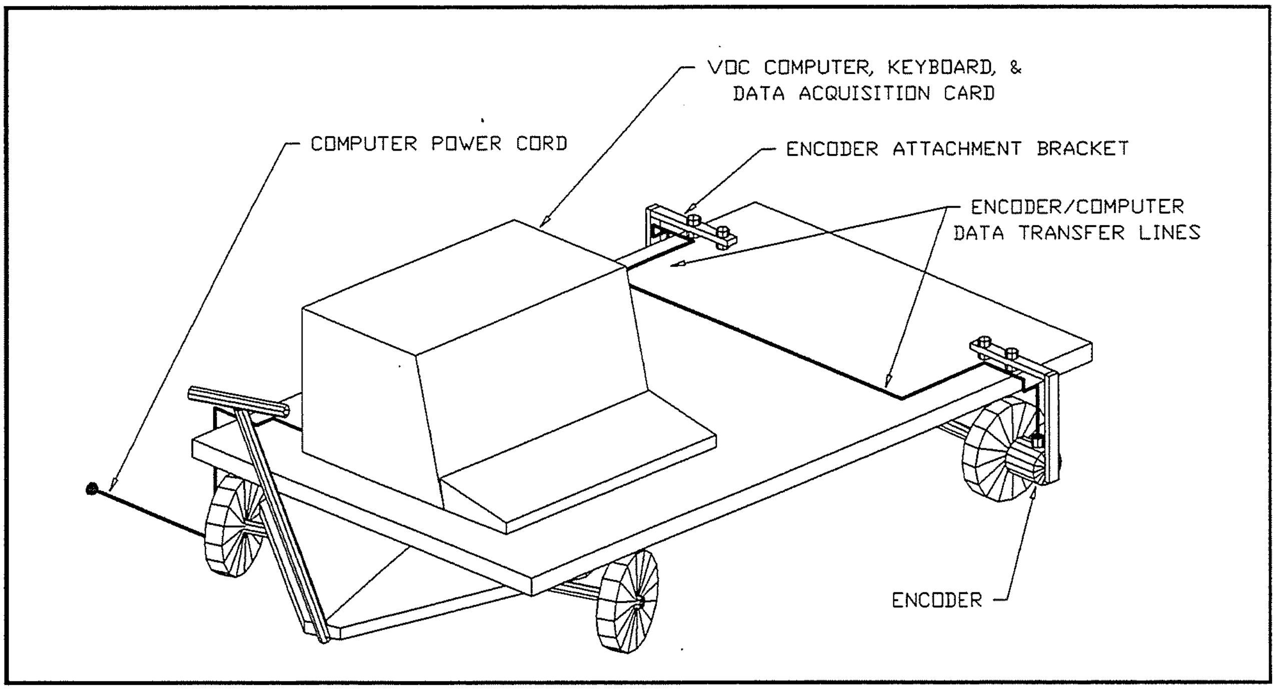


Figure 7.9 *- Schematic illustration of test cart and integrated first generation VOC system prototype.*

7.7 - Component Descriptions

7.7.1 - Fifth wheel

The fifth wheel subassembly is used for providing data to the VOC computer program for the purpose of tracking the position and orientation of the crack sealing truck. The fifth wheel subassembly consists of the following components:

- a wheel that rolls on the road surface and thus turns the rotary encoder,
- an encoder for converting the rotary input to digital, electrical outputs, and
- all linkage, fastening components, and electrical cables necessary for attaching the wheel and encoder to the crack sealing truck and VOC computer.

Refer to Figure 7.1 for a schematic illustration of the integration of the two fifth wheels subassemblies on the crack sealing truck.

7.7.2 - Encoder

A simplified optical, rotary encoder consists of three major parts. These include:

- a disk with radial line slits (see Figure 7.10),
- a light source, and
- a light detector (see Figure 7.11).

As the disk rotates, light is transmitted between radial line slits to the light detector which generates a triangular wave voltage output. This output is fed to a comparator that transforms it to a square wave voltage. The square wave is then fed to a counter which is triggered by the leading edge of the square wave.

Optical incremental encoders are used to detect vehicle motion by tracking the difference of counts between encoder readings. For the VOC, the primary interest is in the forward distance, and therefore only forward motion and distances are tracked. However, the encoders have the capability to detect both forward and reverse truck motion. This capability should be fully implemented in a future VOC system configuration.

7.8 - Technical Progress

7.8.1 - Progress to Date

The development of the VOC system began in early November, 1991. It was decided to install the first generation prototype on a test cart (approximately 3' wide by 5' long - see Figure 7.9) for testing and debugging purposes. The first generation prototype will be refined and a fifth wheel linkage will be developed, manufactured, and integrated with the refined prototype. This will be the second generation prototype. The second generation prototype will be installed on the crack sealing truck and integrated with the VSS, RPS, and ICU.

The following tasks have been completed to date.

- The VOC test cart has been completely designed, manufactured, and tested.
- The encoders and counters have been fully tested and debugged.

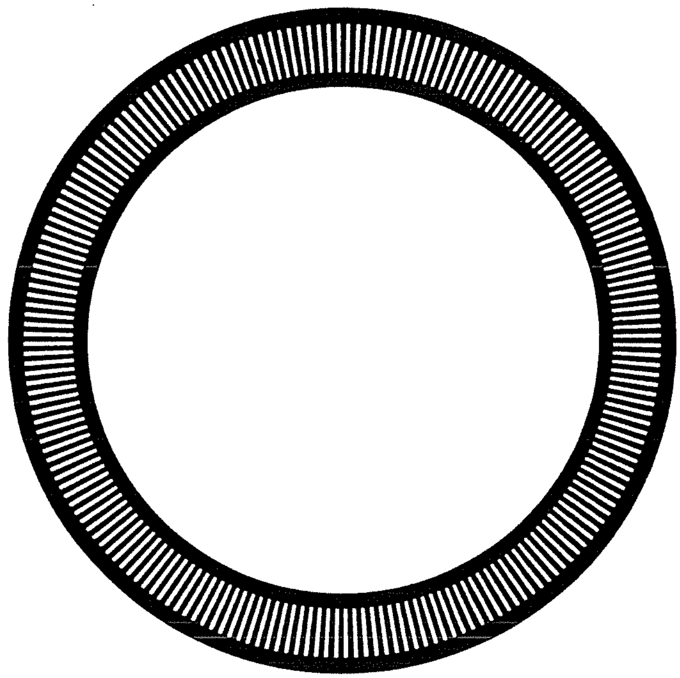


Figure 5.3.7. An incremental encoder disk having 200 radial lines. A resolution of 1.8° is possible with such a device. (Courtesy of Dynamics Research Corp., Wilmington, MA.)

***Figure 7.10** - Schematic Illustration of Encoder Disk with Radial Line Slits.*

- The VOC system components (hardware and software) have been fully integrated with the test cart.
- The crack following kinematics have been completely developed and verified through computer simulation.

7.8.2 - Current Tasks

The following tasks are currently being performed.

- Testing and debugging of the system software is being completed.
- Documentation and drawings of system hardware and software is being completed.

7.8.3 - Future Tasks

The following tasks must still be performed.

- The fifth wheel mounts for the for the crack sealing truck must be designed and manufactured.

- The completed VOC system must be integrated with the truck, VSS, RPS, and ICU.
- The integrated system must be tested and debugged.
- The final report on VOC system must be produced.

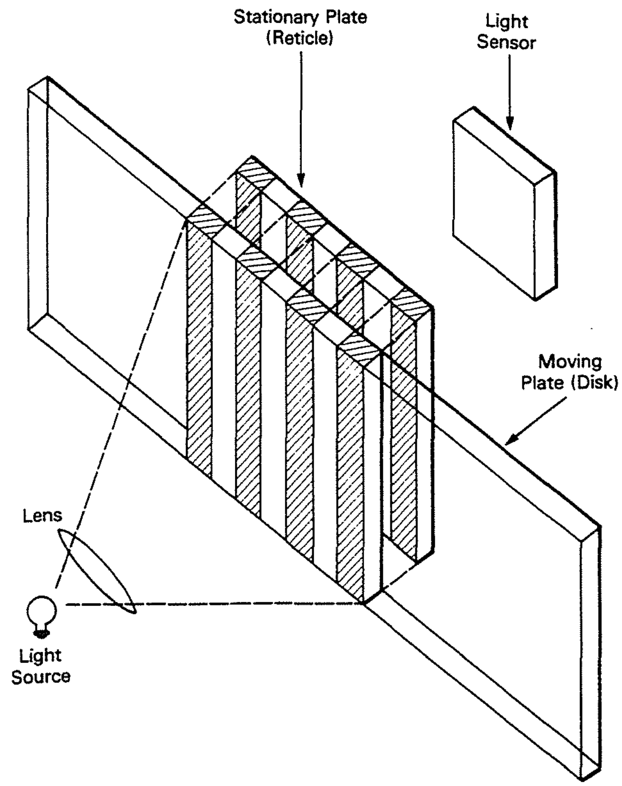


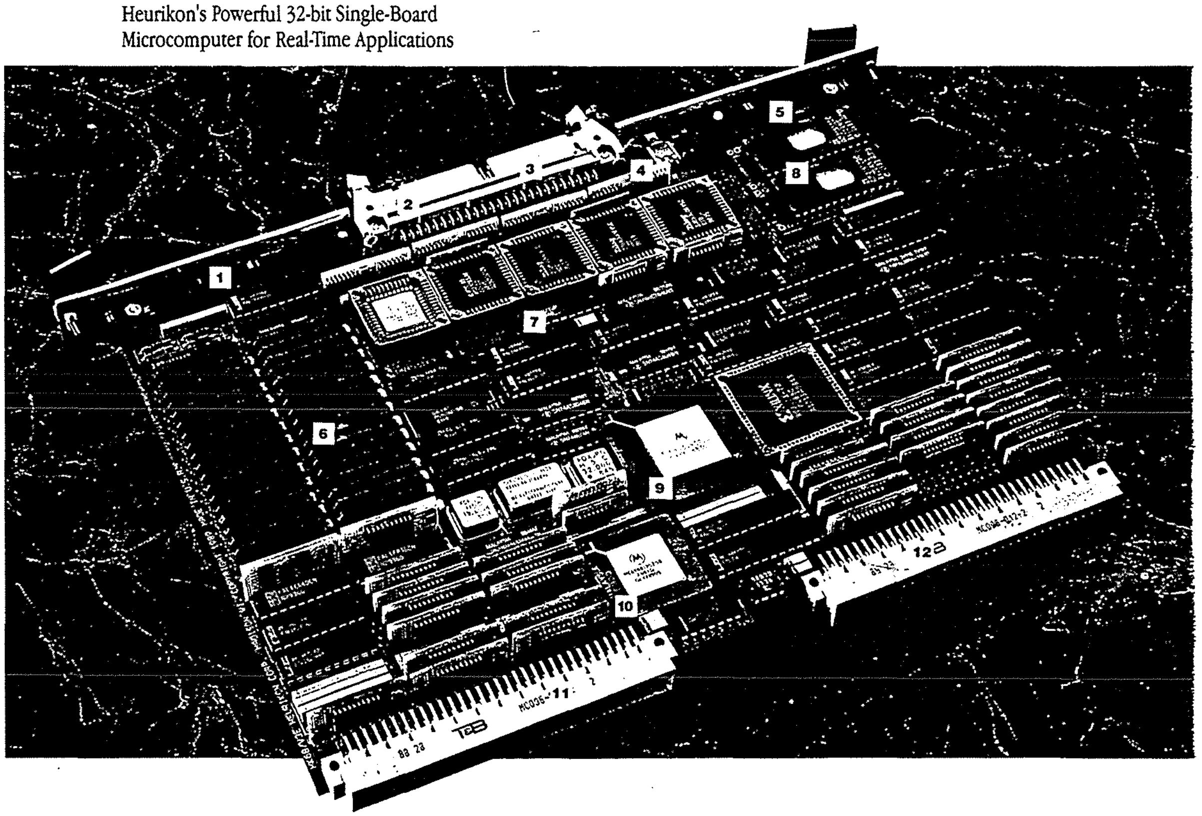
Figure 5.3.9. Section of a single channel encloder. (Redrawn with permission of Dynamics Research Corp., Wilmington, MA. From "Techniques for Digitizing Rotary and Linear Motion." Fig 4-1, p. 4-2, 1976.)

Figure 7.11 *- Schematic Illustration of Encoder Light Source & Light Detector.*

APPENDIX A - ICU SPECIFICATIONS

HK68/V3E

Heurikon's Powerful 32-bit Single-Board Microcomputer for Real-Time Applications



1. Centronics Compatible Parallel Port
2. SCSI Interface
3. 4 RS-232 Serial Ports (RS-422 optional)
4. User-Programmable LEDs
5. Control Panel Interface
6. 1 to 16 Mbytes of DRAM
7. 128 bytes Non-Volatile RAM
8. Up to 2 Mbytes EPROM
9. Up to 33 MHz 68030 CPU
10. Optional 68882 Floating Point Coprocessor
11. VSB Interface
12. VME Interface

Please see reverse side for technical specifications

HEURIKON®
OPEN SYSTEMS :: OPEN TOOLS

HK68/V3E

Technical Specifications

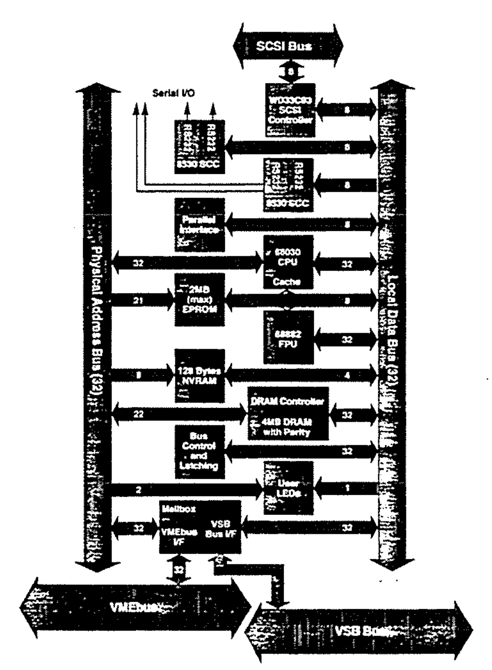
Bus Interface

VMEbus
• VMEbus architecture with 32-bit data path, 32-bit addressing and 7 bus interrupts • Operates in Master or Slave Mode (Compliance Level: D32A32(7)) • System level controller functions including 4 level arbitration • Watchdog timer terminates accesses otherwise causing system deadlock

Mailbox Interrupts
• Allows remote control of the HK68/V3E via specified VMEbus addresses • CPU Halt, reset, interrupt and VMEbus lock functions supported

VSB Bus
• VSB compatible high speed memory expansion for up to 960 Mbytes
• Supports secondary masters

HK68/V3E BLOCK DIAGRAM



Processor

CPU
• Motorola 68030 CPU operating at up to 50 MHz • 32-bit non-multiplexed address and data buses
• 256 byte instruction cache and 256 byte data cache accessible simultaneously • 4 Gbyte direct addressing range • Paged memory management unit providing logical to physical address translation • Watchdog timer terminates accesses otherwise causing on-card deadlock

Floating Point Coprocessor
• 68882 Floating Point Coprocessor on-board • Implements IEEE-P754 Binary Floating Point Standard
• Concurrent execution of floating point operations in hardware at speeds up to 100 times that of the 68030 • Optional optimizing C compiler generating 68882 in-line code

Random Access Memory
• 1, 2, 3, 4, 8, or 16 Mbytes of on-board DRAM with parity • Dual access • Static column mode supported for burst cache refill and sequential accesses • One parity bit per byte • Transparent discrete hardware refresh

Read Only Memory
• Two 32-pin ROM sockets for up to 2 Mbytes EPROM • Compatible with 28-pin ROM chips • Optional paged ROM, EPROM or EEPROM

Non-Volatile RAM
• 128 bytes non-volatile RAM in 256 x 4 configuration • User definable functions such as default baud rates, software and hardware revision levels and system configuration information
• Internal EEPROM • 10 ms store cycle • 100 year retention • 10,000 store cycle lifetime.

Status and User LEDs
• Three on-board LEDs to indicate master, slave and fail • Four additional User-programmable LEDs

Peripheral I/O

Small Computer Systems Interface
• WD33C93 ANSI compatible high-speed SCSI permits connection of up to eight independent, compatible I/O controllers • Burst transfer rates of up to 1.5 Mbytes/sec. asynchronous and 2 Mbytes/sec. synchronous obtainable

Serial I/O
• Four serial I/O ports provided via two Z8530 SCC chips • Asynchronous and synchronous modes • Internal software controlled baud rate generator for each port • RS-232-C standard with EIA RS-422 available via intelligent cable • Transfer rates of up to 38.4K baud asynchronous and 1 Mbit/sec. synchronous obtainable

Parallel I/O
• 8-bit parallel write and 8-bit status input port configurable for direct communication with Centronics compatible devices

CIO
• Three programmable 16-bit counter/timer channels available

Board Support

Software Support
• Ready Systems' VRTX32® Real-Time Executive • Microware's OS-9™ Professional and Industrial • Wind River Systems' VxWorks™ • Real-time development systems

Configuration Options
• CPU—20, 25, 30, or 33 MHz 68030
• 68882 floating point coprocessor
• RS-422 on 2 or 4 serial ports
• Time-of-day clock standard with battery back-up

Physical and Environmental Characteristics
• Multilayer with ground and VCC planes • Board size: 23.35 cm x 16.0 cm (9.19 in. x 6.3 in.) • Power requirements: +5VDC @ 8.0A, +12VDC @ 0.5A, -12VDC @ 0.5A • Operating range: 0 to 55° C. 100% relative humidity (non-condensing)

For more information on Heurikon's line of VMEbus and other microcomputer products, please contact a Heurikon representative. Or Call:

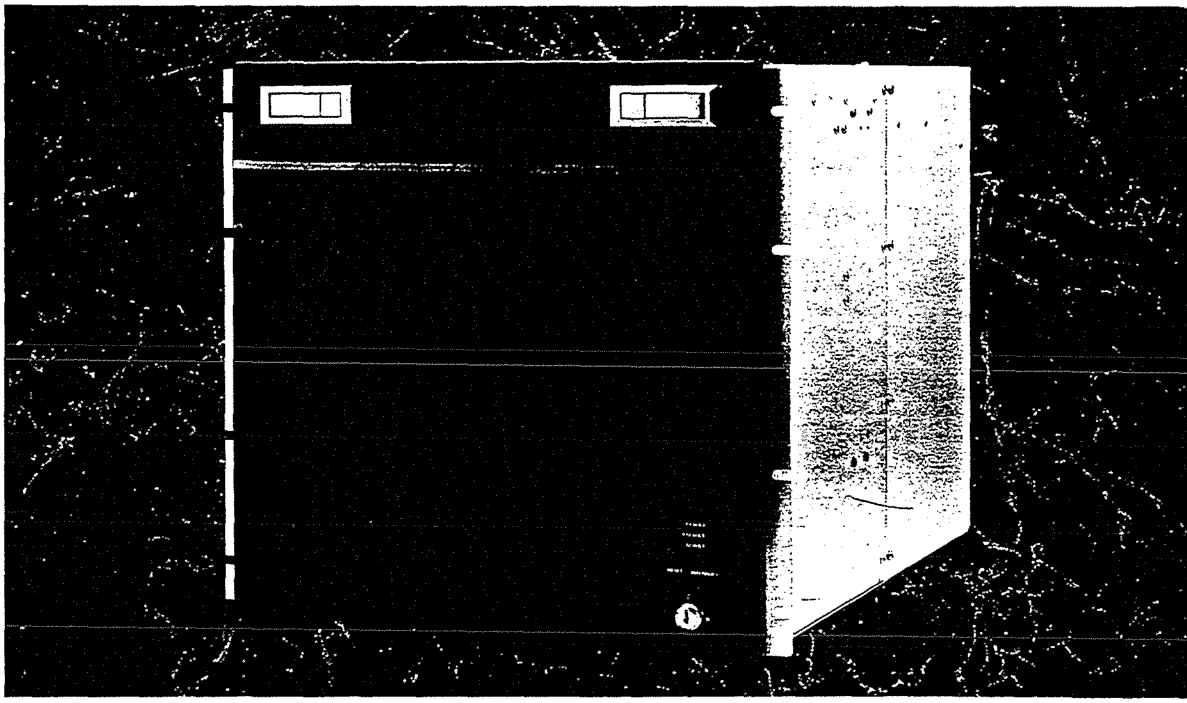
1•800•356•9602

Heurikon Corporation
8000 Excelsior Drive
Madison, WI 53717
608-831-0900
TLX: 469532
FAX: 608-831-4249

Specifications subject to change without notice
9.91.V3E

HEURIKON®
OPEN SYSTEMS :: OPEN TOOLS

HCE/17R-21



- VME 21-card capacity or Multibus II 20-card capacity
- 1000W Supply (1500W optional)
- All metal construction with interlocking joints meeting FCC Class A EMI/RFI
- Optimized design for reliability and ease of cabling.
- Semi-transparent front panel option.

HEURIKON CORP.
OPEN SYSTEMS : : OPEN TOOLS

Please see reverse side for technical specifications

HCE/17R-21

Technical Specifications

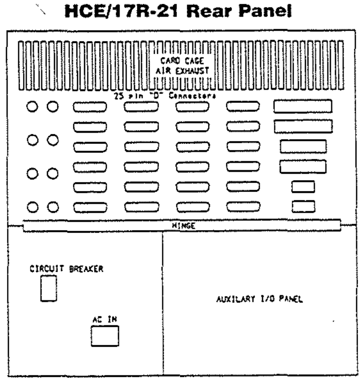
The HCE/17R-21 System Enclosure is designed for VME and Multibus II applications requiring 21-slot card capacity and minimum space. Power and cooling provisions have been provided to accommodate a fully loaded card cage.

With Heurikon's board and systems manufacturing experience, we understand the needs of the system integrator. That's why we've paid particular attention to both the mechanical and thermal elements to provide optimum operating conditions for your system. This affords you not only maximum card capacity, but a stable operating environment as well.

Dimensions

- 17.5" H x 17.0" W (19" with flanges) x 21.0" D
- Enclosure Weight: approximately 40 lbs (without boards).
- Operating Temperature: 10° - 50°C; 5 - 95% non-condensing humidity

HCE/17R-21 Rear Panel



Construction

- All metal enclosed construction for mounting in a standard 19" RETMA rack.
- Construction and materials compliant to FCC Class A, listed to UL 1950, classified to IEC 950
- Three 100 cfm fans with filtered intake providing a properly cooled and thermally stable operating environment.
- Interlocking seams mean maximum shielding and construction durability with an efficient grounding structure to minimize noise.
- Cable routing channels providing easy access to front to back cabling and P2 to back. Maximum clearances maintained between cabling and cabinetry.
- Fully featured front panel with remote DC inhibit rotary switch, power-on indicator, reset switch, interrupt switch, and output voltage monitor.
- Semi-transparent front panel option providing easy viewing of all board front panels.
- Optional peripheral storage subsystem for additional drive capacity.
- Rack slide mount option.

Power

- Operating Range: 90-132/180-264 VAC; 47-63 Hz (operator selectable; consult factory for exact specifications).

20A input connector-U.S.
16A input connector-International

- Output: 1000W maximum output standard—DC power +5V @ 150A; ± 12V @ 10A. 1500W optional configuration—5V @ 200A; ± 12V @ 20A.
- Switched AC breaker
- All outputs may be referenced to each other or to chassis ground as required.
- The bus bar distribution scheme ensures maximum power to the card cage at all times.

Rear Panel

- Clearances have been designed into the HCE/17R-21 to allow easy access for cabling or expedient servicing of the unit minimizing MTTR.
- Easy access to bus backplane to allow cabling such as VSBbus or I/O connectors on the P2.
- J1 backplane complies with VMEbus specifications (IEEE-P1014). J2 complies with VMEbus specifications and allows VSBbus configurations.

Rear Panel Connectors:

DB-15	2 positions
DB-25	24 positions
DB-50	2 positions
Centronics	1 position
IEEE-488	1 position
BNC	8 positions

In additon to the standard back panel, Heurikon offers a wide range of customization services to meet demanding applications. For example, new back panels can be fabricated for applications requiring extensive serial, video or other types of custom I/O. Heurikon also offers FCC and safety standards certification services.

For more information on Heurikon's line of microcomputer products, please contact a Heurikon representative, or call:

1•800•356•9602

Heurikon Corporation
8000 Excelsior Drive
Madison, WI 53717
608-831-0900
TLX: 469532
FAX: 608-831-4249

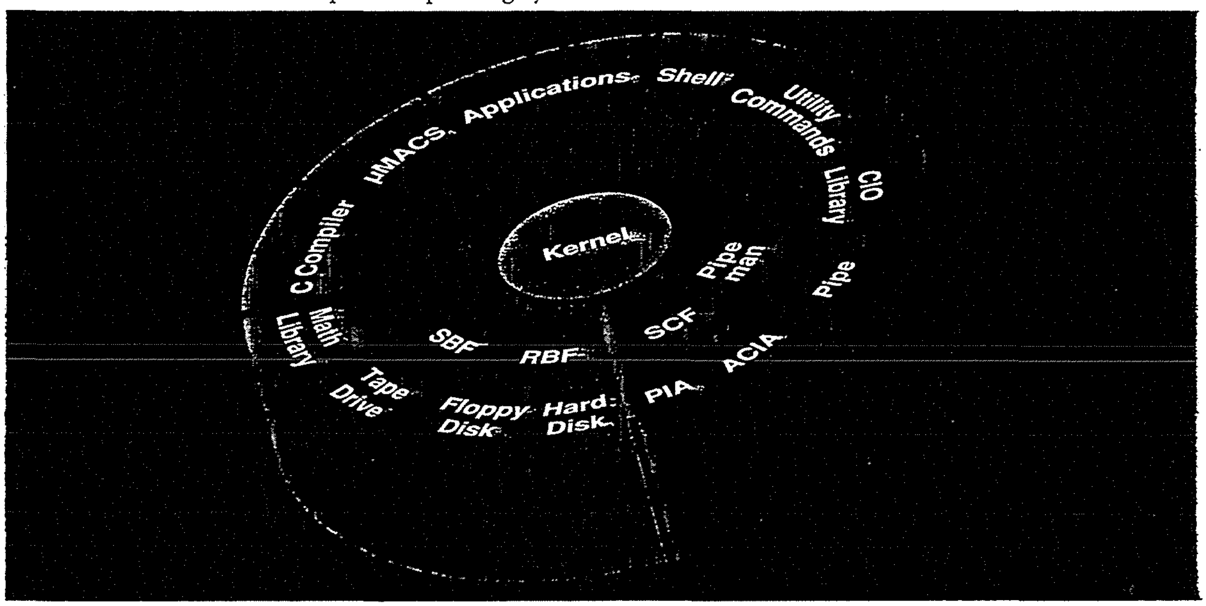
HEURIKON
OPEN SYSTEMS : : OPEN TOOLS

Specifications subject to change without notice
9.91.HCE/17R-21

PRELIMINARY

OS-9

Real-Time Unix-Compatible Operating System



OS-9 is a multitasking, multiuser real-time operating system which works on a range of Heurikon 680x0 single board computers and complete systems. It's user interactive capability as well as its real-time response make OS-9 ideal for a range of applications from image processing to industrial control.

The OS-9 design brings you many benefits:

- Extensive and efficient management of all system resources including I/O, memory and CPU time, allows you to design a system with the deterministic qualities critical to real-time.
- An optional C Source Debugger helps you debug your applications and speed your time to market.
- A powerful and user friendly interface lets you to learn how to use the operating system quickly which means you can bring your product to market or project to completion more quickly.
- OS-9 can be self hosted which means you don't have to purchase both a host development environment and a target run-time system. OS-9 also supports cross development environments.
- A modular approach means you can use exactly the modules necessary for your application without the performance and memory space overhead of unused features.
- Full support for ROMed applications lets you develop systems which don't require magnetic media.
- Re-entrant programming allows many processes to use a single resource saving valuable memory.
- A low price gives you the flexibility you need to keep costs under control.
- An advanced symbolic debugger helps you debug your applications quicker and a system state debugger speeds development of custom drivers.

HEURIKON®
OPEN SYSTEMS :: OPEN TOOLS

The Heurikon Advantage

High Performance

OS-9 applications are segmented into tasks or processes which are allocated CPU time based on user defined scheduling priorities. It's the efficient management of tasks and system resources which in part give OS-9 its extremely high performance. Other factors contributing to OS-9 performance are the advanced kernel, I/O system modules and device drivers which are optimized assembly language system programs. Other system resources which are not speed critical such as the Shell and command set, are written in C.

The ability of the user to dynamically define task priorities makes OS-9 highly deterministic. Context switch time and interrupt latency can easily be calculated as a function of the hardware and number of tasks running at a given time.

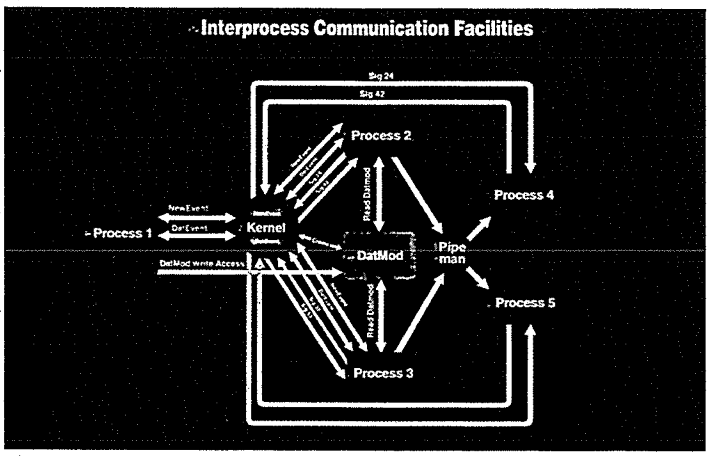
Sample System Response Times

		µSec
Send	Send Signal	86
SPrior	Change process priority	50
Task Switch	Change active tasks	55.1 + 1.5t*
Interrupt	Time to reach the first instruction of interrupt service routine	6 + 5.1p†

* t represents the number of tasks in the active process queue and t > 1. † p represents the polling sequence number of a driver on a particular vector.
Note: times are based on a 20 MHz 68020.

Modularity

OS-9 is a highly modular operating system. It has been designed so that each module provides specific functions.



In our example assume:

DatMod:	A globally accessible Data Module.
DatEvent:	An Event created by Proc1, and linked to by Proc2 & Proc3.
NewEvent:	An Event used by Proc1 to signal other processes that Proc1 wants to access DatMod for a global update. This will prevent a race condition which would not allow Proc1 to take control of DatMod.
Proc1:	A process that updates DatMod.
Proc2:	A process that reads DatMod and communicates the data to Proc4.
Proc3:	A process that reads DatMod and communicates the data to Proc5.
Proc4:	A process controlling a robotic arm requiring data input via Named pipe from Proc2.
Proc5:	A process controllin a robotic arm requiring data input via Named pipe from Proc3.
np24:	A Named Pipe for communication between Proc2 and Proc4.
np35:	A Named Pipe for communication between Proc3 and Proc5.
Sig24:	A Signal sent from Proc2 to Proc4 to indicate a refresh is available in np24.
Sig42:	A Signal sent from Proc4 to Proc2 to request a data refresh.
Sig35:	A Signal sent from Proc2 to Proc4 to indicate a refresh is available in np24.
Sig 53:	A Signal sent from Proc5 to Proc3 to request a data refresh.

The modularity of OS-9 allows individual modules to be included or deleted in the system when OS-9 is configured for a specific computer (depending on the functions that the operating system is to perform). For example, a small, ROM based control computer does not need the disk related OS-9 modules. OS-9 modularity allows you to use exactly the modules you need for your application without the performance and memory overhead of unused modules. It also allows for easy expansion and in-field maintenance.

The operating system also has extensive support for modular software programming techniques which allows OS-9 to be easily customized or reconfigured by users. Customization does not require recompilation of the entire operating system, but only the specific memory module supporting the additional service. In addition, customization may be accomplished while the operating system is up and running, and does not require a new boot file.

OS-9 can be readily configured for use on almost any type of system, from small single-board computers up to large multiuser systems. OS-9 is ROMable and has extensive support for ROMed application software.

Professional Ease of Use

OS-9 Professional is designed to be easy to use, but with the sophistication necessary for demanding real-time applications. The C language has become the defacto industry standard for application development and is a fundamental part of OS-9. Microware C follows the Kernighan and Ritchie guidelines with powerful VAX/Unix extensions. And a special set of OS-9/Unix library routines are included for application portability. Advanced development tools such as the µMACS editor which allows a user to open multiple files and cut and paste between them, work to drastically shorten your development time. Other development tools like Make and a symbolic debugger plus over 90 other utility commands are

In Open Systems for Real-Time

Interprocess Communications

Feature	Function
Data Modules	Analogous to global memory, allowing multiple processes to share data with security and error checking.
Pipes (named and unnamed)	Enable concurrently executing processes to communicate data as a "first in first out" (FIFO) serial device.
Events or Semaphores	Ensure global data module data integrity and facilitates inter-process synchronization. Events can also control execution of asynchronous processes.
Signals	Control execution and passes control of multiple, asynchronous processes.
Alarms	Signals from the kernel to a process for sequencing.

a standard part of the OS-9 Professional operating system. Interactive archiving utilities are provided for convenient backup, vital for project security.

An optional source level debugger is available for testing and debugging OS-9 C language programs. It allows you to execute C programs interactively with the debugger to significantly decrease your software development time. Another optional debugger is the System State Debugger. The System State Debugger is intended for debugging both system and user state programs resident on the OS-9 host/target. The debugger is a very powerful tool for testing and debugging resident target system hardware device drivers and device descriptors. It runs in system state and takes effective control of the CPU by causing the kernel to ignore other processes while active.

Industrial OS-9

Industrial OS-9 was designed to provide the system support critical for real-time applications and is intended for ROMed applications. Industrial OS-9 applications are developed under Professional OS-9 and are ROMed as a subset of the professional version. The kernel was written in native assembly language for outstanding performance with minimal memory requirements.

Industrial OS-9 supports over 125 system calls and requires less than 24K ROM/RAM.

File System

The OS-9 file system has a hierarchical organization similar to the Unix™ operating system. This gives you a great deal of flexibility for file organization. Under OS-9, files can be stored contiguously for faster access or segmented for efficient disk space usage. OS-9 also provides file attributes to prevent accidental changing or removal of files and for file access security. In addition, to make files portable, OS-9 offers an option which supports the DOS file format.

OS-9 differs dramatically from Unix in that it pushes a majority of the I/O processing from the kernel to file managers. I/O is also interrupt driven and byte stream oriented which allows it to respond in real-time.

OS-9 utilizes file managers which are a collection of major subroutines and provide I/O for a process to a physical device. File managers reside in OS-9 as standard memory modules. They are position independent and can be shared by multiple processes and physical devices.

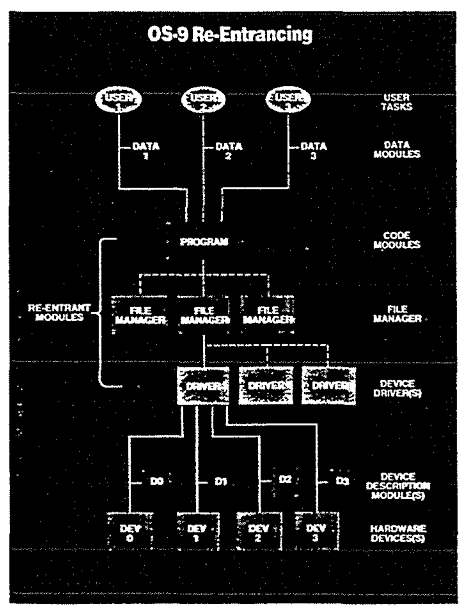
The function of a file manager is to process the raw data stream to or from device drivers for a class of similar devices. The file manager makes a device driver conform to the OS-9 standard I/O and file structure by removing as many unique device operational characteristics as possible from I/O operations. File managers are also responsible for mass storage allocation and directory processing if applicable to the class of devices they service. A memory saving feature of OS-9 is that only the file managers required by the application will be loaded into the system. For instance, if there is no disk storage, RBF will not be present. Four file managers typically in an OS-9 system are:

- RBF (Random Block File Manager): This manager operates random-access, block-structured devices such as disk systems.
- SCF (Sequential Character File Manager): This manager is used with single-character-oriented devices such as CRT or hard copy terminals, printers and modems.
- PIPEMAN (Pipe File Manager): This manager supports interprocess communication through memory buffers called "pipes".
- SBF (Sequential Block File Manager): This manager is used with sequential block-structured devices such as tape systems

Connectivity

OS-9 has an optional extension called NFM (Network File Manager) to provide a powerful software-based network architecture. It provides the same functionality as the disk file manager (RBF) over a network, allowing files and devices resident on remote systems to be accessed in the same manner as if they were resident on a local machine.

Another optional package called ESP/ISP allows communication between OS-9 and other operating systems over Ethernet using TCP/IP. Standard features such as FTP (File Transfer



Protocol), BSD Sockets and Telnet (a virtual terminal interface) provide the functionality necessary for networked applications. NFS™ (Network File System) is also available as an OS-9 option providing industry standard transparent file transfer and file access over a network.

Shell and Utilities

OS-9 provides a Unix-like "shell" command interpreter program that allows users a high-level interface to the internal functions of the operating system. The OS-9 Shell Utility Set contains over 90 commands. These commands set the "user" environment, allocate memory, redirect I/O, monitor processes, match wild card patterns, manipulate files, manage time, edit text and provide a host of other functions.

Complete System Solutions

In addition to offering OS-9 on a range of 68000 to 68040 Multibus I and VME single board computers, Heurikon has complete OS-9 Professional development packages called Orion. Orion systems are available in 3 or 9 slot rugged metal enclosures with a range of both hard disk and floppy disk drives. By letting Heurikon do the system integration, you can concentrate on your application rather than worrying about the details of making the hardware work together.

OS-9 can be completely self hosted or used in a cross development environment. Being self hosted gives you a big advantage — you don't have to purchase both a host development environment and a target run-time system.

OS-9 Shell/Utility Commands

attr	Display or change file attributes	load	Load a module into memory
backup	Make backup copy of a disk	login	Timesharing security log-in system
binex	Convert binary data to S records	logout	Terminate current SHELL; execute :.logout" file
build	Build a short text file from standard input	makdir	Create a new directory file
cfp	Create/execute temporary procedure file	make	Program maintenance tool
chd	Change data directory	mdir	Display module directory
chx	Change execution directory	merge	Merge file(s) to standard output
cmp	Compare two files	mfree	Display system memory information
code	Return hex value of terminal key	os9gen	Create boot on disk
compress	Compress an ASCII file	pd	Print path of data or execution directory
copy	Copy file(s)	pr	Display file in specified format
count	Count characters, lines and words in a file	printenv	Display SHELL environment variables
date	Display system date and time	procs	Display user/system process information
dcheck	Check directory/file integrity	qsort	Quick sort of file in memory
deniz	Detach devices	rename	Rename a file or directory
del	Delete files	save	Save modules to files
deldir	Delete a directory	set	Set SHELL options
dir	Display directory contents	setenv	Set environment variable to value
dsave	Copy directory structure	setime	Set system data and time
dump	Formatted display of file contents	shell	Command interpreter
echo	Echo text to output	sleep	Suspend process for ticks/seconds
edt	Line-oriented text editor	tape	Tape device special control commands
ex	Direct execution of specified program	tee	Copy input to multiple output paths
exbin	Convert S record(s) to binary data	tmode	Display/change terminal characteristics
expand	Expand a compressed file	touch	Update the date of a file
fixmod	Fix module CRC and parity	tr	Convert all occurrences of chars in two strings
format	Format an RBF device	tsmon	Timesharing device monitor
free	Report free space on disk	unlink	Unlink modules from memory
frestore	Restore directory structure(s)	unsentenv	Clear value of environment variable
fsave	Back up directory structure	w	Wait for last process to die
grep	Search file for lines matching expression	wait	Wait for child process to die
help	Display usage of OS-9 utilities	xmode	Display/change SCF device descriptor options
ident	Display module information		
iniz	Attach devices		
kill	Abort specified process		
link	Link a module in memory		
List	List contents of a file		

Your application development and run-time code can use the same hardware saving time and money. However, if you already own a development workstation such as a SUN or PC or you need to link your OS-9 application to Unix or PC-DOS, UniBridge and PCBridge offer cross development options.

PCBridge is an optional low-cost, easy-to-use, PC-hosted development and supervisory system. PCBridge can be linked to a variety of real-time tasks, and can provide a gateway for OS-9 data and applications on PC-DOS. A total distributed application can be developed on the PC host and integrated into an OS-9 real-time environment using PCBridge.

UniBridge is an optional software package for C and Assembly Language development and communication connecting Unix to the OS-9 real-time operating system. UniBridge is an integrated collection of Unix and OS-9 software modules designed to support distributed OS-9 C programming, remote debugging and Unix supervision of real-time processes. Supported Unix hosts include Sun 3 and 4, Apollo, VAX and others.

Heurikon retains the right to make changes to these specifications at any time, without notice.

For more information on Heurikon's line of microcomputer products, please contact a Heurikon representative. Or Call:

1 • 800 • 356 • 9602

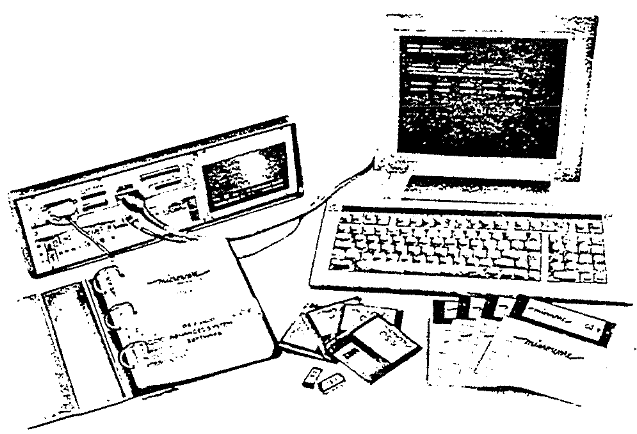
Heurikon Corporation
8000 Excelsior Drive
Madison, WI 53717
608 • 831 • 0900
Telex: 469532
Fax: 608 • 831 • 4249

HEURIKON®
OPEN SYSTEMS :: OPEN TOOLS

1.91.HKLynx

OS-9

REAL-TIME OPERATING SYSTEM



PRODUCT OVERVIEW

microware®

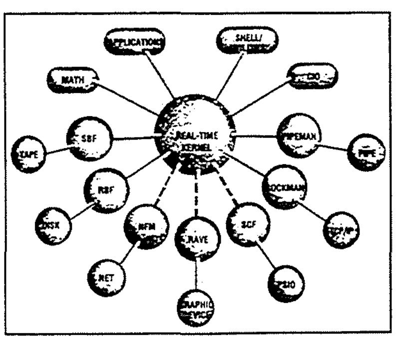
Advanced Features For Demanding Applications

High Performance and Real-Time Response

OS-9 was carefully designed for maximum efficiency with minimum overhead. All speed-critical portions of OS-9 were carefully hand-coded in native assembly language, so system performance does not suffer from compiler-generated code. OS-9 includes special features to facilitate real-time programming. These features include preemptive task switching, process execution control, flexible interrupt service routines and fast interprocess communication facilities.

A Modular Architecture

OS-9 consists of a collection of independent modules dynamically linked by a memory management system at execution time. Each object in memory is named and kept in a standardized memory module format. A memory module directory containing the name and address of each module is maintained by the kernel. Multiple applications can dynamically "link" to memory modules, sharing common code and data to dramatically reduce system RAM requirements. Users can easily install or replace new modules (including I/O drivers) while the system is running for easy field configuration.



OS-9 Modular Architecture

System-Level Extensions: Customizing Your OS-9 Environment

Input/Output: Capabilities Beyond Limitation

OS-9 features an I/O system crafted for versatility, reliability and high performance. Input/output redirection, pipelines and device-independent, interrupt-driven I/O are standard features. OS-9 systems can be configured to support virtually any combination of flexible disks, hard disks, tape drives, terminals, printers, modems and other peripherals.

Network Options: Tying Your Systems Together

Microware offers three options for linking multiple OS-9 systems, as well as linking OS-9 systems to UNIX, VAX and other operating system environments.

OS-9/NFM (Network File Manager) is a hardware-independent link between multiple OS-9 systems. OS-9/NFM fits directly into OS-9's unified I/O system and is compatible with all popular networking hardware, including ARCNET, Ethernet, OMNINET and others. OS-9/NFM can also be used for multiple processor support allowing communication between CPUs sharing a common data bus.

OS-9/ISP (Internet Support Package) supports network communications between OS-9 and other systems using the DARPA Transmission Control Protocol/Internet Protocol (TCP/IP). OS-9/ISP is modular and features a Socket File Manager (for BSD4.3 UNIX socket-style interface) and a complete Internet C library. The package also includes gateway and IP packet routing, and FTP and Telnet protocols for file transfer and remote login. A device-dependent interface layer allows OS-9/ISP to be used in almost any network transport hardware including communications in multiple processor systems. OS-9/ISP is also fully ROMable for dedicated applications and can be used for both system booting (BootP) and system communications.

OS-9/N.F.S. (Network File System) provides an integrated and seamless software environment for distributed application development and implementation. OS-9/N.F.S. allows software developers to write an application on a single host, compile the code and store the application on the host's disk. Then, the remote systems, regardless of operating system or hardware platform, can mount the host's file system via the standard OS-9 I/O interface and transparently execute the application at the remote location. The distribution of applications is reduced which decreases development time and speeds your products to market.

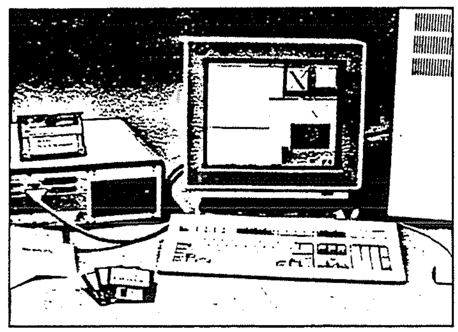
Graphics Options: Multimedia Development and X Windows Support

RAVE (Real-Time Audio/Video Environment)

As more powerful hardware, coupled with high-quality video and audio become the standard, man/machine interfaces (MMIs) are required that virtually anyone can use. Interfaces must be designed so that objects look and sound so much like real objects that the user intuitively understands how to control the process. Microware's **RAVE** provides the tools necessary for creating these real-world MMIs. RAVE speeds the development of MMIs by automatically generating source code for objects represented by the man/machine interface. This capability drastically reduces development time and speeds delivery of products to market.

OS-9/X Windows

X Windows is an industry-standard graphics windowing system designed to operate over a TCP/IP communications network. **OS-9/X Windows** is a robust implementation of MIT's X Windows System. It gives designers the tools necessary to develop and deploy powerful graphics-based applications under OS-9 and other computer platforms across an Ethernet network.



OS-9/X Windows

OS-9's Outstanding Multilingual Abilities

OS-9 is supported by a suite of top-notch compiler systems for the most-wanted programming languages. All Microware programming languages produce compact, ROMable, reentrant and position independent code.

C Language — The OS-9 C Compiler system represents highly advanced C language technology for the 680X0 microprocessors and is a complete implementation in accordance with Kernighan and Ritchie specifications. The comprehensive OS-9 C Compiler standard library includes both unique OS-9 system calls, as well as UNIX system call equivalents. This permits direct compilation and execution of virtually any UNIX application software. Microware offers cross-versions of the C Compiler for the most popular UNIX-based workstations. An optional OS-9 C Source Level Debugger is also available to decrease software development time and simplify programming.

Pascal

- Implementation according to ISO 7185.1
- Extended file access for sequential, random and interactive files
- Bitwise logical operators
- Produces highly optimized 680X0 assembly language source code

Microware BASIC

- All standard BASIC statements
- Pascal-type loop constructs and data structures
- Interactive compiler design for error reporting at time of input
- Integrated string and line number oriented text editor
- Symbolic debugging system included

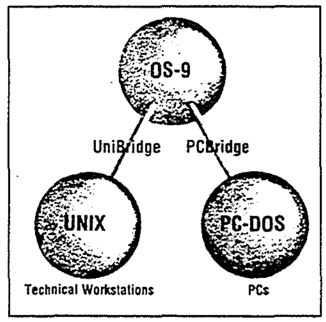
OS-9 Fortran 77

- Two-pass compiler generates optimized 68000 and 68020 object code
- Superior debugging facilities including trace, breakpoint, disassemble and examination/alteration of variables

Cross-Development Tools for Distributed Programming

UniBridge is a software package for C and Assembly Language development and communications connecting UNIX to OS-9. UniBridge is an integrated collection of UNIX and OS-9 software modules designed to support distributed OS-9 C programming, remote debugging and UNIX supervision of real-time processes.

PCBridge is a low-cost, easy-to-use, PC-hosted development and supervisory system for intelligent 680X0-based applications. PCBridge can be linked to a variety of real-time tasks and can provide a gateway for OS-9 data and applications on PC-DOS. A total distributed application can be developed on the PC host and integrated into an OS-9 real-time environment using PCBridge.



OS-9 provides real-time "bridges" to other development platforms.

Productivity Tools: Increasing Your Efficiency

As a total operating system, OS-9 also offers optional productivity tools that increase the efficiency of users. **OS-9/SmartWare** is a fully-integrated office automation software package that includes a Data Manager, Word Processor, Spreadsheet and Time Manager. The **OS-9 Programmer's Toolbox** includes E-Mail, µMacs screen editor, COM communications package and Print Spooler.

Support Services: Added Value for OS-9 Users

Microware offers a variety of support services to help users take full advantage of their investment in Microware software products. **Training and Education Seminars** are regularly conducted at our Des Moines location. Seminars cover a wide variety of topics and are a combination of lecture, example implementations and hands-on lab exercises. Microware also offers specialized seminars at any Microware location or on-site at your facilities.

Microware Technical Software Support provides direct communication between OS-9 users and our programming staff. The Technical Support team is staffed by software engineers who can save you valuable time when you need assistance regarding installation and use of all Microware products.

OS-9 is a complete real-time operating system for the Motorola 680X0 family of microprocessors. The OS-9 Operating System features a modular, scalable architecture for maximum flexibility and is the only operating system that can be used across the entire spectrum of 680X0 family systems—from small ROM-based systems to large multi-user systems. OS-9 and its companion programming languages and software tools can play a crucial role in unlocking the performance potential of your 680X0-based system.

OS-9 combines significant operating system concepts and real-time capabilities with an overall architecture that is very compact, highly efficient and incorporates many key UNIX features. The OS-9 development environment provides for advanced programming languages, networking, man/machine interfaces and much more.

Why Microware Software Should Be Your First Choice

At Microware, we believe that every product we create must advance the state of the art in real-time development and offer significant new features for our users. We are proud of the fact that we are specialists in designing products for the Motorola 680X0 family of microprocessors and have become the industry leader for real-time system software.

We listen and respond to users who work with a broad spectrum of microcomputer applications. Then, we incorporate many features into our software based on their real-world experiences. This is reflected by the fact that over 650 leading computer product manufacturers have licensed Microware's OS-9 Operating System and OS-9 now has an installed base in excess of 100,000 systems that continues to grow rapidly.

MICROWARE SYSTEMS CORPORATION

Corporate Headquarters • 1900 N.W. 114th Street • Des Moines, Iowa 50325 • Phone: (515) 224-1929 • Fax: (515) 224-1352

Western Regional Office
Phone: (408) 980-0201

Southeastern Regional Office
Phone: (407) 725-2840

Northeastern Regional Office
Phone: (603) 929-4107

Microware Systems K.K. (Japan)
Phone: (81) 3-3257-9000

Microware Systems (U.K.) Ltd.
Phone: (44) 703 601990

Microware Systems France
Phone: (33) 42 58 63 00

OS-9 UNIBRIDGE

The Complete Unix/Real-Time Connection.

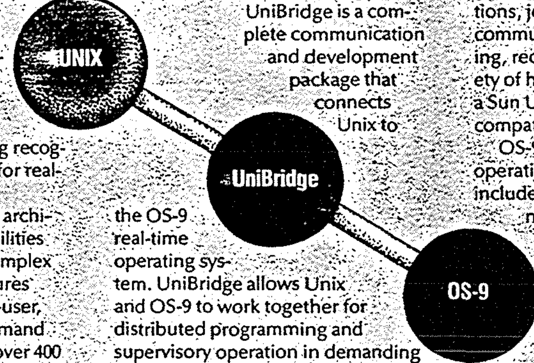
microware®

Unix has emerged as the preeminent operating system for office automation, computer engineering and software development. Over 1,500 commercially available Unix applications exist for these traditional computing environments. Now the acceptance of popular engineering workstations is bringing Unix to even broader environments including manufacturing automation. Unix is becoming recognized as a development tool for real-time process control.

Unix combines innovative architecture and programming facilities to accommodate the most complex software designs. These features include: multi-tasking, multi-user, hierarchical file structure, demand paging, shell user interface, over 400 utility programs, software generation system, networking and communications, job control, remote file sharing, record locking and finally, the Unix C compiler.

The C Language was originally developed for Unix and has become the premier programming language for process control. However, Unix is not well suited for real-time and must be separated from the target processor in order for C programs to execute in real-time. This situation presents many challenges to the Unix developer. First, a real-time operating system must be selected for the target processor capable of executing C programs developed from the Unix host. Then, the two operating systems must be linked together to allow efficient access and file transfer of system utilities and C applications.

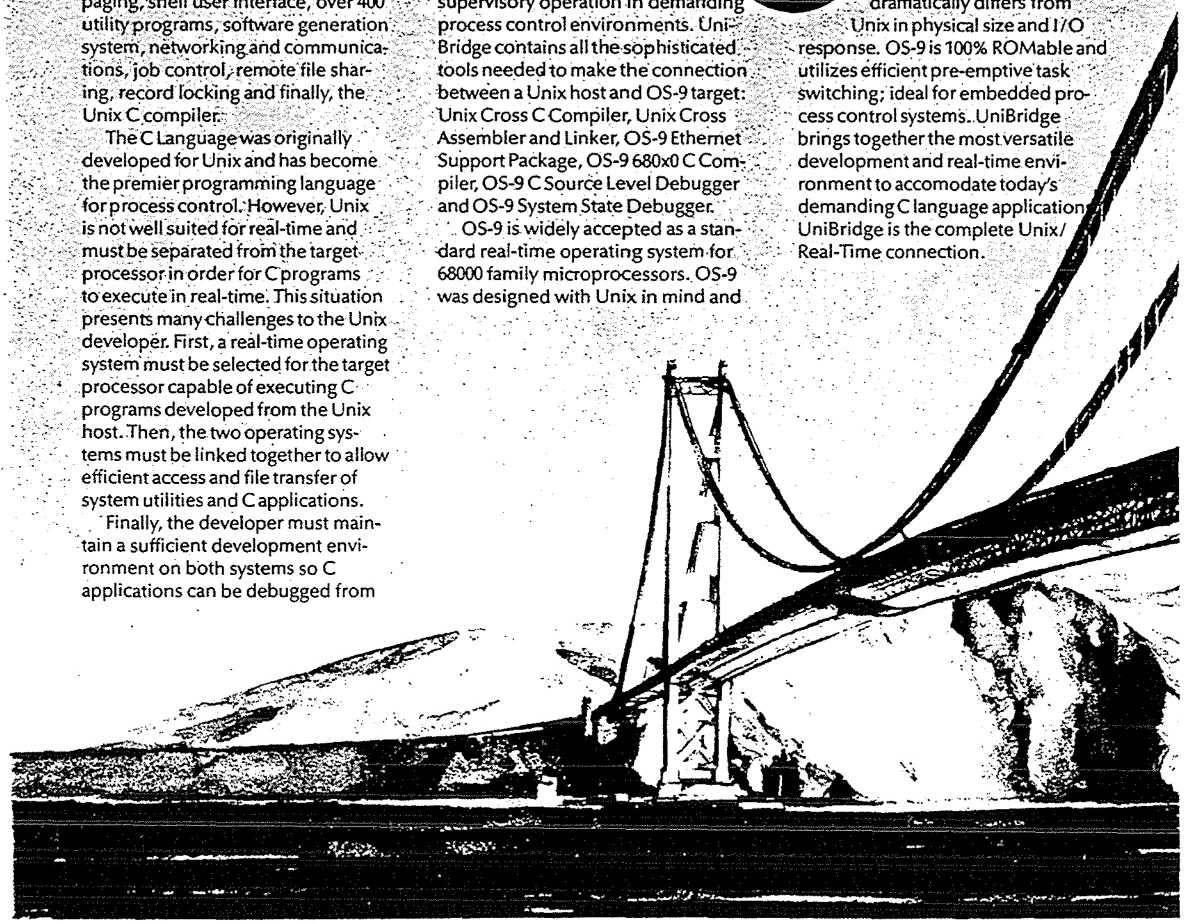
Finally, the developer must maintain a sufficient development environment on both systems so C applications can be debugged from the host or target while the systems are connected or separated. Microware Systems Corporation responds to these challenges and connects Unix to Real-Time with one complete solution... UniBridge.

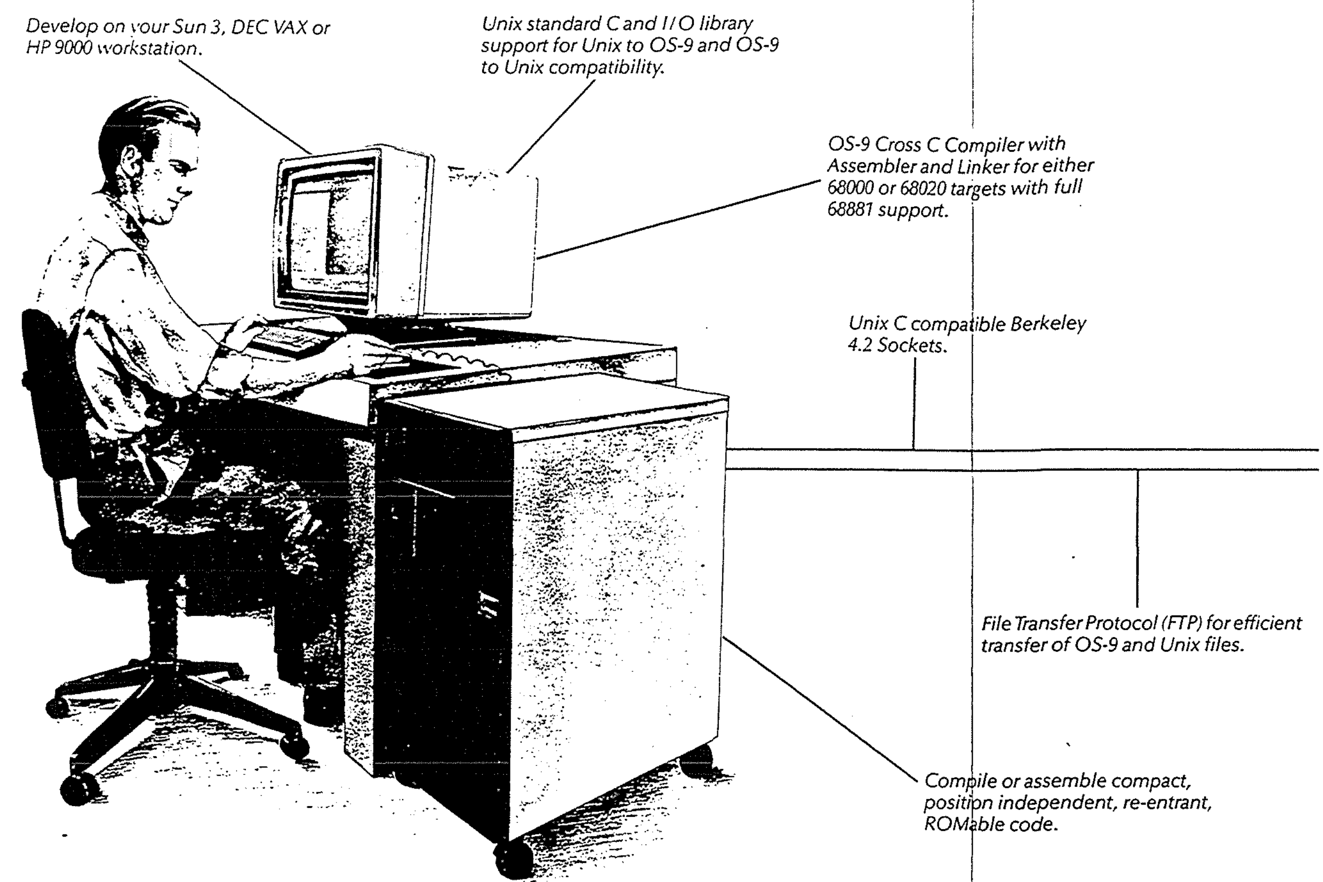


UniBridge is a complete communication and development package that connects Unix to the OS-9 real-time operating system. UniBridge allows Unix and OS-9 to work together for distributed programming and supervisory operation in demanding process control environments. UniBridge contains all the sophisticated tools needed to make the connection between a Unix host and OS-9 target: Unix Cross C Compiler, Unix Cross Assembler and Linker, OS-9 Ethernet Support Package, OS-9 680x0 C Compiler, OS-9 C Source Level Debugger and OS-9 System State Debugger.

OS-9 is widely accepted as a standard real-time operating system for 68000 family microprocessors. OS-9 was designed with Unix in mind and incorporates many similar features such as: multi-tasking, multi-user, hierarchical file structure, shell user interface, utility programs, resident macro assembler/linker/and debugger, networking and communications, job control, interprocess communications, remote file sharing, record locking and finally a variety of high level languages including a Sun Unix/Kernighan & Ritchie compatible C compiler.

OS-9, like Unix, is a complete operating system. Its architecture includes a full function real-time kernel and independent file managers to accomodate virtually every class of I/O device, peripherals, networks and interprocess communications. Yet OS-9 dramatically differs from Unix in physical size and I/O response. OS-9 is 100% ROMable and utilizes efficient pre-emptive task switching; ideal for embedded process control systems. UniBridge brings together the most versatile development and real-time environment to accomodate today's demanding C language applications. UniBridge is the complete Unix/Real-Time connection.



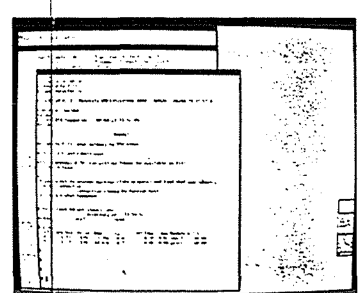


OS-9/XCC

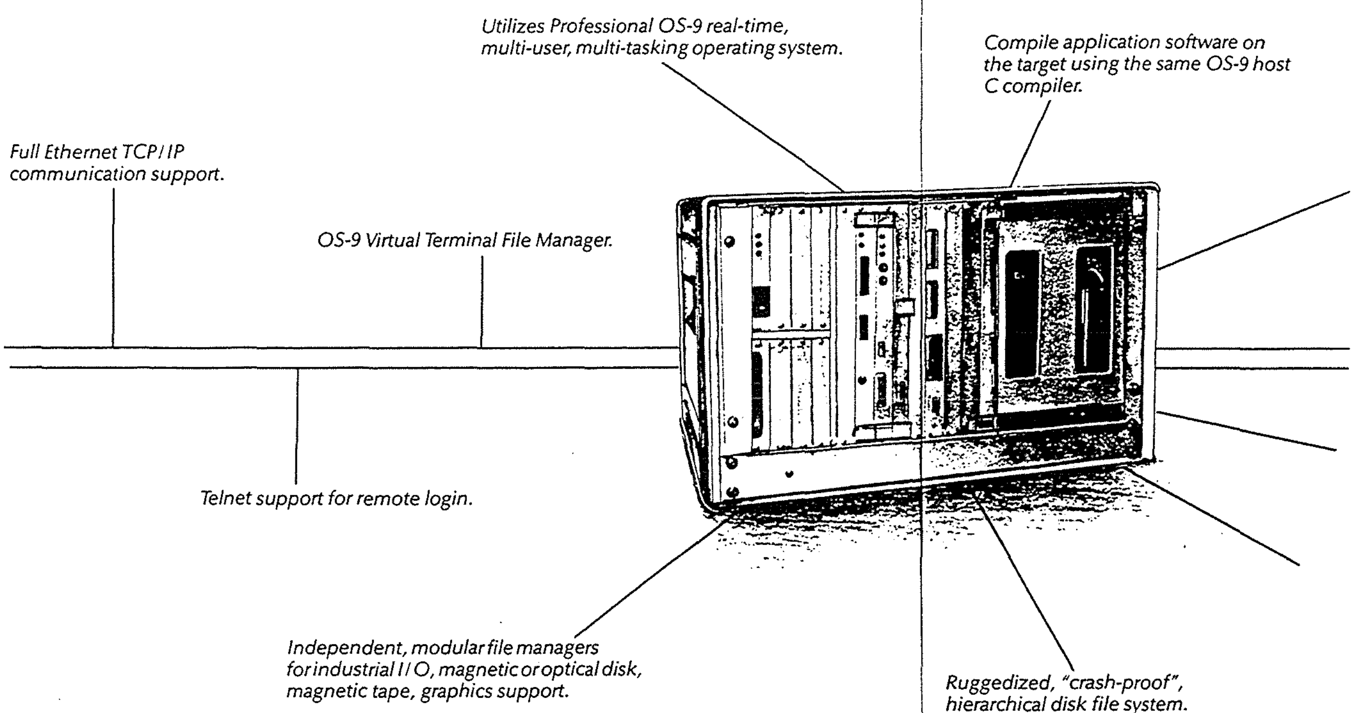
UniBridge contains both Unix and OS-9 resident C compilers for either 68000 or 68020 microprocessors with full 68881 support. Users have the unique option to compile on the host or target to produce compact, re-entrant, position independent object code for real-time execution. OS-9/XCC is available for use on a variety of popular development systems including:

- VAX BSD 4.2
- HP/UX
- MOTOROLA V68
- SUN/OS
- APOLLO/DOMAIN

OS-9/XCC serves as a gateway between these host environments and OS-9. Since the OS-9 C Compiler utilizes UNIX C standard libraries, C programs can be compiled with OS-9/XCC to operate on OS-9 resident systems without program conversion. Unix standard libraries also allow OS-9 C programs to be easily ported to the host environment.



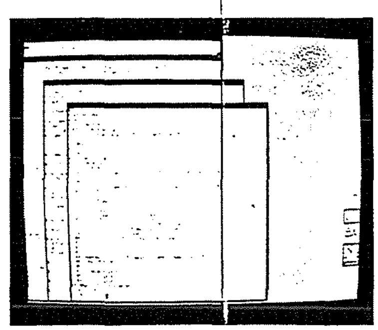
OS-9/UNIBRID



OS-9/ESP

OS-9/ESP Ethernet Support Package provides complete Ethernet TCP/IP communication between the host environment and OS-9 based systems. OS-9/ESP incorporates both FTP and Telnet protocols for efficient file transfer and remote login. Users can easily access OS-9 from the Unix host, Unix from OS-9, and OS-9 from OS-9 for distributed software development and supervisory real-time execution.

OS-9/ESP features a C-compatible Berkeley 4.2 socket library combined into an Internet database as a single OS-9 data module. And since OS-9 data modules are re-entrant and position independent, OS-9/ESP can be added to OS-9 ROM-based target systems.



GE

Resident C Source Level Debugger for increased productivity.

Unix oriented tasks: exe
exit, sleep, set priority, w

Symbolic System State Debugger for dynamic monitoring of target system state processes.

Versatile in
facilities: d
named pip
signals and

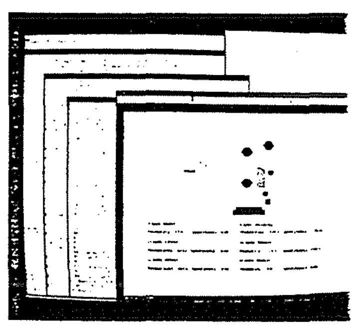
Unix-like Shell user interface.

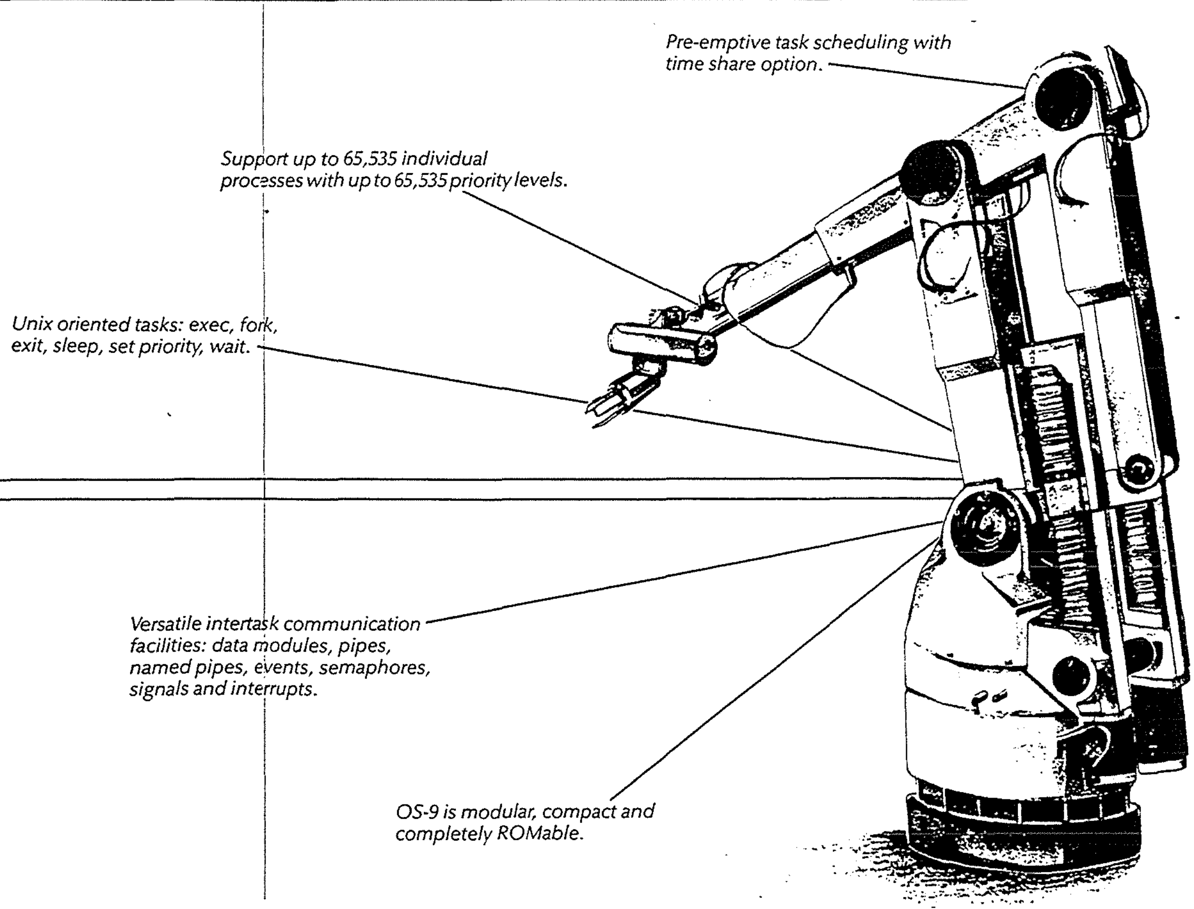
OS-9 / Debuggers

UniBridge contains a high-level C source debugger and a powerful system state debugger to provide a robust environment for developing C and Assembly language programs.

UniBug is a distributed C source level debugger that allows users to debug code developed under UNIX on the OS-9 target. Object, symbol and debug files are automatically downloaded to the target over Ethernet when UniBug is invoked. UniBug features a C expression interpreter with full debugger control, communications, data manipulation and system commands.

SYSDBG provides complete system state debugging of device drivers and system tasks on the OS-9 target.





UniBridge

UniBridge is the complete communication and development package for distributed programming and supervisory control of 68000 family-based real-time applications.

UniBridge is distributed on magnetic tape and diskette and includes:

- OS-9/XCC C Compilers
  - Unix resident Cross C Compiler
  - OS-9 resident C compiler
- OS-9/ESP Ethernet Support Package
- OS-9/SRCDBG
  - OS-9 resident C Source Level Debugger
  - OS-9 resident System State Debugger
- Complete documentation and hotline support

UniBridge is written entirely by Microware to assure 100 percent compatibility with every module in the UniBridge package. At Microware, we believe that every product we create must advance the state of the art and provide a complete solution. But our job doesn't stop there. Every Microware product is backed by our comprehensive software support program and Microware's total commitment to customer satisfaction.

Contact Microware today and ask us for UniBridge: *The Complete Unix/Real-Time Connection.*

MICROWARE SYSTEMS CORPORATION

Corporate Headquarters • 1900 N.W. 114th Street • Des Moines, Iowa 50322 • Phone: 515/224-1929 • Fax: 515/224-1352

Western Regional Office
4401 Great America Parkway
Santa Clara, California 95054
Phone: (408) 980-0201

Microware Systems K.K.
17-3 Sotokanda 2-Chome
Chiyoda-Ku
Tokyo 101, Japan
Phone: 81-3-257-9000

Microware Systems France
Chateau de la Saurine
Pont de Bayeux
13590 Meyreuil, France
Phone: (33) 42 58 63 00

Microware Systems U.K. Ltd.
1626 Parkway, Solent Business Park
Whiteley, Fareham, Hampshire
England PO15 7AH
Phone: (44) 489 886699

Real-Time Audio/Video Environment

microware®

RAVE

Real-Time Audio/Video Environment

RAVE (Real-Time Audio/Video Environment) is a multimedia development tool and user interface that greatly simplifies the design of realistic man/machine interfaces for real-time process control systems. As an extension of the OS-9 real-time operating system, RAVE enables designers to combine high-quality audio and video, computer generated graphics and customizable menus in the same user interface. With RAVE, designers can quickly configure realistic user interfaces and control panels using real-world sounds and images. Because the resulting user interface better represents the actual control environment, it can be manipulated and understood by non-technical users.

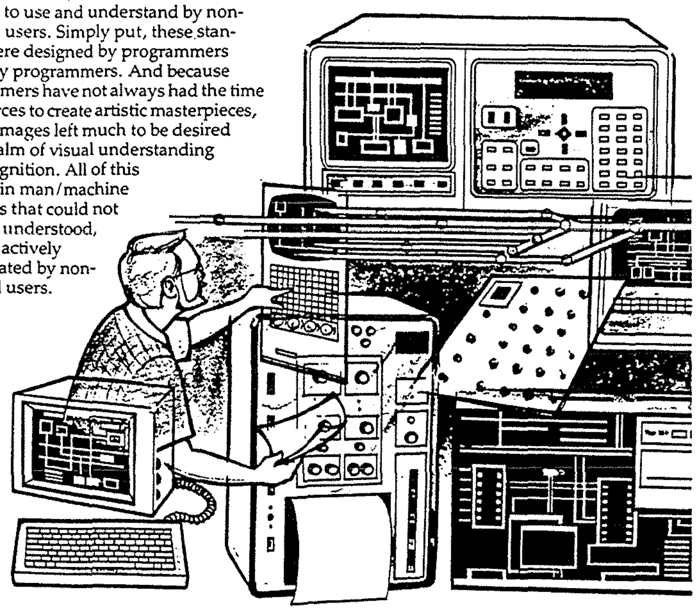
The Evolution of User Interfaces

Historically, the user interfaces available for embedded systems and process control applications have been difficult to use, and in some cases, intimidating. These interfaces typically consisted of non-interactive displays or light boards. At best, they were based on black and white graphics drawn on a conventional CRT.

In the early 1980's user interfaces such as GKS and VDI were developed and popularized. Users could now hope to find at least color drawings representing actual devices that the system controlled. Audio capabilities, if any, were pretty much limited to "beeps" and "buzzes" and other non-descriptive noises. To compound the problem, these emerging interfaces were designed for UNIX or IBM Personal Computer systems without any consideration for real-time software requirements. Because these standards had not been integrated with a real-time operating system or kernel, factory floor systems were still largely limited to 1960's-style user interfaces.

RAVE was developed on the simple premise that non-technical users can intuitively understand real-world visual representation — or pictures — far easier than basic drawn images.

Furthermore, these interfaces were still hard to use and understand by non-technical users. Simply put, these standards were designed by programmers for use by programmers. And because programmers have not always had the time or resources to create artistic masterpieces, graphic images left much to be desired in the realm of visual understanding and recognition. All of this resulted in man/machine interfaces that could not be easily understood, let alone actively manipulated by non-technical users.



Introducing RAVE

Recognizing this complete lack of an easy-to-use and easy-to-understand man/machine interface for real-time process control systems, Microware has developed RAVE (Real-Time Audio/Video Environment). RAVE was developed on the simple premise that non-technical users can intuitively understand real-world visual representation — or pictures — far easier than basic drawn images. Now, with RAVE the tools for user interface development are a microphone and camera, rather than a mouse and keyboard. Not only does RAVE support high-resolution, real-world pictures, but it also offers full-motion video and CD-quality sound. These advanced features allow a process or model to be represented by its natural image and natural sounds, as opposed to a programmer's personal conception of how that item should be represented.

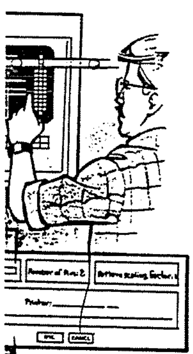
RAVE consists of three packages:

- The Graphic File Manager
- Graphics Support Library
- The Presentation Editor

The **Graphics File Manager (GFM)** provides the audio, video and input drivers needed to support the run-time user interface. The input drivers support a keyboard, as well as pointing devices. The keyboard driver supports any keyboard, from an IBM PC compatible keyboard, to a custom keyboard designed specifically for an application. The pointing device may be a mouse, touch pad, touch screen or any device that returns X:Y coordinate information.

The **Graphics Support Library (GSL)** builds upon the GFM to create the more complex concepts required for an application. These include controls, indicators, and menus. Controls are objects on the display that mimic the behavior of switches. Indicators are objects on the display that mimic the behavior of output devices. Both controls and indicators may be implemented as computer generated objects, or by digitizing an actual image of the device.

RAVE's third package, known as the **Presentation Editor**, draws upon the GSL and GFM to provide an interactive, menu-driven development environment for building applications. With the Presentation Editor, designers create the controls, indicators, and menus supported by the Graphics Support Library.



Before RAVE, man/machine interfaces (like the ones shown above) were difficult to use and understand.

Designers interact with the Presentation Editor via a keyboard and mouse. Audio can be input directly through a microphone, or loaded from disk. Video can either be captured via a camera, or built from scratch using graphics primitives. A Paintbox can be used to modify both computer-generated or real-world video images.

To use RAVE on new hardware, designers need only to port the low-level graphics, audio and input drivers.

And RAVE was implemented as an extension to Microware's OS-9 Real-Time Operating System. RAVE provides users with complete access to the real-time functionality of OS-9, which is vital for many process control applications. Exceptionally fast interrupt response, preemptive task switching and a ROMable modular architecture make OS-9 the operating system of choice for real-time factory floor applications.

The OS-9 Real-Time Operating System

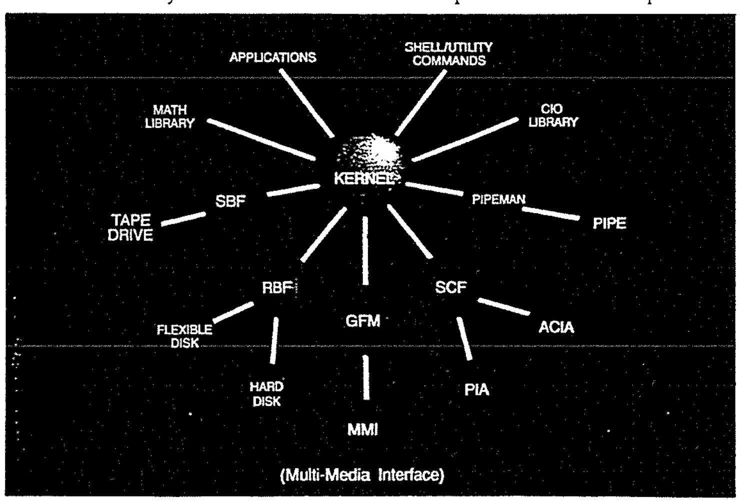
RAVE runs on top of the OS-9 Real-Time Operating System, the pre-eminent operating system for the Motorola 68000 family of microprocessors. OS-9 incorporates a number of powerful programming features such as multitasking, "SHELL" user interface, utility programs, hierarchical file structure and record locking, a complete suite of resident development tools, networking and a host of high-level languages including a C Compiler with UNIX/BSD 4.2 extensions.

OS-9 features a full-function, real-time kernel and independent file managers that accommodate every class of I/O device and peripherals, plus networking and interprocess communications. By supporting development, as well as execution on the target, the OS-9 single-source solution not only reduces hardware costs, but greatly simplifies system integration. OS-9 also offers cross development packages for all popular UNIX and PC-DOS environments which provide distributed real-time programming, remote testing and supervision of real-time processing.

To facilitate easy installation and structured programming techniques, OS-9 employs a modular design which permits software engineers to significantly reduce the size of their application and conserve memory. And OS-9

Microware designs and supports all of its own software packages, so you are assured of total compatibility across the entire spectrum of Microware products.

is available from virtually every VME manufacturer world wide. Plus, Microware designs and supports all of its own software packages, so you are assured of total compatibility across the entire spectrum of Microware products.



The modular architecture of OS-9.

The Graphics File Manager (GFM)

The Graphics File Manager (GFM) brings together all the physical resources needed for the user interface. This includes a video driver, an audio driver and drivers for the input devices. The diagram at right shows the hierarchy supported by the GFM.

The Video Driver provides a very robust set of drawing and block copy functions. An application may draw lines, rectangles, polygons, circles, ellipsis, rectangles with rounded corners or text. With all drawing functions, the application may select several variations such as drawing with a pattern, using variable size pens, using dashed lines or any combination of the above.

All drawing is done on what is called a drawmap. The application may create several drawmaps and select any one to be displayed. The application may select a new drawmap to be displayed at any time.

Simple and complex regions are also supported. These regions may be created and mixed very easily. After creating a region, it may be drawn onto a drawmap, or used for clipping. In the later case, all drawing outside the region will be clipped (not drawn).

A very powerful set of block copy and exchange functions are also supported. This allows an application to copy or exchange images between drawmaps. Part of an image can be declared as transparent. This is done by using a clipped region, or using a transparent color.

The Audio Driver supports playback of pre-recorded audio. This audio data can be in memory, or loaded off of disk. The quality of the audio is only limited by the hardware.

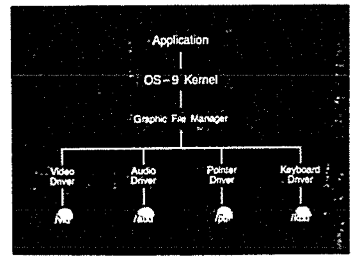
Two types of Input Drivers are supported: pointer and keyboard. The pointing device may be a mouse, touch pad, touch screen or any hardware device that returns X:Y coordinate information. Any type of keyboard may be supported using the GFM. The keyboard may be PC compatible, or one developed specifically for an application.

The Graphics Support Library (GSL)

The Graphics Support Library (GSL) builds upon the GFM to create the more complex concepts needed by an application. These include controls, menus and indicators.

Controls are objects on the display that mimic the behavior of switches and slide-bars. The user may interact with a control on the display to turn something on or off. A slide-bar could be used to mimic something like a volume control.

Menus (called requests in the GSL) give designers a means of configuring an interface that enables users to select various controls and indicators. These menus may be simple text or complex images. The application may also select whether the menu is displayed all the time



A diagram of the RAVE Graphics File Manager.

(menu bar), or only when appropriate (pop-up menu).

Indicators are objects on the display that mimic the behavior of output devices. These include a digital readout, slide indicator, LED meter, linear meter, and a strip chart recorder. These may be computer-generated objects or actual images of a real device. The GSL provides the following controls and indicators:

Controls

1. Push-button controls such as on/off and fire buttons.
2. Multi-state controls such as the source selector or an amplifier.
3. Slidebar controls such as a volume control.

Indicators

1. Linear meter indicators such as the V.U. meter on an audio mixer board.
2. Level indicators such as the fluid level in a tank.
3. Strip chart indicators such as an EKG readout.
4. LED meter indicators such as a record level in a cassette deck.
5. Numeric readout indicators such as the frequency on a frequency generator.

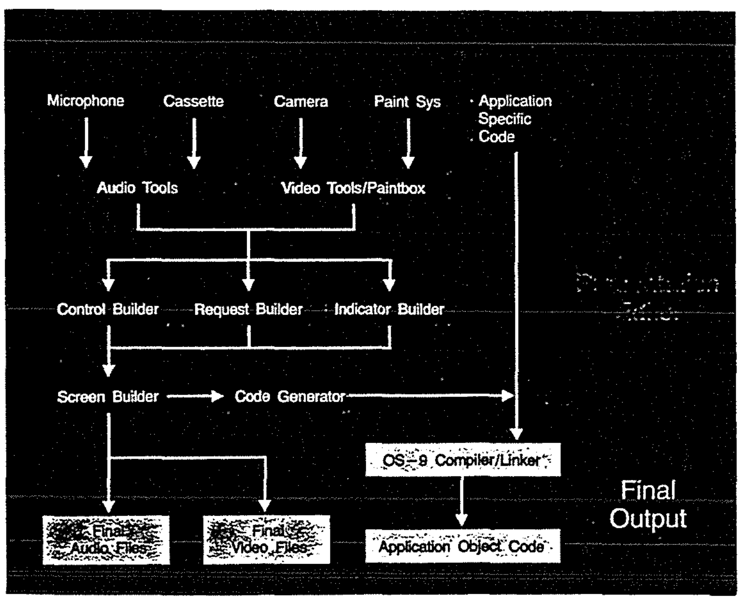
In addition to supporting on-screen objects, the GSL provides a number of housekeeping functions that simplify the development of an application. These include message handling, a clip board, and resources.

The Presentation Editor

The RAVE Presentation Editor is used to develop applications. The Presentation Editor automatically generates C source code for all the software routines necessary to control the user interface. With RAVE the designer is not required to write one line of A/V control code. The entire interface may be designed interactively by using this tool.

With the Presentation Editor, a designer can create the controls, menus and indicators supported by the GSL. These objects may be combined onto the display to form the interface for an application. Since RAVE supports real audio and real images in addition to those computer generated, the Presentation Editor has tools for manipulating this data.

The Presentation Editor audio tools allow the designer to capture, edit and playback audio segments. The video tools allow the same facilities for video images. In addition, a paint facility is available for creating new images or touching up images captured by camera or other means.



A flow chart for building a typical RAVE application.

Configuring RAVE

RAVE is configured to provide both run-time and development environments.

With RAVE the designer is not required to write one line of A/V control code.

RUN-TIME ENVIRONMENT

Rave's Graphic File Manager (GFM) and Graphics Support Library (GSL) form the foundation of the OS-9/RAVE run-time environment. This run-time environment provides a sophisticated man/machine interface for virtually any type of audio and video hardware; including mouse, touch screen, terminal, microphone and speaker. Furthermore, the GSL provides basic indicators and controls so software engineers can build an application without the use of more complex and expensive development tools.

The entire RAVE run-time environment is completely ROMable, compact in size and designed expressly for use in embedded applications. An OS-9/RAVE application can be embedded in systems supporting as little as 128K of system RAM.

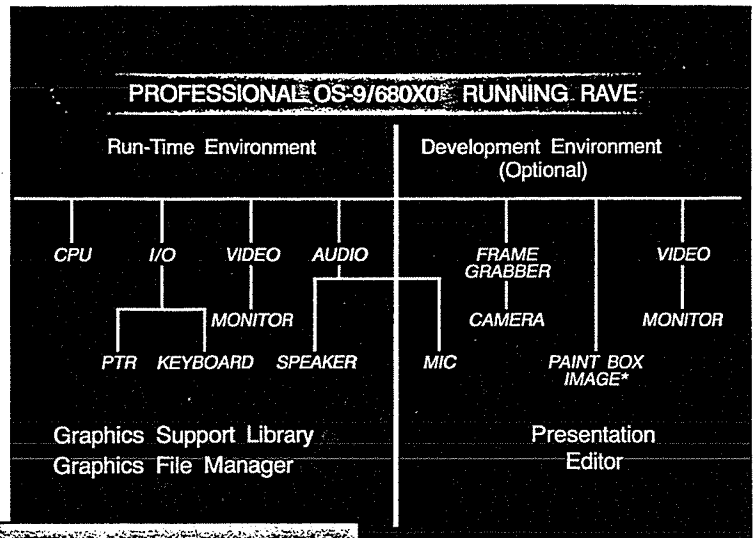
The RAVE run-time environment is configured for distribution under Installation Pak and OEM License. These packages include all of the software source code and documentation necessary to install the run-time environment on a given hardware platform.

DEVELOPMENT SYSTEM

The Presentation Editor and its related hardware (microphone, frame grabber, camera, paint box, video monitor, etc.) comprise the RAVE development environment.

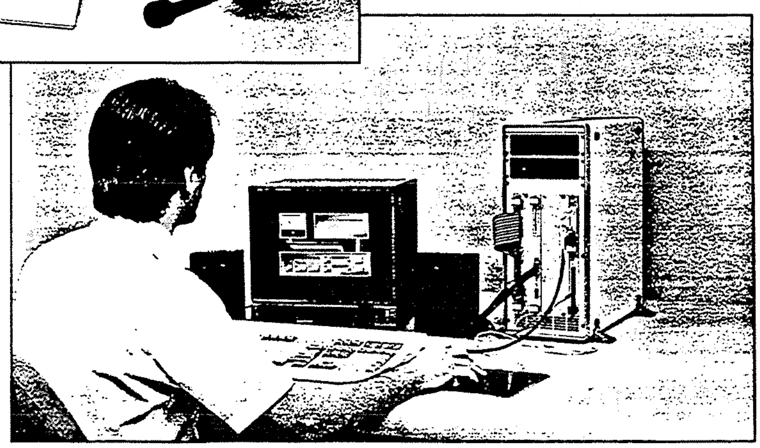
Microware understands that the ever increasing pace of technological advancements make product design time a key factor of a product's commercial success. The time devoted to developing a man/machine interface using conventional programming techniques can render a product obsolete long before it is brought to market. The Presentation Editor reduces the amount of time spent on developing the application by automatically generating, in C source code, all the software routines necessary to control the user interface. Simply put, by using the RAVE development environment, you can get your product to market quicker with less expense.

End user copies of the presentation editor can be purchased individually from Microware and Authorized Microware Distributors.



The two distinct environments in which RAVE operates.

A completely integrated multi-media development environment.



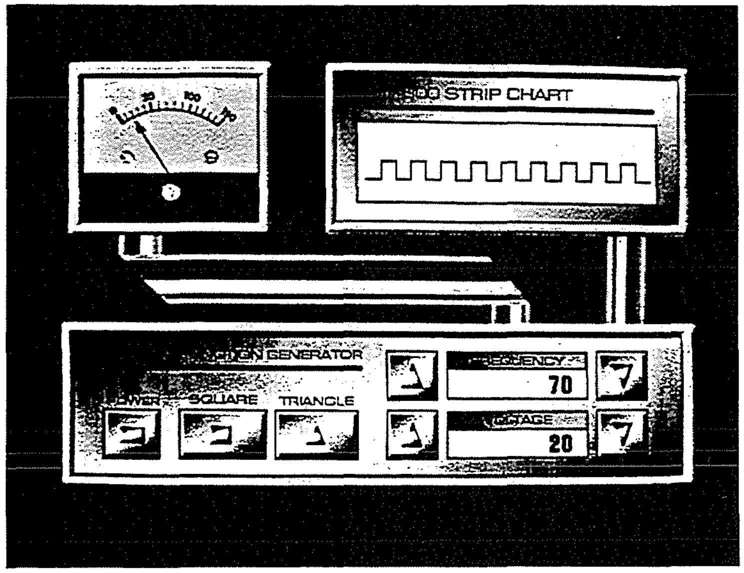
A user interacting with the RAVE Run-Time environment.

Frequency Generator Demonstration

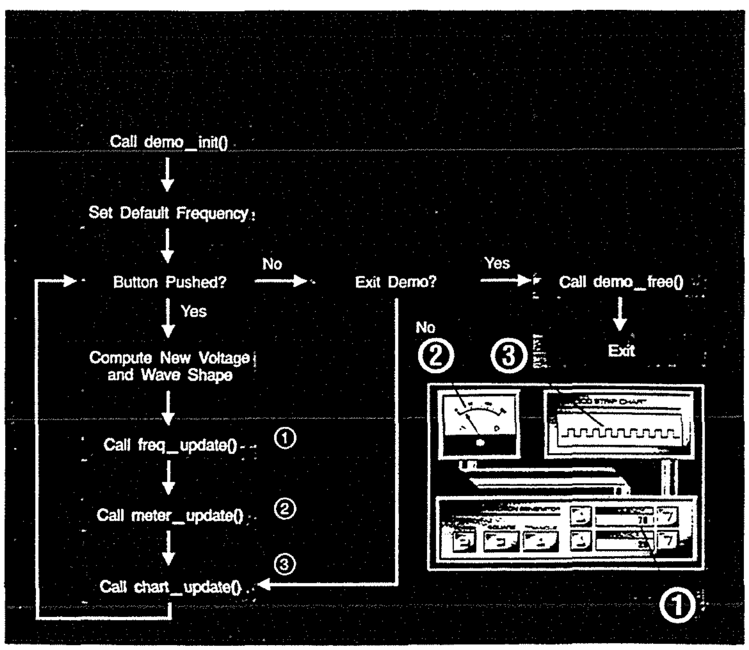
The following is an example application of a frequency generator. A flowchart of the application is shown below, along with a picture of the video display that appears when it runs.

In this application, the user may change the frequency or voltage by touching the respective buttons on the frequency generator. The shape of the wave may also be altered and you may select a square wave, sine wave or triangle wave.

A visual representation of the wave is displayed continuously on the strip chart. In a similar manner, the voltage is shown on the voltmeter.



A RAVE application illustrating a frequency generator. Items displayed include a captured image (voltage meter) and other video images created by using a paint system.



"Frequency generator" flowchart.

> *Simply put, by using RAVE, you can get your product to market quicker with less expense.*

The actual code written by the programmer is very minimal. A flowchart of this code is shown at right. As shown in the flowchart, all code dealing with the manipulation of the display is automatically generated by the Presentation Editor.

The Microware Commitment

At Microware we are committed to producing software that exemplifies the cutting edge of technology and sets the industry's standard for real-time software. RAVE represents our latest effort in the area of an advanced real-time user interface. With RAVE, Microware continues its tradition of providing innovative products that provide a complete solution.

Contact us today and find out more about putting RAVE to work for you.

microware®

MICROWARE SYSTEMS CORPORATION

Microware Systems Corporation • 1900 N.W. 114th Street • Des Moines, Iowa 50322 • Phone: 515/224-1929

Western Regional Office
4401 Great America Parkway
Santa Clara, California 95054
Phone: 408/980-0201

Microware Systems K.K.
6-5-11 Sotokanda
Chiyoda-Ku
Tokyo 101, Japan
Phone: (81) 3-839-9000

Microware France
Bureau Francais, Le Mercure C
B.P. 86, Z.I. d'Aix-en-Provence
13762 Les Milles Cédex, France
Phone: (33) 42 60 48 22

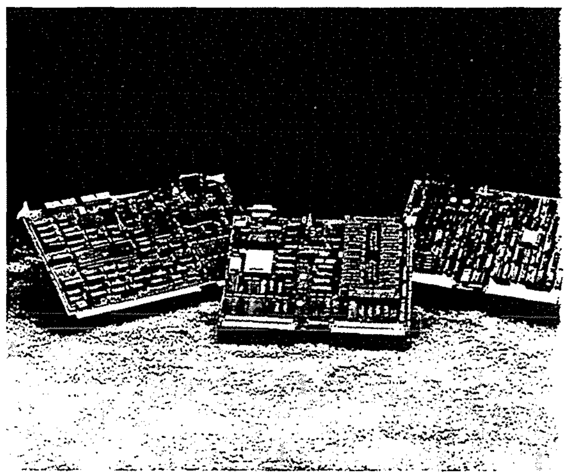
Microware Systems (U.K.) Ltd.
1626 Parkway, Solent Business Park
Whiteley, Fareham, Hampshire
England P015 7AH
Phone: (44) 489 886699

Product Code: RAV 68NA 68SL

ENP™ SERIES for VMEbus and MULTIBUS™

Network Technology for System Builders

- High-performance Ethernet controllers for VMEbus and MULTIBUS systems
  - Link-level controllers for use with host-based network protocols
  - Intelligent protocol processors for off-loading host network protocol processing
- Motorola 68000-family processor onboard
- Dual-ported packet data memory
- Uses AMD Local Area Network Controller for Ethernet (LANCE™)
- Optional 10BASE-T (twisted pair Ethernet) transceiver onboard (ENP-10 Series only)



Description

The ENP Series of Ethernet adapters are low-cost, high-performance networking solutions for builders of VMEbus and MULTIBUS systems. They are ideal in multi-user UNIX® systems, network or file servers, and process control applications. The ENP Series integrate easily with the host operating system using CMC's link-level Ethernet firmware or CMC's advanced TCP/IP or OSI protocol software.

Advantages of an Intelligent Protocol Processor

Designers of high-performance networked computer systems have stringent performance criteria. For these system builders CMC designed the "i" series of intelligent Ethernet protocol processors: for VMEbus, the ENP-10i and ENP-100i; and for MULTIBUS the ENP-30i. These processors have significant advantages over data link controllers. They process networking protocols independently of the host processor, offering high data throughput with minimal impact on host performance. Intelligent protocol processors function best in host systems that must handle large numbers of simultaneous network connections, such as a file server or database server.

Advantages of a Link-level Adapter

Developers of personal workstations and process control systems have built around inexpensive 16- and 32-bit microprocessors to reduce total system cost. For these systems, an intelligent networking solution may be very expensive compared with the system cost. For these users, CMC's "L" series of link-level adapters are optimum: for VMEbus, the ENP-10L and ENP-100L; and for MULTIBUS the ENP-30L. Data link adapters rely on the host to perform the protocol processing function, and provide an efficient link-level interface with host-based protocols. These function best in host systems that generate a limited number of simultaneous network connections.

CMC

A Rockwell International Company

The Power of Partnership.™

Features

- Common internal shared bus architecture for cost-effective memory usage
- Powerful Motorola M68000-family microprocessor unit (MPU) clocked at 10 or 12.5MHz
- 128 to 512KByte DRAM with no wait states
- Up to 128KByte EPROM containing onboard diagnostics, CMC's exclusive K1 Kernel, and link-level firmware
- Am7990 LANCE Ethernet controller
- Optional 10BASE-T (twisted pair Ethernet) or 10BASE2 (thin Ethernet) transceiver onboard (ENP-10 Series only)
- Bus master mode or slave mode operation
- Optional high-performance link-level host interface
- Optional DoD and Internet standard TCP/IP or TOP/GOSIP compliant OSI protocol software ("i" series only)
- Drivers available for many popular real-time operating systems
- Standard two year warranty

The Processor Module

All ENP Series adapters feature a Motorola 68000-family microprocessor unit (MPU). The MPU controls access to the system bus, executes kernel functions, link-level protocols, network communications protocols, provides system timers, and runs diagnostic tests on start-up. From 16KBytes to 128KBytes of program EPROM is available.

The Memory Module

The dual ported DRAM is the central memory for all network/host/MPU data and control interactions. It provides buffering of data between the bus and the network. In the "i" series, network protocol software is downloaded to and executed from this DRAM.

The Host Interface

All ENP Series Ethernet adapters are simple to integrate into host systems. The board appears as memory to the host operating system. Both slave mode and master mode operation is supported. In slave mode, the host processor transfers the data between host memory and the board, in master mode the ENP Series adapter handles the exchange.

The Ethernet Interface Module

The ENP Series utilizes Advanced Micro Devices' Am7990 Local Area Network Controller for Ethernet (LANCE) and the Am7992 Serial Interface Adapter (SIA). These controllers optimize the Physical and Data Link Layer functions as defined by OSI standard 8802/3, minimizing processing burden on the MPU. A full 16-bit registered data path is used between the LANCE and the buffer memory for efficient bandwidth usage.

The Control Firmware and K1 Kernel

The ENP Series adapter executes the physical and link layer protocols through onboard link-level driver firmware. In the "i" series of intelligent processors the network and transport layer protocols are additionally executed onboard, removing this processing burden from the host. The LANCE processor handles OSI 8802/3 standard Ethernet access, while the MPU controls higher layer protocols.

CMC's exclusive K1 Kernel real-time communications executive has years of proven experience in thousands of installations as a reliable and efficient interface between the LANCE and upper-level protocol software. It supervises board-level activities such as network event timing, memory refresh, interrupt scheduling and statistics gathering.

A master mode link-level driver is available as part of the standard firmware. This allows the ENP Series adapter to act as a high-speed data link device for use with host-based protocols. The link level driver is designed to be easily implemented in BSD 4.3 environments.

The Protocol Software

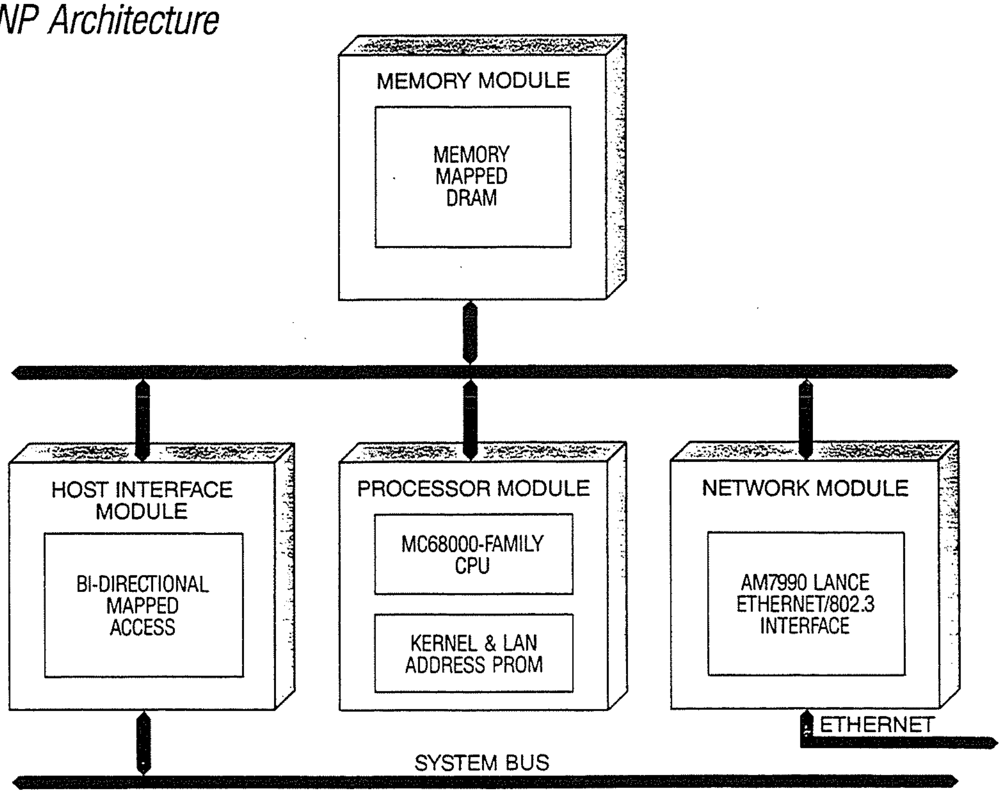
The "i" series of intelligent processors support CMC's optimized TCP/IP protocol software suite. CMC's TCP/IP conforms to the standards established by the Department of Defense, and consists of a board-level component and host-level component. Standard I/O driver and protocol interface software for UNIX System V Release 3 environments is provided and includes STREAMS support.

The board-level component, which runs entirely on the ENP Series processor, includes TCP, IP, UDP, ARP, ICMP, and SNMP agent functionality. Large IP and UDP datagram service is provided. On the ENP-10i and ENP-30i, TCP/IP protocol firmware in EPROM is available for embedded system applications.

The host-side components include the TELNET, FTP and SMTP protocols, and 4.3BSD "r-utilities" such as rlogin, rsh and rcp. For users who prefer to develop their own network applications, CMC supplies a C-language 4.3BSD socket library, as well as a System V Interface Definition (SVID) compliant TLI library.

Full-function lower-layer OSI protocol software is also available from CMC for intelligent processors, conforming to the Government OSI Profile (GOSIP) revision 1.0. The software includes TP4, CLTP, CLNP, ES-IS and LLC1 protocols which execute onboard. The host-side components includes CMC's implementation of popular 4.3BSD "r-utilities" such as rlogin, rsh and rcp, as well as a C-language 4.3BSD socket library. CMC's onboard OSI software is designed to easily integrate with the user's upper-layer OSI applications such as FTAM and X.400.

ENP Architecture



SPECIFICATIONS

ENP Series for VMEbus and MULTIBUS

HARDWARE

Model Number	Bus and Network Interface Type	Memory	Processor	Clock	Bus Master Interface	Bus Slave Interface
ENP-10L	VMEbus link-level	128K	68000	10MHz	D16:A24	D16:A32/A24
ENP-10i	VMEbus intelligent	512K	68010	10MHz	D16:A24	D16:A32/A24
ENP-100L	VMEbus link-level	256K	68020	12.5MHz	D32/D16/D08: A32/A24/A16	D32/D16/D08: A32/A24
ENP-100i	VMEbus intelligent	512K	68020	12.5MHz	D32/D16/D08: A32/A24/A16	D32/D16/D08: A32/A24
ENP-30L	Multibus link-level	128K	68000	10MHz	D16:A24/A20	D16:A24/A20
ENP-30i	Multibus intelligent	512K	68010	10MHz	D16:A24/A20	D16:A24/20

Bus Compliance

—ENP-10L, ENP-10i, ENP-100L, ENP-100i comply with VITA Rev. C.1 and IEEE 1014 VMEbus specifications

—ENP-30L, ENP-30i comply with IEEE 796 MULTIBUS specifications

Ethernet Interface

—Am7990 LANCE and Am7992 Serial Interface Adaptor

—Complies with Ethernet 1.0, 2.0 and IEEE 802.3 specifications

—Onboard 802.3 AUI interface

—ENP-10i and ENP-10L available with optional 10BASE2 (thin Ethernet) or 10BASE-T (twisted pair Ethernet) transceiver onboard

Monitor/Debugger Port

—Dual asynchronous lines via one 2681 DUART

—Optional Software Development Kit (SDK) with EPROM monitor for onboard protocol development

Physical Characteristics

—Power Requirements
+5V: 4.5 A typical; +12V: 500 mA typical

—Operating Temperature
5° to 50° C.

—Storage Temperature
−40° to 85° C.

—Operating Relative Humidity
5% to 95% (non-condensing)

—Dimensions
ENP-10L, ENP-10i, ENP-100L, ENP-100i
233 × 160mm
Occupy single VMEbus card slot (6U form factor)
ENP-30L, ENP-30i
305 × 165mm
Occupy single MULTIBUS card slot (IEEE 796 form factor)

Indicators

—On board visual FAULT and RUN indicators

CMC

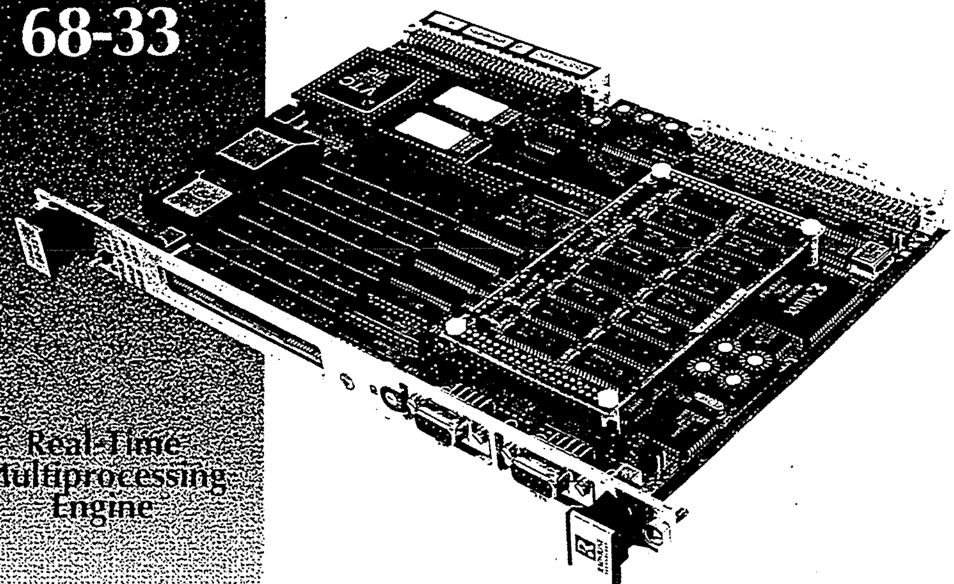
A Rockwell International Company

The Power of Partnership.™

CMC, 125 Cremona Drive, Santa Barbara, CA 93117
Phone: 805/968-4262 1-800-CMC-802.3
Fax: 805/968-6478
CMC U.K. Limited, Central House, 3 Lampton Road
Hounslow, Middlesex, England TWC 1HY
Phone: 44-81-577-2800 Fax: 44-81-572-7716 Telex: 25463 ROCINT G

APPENDIX B - VSS SPECIFICATIONS

68-33



Real-Time Multiprocessing Engine

- 68030 CPU at up to 50 MHz
- Optional 68882 floating point co-processor
- Segmented local bus architecture
- 1 Mbyte Zero wait-state SRAM
- Up to 4 Mbyte high speed SRAM
- High performance VSB interface with DMA
- 32 bit Advanced Processor Extension bus
- Extensive Multiprocessing support
- Two 32 pin JEDEC sites
- Two asynchronous serial ports, RS232 or RS422
- Real-Time Clock
- VIC068 VME interface up to 40Mbyte/sec

The 68-33 is specially designed for applications requiring high data throughput, intensive multiprocessing or extremely fast real-time response. Typical uses include image processing, simulation, data acquisition and scientific systems. 68-33's unique Freeflow architecture with its dual local buses matches data throughput to the speed of the processor, which runs at speeds up to 50MHz. Unlike traditional single board computers, the 68-33 does not become local bus bandwidth limited.

The 68-33 is also suitable as a single-slot networked target board when fitted with APEX-100 Ethernet interface.

Processor

The 68030 CPU operating at clock speeds up to 50MHz is matched with an optional 68882 floating point co-processor and 1 Mbyte zero wait-state SRAM all on a separate local bus. The use of 35ns SRAM with 2-clock-cycle, synchronous mode access gives performance up to 15,000 dhrystones and ensures ultra-fast real-time response.

Segmented Internal Buses

The Radstone 68-33 board has two local buses. The Processor Local Bus holds the 68030, 68882 and 1 Mbyte of zero wait-state SRAM. This is isolated with high speed bus transceivers from the I/O Local Bus which carries an additional SRAM memory module, I/O functions and VME and VSB bus interfaces.

The segmented architecture enables the 68030 to continue processing at up to 50MHz *concurrently* with I/O transfers or large block moves of data between another processor or intelligent controller board and the second SRAM module. This concurrency results in an increase in the local bus total bandwidth and reduced bus latency.

Memory

The 68-33 has 1 Mbyte of 35ns SRAM on the Processor Local Bus.

An additional memory module offering either 1 or 4 Mbytes of 85ns SRAM can be accessed from I/O, VME, VSB and the 68030 processor. Connected to the I/O Local Bus, this memory provides inter-processor and I/O buffer space, and supports VME and VSB block move operation for maximum data throughput. This minimizes the time taken to transfer a block of data across the VMEbus while enabling more data to be transferred between processors without VMEbus bandwidth becoming the limiting factor.

The 68-33 has two 32 pin JEDEC sites for up to 1 Mbyte EPROM.

VSB Interface

The VME Subsystem Bus (VSB) provides a full 32 bit expansion bus and can be used for multiprocessing, memory expansion or to increase total available bus bandwidth. It can also be used to connect intelligent I/O controllers such as SCSI-11, freeing the VMEbus for higher level inter-processor or global transfers within a multiprocessor implementation.

A high performance ASIC design has been adopted for the 68-33 VSB interface. Full master, slave, interrupt, arbitration and block transfer functions to VSB Rev C specification are supported, as well as a single channel DMA controller.

Multiprocessing

The 68-33 is ideally suited to multiprocessing configurations, with dual VMEand VSB buses, high speed multiported memory, separate processor local bus and VIC068 VME controller.

The VIC068 provides eight interprocessor communication registers, four location monitors (mailboxes), four broadcast location monitors and remote reset. These enable specific processors to be addressed or a message to be passed simultaneously to a group of processors.

Up to sixteen boards can be be uniquely identified by the board ID switch which simplifies system configuration.

APEX Interface

The APEX 32 bit extension interface enables the 68-33 to be easily tailored to meet application specific requirements. Extra functionality can be added to the 68-33 board with plug-in modules, while still occupying a single VME backplane slot. A range of standard modules including Ethernet, SCSI, floppy disk, IEEE 488 and parallel I/O interfaces are available.

Custom interface may be added to suit particular application requirements.

Serial Ports

Two asynchronous serial ports are provided using a 68681 DUART device. Individually configurable for RS232 or RS422 operation, access is via front panel mounted 9 way D connectors.

Real-Time Clock

Year, month, day, hours, minutes and seconds. Integral battery backup with automatic fail write protection plus 2 Kbyte battery-backed SRAM.

Configuration

Board-specific configuration parameters such as serial number or network address may be stored in a 128byte non-volatile EEPROM.

A front-panel mounted ID switch serves to identify a particular board in a multiprocessor system, independent of VME slot position.

VMEbus Interface

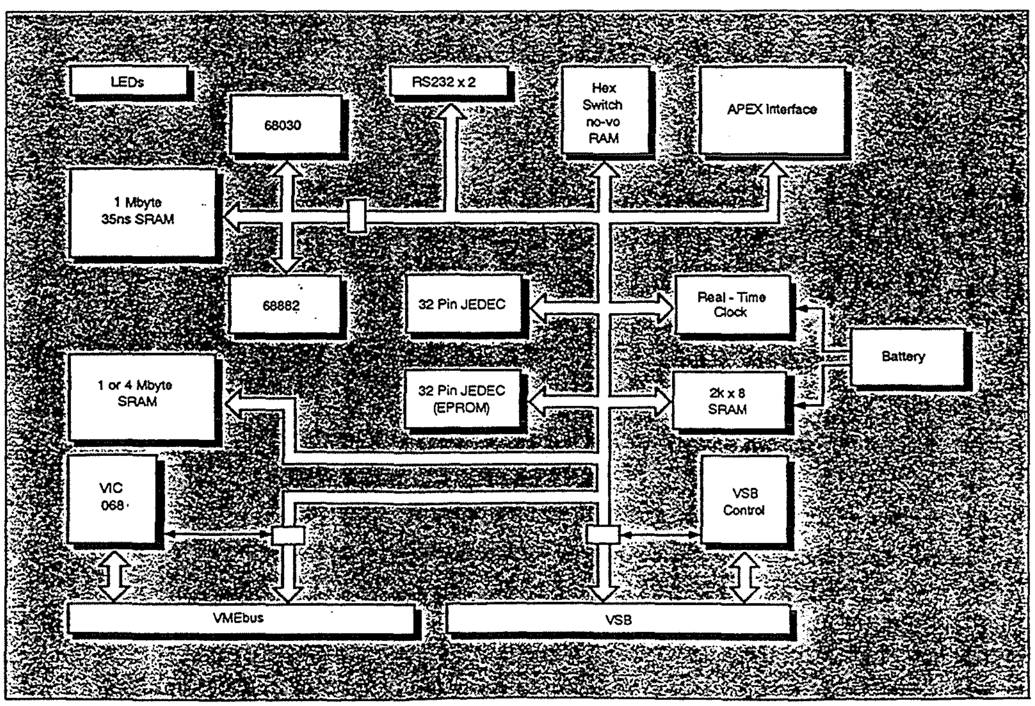
Fully compatible with IEEE 1014

Utilizes VIC068 VMEbus Interface Controller providing:

- Requester with fairness option
- Interrupter
- Write posting of data
- Block transfer cycles
- High speed DMA channel (up to 40 Mbyte/sec VIC to VIC)
- Heartbeat timer
- VMEbus timeouts
- Interprocessor Communication Registers
- 4 level arbiter
- 7 level interrupt handler

Software

The 68-33 processor board is supported by PLUM, Radstone's PROM-based Monitor package, and by a range of operating systems for development and real-time environments. For further details refer to the Software section of this catalog.



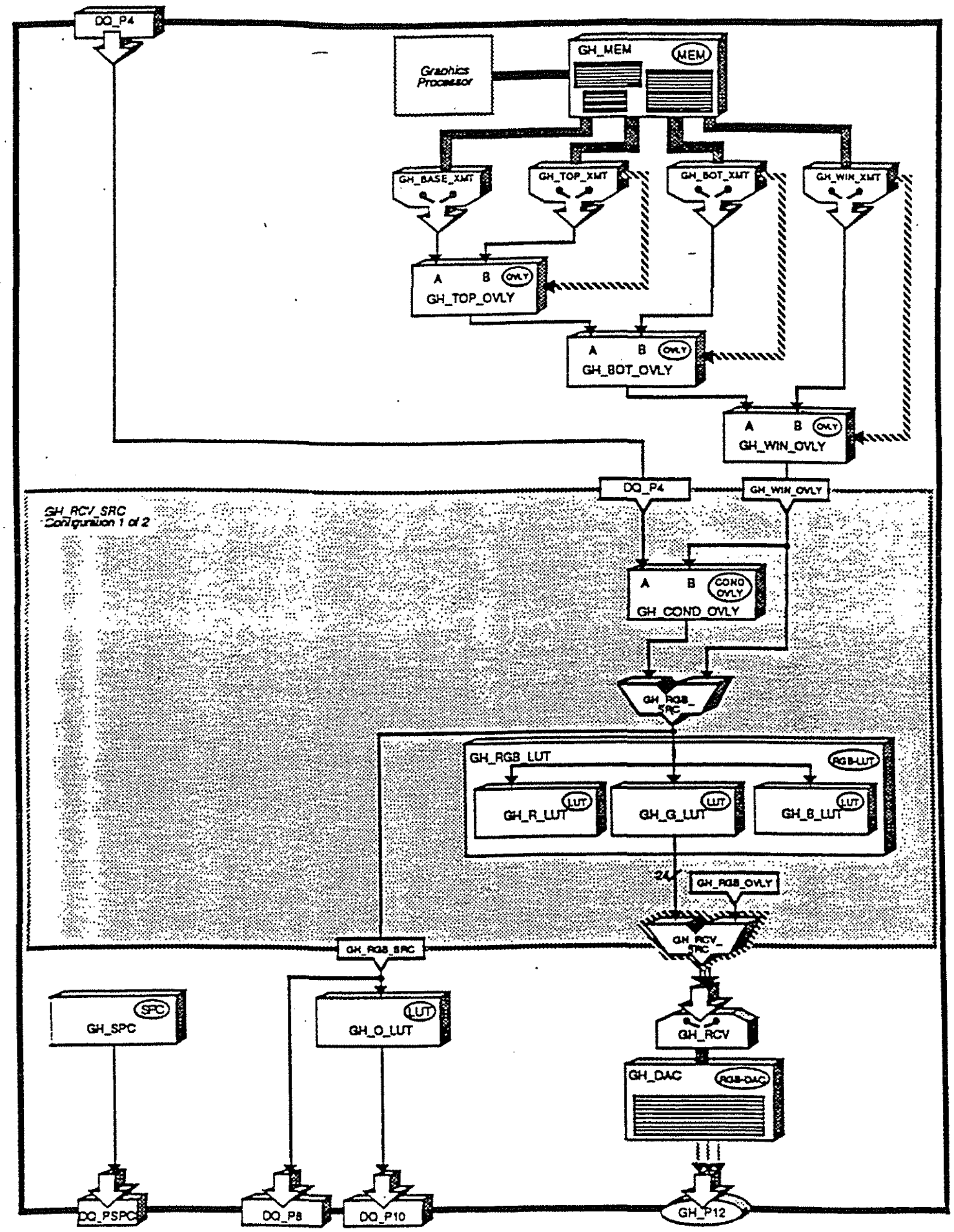


Figure 2-1. MAX-GRAPH Element Flow Diagram (Showing Configuration Block 1 of 2)

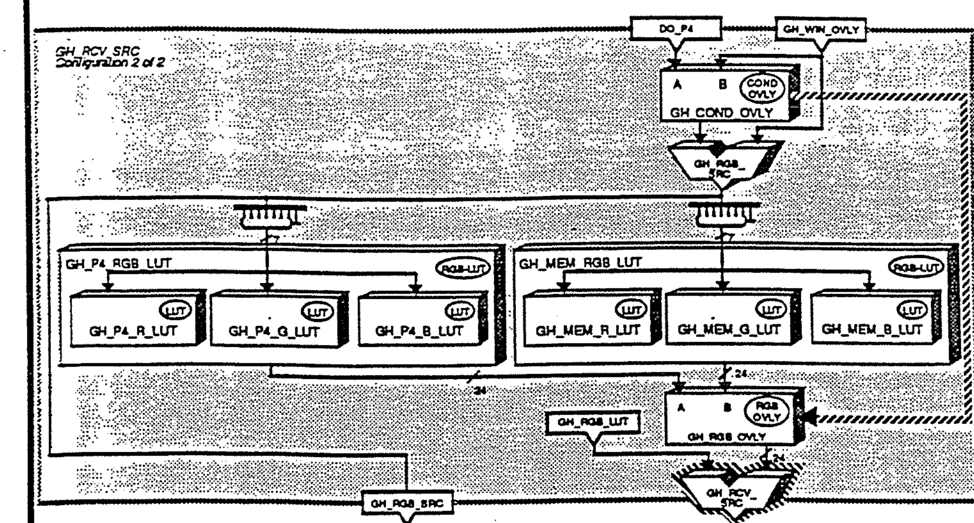


Figure 2-2. MAX-GRAPH Element Flow Diagram (Configuration Block 2 of 2)

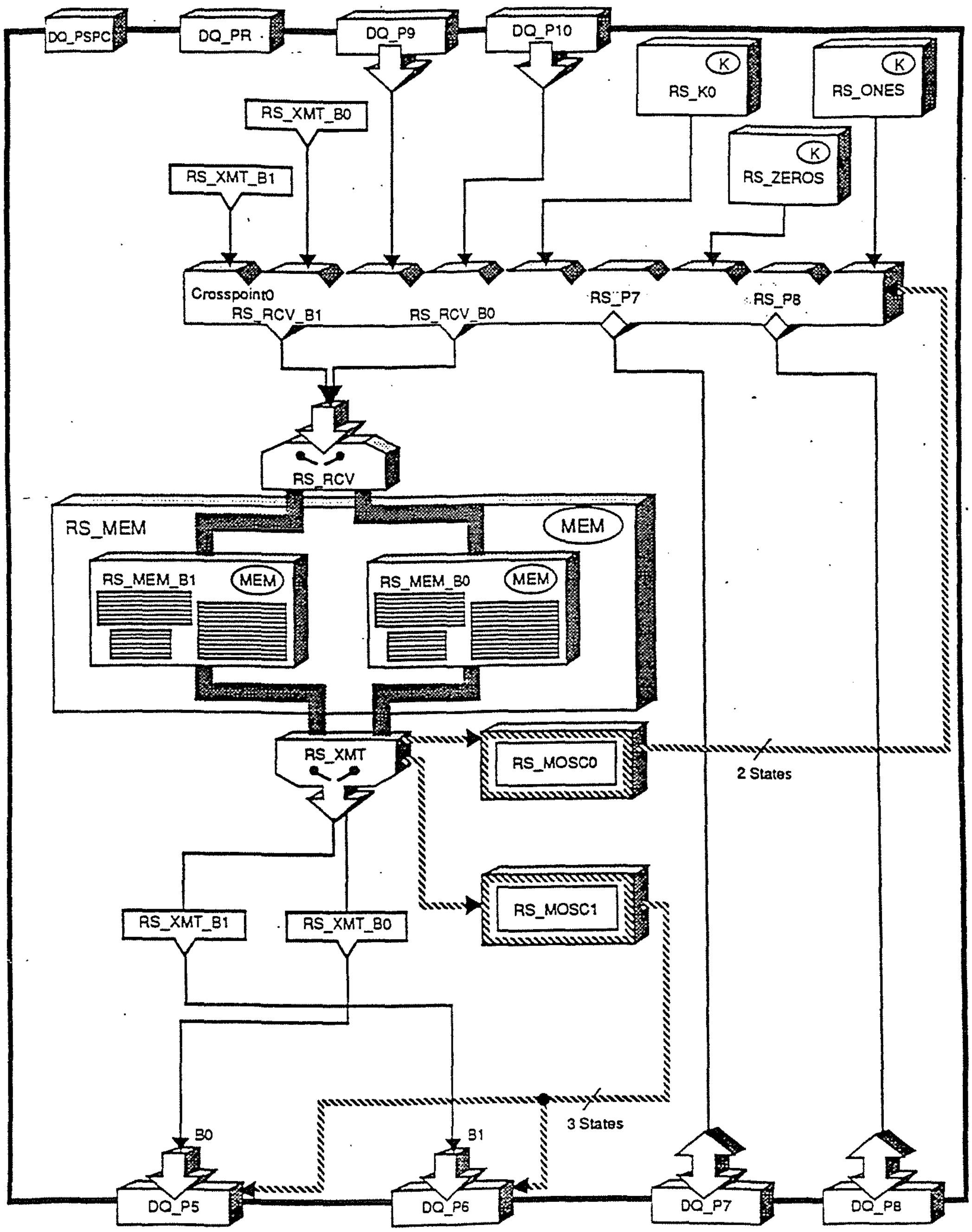


Figure 2-1. ROI-STORE Element Flow Diagram

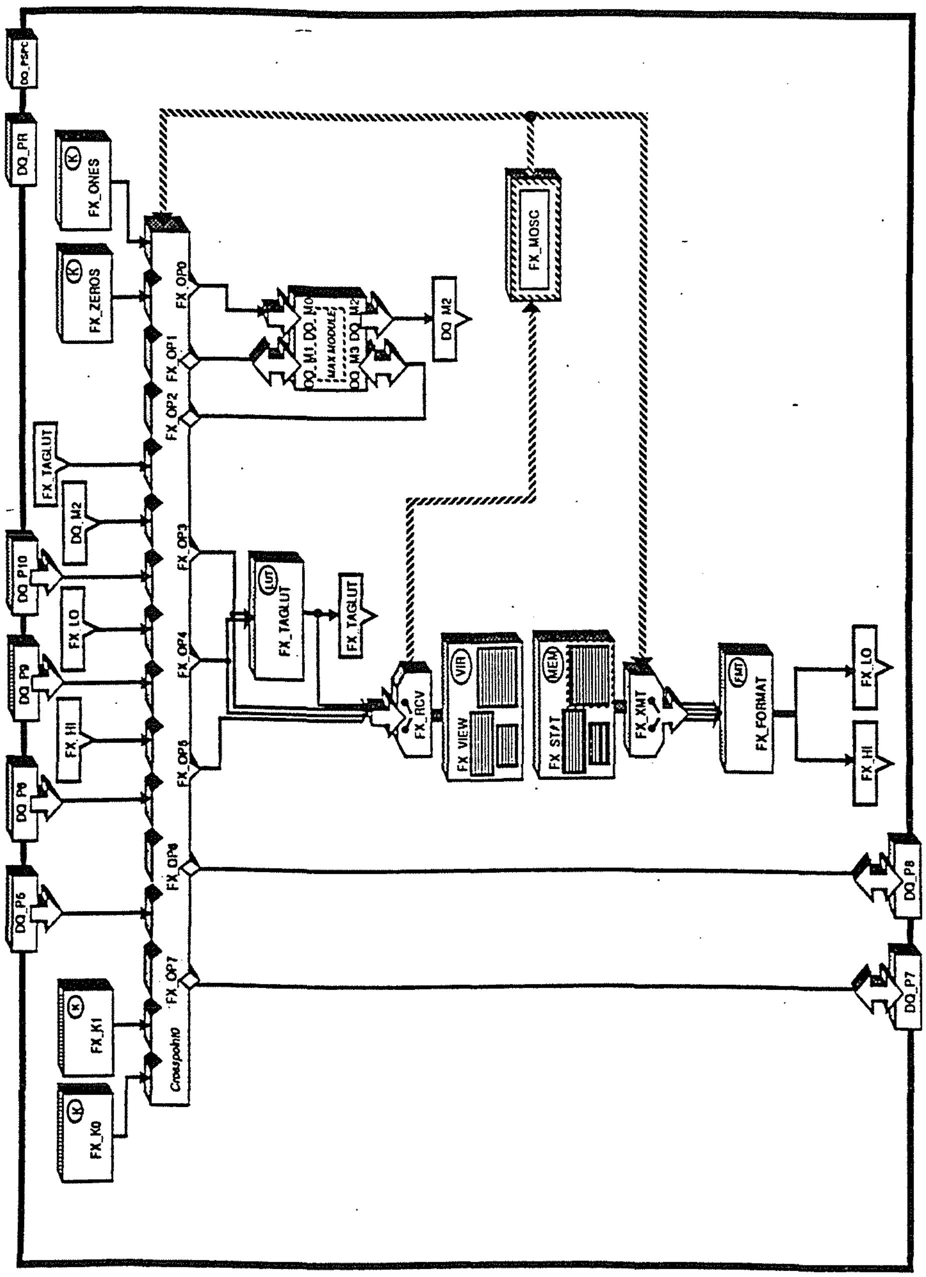


Figure 2-1. FEATUREMAX MKII Element Flow Diagram

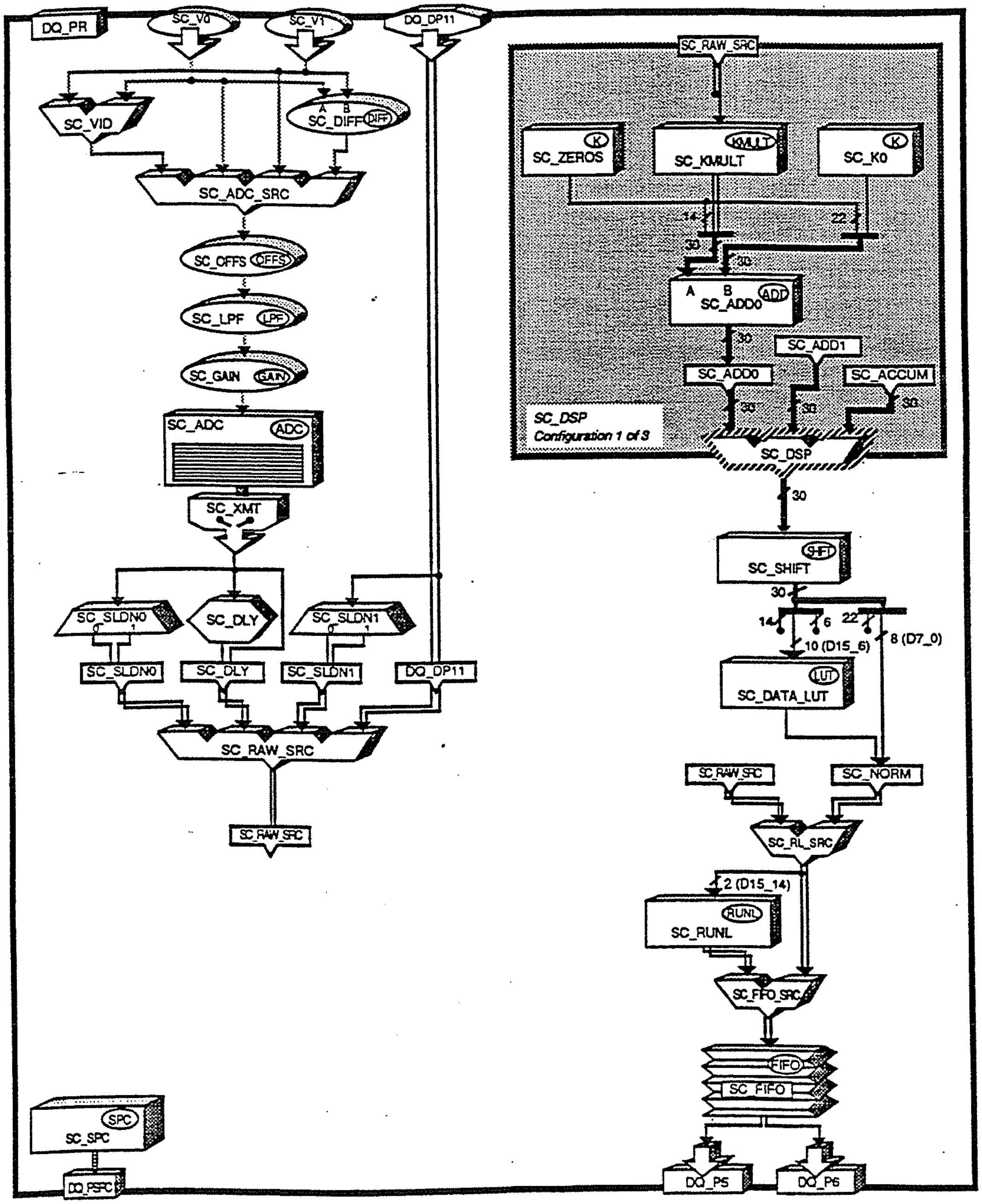


Diagram 1 of 2. MAX-SCAN Element Flow Diagram (Showing Configuration Block 1 of 3)

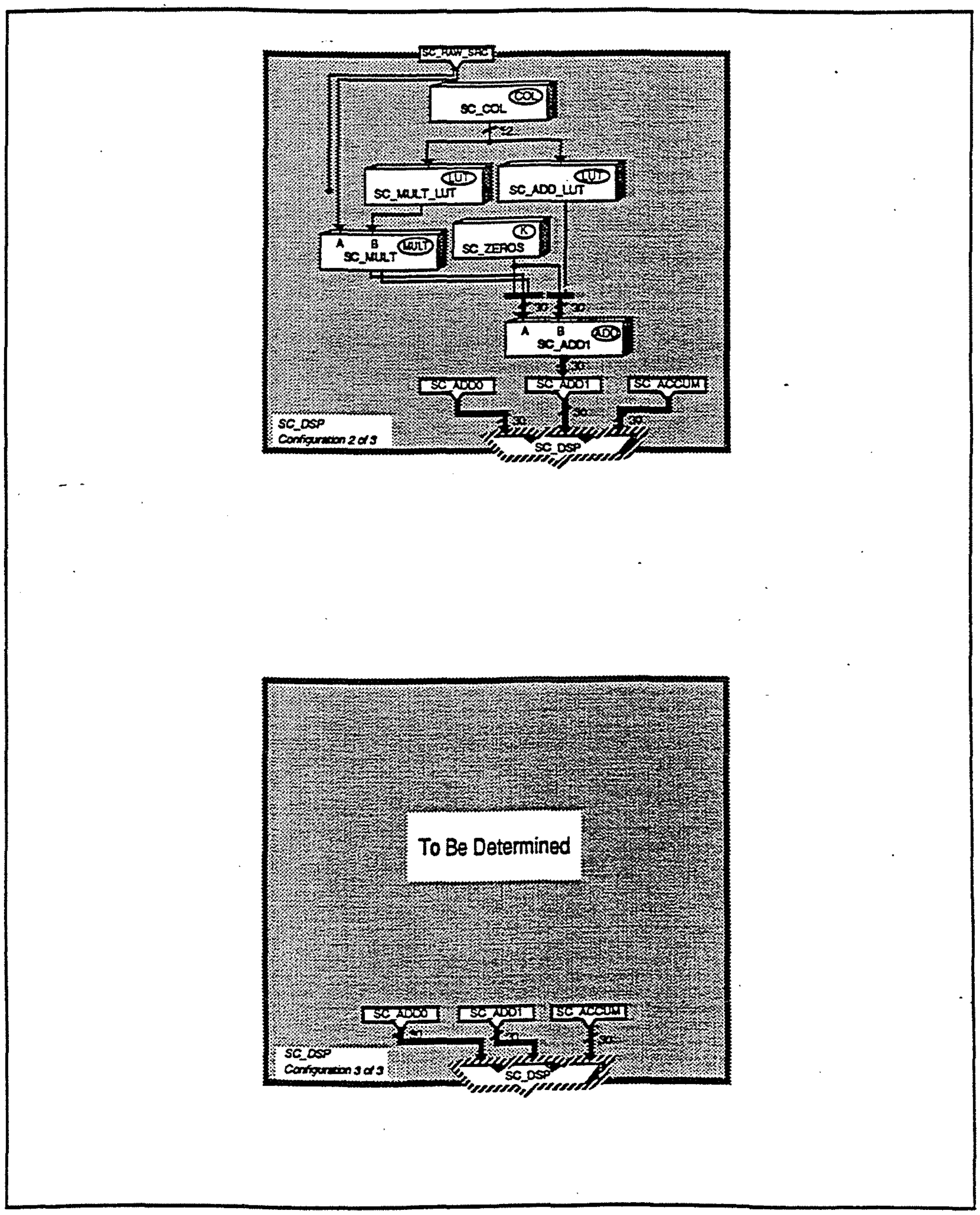
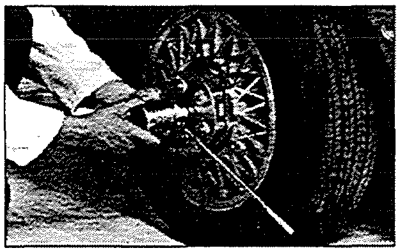
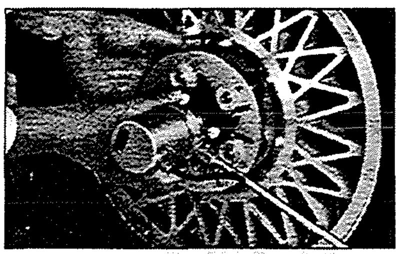


Diagram 2 of 2. MAX-SCAN Element Flow Diagram (Configuration Blocks 2 and 3)

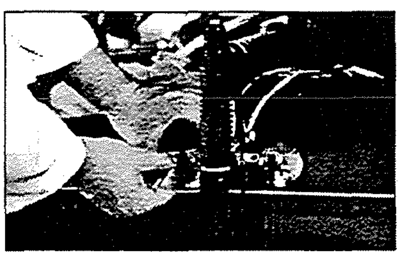
The WPT-1000 Mounts in Three Simple Steps...



STEP 1: Place mounting adaptors flush over wheel nut.



STEP 2: Slide the centering star over the unit and turn until snug against adaptors. Tighten adaptors and remove star.



STEP 3: Attach suction holders.

Complete WPT-1000 KIT includes:

- Wheel pulse transducer with vertical pivot
- Suction mount with 3' (1m) rubber-booted guide tube and horizontal pivot
- Mounting plate for 3, 4, 5 or 6 stud wheels having bolt circles 3.9 - 5.75" (98 - 147 mm) [Other Configurations Available Upon Request]
- Five (5) 17mm or 19mm adaptors
- One (1) centering star
- 13' (4m) cable with LEMOSA connector
- LEMOSA-to-pigtail extension cable
- Hex wrench
- Rugged, shock-resistant carrying case

Options:

- Reference pulse: 1 per revolution
- Quadrature signal
- CORREVIT EEP-2, -3, or -4 computers for data logging

Specifications:

Output:	1000 pulses/rev., 5V, TTL compatible square wave (other resolutions from 50 - 5000 pulses/rev. available)
Accuracy:	+/- 1 pulse
Speed range:	0 - 200 mph (0 - 320 kmph) 0 - 3000 rpm
Power requirements:	5V DC, 0.6W
Cable length:	13' (4 m)
Cable connector O.D.:	.583" (14.8 mm)
Weight:	5.5 lb. (2.5 kg), including mounting hardware
Temperature range:	-40°F to +230°F (-40°C to +110°C)
Dust/splash protection:	Meets IP 64 (DIN 40050, IEC 529)
Permissible vibration (including mounting):	216 ft./sec.^{2} (65 m/s^2), 10 - 2000 Hz
Permissible acceleration (including mounting):	2160 ft./sec.^{2} (650 m/s^2)
Allowable suspension travel:	5" (125 mm)

Specifications subject to change without notice.

DATRON
TECHNOLOGY
1-800-832-0732

34115 West Twelve Mile Road, Suite 120
Farmington Hills, MI 48331
313.489.3140 • FAX: 313.489.3144

PRELIMINARY

FAIRCHILD WESTON SYSTEMS

CCD IMAGING DIVISION

CAM1800 Series Line Scan Cameras

TOM SPENCER (408) 433-2675

FEATURES

1024 for 2 camera setup

- 2592 or 2048 element CCD sensor
- Anti-blooming
- Electronic exposure control
- AR coated window on sensor
- Precision sensor alignment
- Single channel DC restored video output
- Remote operation
- Dynamic range 2000:1 minimum
- Video data rate to 20 MHz

DESCRIPTION

The Fairchild Weston CAM1800 is a rugged line scan camera designed for incorporation into non-contact electro-optical measurement and process control systems. The CAM 1800 comes in two versions (2592 or 2048 × 1 pixels) and incorporates such features as anti-blooming, electronic exposure control and a single channel DC restored video output.

This camera is an entirely new design, offering several performance improvements, including lower RMS noise, reduced clock coupling into the video output, an improved grounding system, precision sensor alignment, improved MTF at high data rates, and higher speed operation.

Two differential clock signals are required for controlling the camera's data rate, line rate, and integration time. The camera will accept 3 clocks for added flexibility. The data rate clock, CLK.DR, determines the rate the video is clocked out of the camera. The line clock, CLK.LINE, determines the scan rate of the camera. The integration control clock, CLK.INT, determines the integration time of the sensor. CLK.LINE and CLK.INT may be tied together, in which case the duty cycle of the combined signal will determine the integration time.

The CAM1800 supplies as outputs 2 line synchronization signals—Valid Video (VV), which is high when pixel data is present at the video output, and φX, which triggers on the prescan elements. In addition, a chain of sampling pulses, synchronized with the pixel data at the video output, is generated by the camera. This output may be used to trigger a flash A/D or a Sample/Hold amplifier. The video data is available on a single 75 Ω coaxial line. Video amplitude is 1 volt when terminated with 75 Ω.

The camera requires power supply inputs of +5, +15, and −15 volts regulated DC. Optionally, it may be configured to accept ±5V regulated and ±20 V unregulated power. The camera uses a single D type connector with an integral coaxial pin for video. Three separate grounds are used inside the camera—analog, digital, and case ground. These should be tied together at a single, low impedance point in the user's system.

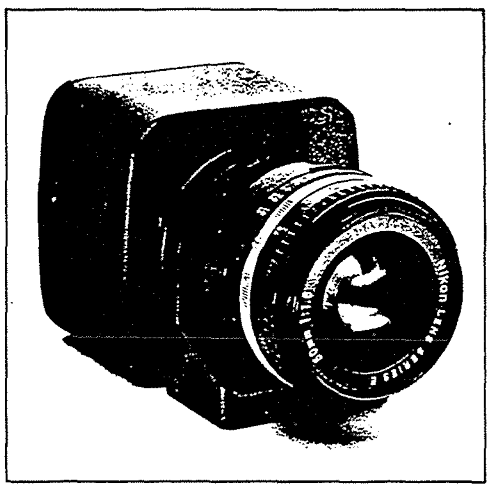
FUNCTIONAL DESCRIPTION

The circuitry within the camera is comprised of differential line drivers and receivers, timing control logic, high capacitive load clock drivers, a CCD181 linear imaging sensor, video amplifiers with adjustable gain, DC restoration, video multiplexing circuitry, and a video output buffer.

IMAGE SENSOR

The Charge Coupled Device (CCD) employed is the Fairchild Weston CCD181 high speed linear imaging sensor. This device is a monolithic component containing a single row of 10μm × 10μm light sensing elements (photosites or pixels), two analog shift registers, and two output sense amplifiers for the sensor's two channels of video. The sensor has enhanced spectral response in the blue region, anti-blooming, and integration control. Light energy detected by the photosites generates electron charge packets proportional to the product of integration time and incident light intensity. The device integrates when the CLK.INT clock signal sent to the camera is at a logic low level. The photosite charge packets are transferred in parallel to analog transport registers in response to the low to high edge of CLK.LINE. The transport registers, in response to CLK.DR, deliver the charge packets to a charge sensing amplifier where they are converted into proportional voltage levels.

The advantages of Fairchild Weston's isoplanar buried channel CCD sensor include high data rate capability, high transfer efficiencies, low noise and small pixel sizes.



OPERATION

The CAM1800 is operated by supplying three clock inputs and power.

Clock Signals—The output data rate is controlled by CLK.DR. This signal may vary in frequency from 0.5MHz to 20MHz. Pixels are output from the camera at this frequency. The duty cycle of this clock must be 45–55%. This is critical only at the higher frequencies. A higher duty cycle at high frequency will cause a reduced MTF. A lower duty cycle will cause a greater drooping of the video between pixels.

The line scan rate is controlled by CLK.LINE. A low to high transition of this clock causes a new line to appear at the output. The level of this clock is sensed synchronously, at rising edges of CLK.DR, so any changes in the level of CLK.LINE are valid only if they occur over at least one rising edge of CLK.DR.

The integration time is controlled by CLK.INT. Photo-charge is dumped to the substrate when this clock is high. Thus, the integration time is the time between the low to high transition of CLK.LINE and the previous high to low transition of CLK.INT (in fact, the integration time ends 22 CLK.DR periods after the rising edge of CLK.LINE). CLK.INT may go high at the same time CLK.LINE does without affecting the previous integration time. Thus, the two lines may be tied together (it is best to do this at the users end of the cable, from a line termination point of view). The duty cycle of this combined signal will then determine the integration time.

Requests for a new line during the time a line is being clocked out are stored until the current line is finished. Pixel 1 of the next line will occur 44 CLK.DR periods after the last pixel of the previous line.

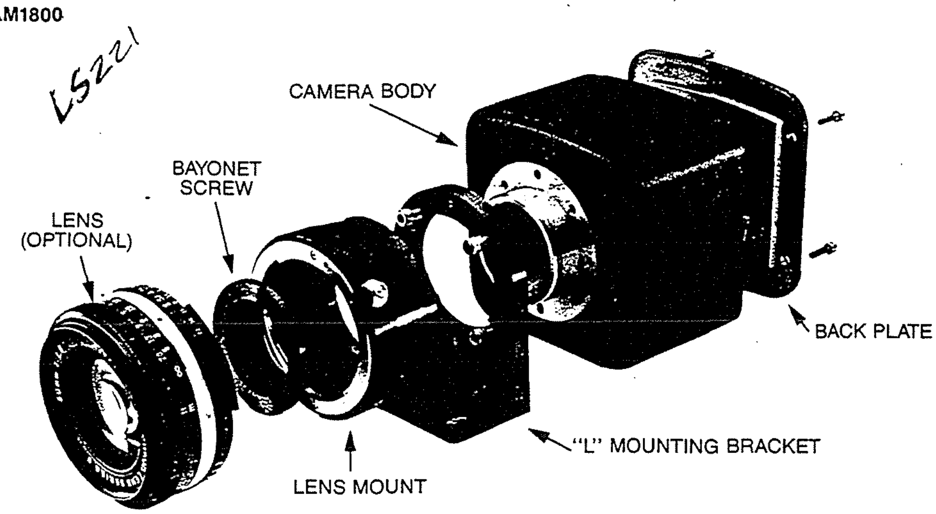
Driving Differential Signals—For long cable lengths or high frequency signals, the best method to drive the camera inputs is to use differential drivers, such as the 75ALS192, and twisted pair wires. Under some circumstances biasing the − input to 1.0V and driving the + input with a single ended signal may be possible. The + and − inputs are terminated inside the camera with a 100 Ω resistor between them.

Sensing the Differential Outputs—The recommended method of sensing the differential outputs is to use a differential receiver, such as the 75ALS195, with the twisted pairs terminated with a 100 Ω resistor between them. The output signal is not a floating signal in the sense that one end may be tied to any common mode voltage. Both the + and − outputs swing from 0 to 5 volts, 180 degrees out of phase with each other. Do NOT tie either output to a DC voltage.

Power Supplies—The +15V supply is the most critical for low noise operation. Noise on this line will couple into the output. DC levels away from 15.0 Volts will first affect the anti-blooming operation. Higher DC levels will decrease the saturation voltage (V_{sat}) amplitude, and lower levels will increase V_{sat}, but reduce the effect of the antiblooming circuitry. For applications such as long cable lengths where controlling this voltage is difficult, the camera may be ordered in a version which has internal regulators for + and − 15 volts, and requires instead +20 volts on pin 6 and −20 volts on pin 5.

Outputs—A line of video output consists first of transferring photosite charge from the photo sites to the shift registers inside the CCD181. This occurs during the time ΦX is high. ΦX stays high for 20 CLK.DR periods, starting at the third rising edge of CLK.DR after the rising edge of CLK.LINE. Following the falling edge of ΦX is the output of 4 isolation cells, 8 dark reference cells and 8 more isolation cells. At this point, VV (valid video) goes high and the first photosite pixel is output. Pixels are then clocked out until the last, when VV goes low again. Between lines, i.e. after the last pixel is clocked out and before a new line request is made, the camera keeps clocking the shift refisters and sampling the outputs. The video present, however, is due only to dark current, blooming (if the light intensity is more than 5 times greater than saturation), or optical crosstalk. Optical crosstalk is greater if IR radiation is incident on the sensor. No IR filter is within the camera.

CAM1800



The video output is DC referenced to the level of the dark reference cells. The 6th and 7th dark reference cells are clamped to 30 mV. Under conditions of extreme IR radiation on the CCD, the dark reference cells will be driven to a high signal level. When the video is then referenced to this high level, the resulting output video signal will be reduced.

When IR is present in the image spectrum, an IR stop filter should be employed. For best optical performance, this filter should be placed in front of the lens.

The pixel sampling clock (ODV) provides a rising edge near the center of each pixel. This signal provides a convenient sampling pulse. It may be used as the hold signal on a sample/hold amplifier or as the convert command on an ADC, for example. The VV signal may be used to gate these pulses, so that they will sample only valid pixel data.

NOISE

Both coherent and incoherent noise can exist on the output video. Coherent noise (in sync. with the pixel data rate) will be found as ringing between pixels and a sampling feed-through spike in the center of each pixel as the internal sample-and-hold switches to hold mode. A small pedestal step may occur at this point as well. Thus, as long as the sampling occurs on a specific portion of the pixel, the coherent noise produces only an offset to the signal.

The dynamic range limitation comes only from the random noise. This can be measured by subtracting a long term (greater than 32 lines) average of the video signal from itself, and making an RMS measurement of the result. It is this signal that is specified as noise at the factory.

Operating Conditions

Symbol	Parameter	Min	Typ	Max	Units
t_{su}	Set up time CLK.INT and CLK.LINE to CLK.DR		25	35	ns
t_h	Hold Time		-20	-10	ns
f_{dr}	CLK.DR Frequency	0.5		20	MHz
f_{line}	CLK.LINE Frequency	0		10	MHz
V_{cm}	Differential input common mode range			±7	V
I_{out}	Differential output current			±20	mA
+15V	15 Volt Supply	14.8	15.0	15.2	V
+5V	5 Volt Supply	4.5	5.0	5.5	V
-15V	-15 Volt Supply	-15.5	-15.0	-14.5	V
T_A	Operating Temperature	0.0		60	°C
T_S	Storage Temperature	-40.0		100	°C

Performance Characteristics (Conditions: T_a = 25°, f_{dr} = 5MHz, nominal voltages.)

Symbol	Parameter	Min	Typ	Max	Units
V_{sens}	Differential input sensitivity	200			mV
V_{hys}	Differential input hysteresis	120			mV
V_{sat}	Saturation Output Level	0.95	1.0	1.05	V
V_{ripple}	Output Signal Coherent Noise (P-P)		30	60	mV
N_{PP}	Random Noise (P-P)		1.3	2.0	mV
N_{RMS}	Random Noise (RMS)		350	450	μV
V_{off}	DC Offset	0	25	50	mV
DR	Dynamic Range (relative to P-P noise) (relative to RMS noise)	 500:1 2000:1			
SE	Saturation Exposure		0.3		$\mu J/cm^2$
CTE	Charge Transfer Efficiency	.99996	.99999		
PRNU	Photoresponse No-uniformity (P-P)		60	160	mV
DSNU	Dark signal Non-uniformity		5	10	mV
R	Reponsivity		5		$Vcm^2/\mu J$

Notes

1) V_{sat} will drop slightly at higher frequencies. It drops to 0.7 volts (min) at 20MHz.

2) V_{ripple} will increase with frequency. It becomes 150mV P-P (max) at 20MHz.

SIGNAL DESCRIPTIONS

Power and Grounds

Signal Name	Pin	Description
AGND	16	Analog ground. All the analog ground pins are connected internally.
DGND	14	Digital ground. This ground is isolated from AGND.
CGND	15	Case ground. This ground is isolated from AGND and DGND.
+15V	6	+15 Volt supply (280mA @ 20MHz, 100mA @1MHz).
+5V	4	+5 Volt supply (450mA @ 20MHz, 380mA @ 1MHz).
-15V	5	−15 Volt supply (80mA @20MHz, 70mA @1MHz).

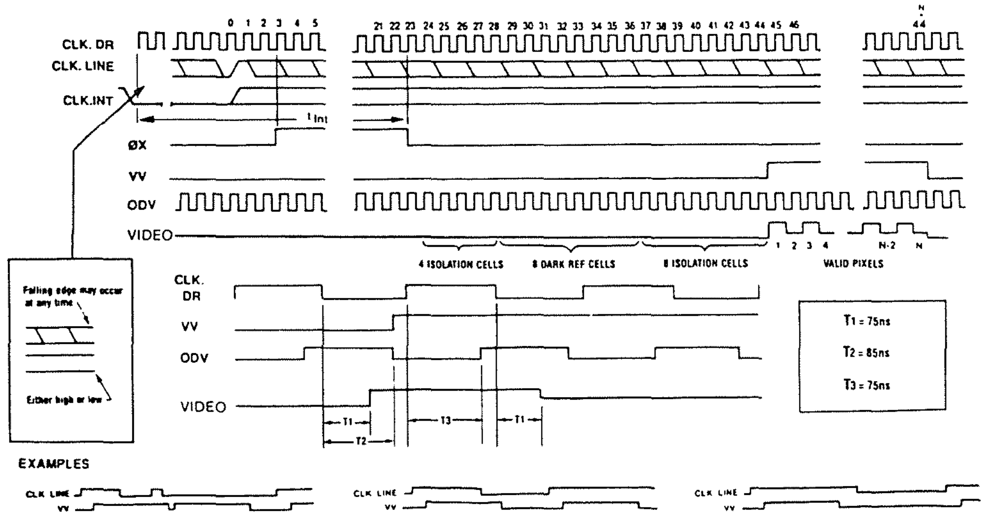
Inputs

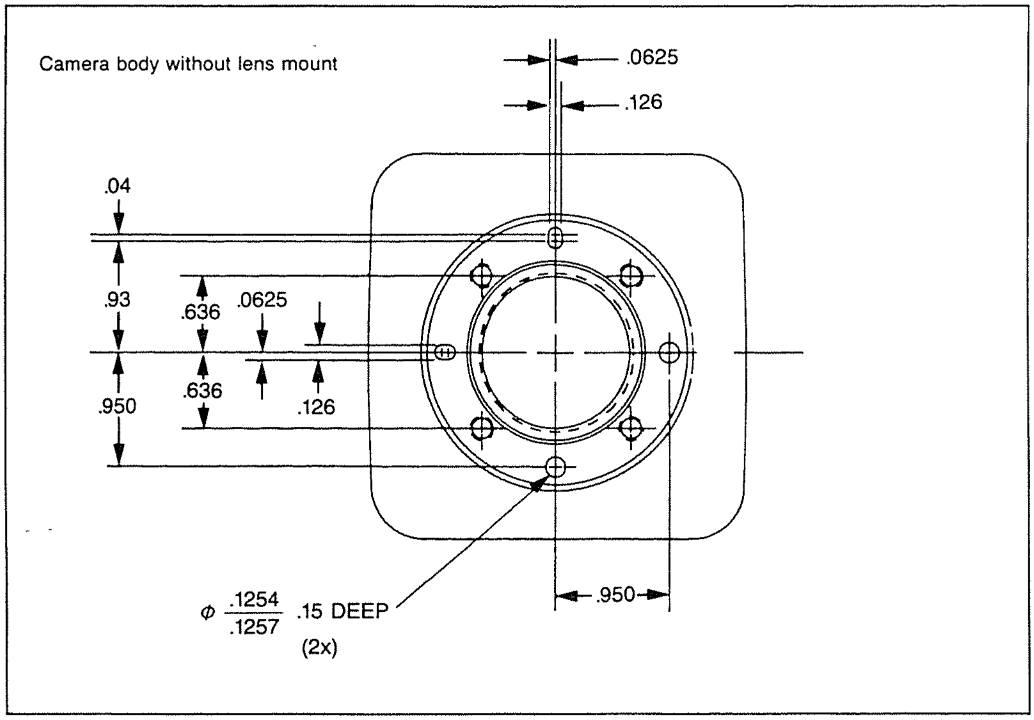
Signal Name	Pin	Description
CLK.DR (+) *CLK.DR (−)*	1 11	Data rate clock. Duty cycle must be 45-55%. Data is output at this frequency.
CLK.LINE (+) *CLK.LINE (−)*	2 12	Line control clock. New lines are started on the low to high transition of this clock. The state of this clock is sensed on the rising edge of CLK.DR. Requests for a new line which occur before the previous line is finished are stored, causing a new line to start as soon as the previous one ends.
CLK.INT (+) *CLK.INT (−)*	3 13	Integration control clock. When low, photosites accumulate charge. When high, charge previously accumulated is dumped to the substrate. Changes in state are sensed synchronously on the rising edge of CLK.DR.

Outputs

Signal Name	Pin	Description
VOUT	A	Video output.
VV (+) *VV(−)*	8 18	Valid Video. This signal is high when actual photosite data is present.
ØX (+) *ØX (−)*	9 19	Pulse indicating start of new line.
ODV (+) *ODV (−)*	10 20	Output sampling pulses, synchronized with pixel data.

LINE TIMING DIAGRAM





MOUNTING THE CAM1800 CAMERA

Mounting considerations vary between applications. There are several methods of mounting and aligning the CAM1800 camera which vary in mounting accuracy and complexity.

The foot of the L bracket has a ¼-20 tapped hole and 2 through holes. The simplest mounting scheme is to attach the camera to the user's system using one or more of these holes. Mounting at this point will provide for a repeatability of ±0.15 inch.

The L bracket may be rotated around the camera optical axis at 90° increments. See the next section for details.

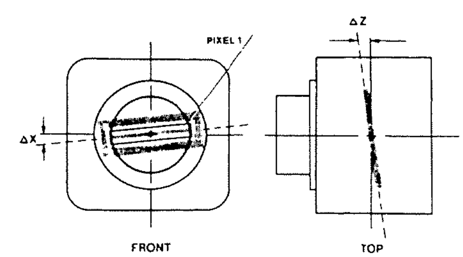
Alignment holes are provided in the foot of the L bracket for greater repeatability in mounting. Aligning off of the hole and slot will provide for repeatability of ±.005 inch.

An alignment accuracy of ±.003 inches may be obtained by removing the lens mount and L bracket, and aligning the customer's system directly off of the alignment features on the camera body itself. See the mechanical drawing for these features.

REMOVING THE L BRACKET

The lens mount and L bracket may be removed as follows. First, using the special tool included with the camera, unscrew the bayonet screw, located inside the lens mount. The mount will then slide off. Now the cap screws holding the L bracket may be removed. When remounting the L bracket, care must be taken to preserve the alignment. The pins on the L bracket align to a hole and a slot on the camera body. The L bracket should be pushed counter-clockwise with respect the camera body (front view) before the screws are tightened. This will ensure the alignment pin is pressed against the reference edge of the slot in the camera housing. This bracket may be mounted in any of 4 positions.

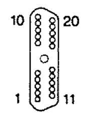
SENSOR ALIGNMENT

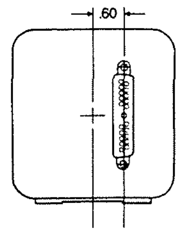


The sensor is aligned at the factory so that ΔX and ΔZ are less than 0.002 inches.

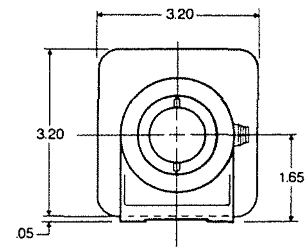
MECHANICAL DIMENSIONS
ALL DIMENSIONS ARE IN INCHES

CONNECTOR

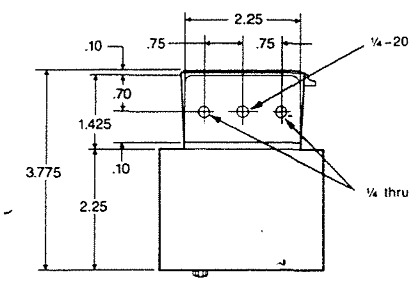




REAR VIEW



FRONT VIEW



BOTTOM VIEW

Mating Connector:
ITT Cannon DBM21W1S
with a DM53742-1 Coax Insert

Pin	Signal	Pin	Signal
1	*CLK.DR(+)*	11	*CLK DR(-)*
2	*CLK.LINE(+)*	12	*CLK LINE(-)*
3	*CLK.INT(+)*	13	*CLK.INT(-)*
4	*+5V*	14	*DGND*
5	*-15V*	15	*CGND*
6	*+15V*	16	*AGND*
7	*NC*	17	*NC*
8	*VV(+)*	18	*VV(-)*
9	*øX(+)*	19	*øX(-)*
10	*ODV(+)*	20	*ODV(-)*

ORDERING INFORMATION

CAM1830—2048 pixels
CAM1840—2592 pixels
1024 for two camera setup.

Add suffix O for Olympus lens mount
Add suffix N for Nikon lens mount

Add suffix U if unregulated ±20 Volt input is required.

WARRANTY

Within twelve months of delivery to the end customer, Fairchild Weston CCD Imaging will repair or replace, at our option, any Fairchild Weston camera product if any part is found to be defective in materials or workmanship. Contact factory for assignment of warranty return number and shipping instructions to ensure prompt repair or replacement.

CERTIFICATION

Fairchild Weston CCD Imaging Division certifies that all products are carefully inspected and tested at the factory prior to shipment and will meet all requirements of the specification under which it is furnished.

SPECIALS

All Fairchild Weston CCD cameras and camera systems can be modified to suit unusual applications. The CCD Imaging Division is interested in developing and manufacturing customized versions of the basic camera for volume purchasers and is willing to assist low-volume purchasers in development of custom modifications by provision of design and applications engineering assistance.

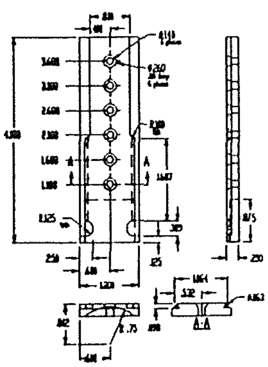
FAIRCHILD WESTON SYSTEMS INC.
CCD IMAGING DIVISION · 1801 McCarthy Blvd., Milpitas, CA 95035
(408) 433-2500 · 1 800 325-6975

APPENDIX C - LSS SPECIFICATIONS

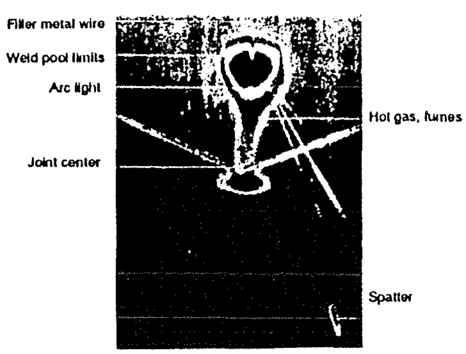
Resolution and Accuracy

The Laser Vision camera is calibrated to work in the above mentioned optimum area. All accuracy and resolution specifications are specified for this area.

	Horizontal		Vertical
Speed images/sec	60	30	
Resolution:	0.005" 0.125mm	0.0025" 0.064mm	0.006" 0.15mm
Accuracy position:	0.006" 0.15mm	0.003" 0.076mm	0.008" 0.2mm
Accuracy mismatch:			0.002" 0.05mm
Accuracy gap:	0.012" 0.3mm	0.006" 0.15mm	



Camera Bracket



MVS-30 Weld pool

Mounting

The LaserVision sensor is mounted on the torch using the camera bracket supplied. This **precision machined** part should be installed without any warping on a custom machined and **insulated** bracket mounted on the welding torch. Mounting should ensure flexibility of vertical or lateral adjustment. A 5° sensor tilt towards the torch tip is recommended. The distance to torch tip should be as short as possible, but at least 0.5" longer than the longest expected tack weld.

Applications

The **MVS-30** LaserVision sensor is a **medium resolution** sensor specifically designed for both **tracking and inspection robotic** applications. The elongated field of view helps in the initial part location, as well as the **weld pool** observation. It is best used for **V-grooved butt** joints, **large lap** joints and **fillet joints**. The maximum lap joint height is about 1" or 25mm. MVS-30 sensor is designed for **MIG**, **subarc**, **plasma** and **fluxcore** with welding currents up to **900A**.

Specifications

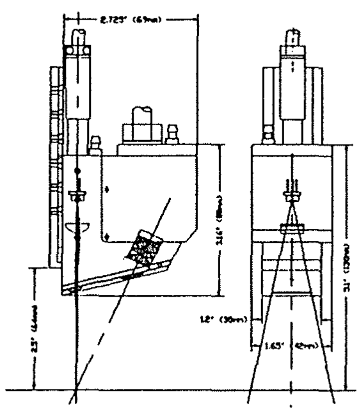
Speed:	60 images per second - RS170 50 images per second - CCIR standard
Cooling:	liquid 1/4 US gallon (1l) per minute (air cooling for subarc and currents up to 50 A)
Air:	0.11 CFM (3l per minute)
Weight:	9oz (250g)

MVS Modular Vision Systems Inc., 3195 De Miniac, Montreal, Canada, H4S-1S9, (514)-333-0140, FAX (514)-333-8636

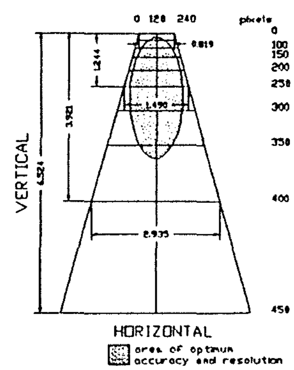
LaserVision Sensor MVS-30 Specifications

General

LaserVision is a new generation of highly ***reliable*** laser range (profile) sensors with ***no moving parts***, specifically designed for welding and sealant dispensing applications. It is the first really ***affordable*** vision based sensor, providing ***high processing speed*** and reliable tracking with more than adequate information for statistical process control and improved parameter control. At the same time, LaserVision is ***simple to use*** and ***rugged*** enough to provide trouble free service in any welding or other hostile industrial environment. A unique patented[1] design allows for ***over 200 hours of maintenance free operation*** under extreme spatter conditions (900A fluxcore). The output from the sensor is a common TV signal, allowing the images to be recorded for the Quality Assurance on a standard VCR.



MVS-30 Outline and Optics



MVS-30 Field of View

Principle of Operation

The LaserVision sensor uses a laser light projected in a plane approximately perpendicular to the observed joint. The cross section of the laser plane of light and the part produces a bright line. When this line is observed by a CCD camera at an angle (20° to 30°) it shows the surface features.

A dedicated vision processor board LPB-200 extracts the surface profile of 60 times per second - even under extreme arc light and spatter conditions. The relative distance of the surface points under the sensor is then calculated (by triangulation) and features of the profile, such as joint position and geometry, are extracted and measured.

Field of View

The field of view is trapezoidal in shape (see drawing) due to the angle of observation of the laser plane. An important feature of this approach is that a straight line remains a straight line, but angles are not preserved. This geometry allows for all the tracking algorithms to be performed in the camera space. A simple set of equations, with eight coefficients obtained by the LaserVision camera calibration procedure, describes the camera space and all the range points can be easily calibrated. The shaded area is the optimum working area for the LaserVision camera where resolution is highest, focus for both the laser line and the camera is optimal and distortion of the optics is minimal.

[1] US patent #4,859,829, August 22, 1989. Canada, Western Europe and Japan applied for.

Imprimerie Astra Salisbury Inc.

3 LASERVISION SENSOR AND PROCESSOR

3.1 Introduction

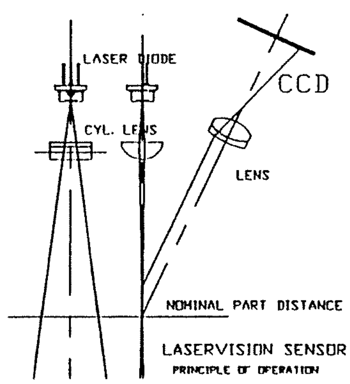


Figure 3.1.1 LaserVision Sensor Optics and Principle of Operation

The LaserVision sensor is a **range** type sensor. It uses a laser light projected in a plane approximately perpendicular to the observed joint. The cross section of the laser plane of light and the part produces a bright line. When this line is observed by a CCD camera at an angle (20° to 30°) it shows the surface features. A dedicated vision processor board LPB-200 extracts this ***profile*** of the surface 60 times per second even under extreme arc light and spatter conditions. A relative distance of the surface points under the sensor is then calculated (by triangulation) and features of the profile, as joint position and geometry, are calculated by an array processor SKY-320 and the AT-PC compatible computer. Each calculated joint position point is further verified, filtered and stored into the memory as a ***trajectory queue***. This point is then output at appropriate moment to the positioning subsystem when the torch arrives at the position where this particular joint position is measured (see the Motion Control section of this manual).

3.2 The LaserVision Sensor

Warning: Please read LASER SAFETY INFORMATION! A serious eye injury can result if the laser safety is not respected.

The LaserVision sensor consists of a CCD camera (a solid state TV camera) and a semiconductor laser. A pinhole, lens and filter combination serves as the objective for the CCD camera. A cylindrical lens is used to focus the laser beam into a plane of light. The beam is further restricted by the slot on the sliding protective plate. Small glass windows are used behind the slots and in front of the lens in order to further protect the lenses from spatter and metal fumes.

The entire camera is pressurized to prevent welding fumes from entering. Pressure is relieved through both the laser slot and the pinhole. In order not to disturb a gas shield around the torch the direction of the blown gas is away from the weld pool and the amount of the gas used is minimal (3.5 litres, or slightly less than one US gallon per minute). A clean pressurized air or inert gas should be used. If shop compressed air is used a reliable water, oil and dust filter should be installed in the air line. 1/8" barbed connectors are used for air and cooling water connection, suitable for 1/8" PVC tubing. The connector is rated for 150 psi of pressure when proper tubing is used.

Water cooling is mandatory for open arc currents of more than 50A. Air cooling can also be used for applications of less than 50A on open arc or a subarc system with currents up to 200-300A .

The interference filters are:

* 30nm bandwidth for TIG arc up to 100A and wire feeder in front; up 50A TIG without wire feeder in front and subarc applications.

* 10nm bandwidth for higher current TIG, plasma, MIG and flux core wire.

* 5nm bandwidth for some very bright arcs, usually plasma, with use of a fibre optic laser.

In case of 10nm filter bandwidth chilled (and heated in case of low operating temperatures) water is required to maintain a precise operating temperature for the laser (±3°C).

For more information consult the LaserVision sensor data sheets.

3.3 LaserVision Sensor Control and Processing

The camera video and synchronization signals are fed via the camera power supply to the LaserVision Processing Board LPB-200 (200-SYS-01). The camera power supply is factory adjusted. If required, please refer to the CCD camera and power supply information included.

The laser intensity is also controlled by the same processor board via signal IPUL (ILIN in earlier versions). A Laser Filter Board LFB-265 (265-SYS-02) provides optical isolation for the laser intensity control signal and a dedicated *floating* laser power supply connections. The laser control signal is a pulse with modulated signal with 60Hz base frequency. Maximum intensity and linearity of the control is adjusted by the potentiometer P1.

The laser power supply +5.25V and -12.0V is switched by the relay R1 by the interconnection board IB-240. The IB-240 board enables the laser only if:

* the EMERGENCY STOP is not pressed,

* there is no ALARM condition (watch-dog timer) and

* the LASER push button is engaged.

The signal received by the LPB-200 board as well as the processed profiles and tracking cursors can be observed on a profile monitor fed by the LPB-200.

For more information on the LaserVision Processing Board see the LaserVision Profile Processing Board - Technical Description

For the maintenance consult the LaserVision Camera Maintenance section.

4 LASERVISION PROFILE PROCESSING BOARD LPB-200

4.1 Introduction

MVS LaserVision Profile Board (LPB) is an image processing board specifically designed for extracting profiles of objects using a structured light and CCD camera. These profiles are generated by projecting a laser line on an object and observing it at an angle with a standard CCD video camera. Digital filtering techniques are used in order to ensure reliable operation in a high noise environment (i.e. arc welding) and suppress reflection artifacts.

LPB plugs into a single slot of an IBM-AT compatible computer.

4.2 LPB Main Features

The LPB can be used either alone as the only vision module in the system or with additional modules for increased performance, such as the DSP board with the Texas Instrument DSP processor TMS32010. A separate output port is provided for the transfer of profile data to the DSP board.

The principal features of the LPB module:

* Camera input, digitized at 8 bit per pixel.
* High resolution of 512 pixels per line standard.
* Highly stable digital phase locked loop synchronization of the internal pixel clock to the horizontal sync signal. A non cumulative jitter is less than +/- 12% of the pixel clock period, allowing for sub-pixel measurement accuracy. A reliable operation is achieved even with the standard VCR.
* Two groups of 2Kx8 (8Kx8 optional) bit input Look-up Tables, one group for processing and other for histogram.
* Monitor output with 8Kx8 (32kx8 optional) bit output Look-up Tables.
* Histogram circuit for 256 possible levels operating either on entire frame or area of interest window.
* Real time digital filter for the accurate feature extraction (profile)
* Profile extractor stores x, y coordinates and intensities of the most probable line points into 2Kx16 (8Kx16 optional) profile memory capable to contain 4 (16) profile vectors of 240 coordinates. This memory is accessible either to the AT host or a separate DSP processor board via a DSP output port.
* Eight selectable Area of Interest windows, easily movable around the picture area by specifying only the X-Y offset coordinates. Both histogram and profile extractor can be set to work only within this area of interest window.

* Flexible RAM based video clock and cursor generation allows for easy synchronization with wide range of standard and nonstandard video inputs.
* Capability to display "raw" profile or other intermediate results by simply loading pixel coordinate for each line into FIFO circuit.
* Laser intensity control output at 8 bit resolution.

4.3 Functional Overview

Main functions of the LaserVision Profile Board are shown on the Block Diagram (LPB.DWG).

The LaserVision camera is connected directly to the LPB via the provided cable. External synchronization is normally used, but there is a provision to use internal sync extraction from the video signal (VCR use) with some sacrifice in vertical positioning accuracy. Generation of internal synchronization signals is RAM based and allows for nonstandard video signals.

Initialization program supplied with the LPB loads necessary values for the RS-170 standard (North American B&W video) or CCIR standard (European) depending on type of camera. Same memory also serves for generation of two independent cursors.

The video signal coming from the camera is first conditioned then digitized to 8 bit accuracy. Two sets of look-up tables are provided, one for the digital filter and other for the histogram circuit. This allows entirely independent operation of the histogram circuit.

The digital filter is optimized for both noise suppression and laser line signal extraction. The laser line signals are enhanced and all other noise signals as ambient light are attenuated.

The digital filter circuit is followed by the profile extraction circuit. This circuit selects the peak of the laser line signal for each active video line and stores the result into Profile Memory during the horizontal blanking interval.

Results stored in the Profile Memory are accessible for further processing either by the host computer or via the DSP Output Port by the DSP board.

In order to further improve the noise immunity of the processing the LPB features the Area of Interest Window. Up to 8 different windows can be stored into window memory. Windows are selected through the control registers and they can easily be moved around the active video frame via X-Y offset registers. Both Histogram and Peak detector circuits can be set to operate only within the window and to ignore areas outside the window.

Typically the window shape is selected to closely match the expected joint profile. Once the joint profile is recognized and tracked, the window is set to closely follow the joint profile. Thus any noise outside the window of interest is automatically rejected. The described windowing technique also improves rejection of reflection artifacts.

The calculated profile or results of other intermediate calculations can be displayed on the monitor via the FIFO (first in first out) circuit. The FIFO has depth of 512 9 bit words, and it can be accessed via a single port. Total of 512 accesses fills the FIFO memory. When activated, the content of the FIFO memory is read synchronously with every active video line starting from the "zero" location. A single dot is output to the screen for every of 480 active lines at the pixel position equal to the address value stored into the corresponding FIFO location. The same output is automatically replayed every video frame without further program intervention.

The Output Look-Up Table circuit assigns gray levels to the digital filter results and the filtering operation can be observed in real time on the monitor. Windows, profile (FIFO) and cursors are displayed as bright overlay.

4.4 Specifications

Camera Input:	Video: 1Vpp Sync: TTL compatible, Standard RS170 or CCIR, other standards can be programmed.
Monitor Output:	RS170 or CCIR Composite sync.
Digitization:	Rate: 9.8304 Mhz standard Resolution: 8 bits. Jitter: less than +/- 12% of pixel width, Non cumulative.
Processor:	IBM-AT compatible, up to 8 Mhz, bus speed, requires 64K memory mapped space.
Output Port:	16 bit data, TTL compatible handshake control, up to 10 Mhz transfer rate, SKY320 compatible.
Measurements:	Width resolution: 240 points at 60 images per second, 480 points at 30 images per second, RS170 standard, or 256 points at 50 images per second, 512 points at 25 images per second, CCIR standard. Height resolution: 512 points. Nonlinear field of view due to triangulation technique used; however straight lines in actual space remain straight lines in transformed (camera) space. Calibration can be applied on final results only (i.e. after segmentation).

APPENDIX D - RPS SPECIFICATIONS AND DRAWINGS

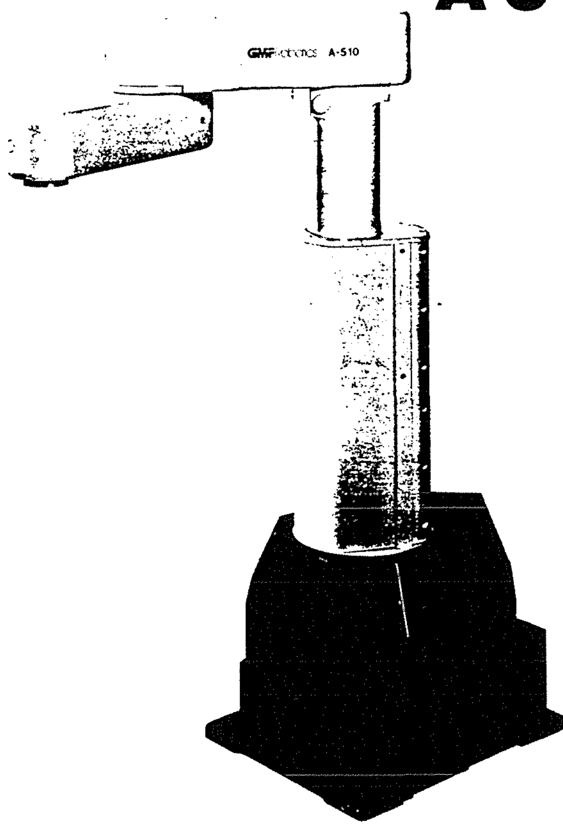
D.1 - General Positioning System

GMF Robotics

A-510

Basic Description

The GMFanuc A-510 is a four-axis horizontally articulated SCARA type robot featuring maximum versatility for electrical/electronic assembly, mechanical assembly, material handling, palletizing, and dispensing. In fact, it is also the highest performance robot of its kind. The ultra-reliable KAREL® controller utilizes the latest proven technologies in the industry. Flexibility is further enhanced by the powerful KAREL programming language and available INSIGHT™ vision system.



Features and Benefits

- **All-electric AC servo drive eliminates brush maintenance.**
- **Easy to install and program for quick pay-back.**
- **Rugged construction for long service life.**
- **Can operate in environments from the harshest to Class 10 clean room.**
- **17.2 ft³ (0.487 m³) work envelope* for real-world applications.**
- **Hollow design encloses all cable routing to eliminate snagging.**
- **99 lb. (45 kg) vertical force for pressing parts**.**
- **Integral fail-safe brakes for safety.**
- **Absolute position detection system provides automatic calibration.**
- **Hefty 44lb. (20kg) payload** for realistic EOAT design and part weight.**
- **Base-located Z-axis improves clearance for restrictive installations.**
- **Proximity switches for overtravel protection.**

* Floor Mount configuration only.
**Floor and Inverted Mount configurations.

Inverted Mount Configuration Features and Benefits

- Robot can now "double-back" on itself for increased access space.
- Placement directly over conveyors for maximum part manipulation.

Extended Reach Option Features and Benefits

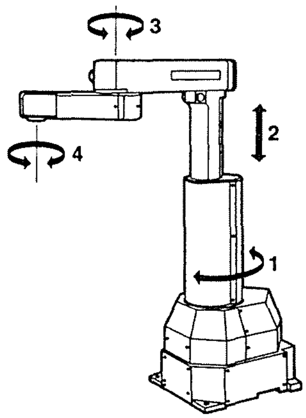
- Maximum reach increased by 28.4% for an even larger work envelope.
- Available in standard and inverted mount configurations.

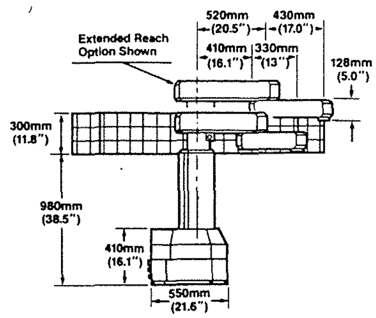
Clean Room Option Features and Benefits

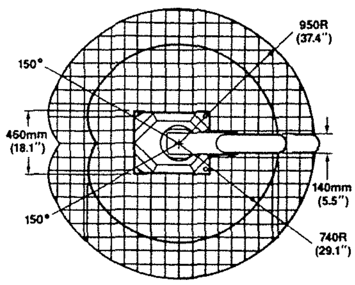
Class 10 configuration provides additional customer benefits:

- Meets IES-RP-CC-006--84-T and ASTM 50-83 clean room standards.
- Centrifugal blower and hosing for particulate evacuation.
- Z-axis in base reduces motion over the work area.
- Internal cable routing reduces contamination and laminar air-flow agitation.

Dimensions

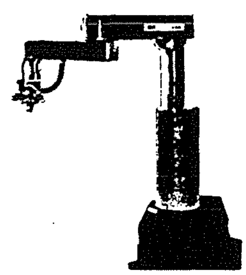


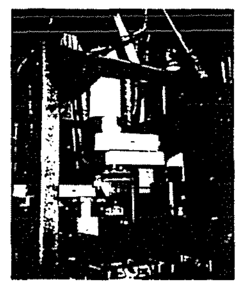




Grid Scale:
1 block = 100mm (3.9")

Specifications





Configuration/ Option Available	Floor Mount Standard and Clean Rm.	Floor Mount- Ext. Reach Standard and Clean Rm.	Inverted Mount* Standard
Payload	44lb (20kg)	22lb (10kg)	44lb (20kg)
Moment (Axis 4)	70 kg x cm	50 kg x cm	70 kg x cm
Repeatability	±0.002" (±0.05mm)	±0.003" (±0.065mm)	±0.002" (±0.05mm)
Work Envelope Maximum Reach	29.1" (740mm)	37.4" (950mm)	29.1" (740mm)
Axis 1 (Base) Rotation Speed	300° 300°/sec	300° 270°/sec	300° 300°/sec
Axis 2 ("Z") Stroke Speed	11.8" (300mm) 27.6"/sec (700mm/sec)	11.8" (300mm) 23.6"/sec (600mm/sec)	11.8" (300mm) 27.6"/sec (700mm/sec)
Axis 3 (Elbow) Rotation Speed	300° 300°/sec	300° 270°/sec	300° 300°/sec
Axis 4 (Wrist) Rotation Speed	540° 540°/sec	540° 540°/sec	540° 540°/sec
Weight-Mechanical Unit	330 lb (150kg)	340 lb (154kg)	330 lb (150kg)

Specifications subject to change without notice.

*Extended Reach Option available.

GMF Robotics

GMFanuc Robotics Corporation
2000 S. Adams Road
Auburn Hills, MI 48057-2090
Literature Request 1-800-634-0189
Main Office (313) 377-7000

GMFanuc Robotics Canada, Ltd.
6395 Kestrel Road
Mississauga, Ont. L5T 1S4
Canada
Main Office (416) 670-5755

GMFanuc Robotics Europe (GmbH)
Heinrich-Hertz-Str. 4
4006 Erkrath-Unterfeldhaus
West Germany
Main Office 011-49-211-250040

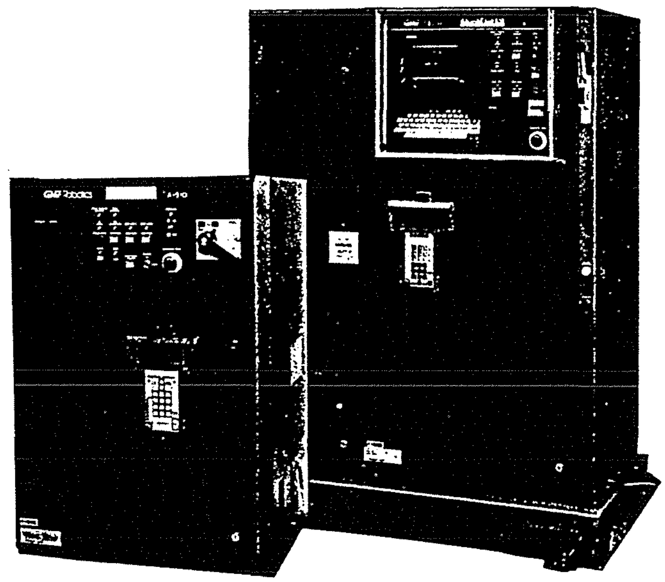
5M 2-90 F & B LITHO IN U.S.A.

GMFanuc Robotics

KAREL® Controller

BASIC DESCRIPTION

The GMF KAREL® Controller is a self-diagnostic robot control system with full program development and edit capabilities. It is available in two enclosure sizes, both of which feature teach pendant, multiple Motorola 68000 microprocessors, two optional I/O interface styles, built-in operator panel, and optional integral or remote keyboard/CRT. This state-of-the-art controller is designed for compatibility with all GMF robot mechanical units. The controller hardware has been developed from proven performance in over 300,000 NC controller and 10,000 robot controller installations.



KAREL features include:

- Powerful KAREL programming language featuring all new, easy to use operator interface.
- Menu driven operator functions
- Advanced Technology Digital Servos
- Up to nine axis simultaneous control
- Optional Integral MAP interface
- INSIGHT™ (Integral vision system option)
- Remote robot operation
- Remote keyboard/CRT option
- Up to 128 discrete digital I/O points with optional modular or fixed I/O interface
- Analog I/O
- Two enclosure sizes, both featuring single door access.
- Auxiliary axis control

KAREL OPERATOR PANEL

The KAREL operator's panel contains system status LED's along with the control switches needed for day-to-day operation of the robot.

The Operator Panel Features Include:

- Long-Life LED system status indicators
- Remote/Local Operation Keyswitch
- Overtravel Release Pushbutton
- Fault Indication LED and Reset Pushbutton
- Programmable "Cycle Start" Pushbutton
- Full Size Emergency Stop
- 2 User Programmable Pushbuttons and LED's
- Calibration Status LED and Calibrate Pushbutton
- Serial Port connections for Optional CRT unit (portable unit only) and disk drive unit or user device (printer, host computer, etc.)

KAREL I/O (INPUTS/OUTPUTS)

The KAREL controller suports either a Modular (rack) style I/O system or a Fixed (card) I/O system. The modular system is designed for applications requiring a wide variety or larger quantity of I/O points. The fixed I/O card is designed for applications with more limited I/O requirements.

Modular I/O System: Supports both analog and digital I/O modules which plug into a rack mounted within the controller enclosure. Modules are available in either 8 or 16 point configurations.

Discrete Inputs:
24 VDC, 120 VAC 50/60 HZ

Discrete Outputs:
24 VDC sink or source 120 and 240 VAC 50/60 HZ

Analog Inputs:
4 channels per module, voltage or current input, 12 bit resolution

Analog Outputs:
2 channels per module, voltage or current input, 12 bit resolution

Fixed I/O System:
Single system board which supports the following I/O on a simple quick disconnect connector:
24 point 24 VDC outputs
32 point 24 VDC inputs

Additional Modular I/O features include:

- Quick disconnect terminal strips
- Individual LED indicators on each I/O point
- Fused 120 VAC and 240 VAC output modules with blown fuse indicators.

KAREL TEACH PENDANT

The all new "T" style hand held teach pendant is used for jogging the robot and teaching positions. A large 8 line by 40 character display provides axis coordinates, robot program data, descriptive user messages and diagnostic information.

Additional features include:
- Ergonomically designed lightweight plastic case
- Integrated "Deadman" safety switch for programmer protection
- Sealed full travel keypad
- Hard-wired Emergency Stop switch
- Backlit LCD Display
- Menu driven function displays

KAREL KEYBOARD/CRT

The optional GMF KAREL Keyboard/CRT is used for programming and system setup of the KAREL controller. It can also be used to display operator messages from a KAREL applications program, as well as diagnostics and status information about a running robot system.

It has the following key features:
- Designed for Industrial Use, Fully Sealed
- Full Action Sealed ASCII Keyboard
- High Resolution 9-inch CRT (built-in), 12-inch CRT (remote)
- 80 Column x 24 Line Display to display operational and robot status information
- Available as a built-in unit (large cabinet only) or as a portable unit that sits conveniently on top of the small enclosure, or on a worktable.
- VT-100 and VT-220 compatibility, terminal emulation for IBM PC, optionally available.

KAREL CONTROLLER CPU (Central Processing Units)

The KAREL controller is based on Motorola 68000 microprocessors, and TMS 32C25digital signal processors for digital servo control.

Hardware features include:
- Digital servo control is used for all servo axes which eliminates temperature drifting and the need for analog adjustments.
- Up to 9 axes of simultaneous control for auxiliary axes. (3 auxilliary axes in addition to the base robot axes).
- Noise immune fiber optic links connect the modular I/O system to the main controller electronics.
- The KAREL controller makes extensive use of VLSI technology. This lowers the chip-count, and improves system reliability.
- Rugged industrial design Bubble Memory has been incorporated to store Controller and User Programs. This permits fast field updating of controller software.
- Up to 4 Mbytes of bubble memory (2.0 Mbytes standard)
- Up to 2 Mbytes of RAM memory(1.5 Mbytes standard)
- Optional Powerfail Recovery support
- Optional integrated grayscale Vision System INSIGHT™ implemented as a backplane plug-in
- Optional MAP interface implemented as a backplane plug-in

KAREL LANGUAGE

The KAREL controller incorporates the KAREL programming language: a general purpose robot and automation programming language which greatly simplifies robot application programming.

Programming features include:
- English-like programming statements.
- Basic and advanced arithmetic functions including trigonometric and logarithmic functions.
- Complete set of program control structures including branching and looping.
- Real-time I/O monitoring and user interrupts.
- Relative motion statements which reduce the number of taught positions.
- Coordinate transforms for position shift, offset, and rotation.
- Continuous path motion.
- English names for positions, variables, and I/O points.
- Operator messages displayed at either the CRT or Teach Pendant.
- User comments for documenting developed programs.

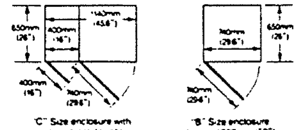
Positional data features include:
- Storage of data in cartesian coordinates.
- Separation of program logic and position point data. This permits:
- Referencing a position multiple times without using additional memory
- Sharing data between multiple programs
- Insert, change, or delete data without altering program logic.
- Use of the same program logic with different sets of positions. This is useful for different parts with a common process.
- Dynamic changing of program and positional data from the keyboard, teach pendant, sensors, or host computers.

SPECIFICATIONS

Ambient Temperature : 0-50 deg C, (32-122 deg F)
Power Requirements : 200 to 575 VAC, 50/60 HZ, 1.7 KWatts (including robot)

Weight:
Large ("C" size) Enclosure 400 Kg. (880 lbs.)
Side Cabinet 140 Kg. (308 lbs.)
Small ("B" size) Enclosure 250 Kg. (550 lbs.)

CONTROLLER CABINET DIMENSIONS



"C" Size enclosure with side cabinet (Height 1700mm (68")

"B" Size enclosure (Height 1300mm (52")

NOTE HEIGHT INCLUDES RISER [200mm (8")]

GMFanuc Robotics

Specifications subject to change without notice

GMFanuc Robotics Corporation
2000 S Adams Road
Auburn Hills MI 48057-2090
Literature Request 1-800-47-ROBOT
Main Office (313) 377-7000

GMFanuc Robotics Corporation
6395 Kestrel Road
Mississauga Ont L5T 1S4
Canada
Main Office (416) 670-5755

GMFanuc Robotics Corporation
Heinrich-Hertz-Str 4
4006 Erkrath-Unterfeldhaus
West Germany
Main Office 011-49-211-250040

GMF Robotics
A-510
Features, Functions and Benefits

DRIVE AND FEEDBACK SYSTEMS

FEATURE	FUNCTION	BENEFIT
FANUC AC SERVO MOTORS	PRIME DRIVER ON ALL AXIS OF ROBOT MOTION	THESE MOTORS ARE SPECIALLY DESIGNED FOR APPLICATION IN INDUSTRIAL ROBOTS AND MACHINE TOOLS. THE TOTALLY ENCLOSED, SELF-COOLED AND BRUSHLESS STRUCTURE GREATLY REDUCES PERIODIC INSPECTION AND MAINTENANCE EVEN IN SEVERE OPERATING CONDITIONS. THE BRUSHLESS DESIGN IS FREE FROM FLASH-OVER OR COMMUTATION LOSS, ALLOWING HIGH TORQUES AT HIGH SPEEDS WITH HIGH EFFICIENCY. • ELEVEN MODELS COVERING A WIDE TORQUE RANGE FROM 1 KG-CM TO 380 ALLOWS FOR CORRECT MATCHING OF MOTOR TO LOAD o PATENTED INTEGRAL STATOR AND CASE DESIGN, ALONG WITH PATENTED ROTOR DESIGN PROVIDES FOR A COMPACT CONFIGURATION, LOW HEAT TRANSMISSION TO THE ROBOT AND HIGH TORQUE TO INERTIA RATIOS FOR QUICK STARTS AND STOPS o PRECISE ROTOR DESIGN ALLOWS FOR SMOOTH ROTATION WITH OUT COGGING o RUGGED FRAME , SHAFT AND BEARING MAINTAIN LONG LIFE AND ACCURATE ALIGNMENT UNDER THE SEVERE LOAD CONDITIONS OF HIGH PEAK TORQUE AT ACCELERATION AND DECELERATION o DIRECT COUPLED PULSE ENCODER EXHIBITS RELIABLE AND STABLE CONTROL CHARACTERISTICS FREE FROM ANY RESPONSE DELAY CAUSED BY DISTORTION OR PLAY IN OF COUPLINGS AND GEARS o THE HIGH ACCURACY PULSE ENCODER PROVIDES SMOOTH ROTATIONAL CONTROL, ASSURING HIGH PRECISION.
DIGITAL SERVO DRIVES	ELECTRONIC DEVICE WHICH CONTROLS THE ELECTRICAL POWER THAT IS SUPPLIED TO THE DRIVE MOTORS	DIGITAL SERVO DRIVES IMPROVE ROBOT PERFORMANCE WITH FASTER POINT TO POINT POSITIONING AND BETTER PATH ACCURACY. THE ANALOG SERVOS USED IN MOST ROBOTS TODAY USE STANDARD "CLASSICAL" TYPE CONTROL THEORY. THEY OPTIMIZE ABOUT FIXED PARAMETERS FOR ONE GIVEN SET OF CONDITIONS. TO CHANGE THESE FIXED PARAMETERS TYPICALLY MEANS MANUALLY "TUNING" PRECISION POTENTIOMETERS IN THE VELOCITY CONTROL UNIT (VCU). THE DIGITAL SERVO AMPLIFIER (DSA) OPERATES UNDER A CONTROL THEORY THAT CLOSES THE CONTROL LOOP AT THE CPU RACK, RATHER THAN AT THE VCU OR DSA. WITH THIS CAPABILITY IT IS POSSIBLE TO ALTER, DIGITALLY, FROM THE CPU, THE PARAMETERS A DIGITAL SERVO AMPLIFIER SETS FOR A GIVEN MOVEMENT. THERE HAS PROBABLY NOT BEEN AN ADVANCE AS SIGNIFICANT IN THE FIELD OF ROBOT MOTION CONTROL SINCE THE SHIFT FROM HYDRALIC DRIVES TO ELECTRIC DRIVES IN ROBOTS
ABSOLUTE PULSE CODERS	DEVICE THAT MEASURES AND TRANSMITS AXIS DRIVE MOTOR POSITION INFORMATION TO THE ROBOT CONTROLLER.	ABSOLUTE PULSE CODERS ALLOW FOR POWERING DOWN OF THE ROBOT SYSTEM WITHOUT THE LOSS OF ROBOT POSITIONAL DATA. IT IS NOT NECESSARY TO CALIBRATE OR "HOME" THE ROBOT ON POWER-UP. SHOULD THE ROBOT AXIS BE MANUALLY MOVED, WITH POWER OFF, THE POSITIONAL DATA WILL NOT BE LOST.
MOTOR CONTROL ACCOMPLISHED BY KAREL CONTROLLER	ALL MOTOR CONTROL IS DIRECTED BY THE GMF KAREL CONTROLLER HARDWARE AND SOFTWARE	THE GMF KAREL CONTROLLER IS A RELIABLE, STATE OF THE ART, FULL FUNCTION ROBOT AND WORKCELL CONTROLLER. PLEASE REFERENCE THE SECTION OF THIS MANUAL THAT ADDRESSES ALL THE FEATURES, FUNCTIONS AND BENEFITS OF KAREL

GMF Robotics
A-510
Features, Functions and Benefits

A-510 MECHANICAL SYSTEMS

FEATURE	FUNCTION	BENEFIT
HIGH SPEED AT HIGH PAYLOAD	MAXIMUM PAYLOAD OF 20 KG (44 LB)	THE RUGGED CONSTRUCTION OF THE MECHANICAL UNIT AND ITS DRIVE SYSTEMS ALLOWS THE A-510 TO HANDLE PAYLOADS THAT ARE BEYOND THE CAPABILITIES OF MOST OTHER SCARA TYPE ASSEMBLY ROBOTS AT SPEEDS THAT ARE AS HIGH IF NOT HIGHER THEN OTHER UNITS IN ITS CLASS.
EVEN HIGHER SPEEDS AT LOWER PAYLOAD	THE SPEED OF THE A-510 CAN BE SET HIGHER AS PAYLOAD DECREASES	AT PAYLOADS OF 7 KG (15.4 LB) A USER ACCESSABLE FUNCTION CAN ALTER THE MOTION CONTROL AND INCREASE THE SPEED OF THE ROBOT TO THE FASTEST IN ITS CLASS.
LARGE WORK ENVELOPE	A LARGER VOLUME OF WORK SPACE ACCESS	THE A-510 CAN ACESS OVER 17 CUBIC FEET OF USABLE SPACE IN PERFORMANCE OF ITS WORK.
INVERTED MOUNTING	THE ROBOT IS CAPABLE OF BEING INSTALLED UPSIDE-DOWN	INVERTED MOUNTING PROVIDES A GREATER WORK ENVELOPE VOLUME THAT CAN BE ADDRESSED BY THE ROBOT, AS IT IS ABLE TO "DOUBLE BACK" ON ITSELF, AND PERFORM WORK IN AREAS THAT WOULD OTHERWISE BE OCCUPIED BY THE ROBOT ITSELF.
HOLLOW JOINT CONSTRUCTION	ALLOWS FOR INTERNAL ROUTING OF ELECTRIC AND PNEUMATIC LINES	THIS REMOVES THE CHANCES OF LINES BECOMING ENTANGLED IN OTHER FIXTURING IN THE ROBOT WORK ENVELOPE, AS WELL AS PROVIDING A "CLEAN" LOOK TO THE ROBOT AND THE WORKCELL.
'Z' AXIS IN BASE	'Z' AXIS DRIVE MOTOR AND MECHANISM IS LOCATED AT BASE OF ROBOT AS OPPOSED TO AT LAST AXIS	THIS DESIGN ALLOWS FOR A LARGE, 300 MM, 'Z' AXIS STROKE WHILE PROVIDING FOR A LOW PROFILE CONFIGURATION AT THE FOURTH, OR WRIST, AXIS. THE LOW PROFILE IS AN ADVANTAGE IN TIGHT WORK SPACES WHERE OBSTACLE AVOIDANCE BECOMES A CONCERN. THIS FEATURE ALSO AIDS IN THE CLEAN APPEARANCE OF THE ROBOT.
SPIRIOD GEAR DRIVE TRAIN	THESE GEAR SETS DRIVE THE 'U' (3RD) AND ALPHA (4TH) AXIS	THE SPIROID GEAR FORM OFFERS LOW BACKLASH CHARACTERISTCS IN A PROVEN AND DEPENDABLE GEAR SET. THIS TECHNOLOGY HAS BEEN USED IN OTHER HIGH RELIABILITY APPLICATION, INCLUDING USE FOR THE MILITARY.
MODULAR DESIGN	MAJOR STRUCTURAL AND DRIVE ELEMENTS ARE INDEPENDENT MODULES	THE MODULAR CONSTRUCTION OF THE A-510 ALLOWS FOR EASY REMOVAL OF THE SEPARATE COMPONENTS FOR EITHER MAINTENANCE OR RECONFIGURING TO AN INVERTED GEOMETRY.
COMMONALITY OF COMPONENTS	CONSTRUCTED WITH ONE COMMON ENCODER SIZE AND ONE COMMON MOTOR SIZE FOR THREE OF THE FOUR AXIS	THIS FEATURES ALLOWS FOR A LOWER INVENTORIES OF SPARE PARTS FOR REPAIR AND A COMMON DRIVE TECHNOLOGY FOR SERVICE FAMILIARITY.
INVERTED FLANGE MOUNTING	CAN BE MOUNTED ON THE FLOOR (UP-RIGHT) WITH FACEPLATE FACING UP	MANIPULATION OF THE WORKPIECE CAN BE ACCOMPLISHED FROM BELOW WITH NO MODIFICATION TO THE ROBOT.
APPLIES HIGH VERTICAL FORCES	CAPABLE OF "PUSHING DOWN" ON PARTS	THE A-510 HAS THE ABILITY, UNLIKE MANY ROBOTS, TO EXERT THE SAME FORCE OF 20 KG WHETHER IT IS APPLIED IN AN UPWARD OR DOWNWARD DIRECTION. THIS IS A BENEFIT WHEN PARTS MOST BE LIGHTLY PRESSED INTO POSITION.

A-510 MECHANICAL UNIT

This chapter describes the A-510 mechanical unit, including its specifications and motion ranges. Complete details on the mechanical unit are provided in the *A-200/A-510 Maintenance and Troubleshooting Reference Manual.*

GENERAL SPECIFICATIONS

The GMF A-510 Robot is a four-axis horizontal articulated type robot powered by brushless AC servomotors. All four axes are controlled simultaneously.

A-510 Mechanical Unit General Specifications

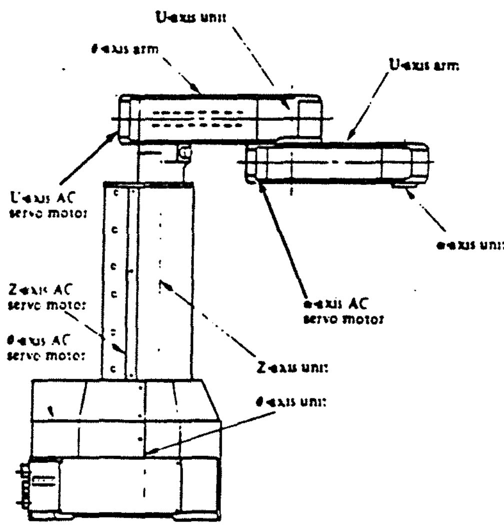
ITEM		SPECIFICATIONS	REMARKS
Coordinate System		Horizontal Articulated Type	
Controlled Axes		Theta, Z, U, Alpha.	
Motion Range (Maximum Speed)	Theta Axis (rotation)	-150° to +150° (300°/second)	
	Z Axis (up/down)	300 mm (700 mm/second)	
	U Axis (rotation)	-150° to +150° 300°/second)	
	Alpha Axis (faceplate rotation)	540° (540°/second)	

A-510 Mechanical Unit General Specifications
(Continued)

ITEM	SPECIFICATIONS	REMARKS
Maximum Load Capacity at Wrist	20 kg 7 kg for faster acceleration and deceleration	
Payload Inertia (kg x cm x sec^2)	0.7 (about center of faceplate)	
Repeatability	±0.05 mm (±0.025 mm based on JIS B6330 testing)	
Drive Mechanism	Electric Servo drive using AC servo motor	
Installation	Floor mount or ceiling mount	
Mastering Fixture	Available	Option
Air Control Set	Available	Option
Installation Environment	Ambient temperature: 0 to 45 °C Ambient humidity: Usual: Less than 75%RH Short period (one month or less): Less than 95%RH Condensation free Vibration: Less than 0.5 G	
Cable		
Power drop to controller (220-550 VAC, 3-Phase)	Customer-supplied	
Robot connection cables (controller to robot)	Standard: 7 meters Optional: 14 meters	
Teach Pendant to controller	Standard: 10 meters Optional: 20 meters	
Remote CRT/KB to controller	Standard: 7 meters Optional: 14 meters	

Major Components

Major components of the A-510 mechanical unit are shown



A-510 Major Components

ROBOT MOTION

Robot motion control is via the servo control system, which controls the drive motors that position the individual robot axes. Position control is done through position encoders, which monitor the position of the drive motor shaft. Some robot systems use incremental encoders; others use absolute pulse coders. The A-510 uses absolute pulse coders (APCs).

This section contains the following information on robot motion specifications:

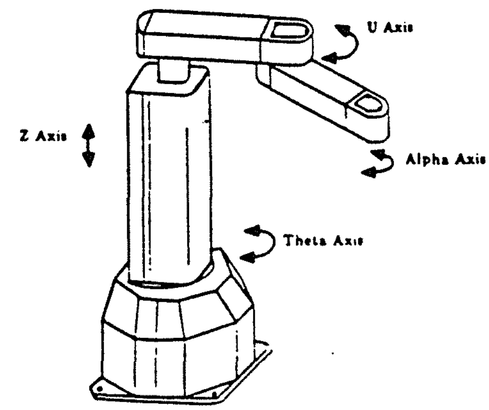
- Motion of controlled axes
- Motion range (work envelope)
- Motion limits
- Positioning repeatability

NOTE

Mechanical unit axes are designated in Greek and English letters (Theta, Z, U, and Alpha). However, the KAREL controller designates axes as 1 through 4:

1 = θ (Theta)
2 = Z
3 = U
4 = α (Alpha)

Motion of Controlled Axes



A-510 Basic Axes

The basic axes of the A-510, as shown

- Z Axis (up/down)

  The Z axis can be continuously moved within a vertical range of 300 mm.

- Theta Axis (rotation)

  The Theta axis can be continuously rotated within a lateral range of 300 degrees.

- U Axis (inner arm rotation)

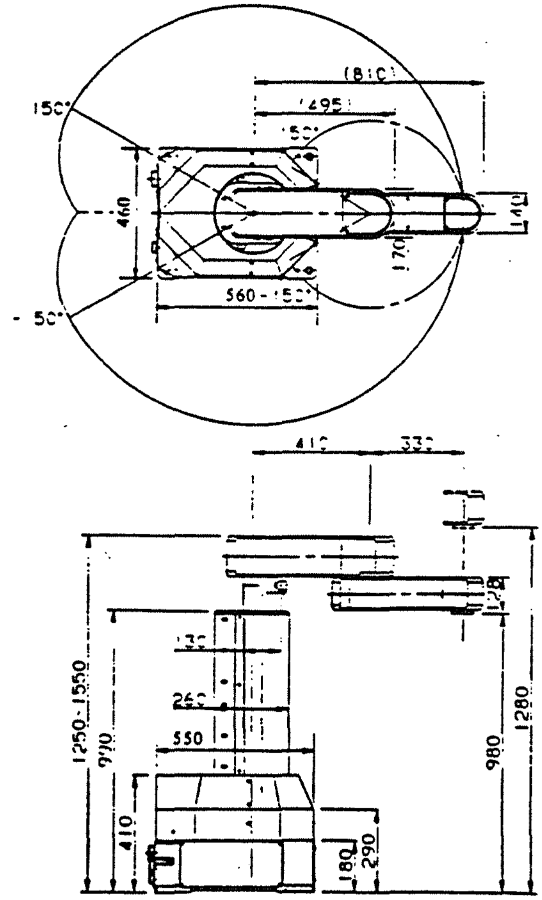
  The U axis can be continuously rotated within a lateral range of 300 degrees.

- Alpha Axis (faceplate rotation)

  The Alpha axis can be continuously rotated within a range of 540 degrees.

Motion Range

The motion range (work envelope) of the A-510 robot is shown



A-510 Robot Motion Range

Motion Limits

Because the axis motions must be limited to the specified motion ranges, the controller monitors each axis to detect axis overtravel. As shown in Figure a limit switch guards each axis to prevent it from exceeding its motion range.

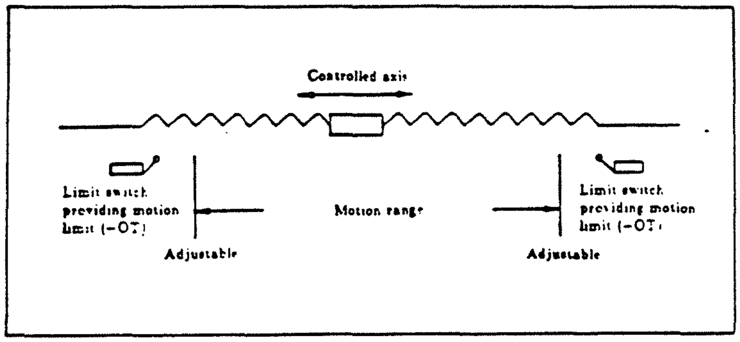


Figure Motion Limit Switches

Once the robot is mastered, an axis cannot exceed its motion range and trip its overtravel switch unless there is a failure of the servo system or a system error causing loss of the mastering information. The overtravel switches prevent the robot axis from hitting the hard stops at the extremes of the mechanical motion limit.

NOTE

During shipment and prior to installation the robot is in an overtravel condition.

The 'U' (third) and Alpha (fourth) axis on the A-510 ARE NOT protected by overtravel limit switches. They ARE protected by software limits ($UPPERLIMS AND $LOWERLIMS). They are mechanically capable of continuous rotation, although this would eventually result in damage to cabling.

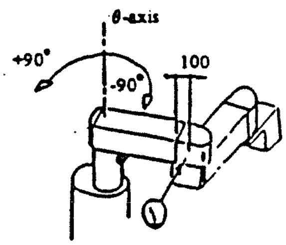
Repeatability Specifications

Positioning repeatability is the value obtained by measuring the position variance when the same motion is repeated while applying the maximum load capacity to the wrist flange.

The positioning repeatability of the A-510 robot is ±0.05mm.

- Theta Axis (rotation)

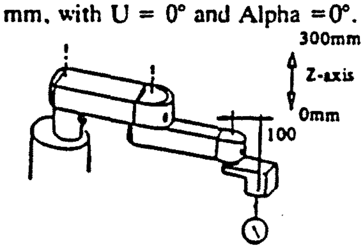
  The positioning repeatability of the Theta axis is measured in the Theta-axis direction, at a point on the U-axis center, when the Theta axis is moved from Theta = -90° to Theta = 90° with Z = 0 mm, U = 90°, and Alpha = 0°.



A-510 Theta-Axis Positioning Repeatability

- Z Axis (up/down)

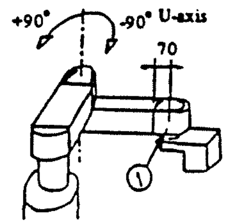
  Positioning repeatability of the Z axis is measured along the Z-axis direction when the wrist is moved from Z = 0 mm to Z = 300 mm, with U = 0° and Alpha = 0°.



A-510 Z-Axis Positioning Repeatability

- U Axis (inner arm rotation)

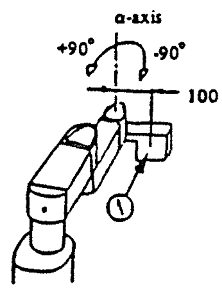
  The positioning repeatability at the rotation center of the Alpha axis along the U-axis direction is measured when the wrist is moved from U = -90° to U = 90°, with Z = 0 mm and Alpha = 0°.



A-510 U-Axis Positioning Repeatability

- Alpha Axis (faceplate rotation)

  Positioning repeatability at 100 mm from the center of the Alpha axis along the Alpha-axis direction is obtained when the wrist is moved from Alpha = -90° to Alpha = 90°, with Z = 0 mm and U = 0°.



A-510 Alpha-Axis Positioning Repeatability

WRIST LOAD SPECIFICATIONS

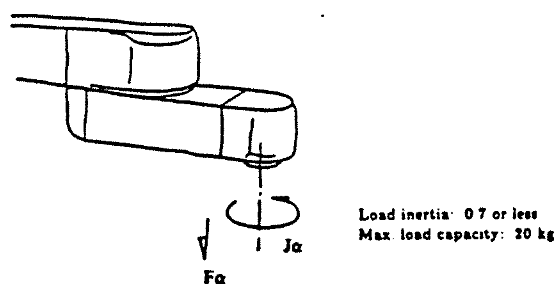
Wrist load refers to the total weight. including the end effector and workpiece, which can be supported by the faceplate.

The maximum allowable wrist load of the A-510 is 20 kg. A payload of 7 kg or less will permit faster acceleration and deceleration, with a corresponding decrease in cycle times. The maximum payload is selected by the adjustment of a system variable. This must be done with the assistance of GMF.

Wrist load specifications for the A-510 are listed in Table 2-3. Figure 2-9 shows wrist load conditions.

A-510 Wrist Load Specifications

ITEM	SPECIFICATION
Wrist Load	20 kg
Wrist Load Inertia about Alpha Axis (kg x cm x sec^2)	0.71
Wrist Static Load Moment about Center of Faceplate (kg x cm)	70



A-510 Wrist Load Specifications

INSTALLATION SPECIFICATIONS

Table provides installation specifications for the A-510.

A-510 Robot Installation Specifications

ITEM	SPECIFICATION		
Electrical			
Input Voltage	220/240/380/415/460/480/500/550/575VAC+10%,-15%		
Power Consumption	Average 1 kW		
Air Pressure			
Feed Pressure	5 - 7 kg/cm^2 (set pressure 5 kg/cm^2)		
Air Consumption	Maximum peak 150 N liter/min (Note 1)		
Physical			
Weight of Mechanical Unit	About 250 kg		
Weight of Control Unit	B Size About 250 kg	C Size About 400 kg	Side Cabinet About 140 kg
Dimensions	Refer to Section 5.2		
Environment			
Allowable Ambient Temperature	0 - 45 degrees C		
Allowable Ambient Humidity	Usual: Less than 75% RH Short period (one month or less): Max 95%RH or less (Condensation free)		
Atmosphere (Note 2)	Free of corrosive gases		
Vibration	Less than 0.5 G		

NOTE 1: This value indicates the maximum capacity of the air control set. Adjust the flow to be less than this value.

NOTE 2: Contact your GMF Service Representative if the robot is to be used in an environment where it will be exposed to any of the following:

- Severe vibration
- Heavy dust contamination
- Cutting oil splash
- Contamination from any other substance

HARDWARE DIMENSIONS

Dimensions given are for the units themselves. An additional area must be set aside to allow for movement around the outside of the operating envelope.

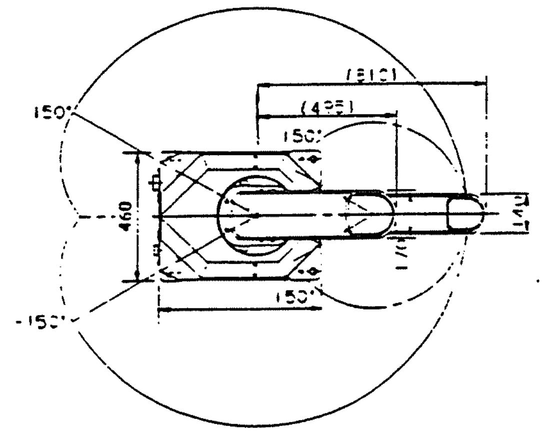
Dimensions for the mechanical unit, controller, and faceplate are in millimeters.

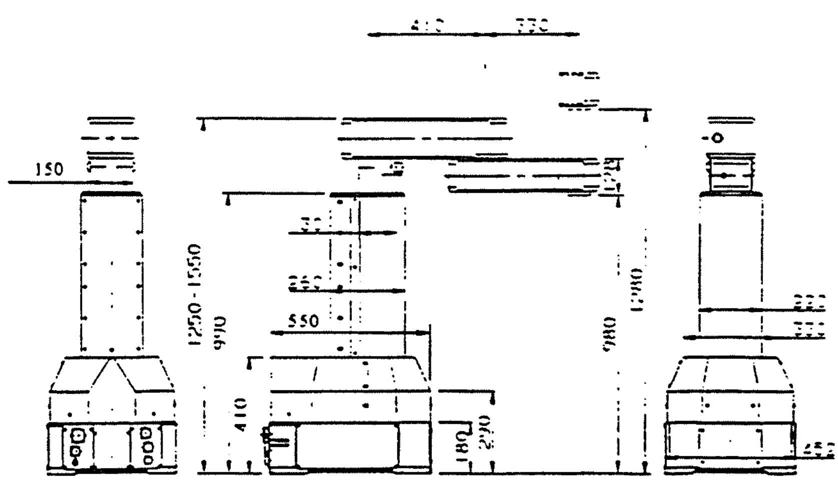
Mechanical Unit

Figure shows the external dimensions (in millimeters) of the A-510 mechanical unit.

NOTE

The robot must be installed in an area clear of objects that could interfere with the robot motion.



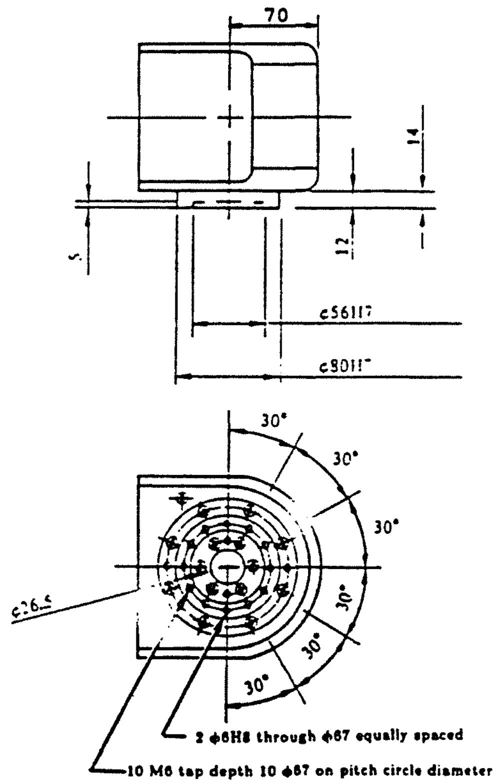


A-510 Mechanical Unit Dimensions

End-Effector Mounting Face Dimensions

This section describes the dimensions of the A-510 end-effector mounting face.

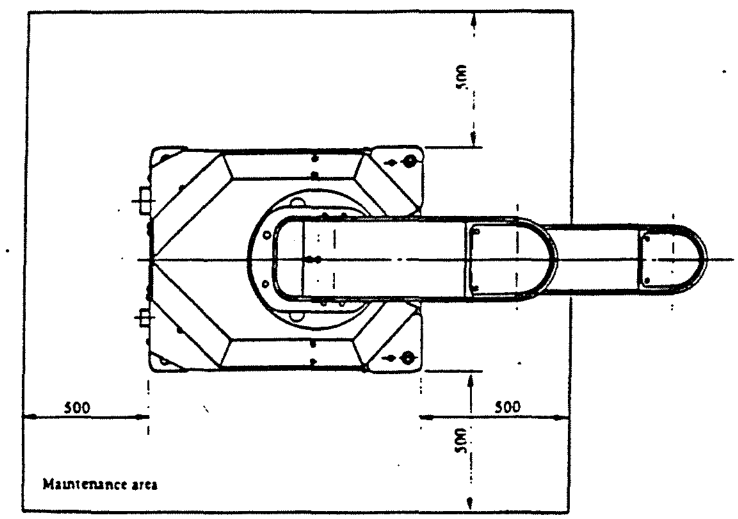
Position the end effector using two ϕ6H8 reamer holes and mount it using 10 M6 tapped holes. The length of the M6 bolts should be 10 mm or less.



End-Effector Mounting Face - A-510

Maintenance Area

Keep adequate space around the mechanical unit and controller clear for maintenance. The maintenance area required for the A-510 is shown in Figure



A-510 Maintenance Area

TRANSPORTATION AND PRE-INSTALLATION

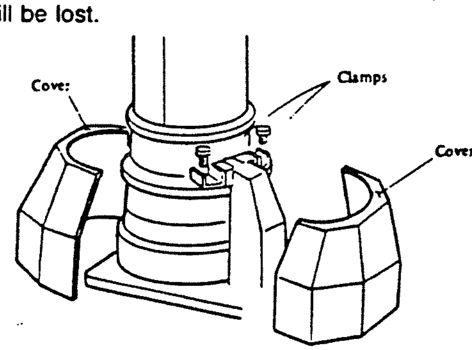
This section describes techniques for transporting the robot and provides pre-installation requirements.

Before transporting the A-510 robot, perform the following procedure:

1. Remove the end effector.
2. Orient the Theta axis toward the center front.
3. Set the Z axis to the lowest position.
4. Set the U axis so that there is approximately 10 mm clearance between the outer arm casting and the Z-axis housing.
5. Secure the Theta axis in place using the shipping clamps provided with initial delivery. Install shipping clamps under the Theta-axis drive unit cover, as shown
6. Disconnect the cable from the KAREL controller.

CAUTION

Do NOT disconnect the battery cables during transportation and installation of the mechanical unit. If the battery cables are disconnected the stored position data will be lost.



Shipping Clamps - A-510

Transportation Methods

The A-510 mechanical unit is furnished with red shipping brackets mounted to the robot base. These shipping brackets allow the robot to be transported by crane or forklift. Brackets may be left in place during installation and operation of the robot.

The A-510 mechanical unit and the KAREL controller can be moved by crane or forklift in the following manner:

Transportation Using a Crane:

Mount four M20 eye bolts to the shipping brackets and move the robot using four ropes or cables as shown in Figure 5-9. To avoid damaging the robot, do not apply external force to the main body of the robot.

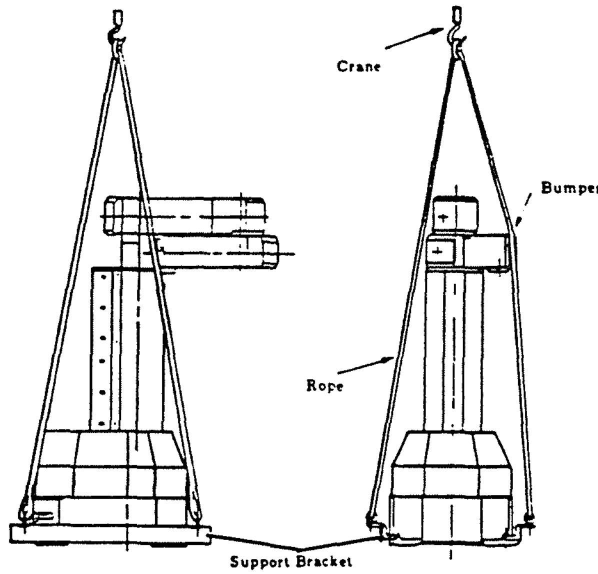
Controller eyebolts are located on the top of the cabinet.

CAUTION

Use a bumper or shielding device to protect the U-axis arm from damage resulting from contact with the rope or cable used in lifting.

Transportation Using a Forklift:

To move the robot with a forklift, the forklift must engage the shipping brackets to a depth that will allow the robot to remain stable while moving.



A-510 Transportation Using a Crane

Pre-Installation

Site Preparation

The base of the robot is pre-drilled with four ϕ18 mm through holes for installation. During installation, four anchor bolts pass through the base to secure it to a prepared surface.

Prepare a foundation as shown in Figure and mount the robot using customer-supplied anchor bolts and leveling plates as shown in Figure The foundation depth is determined by the size of the anchor bolts.

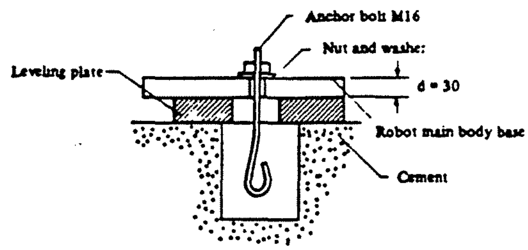


Figure Foundation Installation Diagram

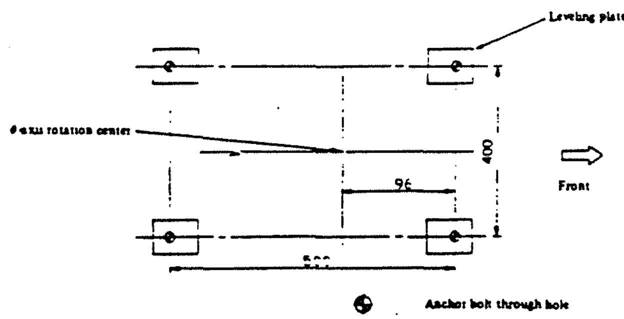


Figure A-510 Base Diagram

Ceiling Installation

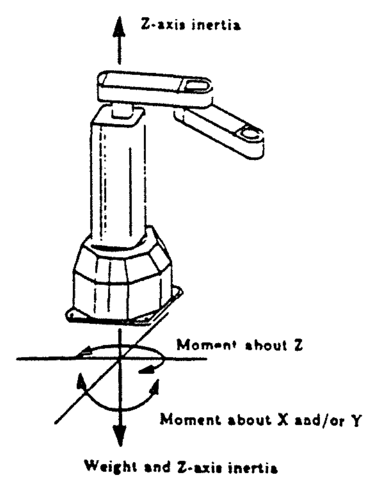
The A-510 mechanical unit can be inverted and mounted upside down after modification by the customer. Modification procedures are detailed in the *A-200/A-510 Maintenance and Troubleshooting Reference Manual.*

For ceiling installation of the A-510 mechanical unit, provide support appropriate to the weight and forces exerted by the robot, end effector, and workpiece during operation.

Table provides baseplate loading specifications for the A-510 mechanical unit.

A-510 Baseplate Loading Specifications

ITEM	SPECIFICATION
Z-axis Inertia	333 kgf
Moment about Z (kg x cm)	5700
Moment about X and/or Y (kg x cm)	24500
Weight and Z-axis Inertia	483 kgf



Base Dimensions

Figure shows dimensions of the A-510 robot base.

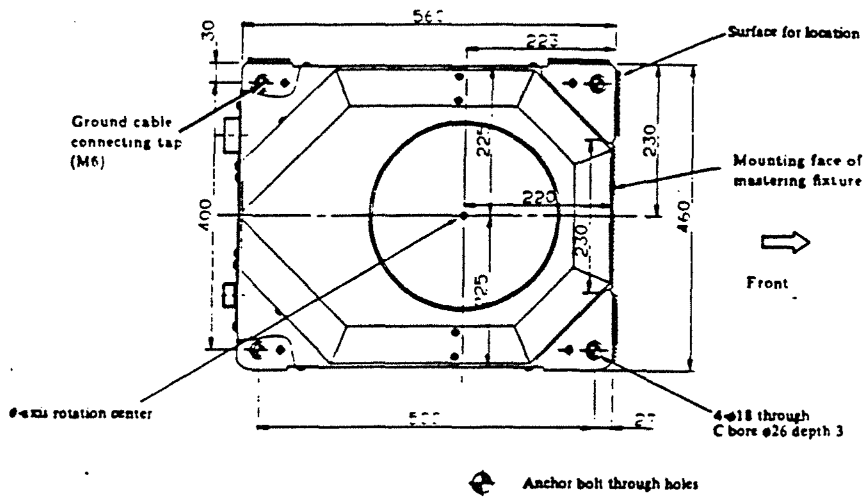
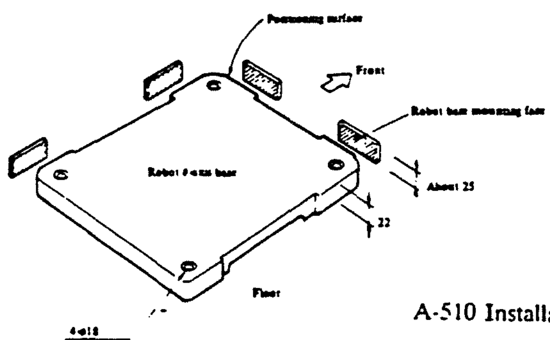


Figure A-510 Robot Base Dimensions

Apply the face indicated by "xxx" in Figure to the prepared reference face or positioning pins, and mount the robot securely. The mounting face for the mastering fixture is indicated by "///". Do not install a projection on this surface which is used for mastering.



A-510 Installation Plate

The robot base has machined surfaces for precise positioning of the mechanical unit and for mounting the mastering fixture. If the path taught to one robot must be transferred to a new robot when the robot mechanical units are exchanged, prepare an installation plate as shown in Figure

The A-510 Extended Reach Option

The GMF A-510 Robot has available an Extended Reach Option that can be supplied to enhance the work envelope capabilities of the standard A-510 robot.

The Extended Reach Option increases the maximum radius of the work envelope from 740mm (29.1 in.) to 940mm (37 in.). This increase is accomplished by increasing the length of both the first (110mm increase) and second (100mm increase) 'arm' of the robot.

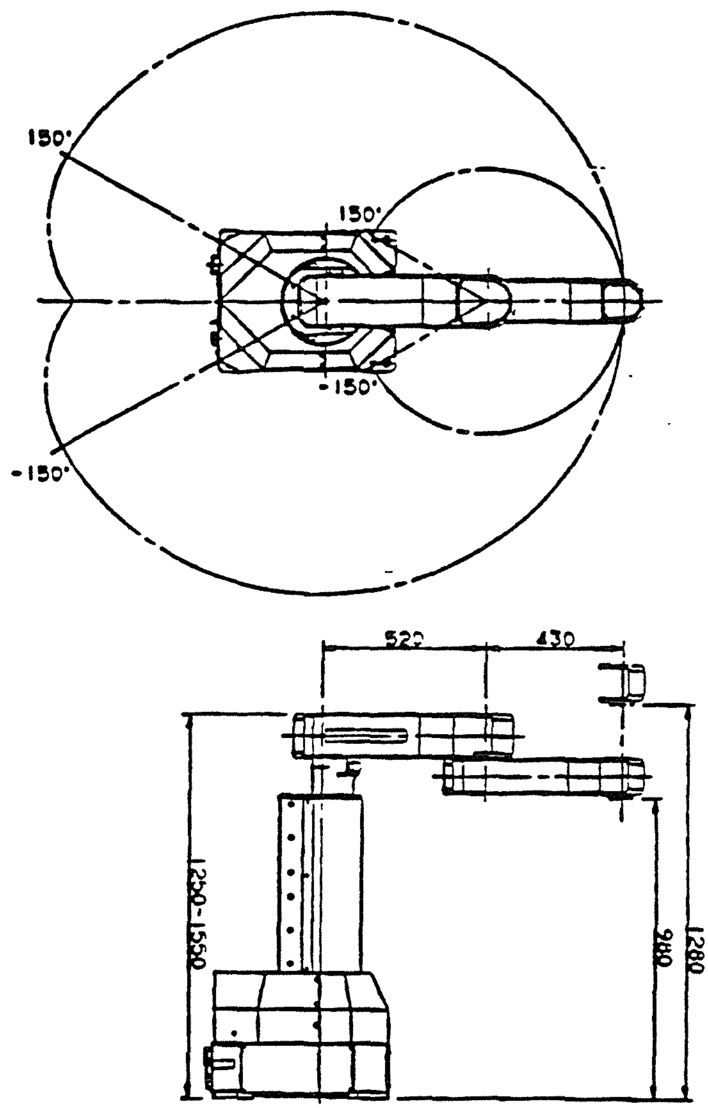
Some compromises must be made in other performance factors to accomplish the expanded work envelope of the Extended Reach Option. The most notable effect is the altered payload capability, which is decreased from 20 kg (44 lb.) to 10 kg (22 lb.). While this change in payload may seem dramatic, a large portion of the applications for which the standard A-510 is used have required even less payload capability.

The utilization of the standard A-510 has often been in applications requiring either its high speed and/or its excellent repeatability. In both of these areas the Extended Reach Option holds close with the standard A-510. The first and third axis perform at 270 degrees/second while the 'Z' axis is controlled to 600mm/sec. The forth, or wrist axis is maintained at its standard 540 degrees/second. The repeatability of the A-510 Extended Reach Option is held to a respectable +/- 0.065mm (.003in).

Overall, the A-510 with the Extended Reach Option presents itself as an excellent choice for those applications requiring a high speed and highly repeatable robot, at lower payloads, with the increased work envelope offered by this option.

ITEM		STANDARD SPECIFICATION	EXTENDED SPECIFICATION
REACH	First Arm Second Arm Maximum	410 mm 330 mm 740 mm	520 mm 430 mm 950 mm
MAXIMUM TRAVEL	Theta axis 'Z' axis 'U' axis Alpha axis	300 degrees 300 mm 300 degrees 540 degrees	300 degrees 300 mm 300 degrees 540 degrees
MAXIMUM SPEED	Theta axis 'Z' axis 'U' axis Alpha axis	300 degrees/sec 700 mm/second 300 degrees/sec 540 degrees/sec	270 degrees/sec 600 mm/second 270 degrees/sec 540 degrees/sec
REPEATABILITY		+/-.040 mm	+/-.065 mm
MAX. PAYLOAD OFFSET		35 mm	50 mm
MAX. PAYLOAD OFFSET		20 kg	10 kg

chh 15feb88



A-510 with Extended Reach Option

The A-510 Class 10 Cleanroom Upgrade Option

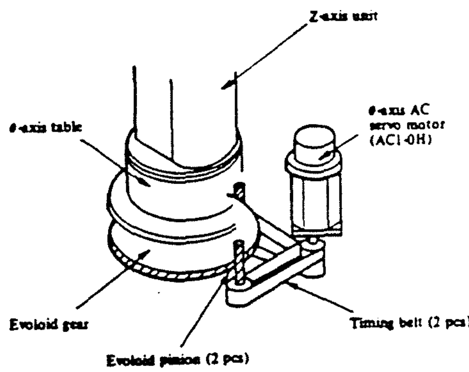
The GMF A-510 Robot has available a Cleanroom Upgrade Option that can be supplied to allow the robot to work in a class 10 cleanroom environment.

Supplied with the Class 10 Cleanroom Upgrade Option are all necessary mechanical unit modifications, and the accessory hardware needed to achieve the class 10 rating for the robot. The accessory hardware includes a centrifugal blower and the connecting hose to the mechanical unit.

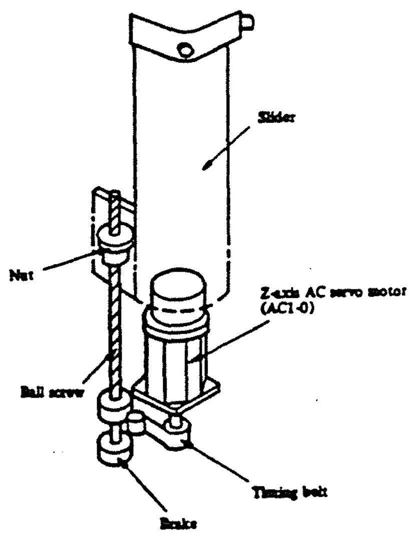
GMF has tested the A-510 with the Cleanroom Upgrade Option under the auspices of an independent cleanroom certification consultant, Dr. Phillip R. Austin and PEL Associates, to meet the requirements of Federal Standard 209C.

Utilization of this option requires no downgrading of any of the operational characteristics or performance of the standard A-510.

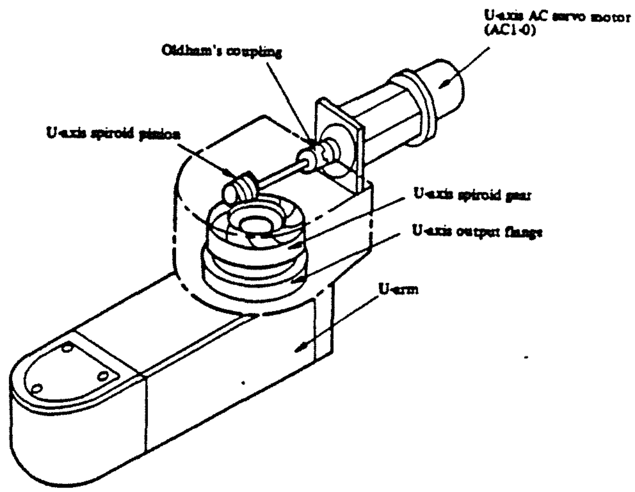
A-510 DRIVE TRAIN



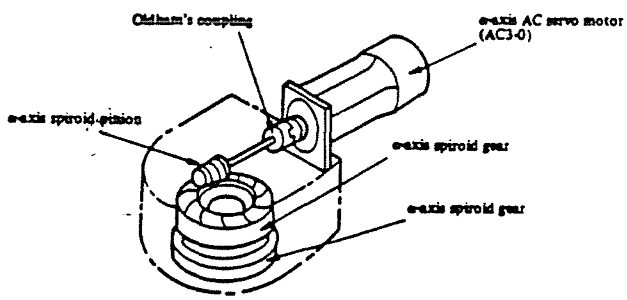
A-510 THETA (1st) AXIS
DRIVE TRAIN DESCRIPTION



A-510 'Z' (2nd) AXIS
DRIVE TRAIN DESCRIPTION



**A-510 'U' (3rd) AXIS
DRIVE TRAIN DESCRIPTION**

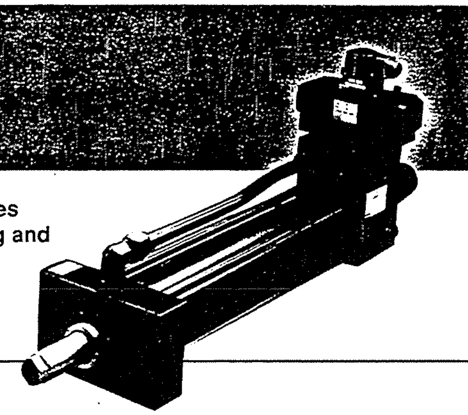


**A-510 ALPHA (4th) AXIS
DRIVE TRAIN DESCRIPTION**

D.2 - Longitudinal Positioning System

D.2.1 - Manufacturer's Specifications

Actuators
Series PLA



The PLA actuator is an integrated assembly that eliminates transducer mounting brackets, valve manifolds, plumbing and other items associated with using separate components. The versatility of the Series PLA allows you to design an actuator for accurate position control.

Features

- Rugged industrial–grade servo valve, pad–mounnted for maximum drive stiffness
- Simplified machine design with integrated components
- Standard JIC mounts available
- Maximum Operating Pressure: 210 bar (3000 PSI), 185 bar (2700 PSI) for 4 inch bore

Available Sizes

The actuator is available in any stroke length up to 36 inches:

1) In three standard mounting styles:

NFPA MT1	Head Trunnion
NFPA MS2	Side Lug
NFPA ME5	Head Rectangular

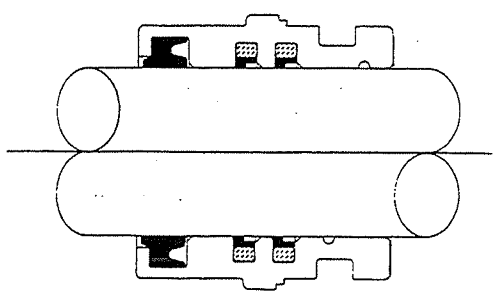
2) In five bore/rod diameter combinations:

Bore (Inches)	Rod Diameter (Inches)
2.0	1.375
2.5	1.375
3.25	1.375
4.0	1.750
5.0	2.000

For other actuator sizes or mounting styles, consult the factory.

Low Friction Gland

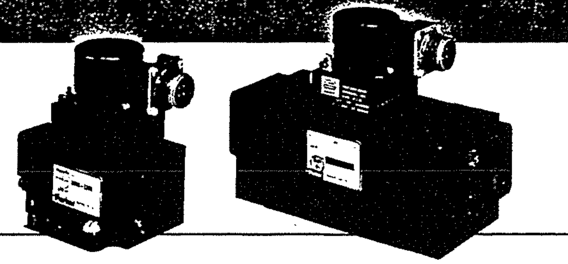
The PLA actuator is provided with a standard low friction gland assembly which features Parker's (screw–in) Jewel Gland for easy service. Below is a cross–sectional representation of a Parker PLA Series low friction gland. The dual step seals are of a bronze–filled PTFE material. The expanders are a fluorocarbon elastomer.



Servo Valves

Series BD

The "BD" Series servo valves provide high resolution in the control of position, velocity and force in motion control applications.



Features

- Rugged, reliable, trouble–free operation
- Reduced contaminant sensitivity
- Linear flow gain characteristics
- Intrinsically safe model available
- Explosion proof model available

Specifications

Rated Flow @ 1000 PSID 3.78 – 151.2 LPM (1.0 – 40 GPM)

Linearity ≤ 5%

Hysteresis ≤ 3%

Threshold ≤ 0.5%

Pressure Gain (Blocked Port) Typical 30%
(% change in pressure per 1% change in input command)

Null Shift
with Temperature < ± 2% per 38°C (100°F)
with Supply Pressure < 2% per 70 bar (1000 PSI)

Internal Leakage (Standard Spool Lap)
BD15 — 1.51–2.08 LPM (.40–.55 GPM)
BD30 — 2.08–2.46 LPM (.55–.65 GPM)

	Model	Typical Step Response Input
Step Response Input	BD15	10 to 90%, 26ms
	BD30	10 to 90%, 30ms
Frequency Response	BD15	50 Hz @ 90°
	BD30	35 Hz @ 90°

Pressure Ranges
For optimum performance, Parker Servo Valves are designed to operate within specific system supply pressure ranges.

System Supply Pressure

180–210 bar (2600–3000 PSI)	48–66 bar (700–950 PSI)
138–172 bar (2000–2500 PSI)	14–45 bar (200–650 PSI)
95–133 bar (1400–1950 PSI)	0–210 bar (0–3000 PSI)
68–90 bar (1000–1300 PSI)	

Filtration SAE Class 3 or better, ISO Code 15/12

Quick Reference Data Chart

Model	Flow Capacities @ 1000 PSID LPM (GPM)	Max. Pressure Rating	Max. Tank Pressure	Electrical Input (Std.) Single Coil	Coil Resistance (Std.) Each Coil	Weight
BD15	3.78 (1.0), 9.45 (2.5), 18.9 (5.0), 37.8 (10.0), 56.7 (15.0), 75.6 (20.0)	210 bar (3000 PSI)	14 bar (200 PSI)	60 mA (Full Flow)	60 Ohms	1.16 kg. (2.6 lbs.)
BD30	75.6 (20.0), 94.5 (25.0), 113.4 (30.0), 151.2 (40.0)	210 bar (3000 PSI)	14 bar (200 PSI)	60 mA (Full Flow)	60 Ohms	2.86 kg. (6.3 lbs.)

Transducers

This magnetostrictive type linear transducer precisely senses a magnet mounted to the rear of the cylinder piston in order to measure position with high accuracy.

Features

- Non–contacting
- Integral protected mount
- High response — standard ruggedized design protects electronics from mechanical and environmental noise

Specifications

Input Voltage ±12 VDC to ±15 VDC

Power Requirements
- Transducer Only — ±15 VDC @ 100mA max., 25mA min. (current draw varies with magnet, position, maximum draw occurs when magnet is 50.8mm (2 in.) from the flange and min. update time is being used.
- Transducer for Digital Option — +15 VDC @ 150mA max., 75mA min., –15 VDC @ 100mA max., 25mA min.
- Transducer for Analog Output – ±15 VDC @ 200mA ±1% Note: max. current draw

Hysteresis 0.02mm (0.0008 in.) max.

Frequency Response Stroke dependent, 200 Hz to 50 Hz is typical for lengths of 304.8mm (12 in.) to 2540mm (100 in.) respectively. Wider response is available. For digital systems, output is updated at discrete intervals.

Nonlinearity <0.05% of full stroke; min. of ±0.05mm (±0.002 in.)

Repeatability <0.001% of full stroke or ±0.0025mm (±0.0001 in.), whichever is greater

Temperature Coefficient
- **Transducer** Less than .005mm/°C + [0.21ppm/°C per mm of full stroke] (Less than 0.00011 in./°F + [3ppm/°F per in. of full stroke])
- **Analog Output Module** 36ppm/°C (20ppm/°F)

Operating Temperature
- **Head Electronics** –40 to 66°C (–40 to 150°F)
- **Transducer Rod** –40 to 85°C (–40 to 185°F)
- **Analog Output Module** –40 to 82°C (–40 to 180°F)

Operating Press. FM certified to 210 bar (3000 PSI) continuous; 550 bar (8000 PSI) static

Output (absolute)
- **Analog** 0 to +10 VDC (other voltages available, consult factory rep.)
- **Digital** TTL level, nominal 0 and 5 VDC, true high, parallel transmission.

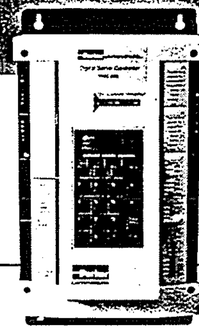
Output Impedance 10 Ω

Velocity Output (optional) 0 to ±10 VDC, pos. traveling away from the transducer head assembly, neg. traveling towards the head assembly.

Digital Version with User Supplied Controls

Stroke mm	(inches)	Number of Recirculations
25.4–152.4	(1–6)	16
177.8–584.2	(7–23)	12
609.6–736.6	(24–29)	8
762.0–914.4	(30–36)	4

Digital Control System
Motion Controllers/Series PMC



The Parker PMC Series controllers combine the output of high performance linear position transducers with advanced digital servo control to provide the utmost in precision motion control.

Functional Description

The Parker PMC series motion controller is designed as a complete stand–alone unit. No additional circuitry is required to implement two axes of feedback servo control. The controller is available in single or dual axis models.

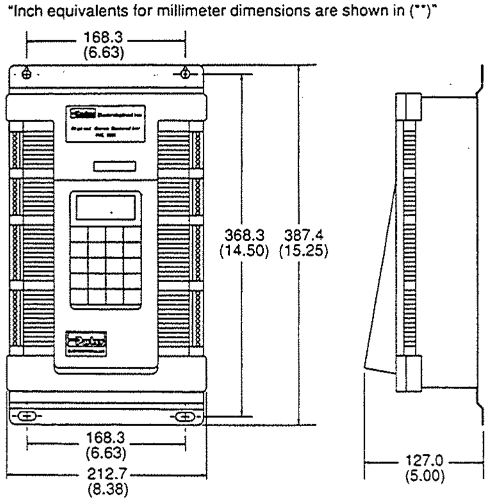
An integral keypad and LCD display are used to set up control parameters, to enter program steps, to monitor functions, to run programs, or to jog an axis directly.

For each axis, the PMC provides the following connections:

- A Temposonics transducer input interface.
- A servo output interface.
- Two limit inputs and a drive enable output.
- A Run input, to start a selected program for the given axis.
- Three program select inputs, to select a program for the axis.
- All connections except the ac power input use removable terminal blocks.

Dimensions

"Inch equivalents for millimeter dimensions are shown in ("")"

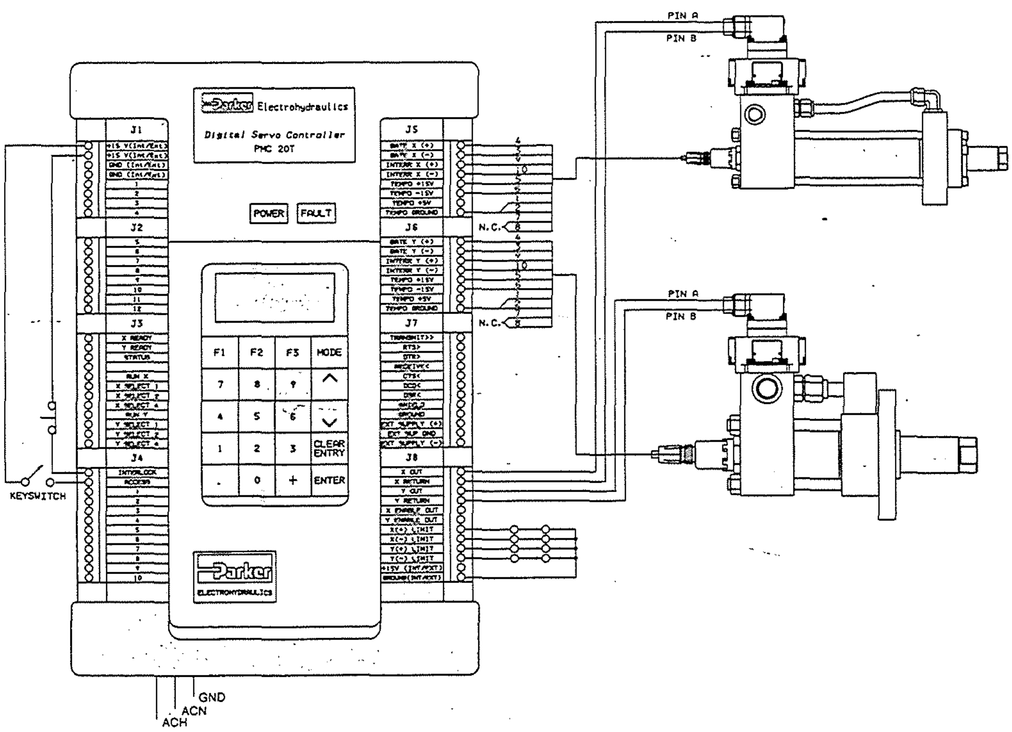


PMC10T/20T

Specifications

Processor	16–bit 80188 CPU
Internal Conversion	12–bit D/A servo command conversation for resolution to ±.05% of full scale
Servo Output	±10 VDC, differential, standard; 0 to +10 VDC, ±5 VDC, sgl. ended or differential, & ±50 mA jumper selectable, other current outputs available
Control Algorithm	Proportional, integral, derivative (PID), dbl. derivative (acceleration), & feed forward loop compensations — 2ms loop update time
I/O	14 input and 5 output dedicated functions; 12 inputs and 10 outputs user programmable; optical isolation to 7500 volts
Operator Panel	20–key pad with 3 software–defined function keys
Display	4 lines by 16 character backlit LCD
Power Supply	Built–in +5, –15 and +15 VDC outputs
Serial Interface	RS232, RS485 for up to 8 units in a multi–drop network, each with its own ID
Weight	3.4 kg. (7.5 lbs.)
Power Requirements	117 VAC ±10% (220 VAC available), 47 to 63 Hz, 1 amp continuous. 5 amp in rush
Operating Environment	0 to 50°C (32 to 122°F); 10 to 90% humidity, non–condensing

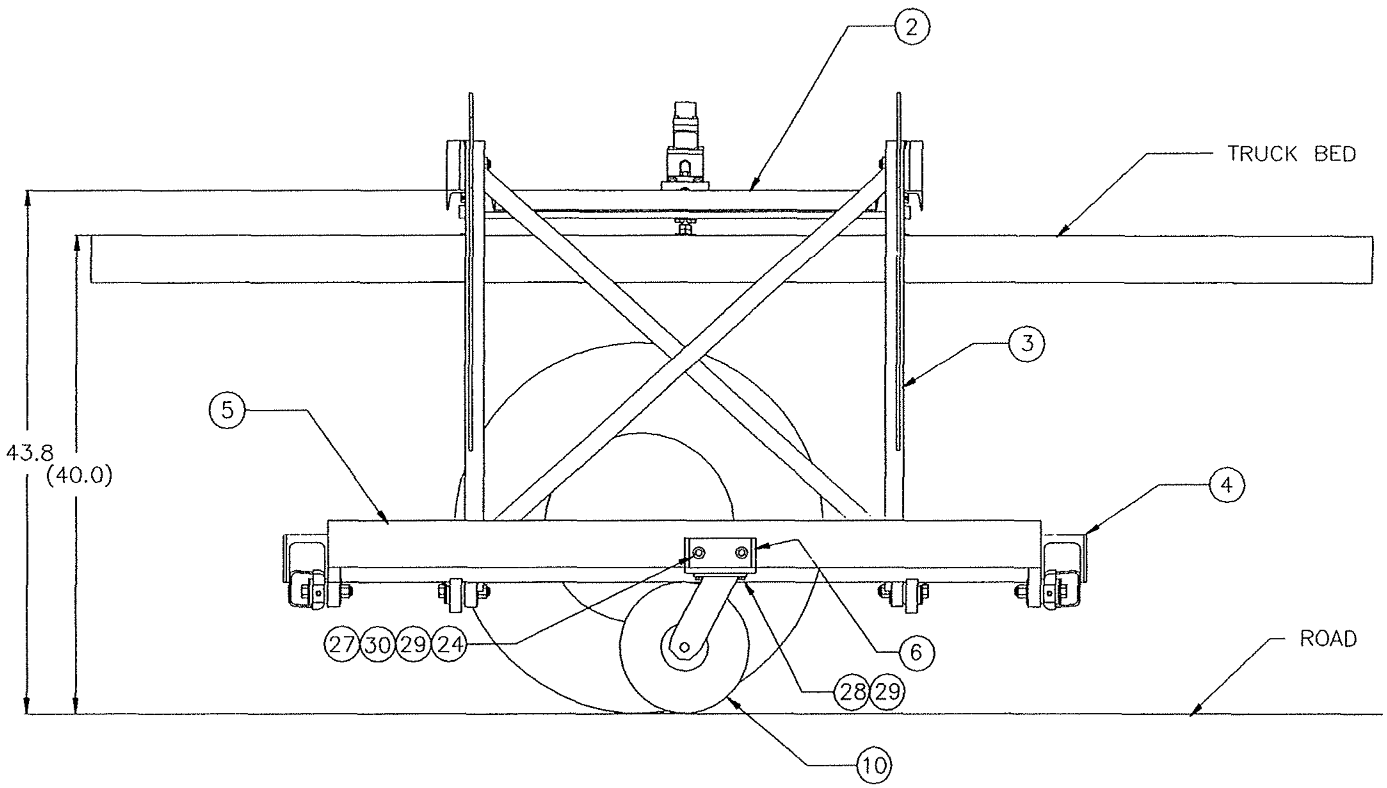
Wiring Diagram



- Power Requirements — 93–132 VAC, 47–63 Hz, 1A continuous
- All electrical signal wiring (DC) to be #22 awg. U.O.S.
- Electrical supply circuit wiring to be #18 awg. 3 conductor stranded shielded wire.
- Interlock must be "on" (connected to +15 VDC) in order for controller to operate actuator.
- Access must be "on" (connected to +15 VDC) in order to gain access to the program and setup modes.
- Limits must have a path to ground when controller is in normal operation.

D.2.2 - Detail Drawings

REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	03/17/92	VAV	DAB



FRONT VIEW

ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
30		.375 PLAIN WASHER	STAINLESS STEEL	4
29		.375 SPLIT LOCK WASHER	STAINLESS STEEL	12
28		.375-16 X .5 HEX CAP SCREW	STAINLESS STEEL	8
27		.375-16 X .750 HEX CAP SCREW	STAINLESS STEEL	4
26		.625-11 X 4.5 THD ROD	GALVANIZED STEEL	5
25		.625-11 LOCK NUT	GAL ST, NYLON LOCK	5
24		.625 PLAIN WASHER	STAINLESS STEEL	4
23		.625 PLAIN WASHER	GALVANIZED STEEL	10
22		.625-11 JAM NUT	GALVANIZED STEEL	10
21		.500 SPLIT LOCK WASHER	STAINLESS STEEL	4
20		.500-13 X 1 HEX HD BOLT	STAINLESS STEEL	4
19		10-24 UNC SOCKET HEAD SCREW	STAINLESS STEEL	34
18		#10 WASHER	STAINLESS STEEL	16
17		M-5X12 SOCKET HEAD CAP SCREW	ALLOY STEEL GRADE 12.9. DIN 912	16
16		GREASE FITTING 1/8 NPT		4
15		.750-10 LOCK NUT	GAL ST, NYLON LOCK	6
14		.750-10 X 1.5 HEX CAP SCREW	GALVANIZED STEEL	4
13		.750 PLAIN WASHER, .15 THICK	GALVANIZED STEEL	8
12		LINEAR BEARING THK SR20V X 100MM	SPECIFICATION	2
11		F-STYLE ACTUATOR FOR PARKER ELECROHYDRAULICS PLA2X12LF7M10NB10	SPECIFICATION	1
10	MMC 22925T52	CASTER 10.9X4.10/3.5-4 PNEU TIRE 11.875 HEIGHT, 500 LB	SPECIFICATION	2
9	LM-A103	BUSHING		4
8	LM-A102	SPACER		8
7	LM-A101	HINGE BOLT		4
6	LM-G100	CASTER BRACKET WELDMENT		2
5	LM-F100	CART WELDMENT		1
4	LM-E100	LOWER LINK WELDMENT		1
3	LM-D100	UPPER LINK WELDMENT		1
2	LM-C100	ACTUATOR TABLE SLIDE WELD.		1
1	LM-B100	ACTUATOR TABLE BASE WELD.		1

PART LIST

1

NOTES: UNLESS OTHERWISE SPECIFIED

1) COAT ITEMS 1,2,3,4,5 & 6 WITH PRIMER AND PAINT (COLOR–OMAHA ORANGE). DO NOT COAT THREADS.

2) WHEN PRESSING BUSHING, ITEM 9, INTO ITEM 4 LINE UP HOLE IN BUSHING WITH HOLE FOR GREASE PORT IN ITEM 4.

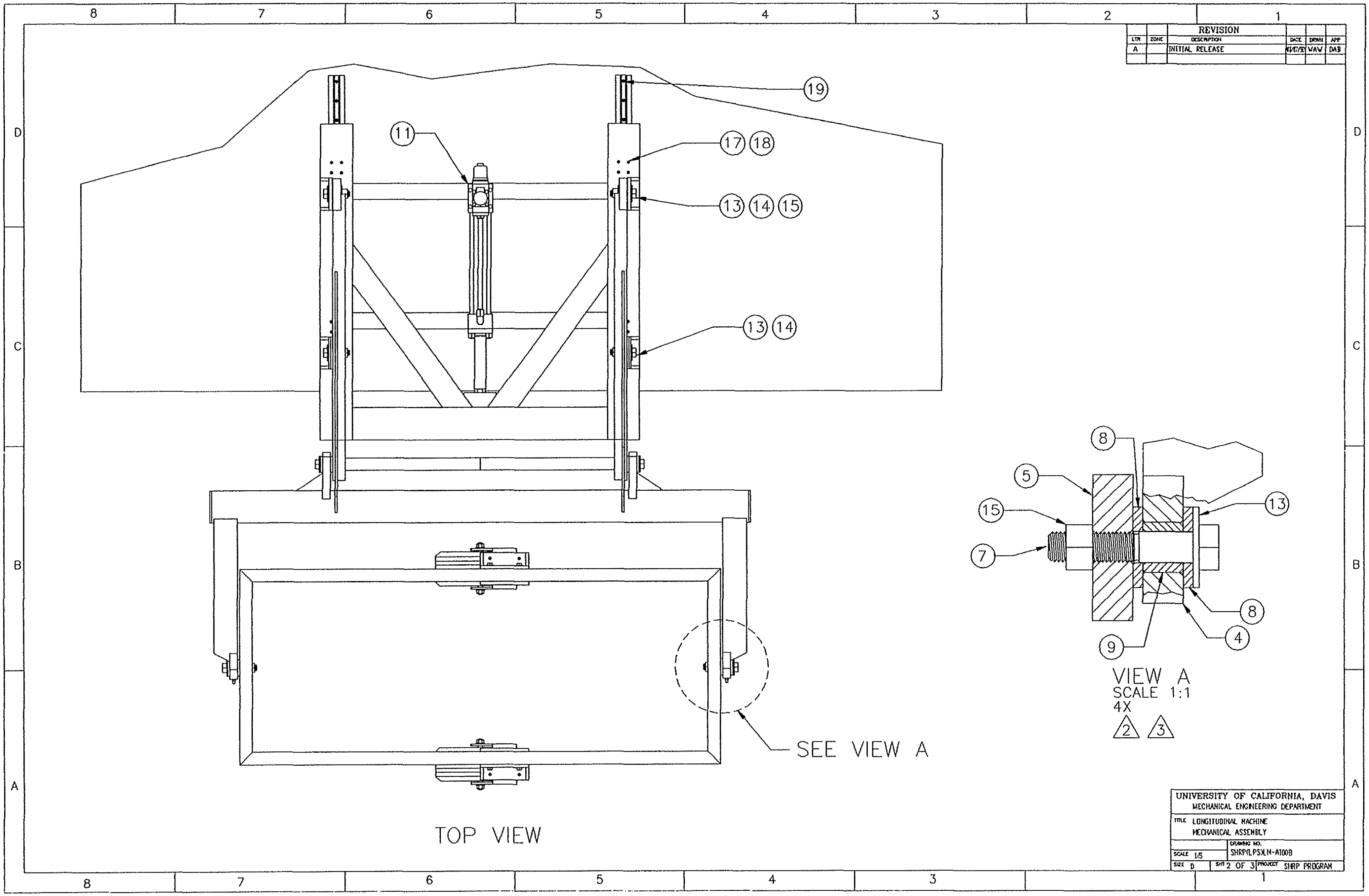
3) BOLT, ITEM 7, SHALL BE INSTALLED ALLOWING SMOOTH ROTATION BETWEEN ITEMS 3,4 & 5.

UNLESS OTHERWISE NOTED: TOLERANCES .XX ±.03 .XXX ±.010 ANGLES ±0.5° 64

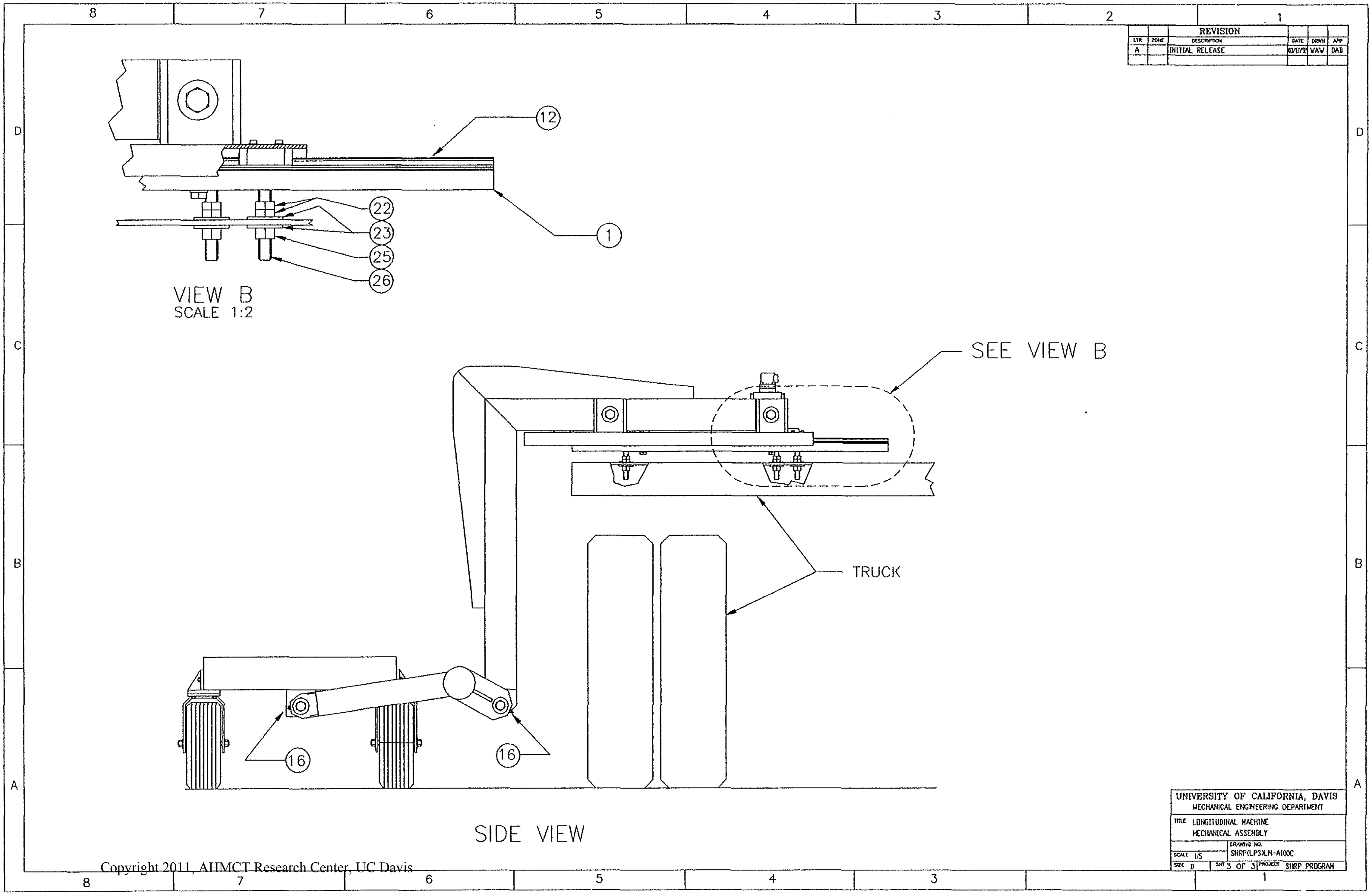
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT

TITLE LONGITUDINAL MACHINE MECHANICAL ASSEMBLY

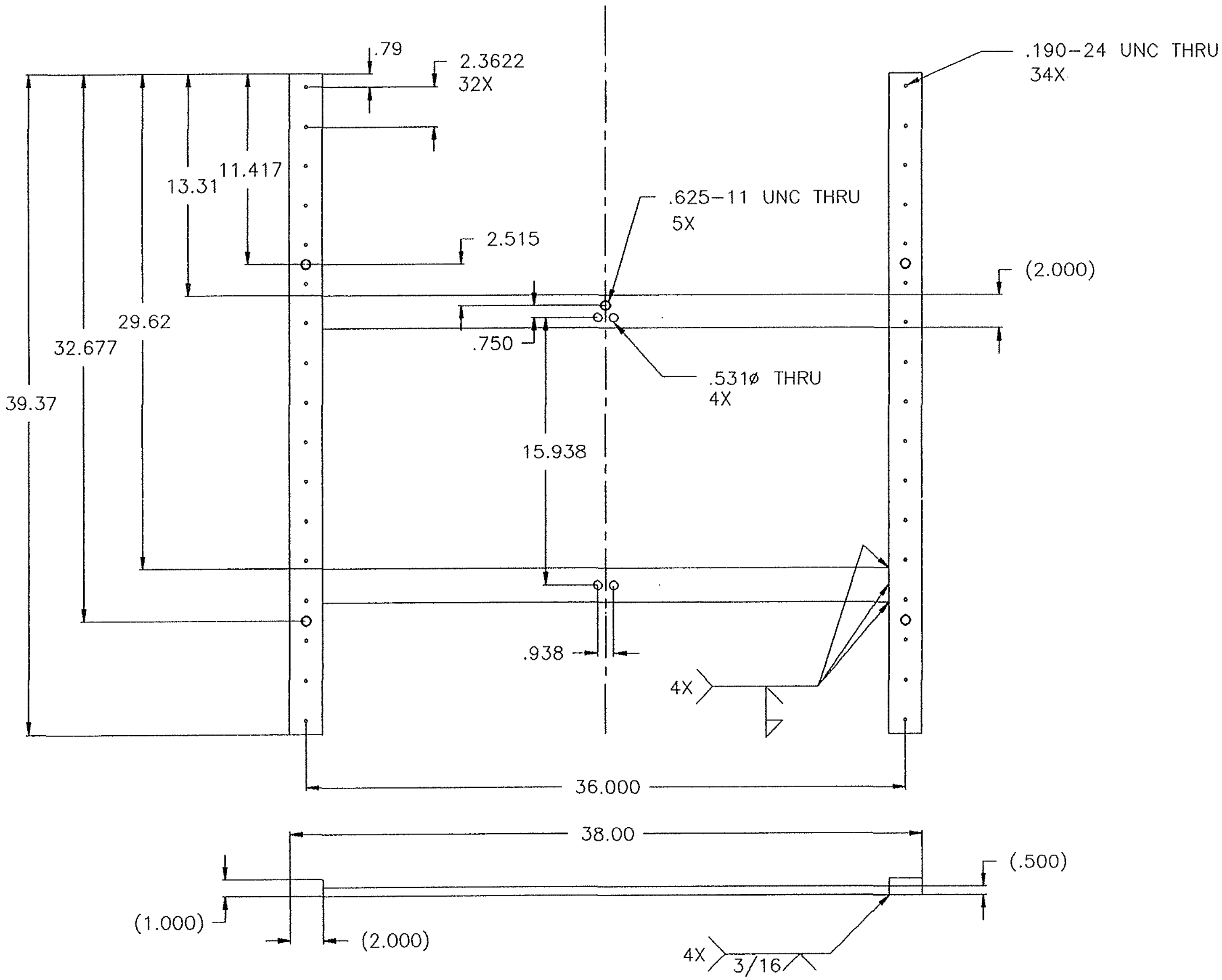
DESIGN VAV	DATE 03/17/92	QTY 1	DRAWING NO. SHRP(LPS)LM-A100A
DRAWN VAV		SCALE 1:5	
APPR'D DAB		SIZE D	SHT 1 OF 3
RELEASE DAB		PROJECT SHRP PROGRAM	



REVISION
LTR
ZONE
DESCRIPTION
DATE
DRWN
APP
A
INITIAL RELEASE
WAV
DAB
19
11
17 18
13 14 15
13 14
8
5
15
13
7
8
4
9
VIEW A
SCALE 1:1
4X
2
3
SEE VIEW A
TOP VIEW
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
TITLE LONGITUDINAL MACHINE
MECHANICAL ASSEMBLY
DRAWING NO.
SHRP(LPS)LM-A100B
SCALE 1:5
SIZE D
SHT 2 OF 3
PROJECT SHRP PROGRAM


REVISION
LTR ZONE DESCRIPTION DATE DRWN APP
A INITIAL RELEASE VAV DAB
12
1
22
23
25
26
VIEW B
SCALE 1:2
SEE VIEW B
TRUCK
16
16
SIDE VIEW
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
TITLE LONGITUDINAL MACHINE
MECHANICAL ASSEMBLY
DRAWING NO.
SHRP(LPS)LN-A100C
SCALE 1:5
SIZE D
SHT 3 OF 3
PROJECT SHRP PROGRAM

REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	03/07/92	VAV	DAB



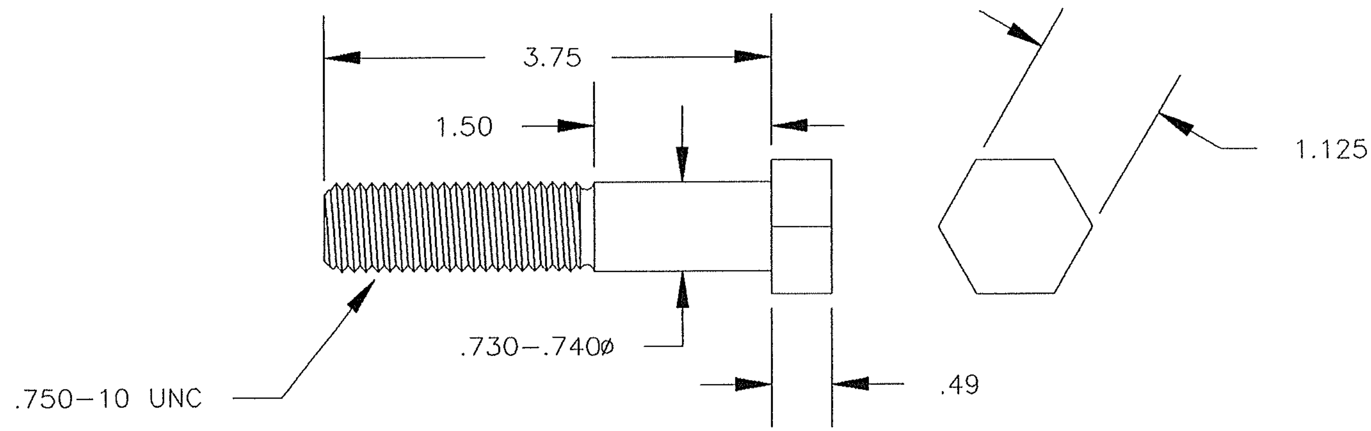
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
2) WELDS SHALL BE AS FOLLOWS:
A. V-GROOVE WELDS SHALL BE 1/4 IN SIZE WITH 60°-90° GROOVE ANGLE. GRIND FLUSH.
B. BEVEL GROOVE WELDS SHALL BE 3/16 IN SIZE WITH 45° GROOVE ANGLE.
C. ALL FILLET WELDS SHALL BE 1/4 IN SIZE.

ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
2	LH-B100-2	CROSS BAR	.5 X 2.0 BAR 1018 STEEL	2
1	LH-B100-1	BEARING BASE BAR	1.0 X2.0 BAR 1018 STEEL	2

PART LIST

UNLESS OTHERWISE NOTED: TOLERANCES .XX ±.03 .XXX ±.010 ANGLES ±0.5° 64	UNIVERSITY OF CALIFORNIA, DAVIS MECHANICAL ENGINEERING DEPARTMENT
DESIGN VAV DATE 03/07/92	TITLE ACTUATOR TABLE BASE WELDMENT
DRAWN VAV RS	QTY 1 DRAWING NO. SHRP(LPS)LH-B100
APPRV DAB	SCALE 1/3
RELEASE DAB	SIZE D SHT 1 OF 1 PROJECT SHRP PROGRAM

REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	03/07/92	WAW	DAB



1				1
ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD

PART LIST

△1

NOTES: UNLESS OTHERWISE SPECIFIED

1) BREAK ALL SHARP EDGES

2) MAKE FROM STANDARD ZINC PLATED BOLT, GRADE 5 OR BETTER. MODIFY AS REQUIRED.

UNLESS OTHERWISE NOTED:
TOLERANCES
.XX ±.03 ANGLES ±0.5°
.XXX ±.010
64√

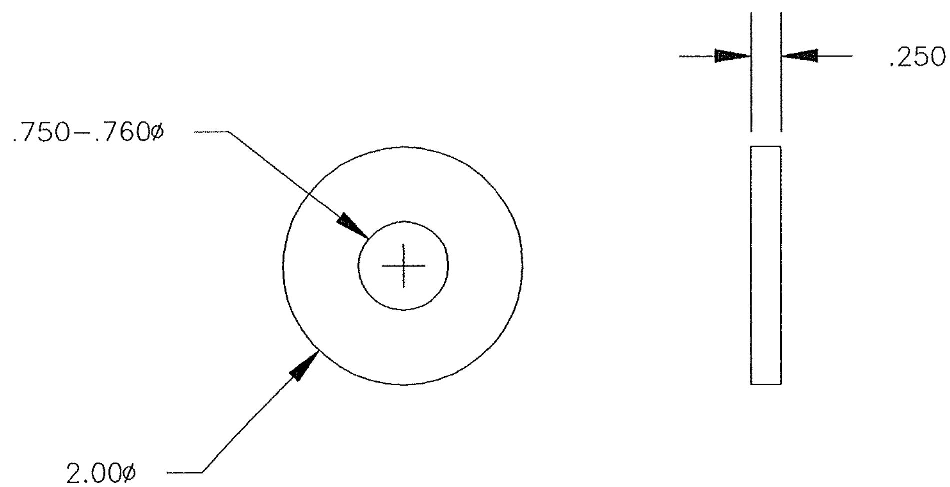
DESIGN WAW	DATE 03/07/92		
DRAWN WAW		QTY 4	DRAWING NO. SHRP(LPS)LM-A101
APPRV DAB		SCALE 1:1	
RELEASE DAB		SIZE B	SHT 1 OF 1 PROJECT SHRP PROGRAM

UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT

TITLE HINGE BOLT

4 3 2 1

		REVISION			
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	03/07/92	WAW	DAB



1				1
ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD

PART LIST

△1

NOTES: UNLESS OTHERWISE SPECIFIED

1) BREAK ALL SHARP EDGES
2) MATERIAL: OIL IMPREGNATED BRONZE

UNLESS OTHERWISE NOTED:
TOLERANCES
.XX ± .03 ANGLES ±0.5°
.XXX ± .010
64√

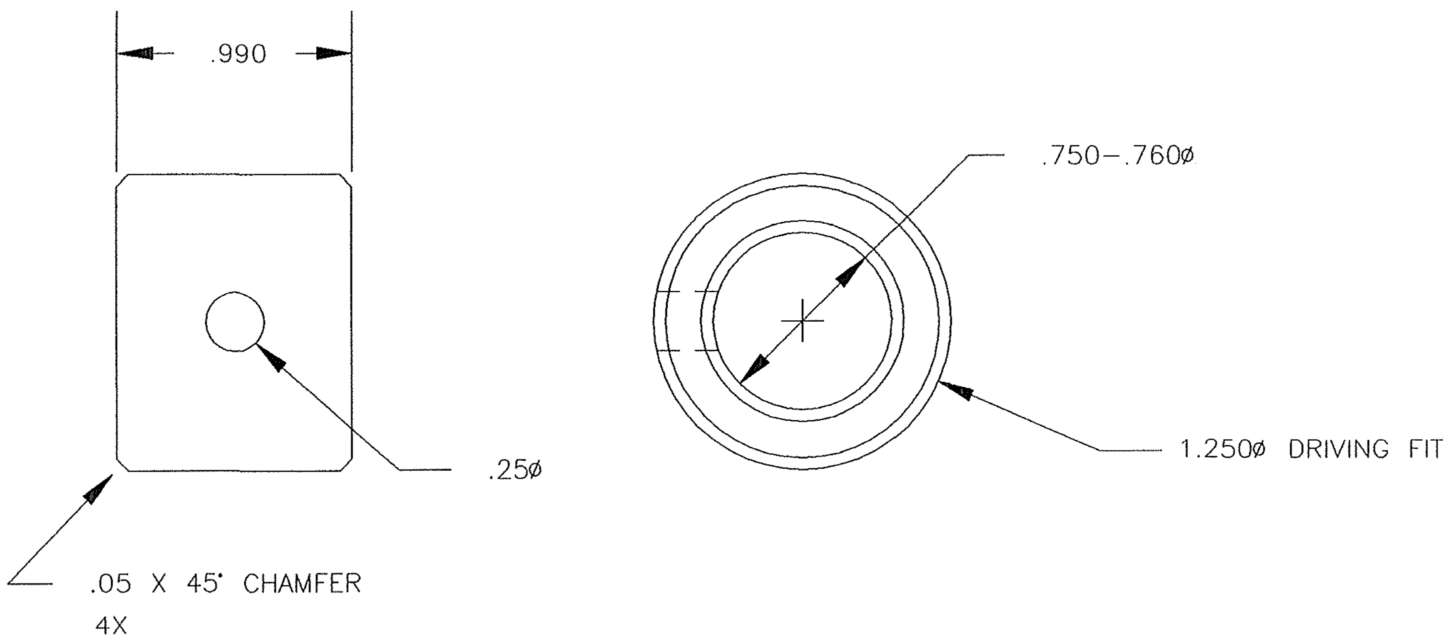
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT

TITLE SPACER

DESIGN WAW	DATE 03/07/92				
DRAWN WAW		QTY 8	DRAWING NO. SHRP(LPS)LM-A102		
APPRV DAB		SCALE 1:1			
RELEASE DAB		SIZE B	SHT 1 OF 1	PROJECT SHRP PROGRAM	

4 3 2 1

		REVISION			
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	03/07/92	WAW	DAB



1				1
ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD

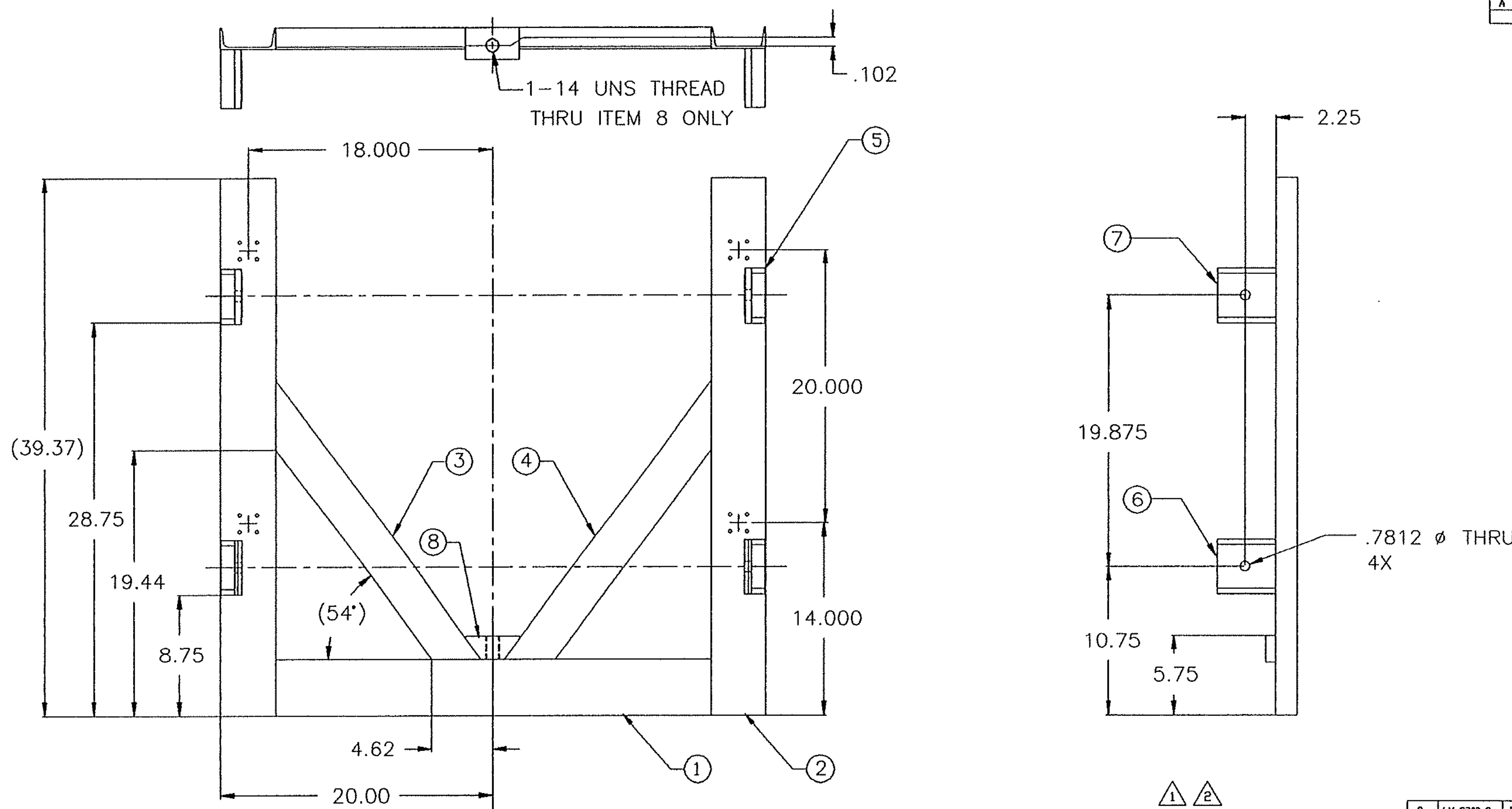
PART LIST

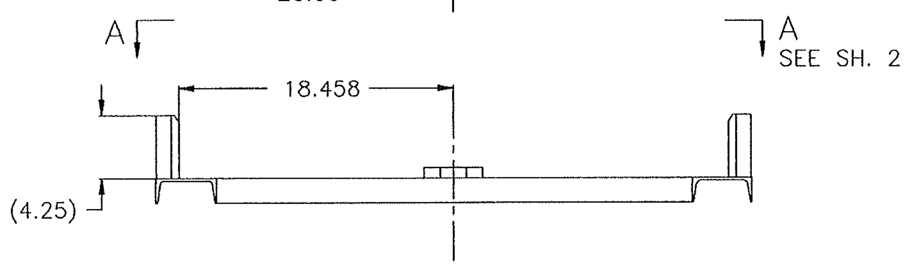
△1

NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
2) MATERIAL: OIL IMPREGNATED BRONZE

UNLESS OTHERWISE NOTED: TOLERANCES .XX ±.03 .XXX ±.010 ANGLES ±0.5° 64√		UNIVERSITY OF CALIFORNIA, DAVIS MECHANICAL ENGINEERING DEPARTMENT	
		TITLE BUSHING	
DESIGN WAW	DATE 03/07/92		
DRAWN WAW		QTY 4	DRAWING NO. SHRP(LPS)LM-A103
APPRV DAB		SCALE 2:1	
RELEASE DAB		SIZE B SHT 1 OF 1	PROJECT SHRP PROGRAM

REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	03/17/92	VAV	DAB





△1 △2

NOTES: UNLESS OTHERWISE SPECIFIED

1) BREAK ALL SHARP EDGES

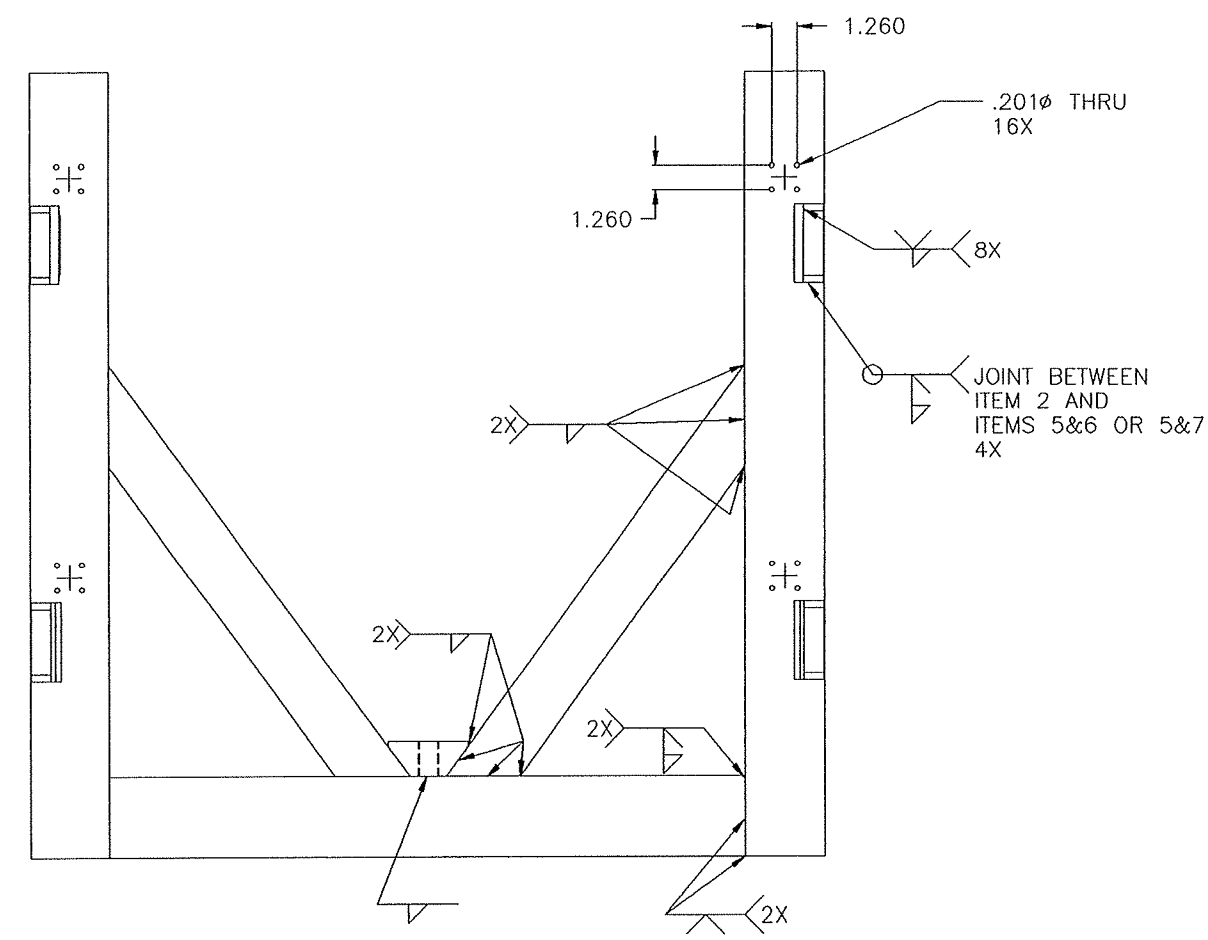
2) WELDS SHALL BE AS FOLLOWS:
   A. V-GROOVE WELDS SHALL BE 1/4 IN SIZE WITH 60°-90° GROOVE ANGLE. GRIND FLUSH.
   B. BEVEL GROOVE WELDS SHALL BE 3/16 IN SIZE WITH 45° GROOVE ANGLE.
   C. ALL FILLET WELDS SHALL BE 1/4 IN SIZE.

ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
8	LN-C200-8	BLOCK		1
7	LN-C200-7	PLATE #2		2
6	LN-C200-6	PLATE #1		2
5	LN-C200-5	GUSSET		8
4	LN-C200-4	C-CHANNEL BRACE #2		1
3	LN-C200-3	C-CHANNEL BRACE #1		1
2	LN-C200-2	C-CHANNEL SIDE PIECE		2
1	LN-C200-1	C-CHANNEL CROSS PIECE		1

PART LIST

UNLESS OTHERWISE NOTED: TOLERANCES .XX ±.03 .XXX ±.010 ANGLES ±0.5° 64√		UNIVERSITY OF CALIFORNIA, DAVIS MECHANICAL ENGINEERING DEPARTMENT
DESIGN VAV	DATE 03/17/92	TITLE ACTUATOR TABLE SLIDE WELDMENT
DRAWN VAV RS		QTY 1 / DRAWING NO. SHRP(LPS)LN-C100A
APPRV DAB		SCALE 1:4
RELEASE DAB		SIZE D / SHT 1 OF 2 / PROJECT SHRP PROGRAM

REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	10/17/93	VAV	DAB



VIEW A

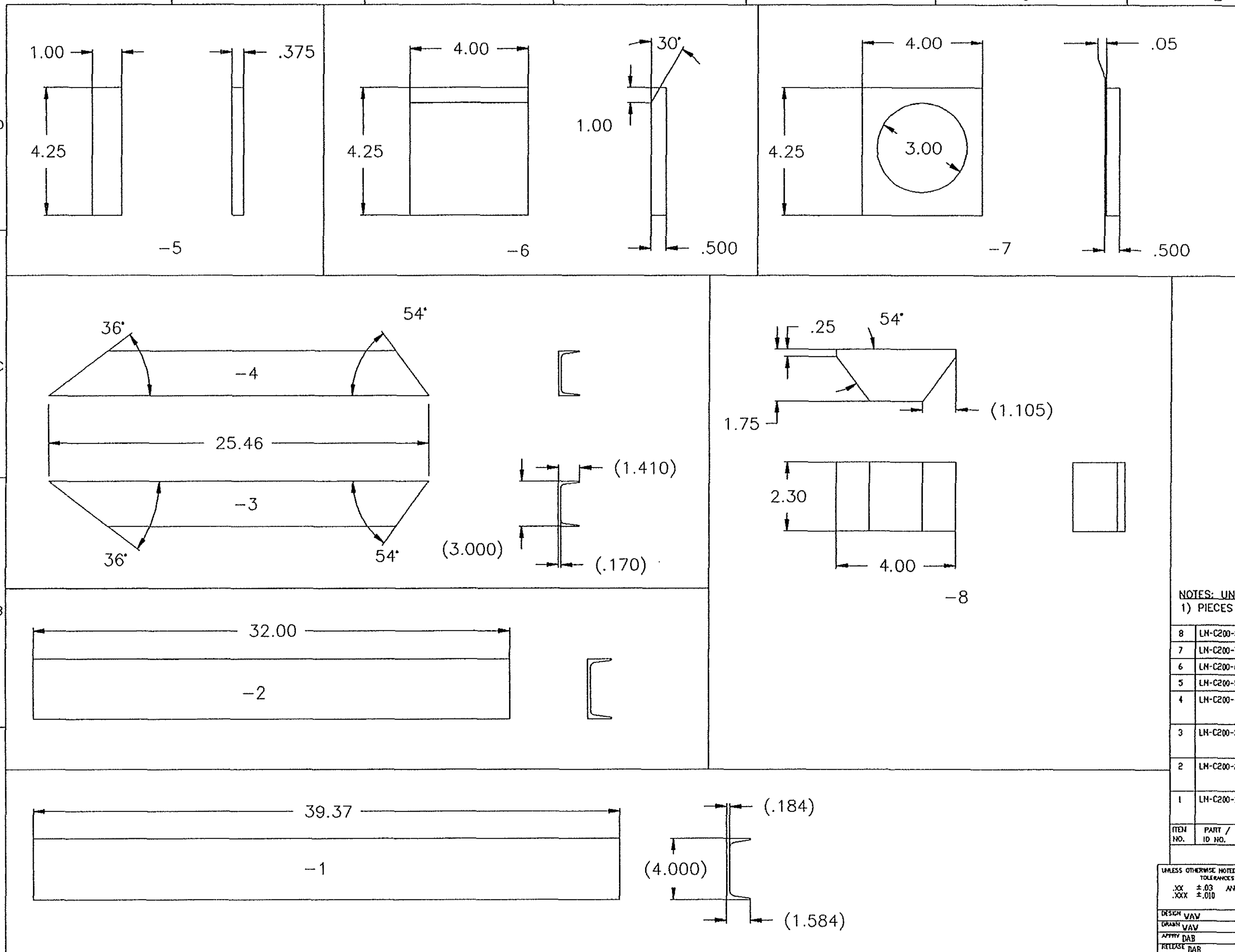
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT

TITLE ACTUATOR TABLE SLIDE WELDMENT

DRAWING NO. SHRP(LPS)LN-C100B

SCALE 1:3

SIZE D | SHT 2 OF 2 | PROJECT SHRP PROGRAM



REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	03/17/92	VAV	DAB

NOTES: UNLESS OTHERWISE SPECIFIED
1) PIECES WELDED AT NEXT ASSEMBLY.

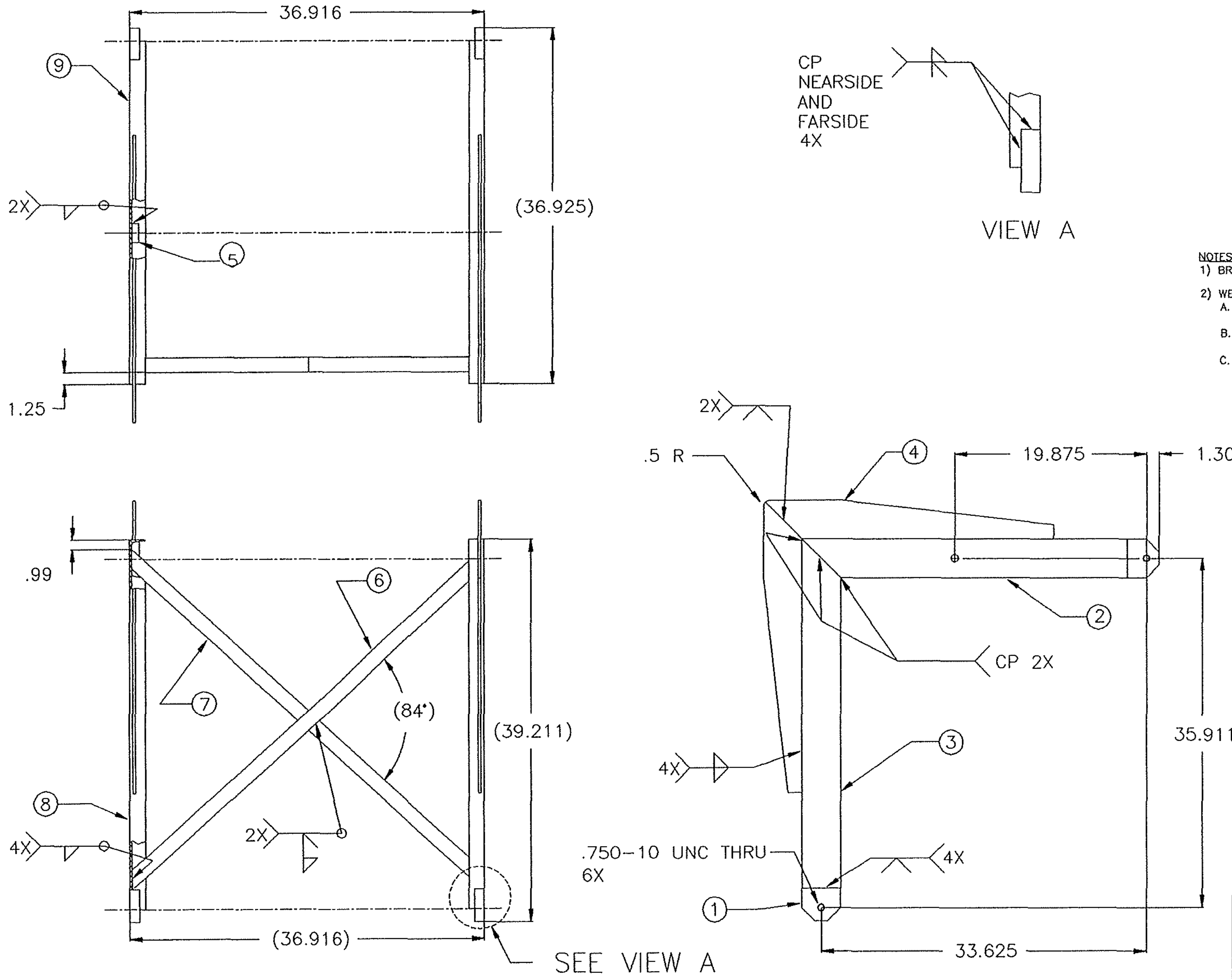
ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
8	LN-C200-8	BLOCK	1018 STEEL	
7	LN-C200-7	PLATE #2	1018 STEEL	
6	LN-C200-6	PLATE #1	1018 STEEL	
5	LN-C200-5	GUSSET	1018 STEEL	
4	LN-C200-4	C-CHANNEL BRACE #2	C3 X 4.1 CHANNEL STEEL ASTM A 36	
3	LN-C200-3	C-CHANNEL BRACE #1	C3 X 4.1 CHANNEL STEEL ASTM A 36	
2	LN-C200-2	C-CHANNEL SIDE PIECE	C4 X 5.4 CHANNEL STEEL ASTM A 36	
1	LN-C200-1	C-CHANNEL CROSS PIECE	C4 X 5.4 CHANNEL STEEL ASTM A 36	

PART LIST

UNLESS OTHERWISE NOTED: TOLERANCES
.XX ±.03 ANGLES ±0.5°
.XXX ±.010 64

DESIGN VAV	DATE 03/17/92	UNIVERSITY OF CALIFORNIA, DAVIS MECHANICAL ENGINEERING DEPARTMENT	
DRAWN VAV		TITLE ACTUATOR TABLE SLIDE WELDMENT PIECES	
APPRV DAB		QTY	DRAWING NO. SHRP(LPS)LN-C200
RELEASE DAB		SCALE NONE	
		SIZE D	SHT 1 OF 1 PROJECT SHRP PROGRAM

REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	03/17/92	VAV	DAB



NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES

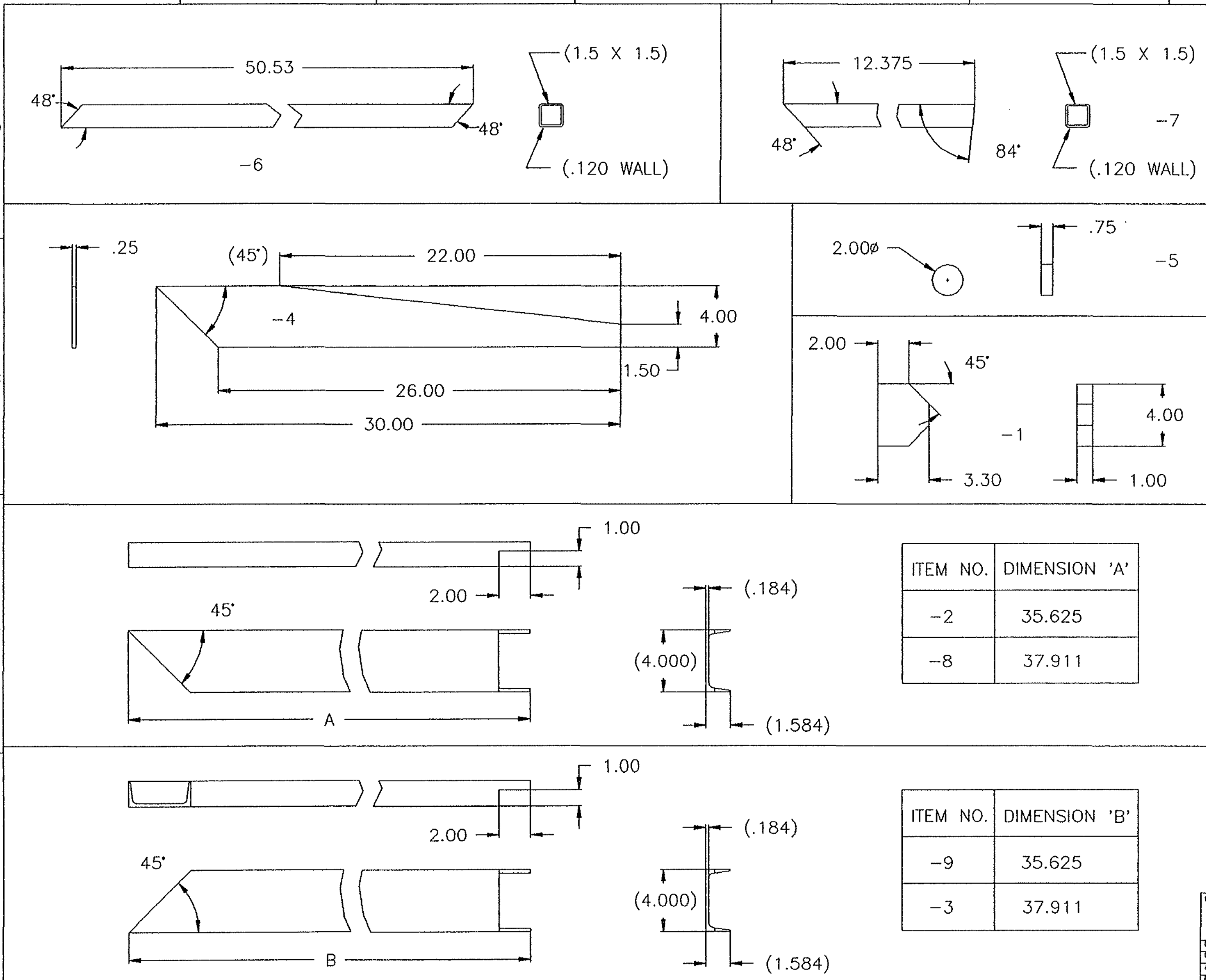
2) WELDS SHALL BE AS FOLLOWS:
A. V–GROOVE WELDS SHALL BE 1/4 IN SIZE WITH 60°–90° GROOVE ANGLE. GRIND FLUSH.
B. BEVEL GROOVE WELDS SHALL BE 3/16 IN SIZE WITH 45° GROOVE ANGLE.
C. ALL FILLET WELDS SHALL BE 1/4 IN SIZE.

ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
9	LN-D200-9	CHANNEL #4		1
8	LN-D200-8	CHANNEL #3		1
7	LN-D200-7	BRACE #2		2
6	LN-D200-6	BRACE #1		1
5	LN-D200-5	BOSS		2
4	LN-D200-4	GUSSET		4
3	LN-D200-3	C-CHANNEL #2		1
2	LN-D200-2	C-CHANNEL #1		1
1	LN-D200-1	FLANGE		4

PART LIST

UNLESS OTHERWISE NOTED: TOLERANCES .XX ±.03 .XXX ±.010 ANGLES ±0.5° 64	UNIVERSITY OF CALIFORNIA, DAVIS MECHANICAL ENGINEERING DEPARTMENT
DESIGN VAV / DATE 03/17/92	TITLE UPPER LINK WELDMENT
DRAWN VAV	QTY 1 / DRAWING NO. SHRP(LPS)LN-D100
APPRV DAB	SCALE 1:5
RELEASE DAB	SIZE D / SHT 1 OF 1 / PROJECT SHRP PROGRAM

REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	03/07/92	VAW	DAB



ITEM NO.	DIMENSION 'A'
-2	35.625
-8	37.911

ITEM NO.	DIMENSION 'B'
-9	35.625
-3	37.911

NOTES: UNLESS OTHERWISE SPECIFIED
1) PIECES WELDED AT NEXT ASSEMBLY.

ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
9	LN-D200-9	CHANNEL #4	C4 X 5.4 CHANNEL STEEL ASTM 36	
8	LN-D200-8	CHANNEL #3	C4 X 5.4 CHANNEL STEEL ASTM 36	
7	LN-D200-7	BRACE #2	1.5X1.5X1.2 WALL STEEL ASTM-500	
6	LN-D200-6	BRACE #1	1.5X1.5X1.2 WALL STEEL ASTM-500	
5	LN-D200-5	BOSS	1018 STEEL	
4	LN-D200-4	GUSSET	1018 STEEL	
3	LN-D200-3	C-CHANNEL #2	C4 X 5.4 CHANNEL STEEL ASTM 36	
2	LN-D200-2	C-CHANNEL #1	C4 X 5.4 CHANNEL STEEL ASTM 36	
1	LN-D200-1	FLANGE	1018 STEEL PLATE	

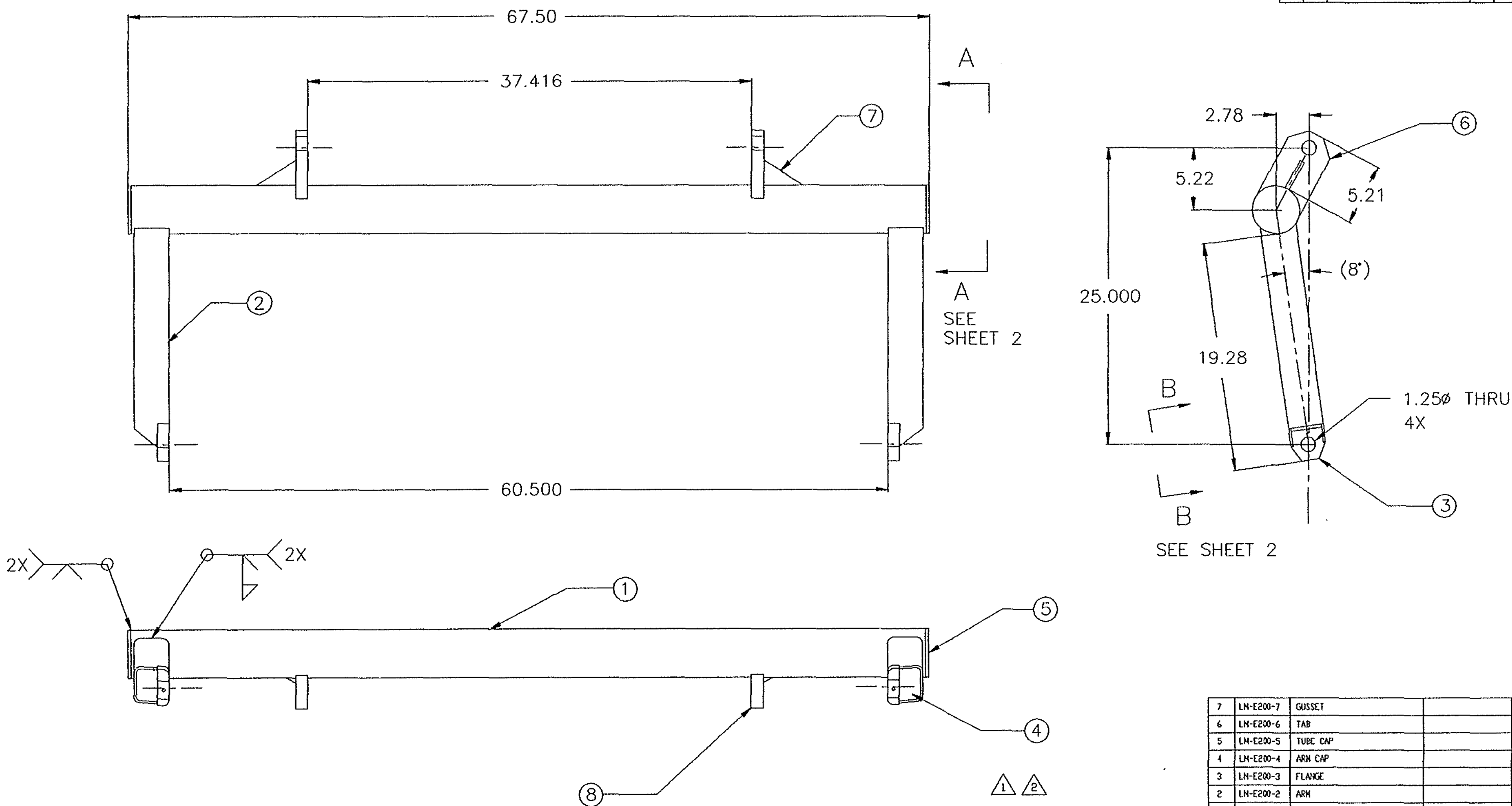
PART LIST

UNLESS OTHERWISE NOTED: TOLERANCES
.XX ±.03 ANGLES ±0.5°
.XXX ±.010
64

UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT

DESIGN VAV	DATE 03/07/92	TITLE UPPER LINK WELDMENT PIECES	
DRAWN VAV		QTY	DRAWING NO. SHRP(LPS)LN-D200
APPRV DAB		SCALE 1:3	
RELEASE DAB		SIZE D	SHT 1 OF 1 PROJECT SHRP PROGRAM

REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	03/17/92	VAV	DAB



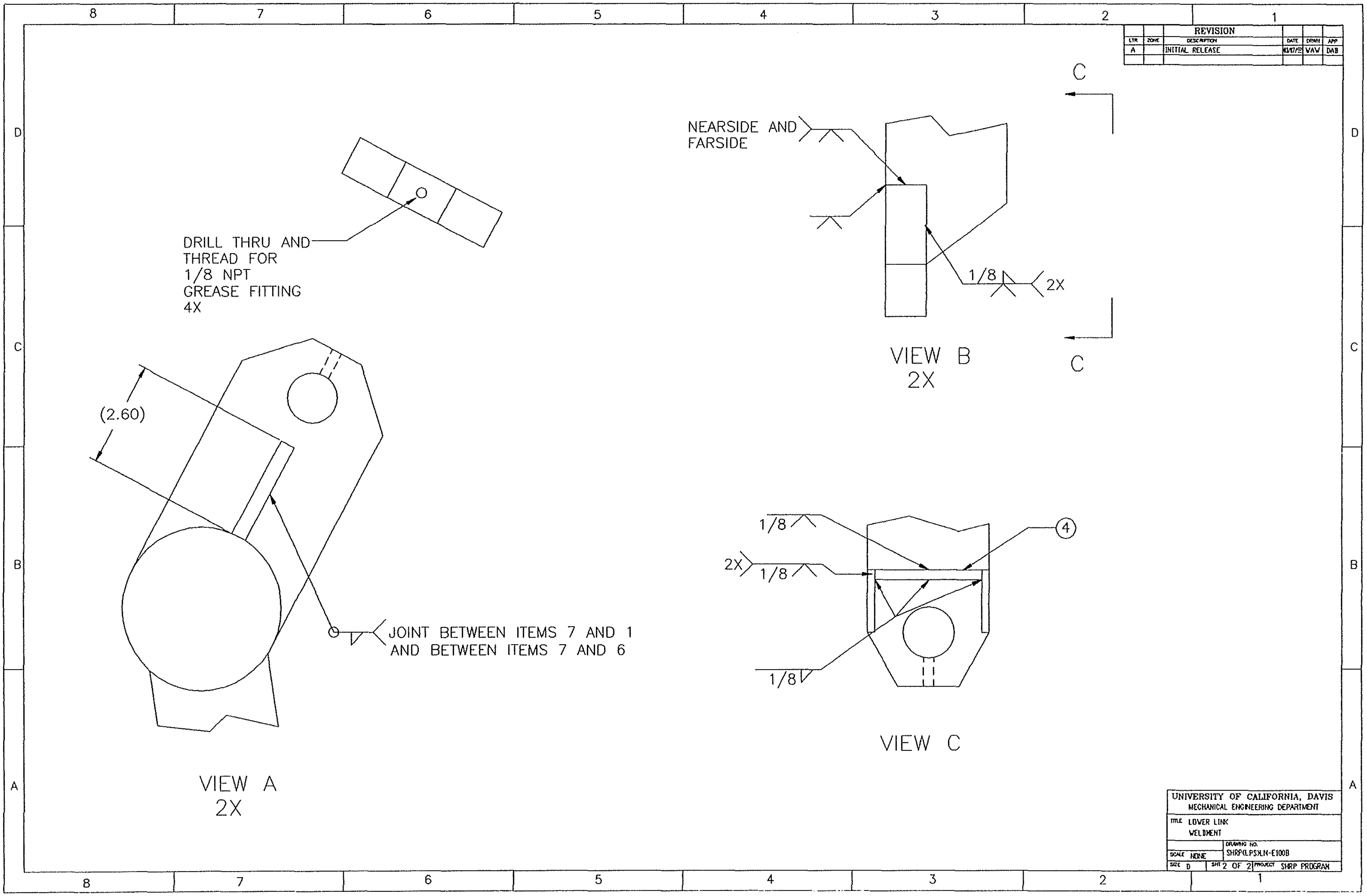
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES

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

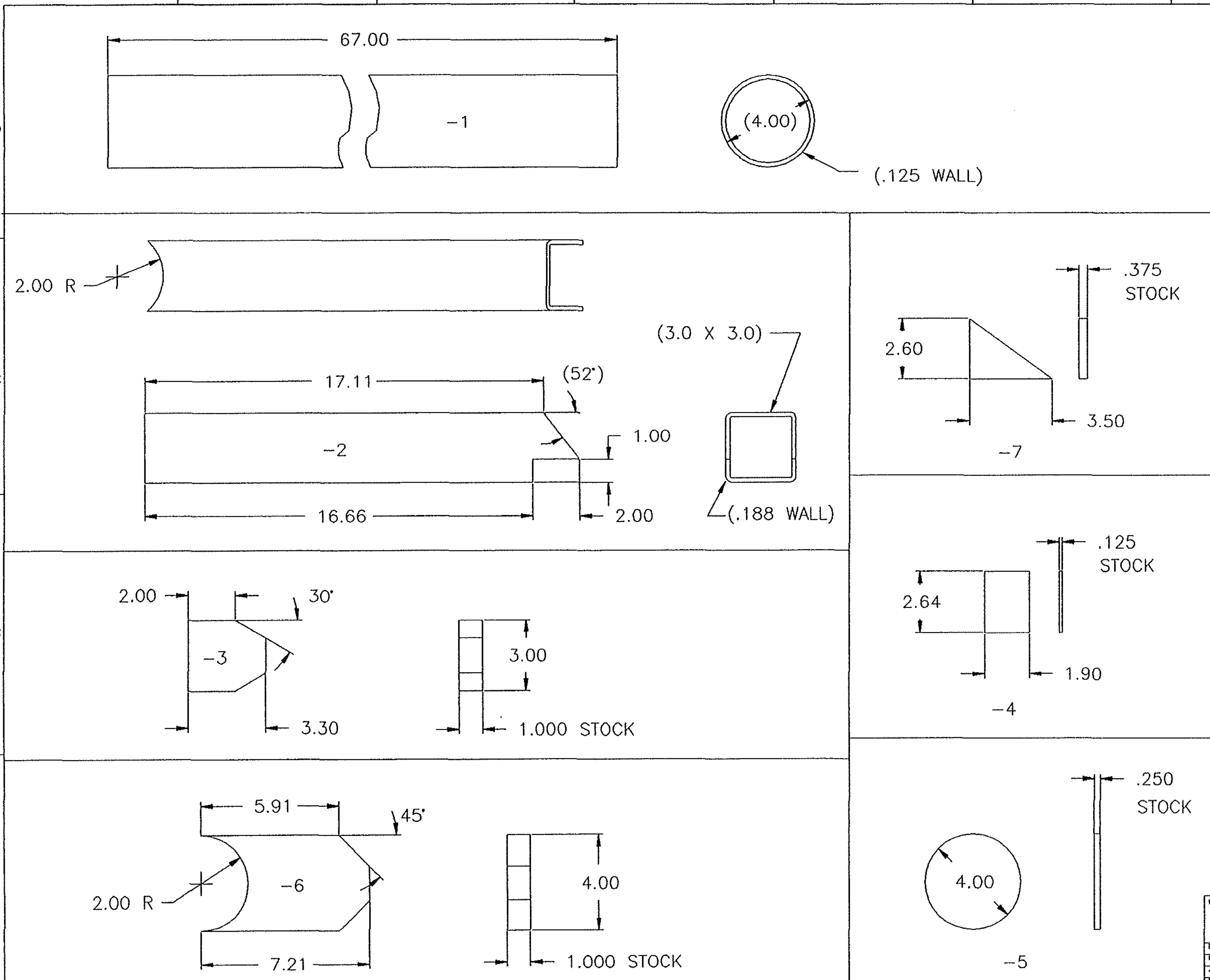
7	LN-E200-7	GUSSET		2
6	LN-E200-6	TAB		2
5	LN-E200-5	TUBE CAP		2
4	LN-E200-4	ARM CAP		2
3	LN-E200-3	FLANGE		2
2	LN-E200-2	ARM		2
1	LN-E200-1	TUBE FRAME		1
ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD

PART LIST

UNLESS OTHERWISE NOTED: TOLERANCES .XX ±.03 .XXX ±.010 ANGLES ±0.5° 64√		UNIVERSITY OF CALIFORNIA, DAVIS MECHANICAL ENGINEERING DEPARTMENT
DESIGN VAV	DATE 03/17/92	TITLE LOVER LINK WELDMENT
DRAWN VAV		QTY 1 — DRAWING NO. SHRP(LPS)LN-E100A
APPRV DAB		SCALE 1:4
RELEASE DAB		SIZE D — SHT 1 OF 2 — PROJECT SHRP PROGRAM


REVISION
LTR ZONE DESCRIPTION DATE DRWN APP
A INITIAL RELEASE VAW DAB
C
NEARSIDE AND
FARSIDE
1/8
2X
VIEW B
2X
DRILL THRU AND
THREAD FOR
1/8 NPT
GREASE FITTING
4X
(2.60)
JOINT BETWEEN ITEMS 7 AND 1
AND BETWEEN ITEMS 7 AND 6
VIEW A
2X
1/8
2X
1/8
4
1/8
VIEW C
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
TITLE LOWER LINK
WELDMENT
DRAWING NO.
SHRP(LPS)LN-E100B
SCALE NONE
SIZE D
SHT 2 OF 2
PROJECT SHRP PROGRAM

REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	03/17/92	VAV	DAB



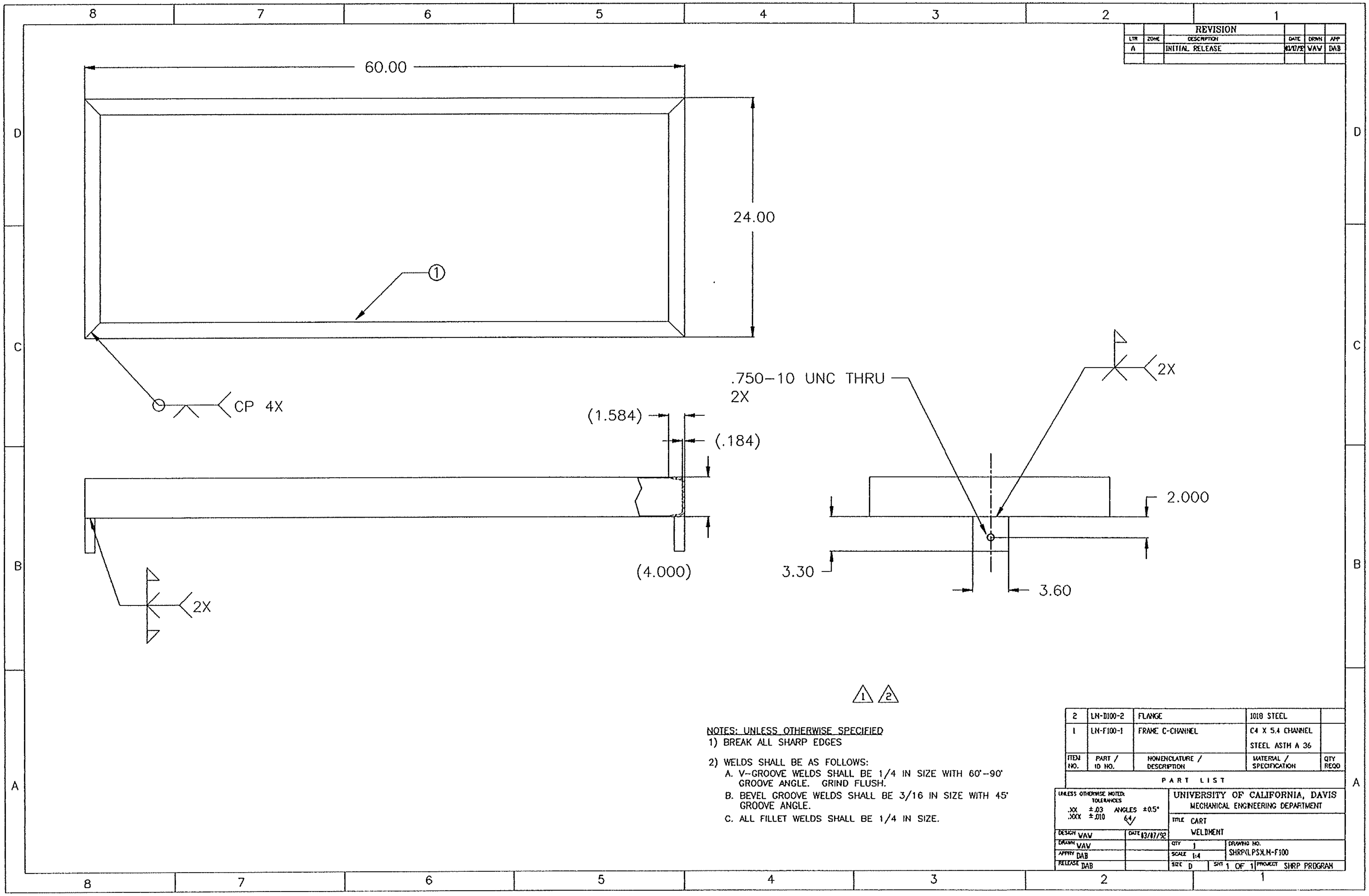
△1

NOTES: UNLESS OTHERWISE SPECIFIED
1) PIECES WELDED AT NEXT ASSEMBLY

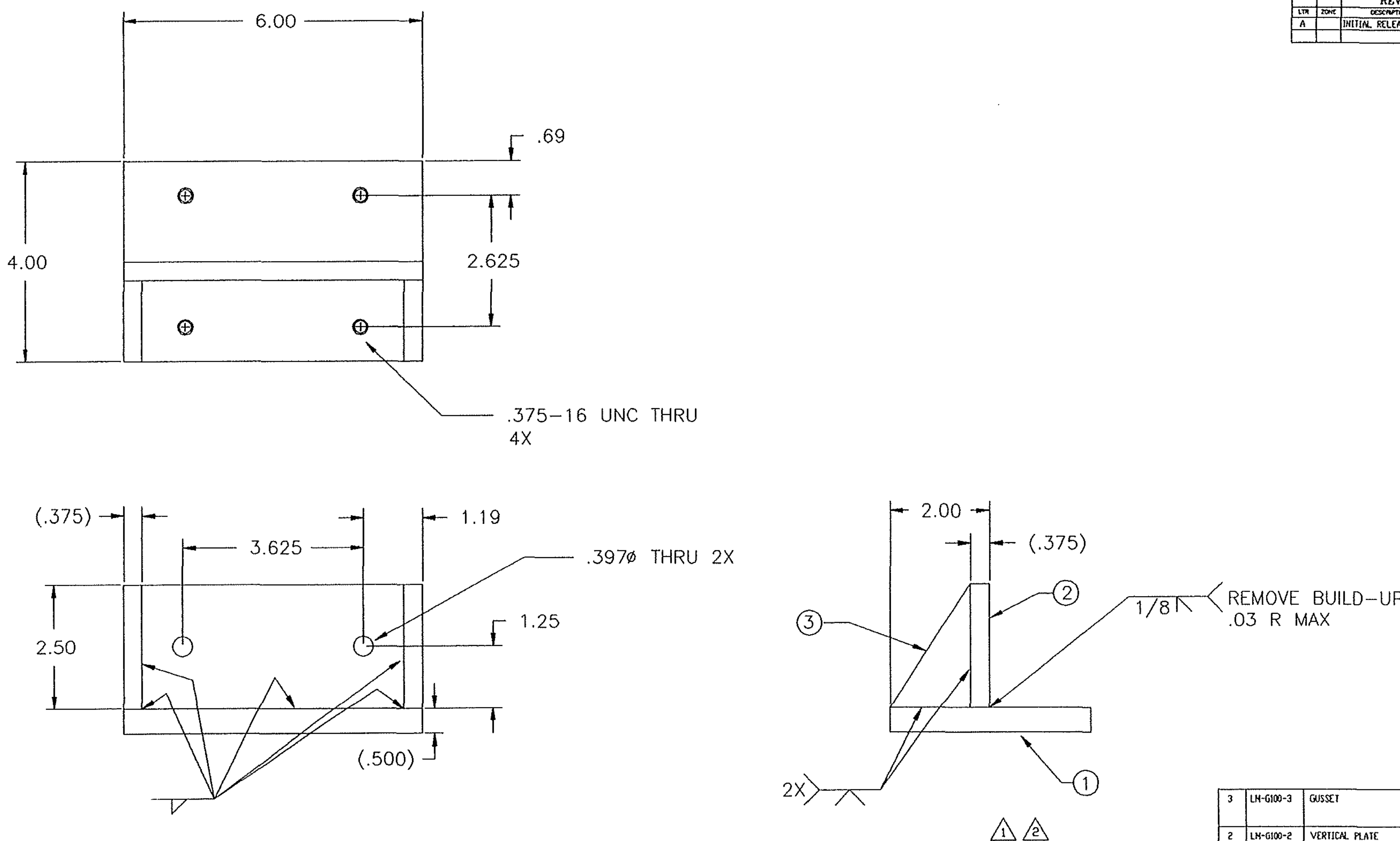
ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
7	LN-E200-7	GUSSET	1018 STEEL PLATE	
6	LN-E200-6	TAB	1018 STEEL PLATE	
5	LN-E200-5	TUBE CAP	1018 STEEL PLATE	
4	LN-E200-4	ARM CAP	1018 STEEL PLATE	
3	LN-E200-3	FLANGE	1018 STEEL PLATE	
2	LN-E200-2	ARM	3 X 3 X .188 WALL STEEL ASTM-500	
1	LN-E200-1	TUBE FRAME	4.0 OD .125 WALL 1018 STEEL	

PART LIST

UNLESS OTHERWISE NOTED: TOLERANCES .XX ±.03 .XXX ±.010 ANGLES ±0.5° 64√		UNIVERSITY OF CALIFORNIA, DAVIS MECHANICAL ENGINEERING DEPARTMENT	
DESIGN VAV	DATE 03/17/92	TITLE LOWER LINK WELDMENT PIECES	
DRAWN VAV		QTY	DRAWING NO. SHRP(LPS)LN-E200
APPRV DAB		SCALE 1/2	
RELEASE DAB		SIZE D / SHT 1 OF 1	PROJECT SHRP PROGRAM


REVISION
LTR ZONE DESCRIPTION DATE DRWN APP
A INITIAL RELEASE VAV DAB
60.00
24.00
1
CP 4X
.750–10 UNC THRU
2X
2X
(1.584)
(.184)
(4.000)
2.000
3.30
3.60
2X
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
2) WELDS SHALL BE AS FOLLOWS:
A. V-GROOVE WELDS SHALL BE 1/4 IN SIZE WITH 60°–90° GROOVE ANGLE. GRIND FLUSH.
B. BEVEL GROOVE WELDS SHALL BE 3/16 IN SIZE WITH 45° GROOVE ANGLE.
C. ALL FILLET WELDS SHALL BE 1/4 IN SIZE.
2 LN-D100-2 FLANGE 1018 STEEL
1 LN-F100-1 FRAME C-CHANNEL C4 X 5.4 CHANNEL STEEL ASTM A 36
ITEM NO. PART / ID NO. NOMENCLATURE / DESCRIPTION MATERIAL / SPECIFICATION QTY REQD
PART LIST
UNLESS OTHERWISE NOTED: TOLERANCES
.XX ±.03 ANGLES ±0.5°
.XXX ±.010
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
TITLE CART WELDMENT
DESIGN VAV DATE 03/07/92
DRAWN VAV
APPRV DAB
RELEASE DAB
QTY 1
SCALE 1:4
DRAWING NO. SHRP(LPS)LN-F100
SIZE D SHT 1 OF 1 PROJECT SHRP PROGRAM

REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	03/07/92	VAV	DAB



NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES

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

ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
3	LN-G100-3	GUSSET	1018 STEEL 1018 STEEL	2
2	LN-G100-2	VERTICAL PLATE	.375 PLATE 1018 STEEL	1
1	LN-G100-1	BASE	.500 PLATE 1018 STEEL	1

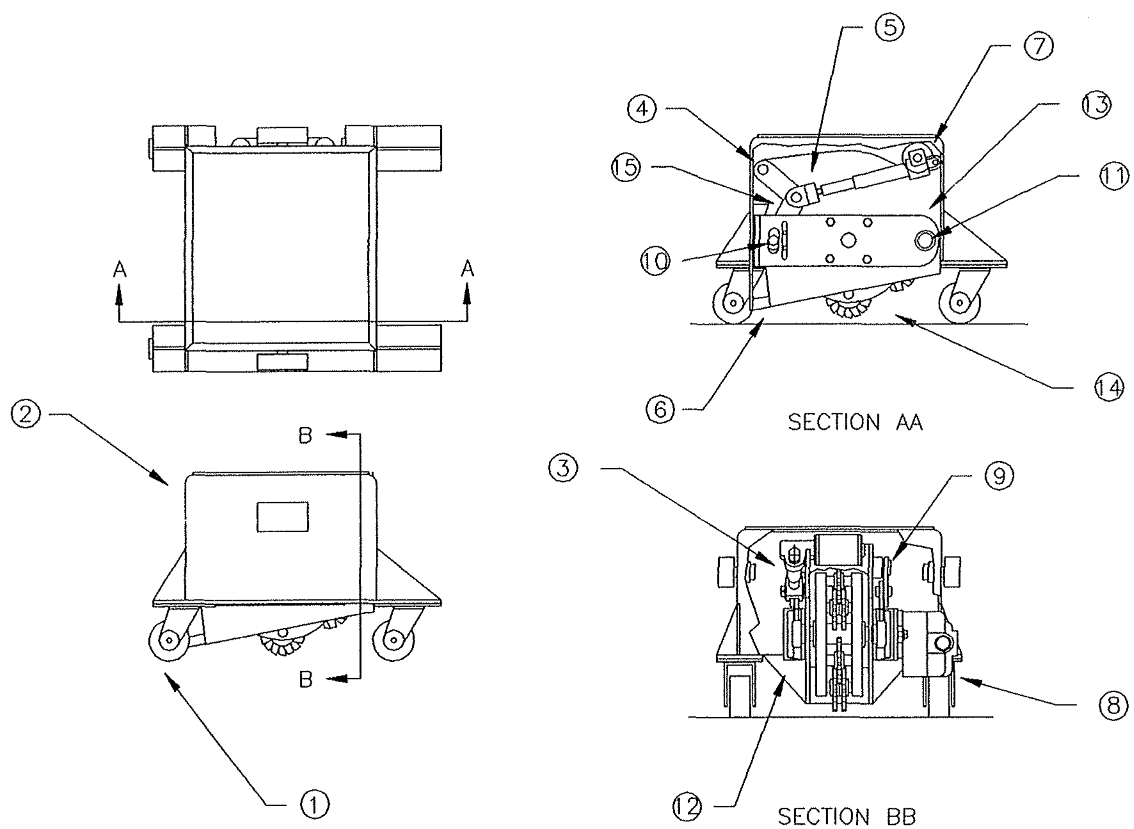
PART LIST

UNLESS OTHERWISE NOTED: TOLERANCES .XX ±.03 .XXX ±.010 ANGLES ±0.5° 64	UNIVERSITY OF CALIFORNIA, DAVIS MECHANICAL ENGINEERING DEPARTMENT
DESIGN VAV — DATE 03/07/92	TITLE CASTER BRACKET WELDMENT
DRAWN VAV	QTY 2 — DRAWING NO. SHRP(LPS)LN-G100
APPRV DAB	SCALE 1:1
RELEASE DAB	SIZE D — SHT 1 OF 1 — PROJECT SHRP PROGRAM

APPENDIX E - APS SPECIFICATIONS AND DRAWINGS

E.1 - Router

REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	1/31/92	KJM	DAB



ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
15	RM-A101	LOWER LINK	1018 STEEL	1
14		ROUTER CUTTING WHEEL		1
13	RM-C100	CUTTER FRAME	1018 STEEL	1
12		SEALED BEARINGS		2
11	RM-A103	C-CHANNEL PIN	1018 STEEL	2
10	RM-A105	LOWER LINKPIN BLOCK	1018 STEEL	2
9	RM-A106	UPPER LINKPIN	1040 STEEL	1
8		HYDRAULIC MOTOR		1
7		LINEAR DRIVE MOTOR		1
6	RM-D100	INNER FRAME ASSEMBLY	1018 STEEL	1
5	RM-A104	UPPER & LOWER LINK CAPTURE	1018 STEEL	2
4	RM-A102	UPPER LINK	1018 STEEL	2
3		ELECTRIC LINEAR DRIVE		1
2	RM-B100	WHEEL SUPPORT FRAME	1018 STEEL	1
1		CASTERS MCM-CARR 2494T81		4

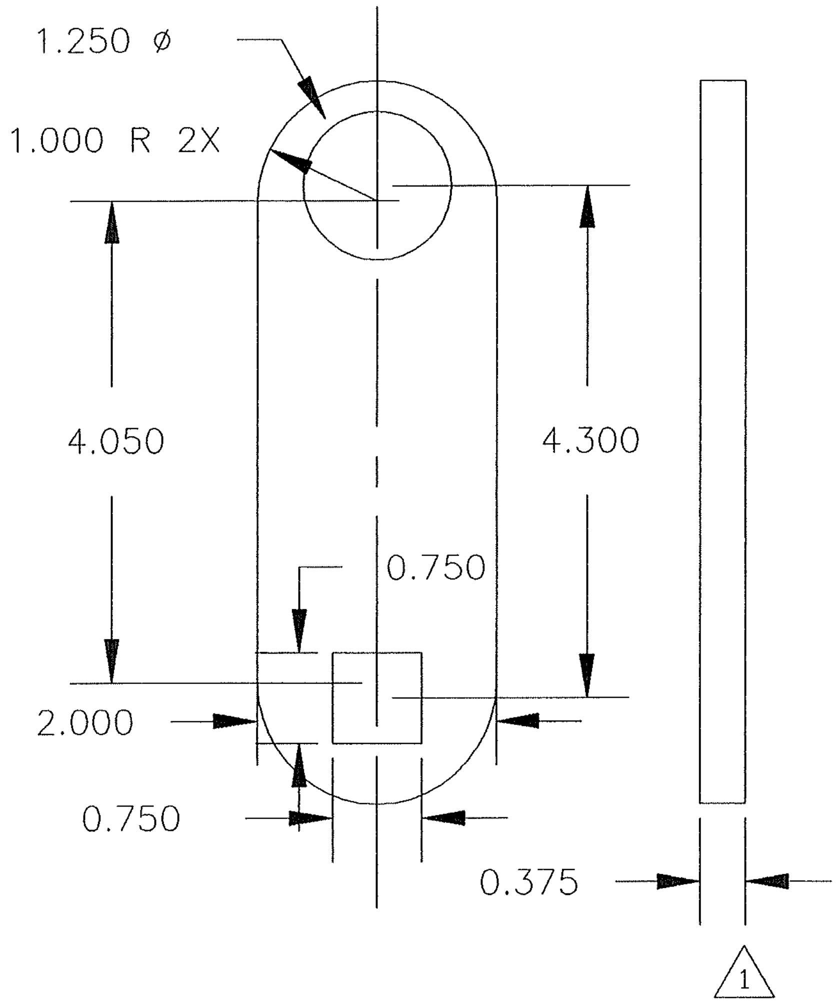
PART LIST

UNLESS OTHERWISE NOTED:
TOLERANCES
.XX ± .01 ANGLES ±0.5°
.XXX ± .005
64

UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT

TITLE ROUTER ASSEMBLY

DESIGN DAB WAW	DATE 1/30/92	QTY 1	DRAWING NO. SHRP(APS)RM-A100
DRAWN KJM		SCALE 1:1	
APPRV DAB		SIZE D	SHT
RELEASE DAB			PROJECT SHRP PROGRAM



REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	1/30/92	KJM	DAB

NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES

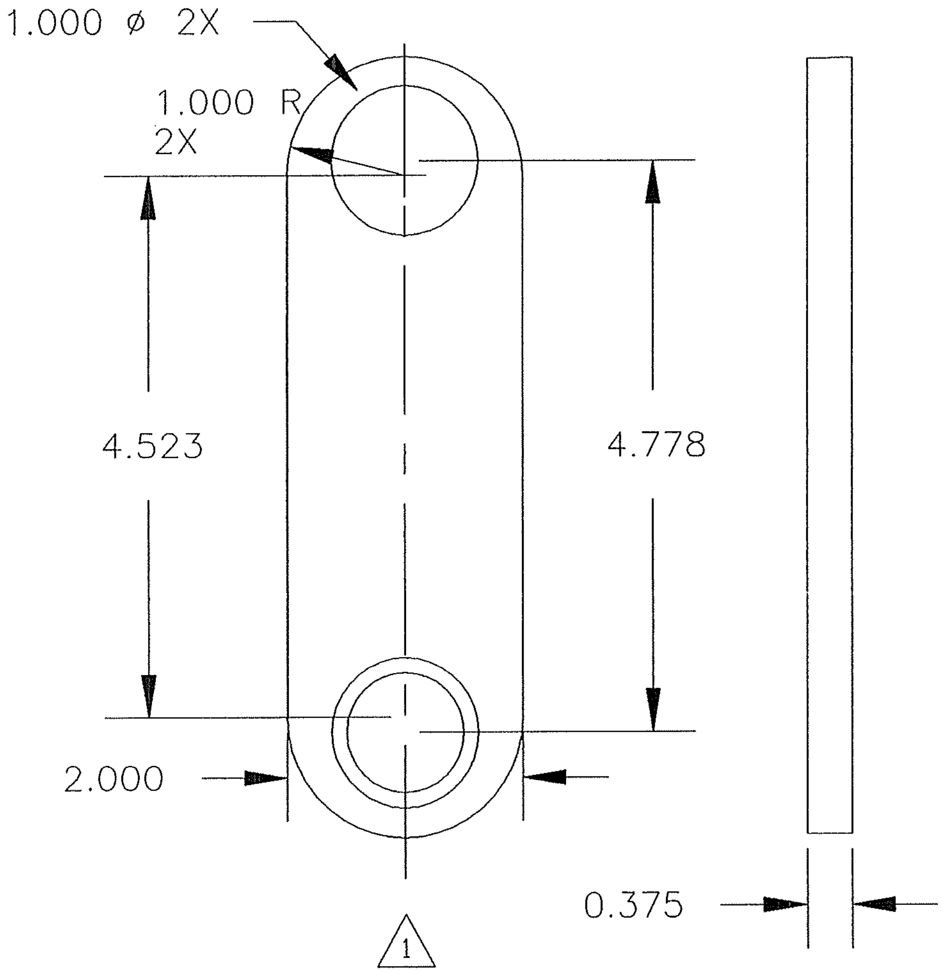
ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
1		6.048x2x.375	1018 STEEL	2

PART LIST

UNLESS OTHERWISE NOTED:
TOLERANCES
.XX ± .01 ANGLES ±0.5°
.XXX ± .005
64√

UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT

DESIGN	DAB WAW
DATE	1/30/92
DRAWN	KJM
APPRV	DAB
RELEASE	DAB
TITLE	UPPER LINK ROUTER ASSEMBLY
QTY	1
SCALE	1:1
SIZE	B
SHT	
DRAWING NO.	SHRP(APS)RM-A102
PROJECT	SHRP PROGRAM



REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	1/30/92	KJM	DAB

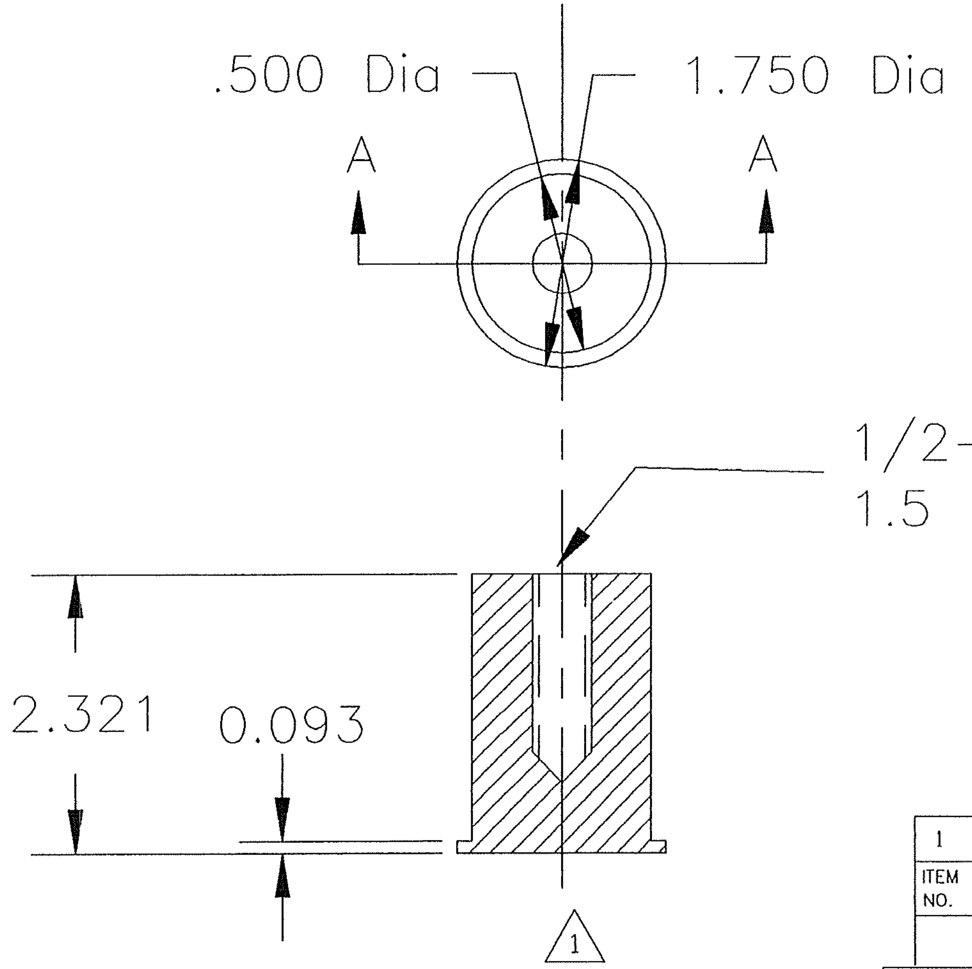
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES

ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
1		6.523x2x.375	1018 STEEL	2

PART LIST

UNLESS OTHERWISE NOTED:
TOLERANCES
.XX ±.01 ANGLES ±0.5°
.XXX ±.005
64√

DESIGN DAB WAW	DATE 1/30/92	UNIVERSITY OF CALIFORNIA, DAVIS MECHANICAL ENGINEERING DEPARTMENT	
DRAWN KJM		TITLE LOWER LINK ROUTER ASSEMBLY	
APPRV DAB		QTY 1 SCALE 1:1	DRAWING NO. SHRP(APS)RM-A101
RELEASE DAB		SIZE B / SHT	PROJECT SHRP PROGRAM



REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	1/30/92	KJM	DAB

ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
1		ø 1.750x2.321	1018 STEEL	1

PART LIST

NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES

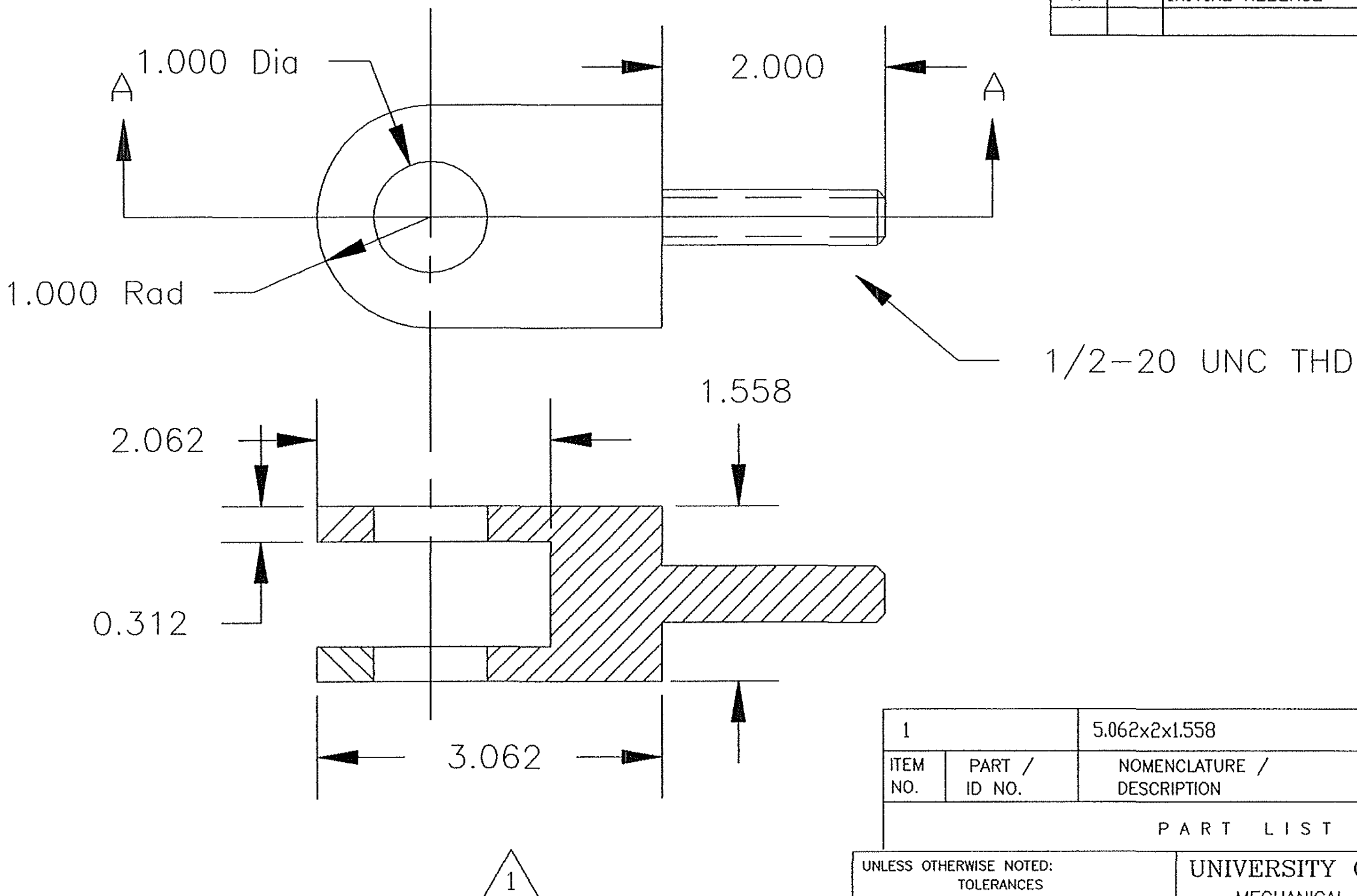
UNLESS OTHERWISE NOTED:
TOLERANCES
.XX ± .01 ANGLES ±0.5°
.XXX ± .005
64√

UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT

TITLE C-CHANNEL PIN
ROUTER ASSEMBLY

DESIGN DAB WAW	DATE 1/30/92	
DRAWN KJM	QTY 1	DRAWING NO. SHRP(APS)RM-A103
APPRV DAB	SCALE 1:1	
RELEASE DAB	SIZE B	SHT	PROJECT SHRP PROGRAM

LTR	ZONE	REVISION DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	1/30/92	KJM	DAB



NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES

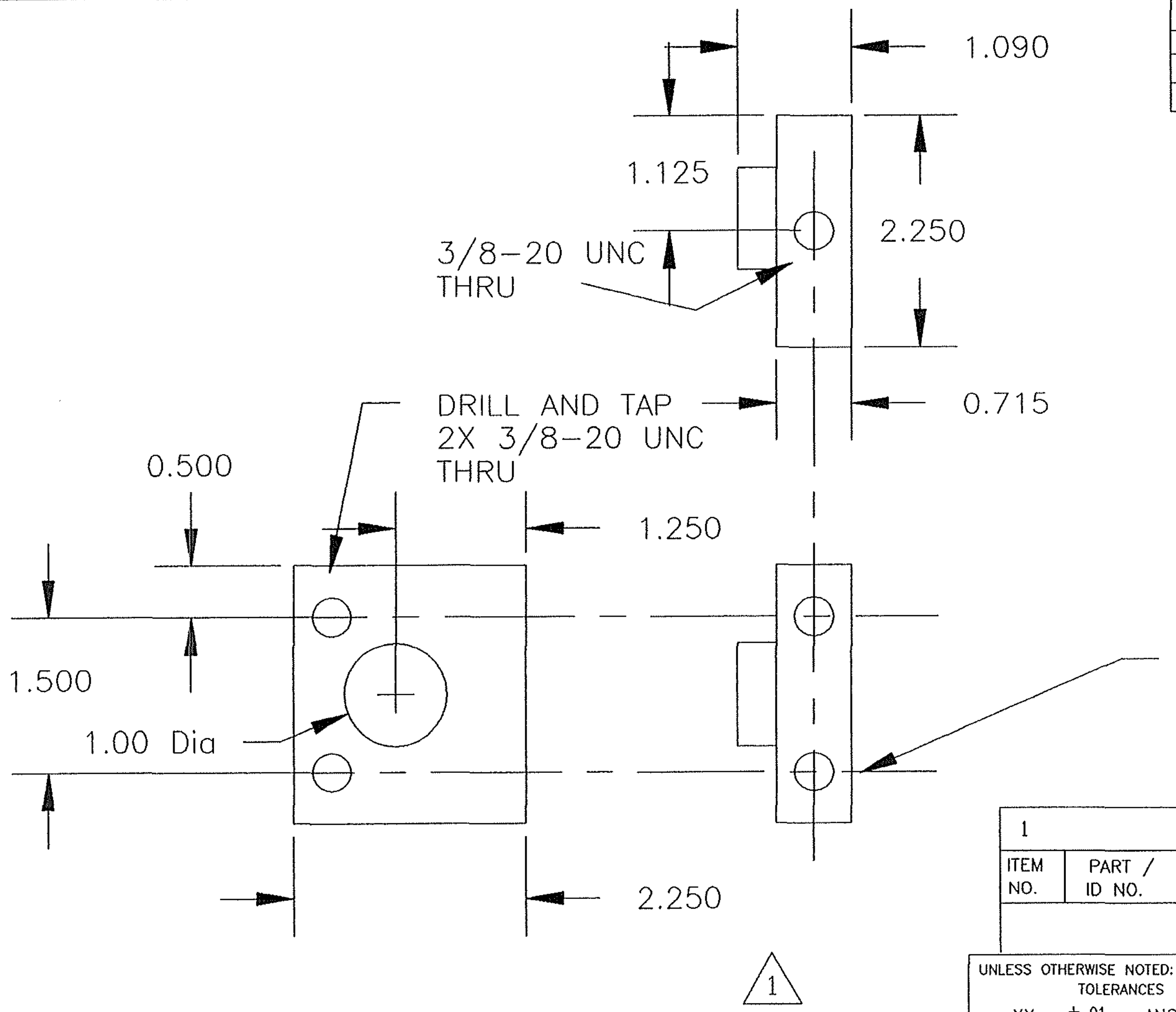
ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
1		5.062x2x1.558	1018 STEEL	1

PART LIST

UNLESS OTHERWISE NOTED:
TOLERANCES
.XX ±.01 ANGLES ±0.5°
.XXX ±.005
64

DESIGN DAB WAW	DATE 1/30/92	UNIVERSITY OF CALIFORNIA, DAVIS MECHANICAL ENGINEERING DEPARTMENT	
		TITLE UPPER & LOWER LINK CAPTURE ROUTER ASSEMBLY	
DRAWN KJM		QTY 1	DRAWING NO. SHRP(APS)RM-A104
APPRV DAB		SCALE 1:1	
RELEASE DAB		SIZE B	SHT	PROJECT SHRP PROGRAM

REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	1/30/92	KJM	DAB



1		2.25x2.25x1.090	1018 STEEL	1
ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD

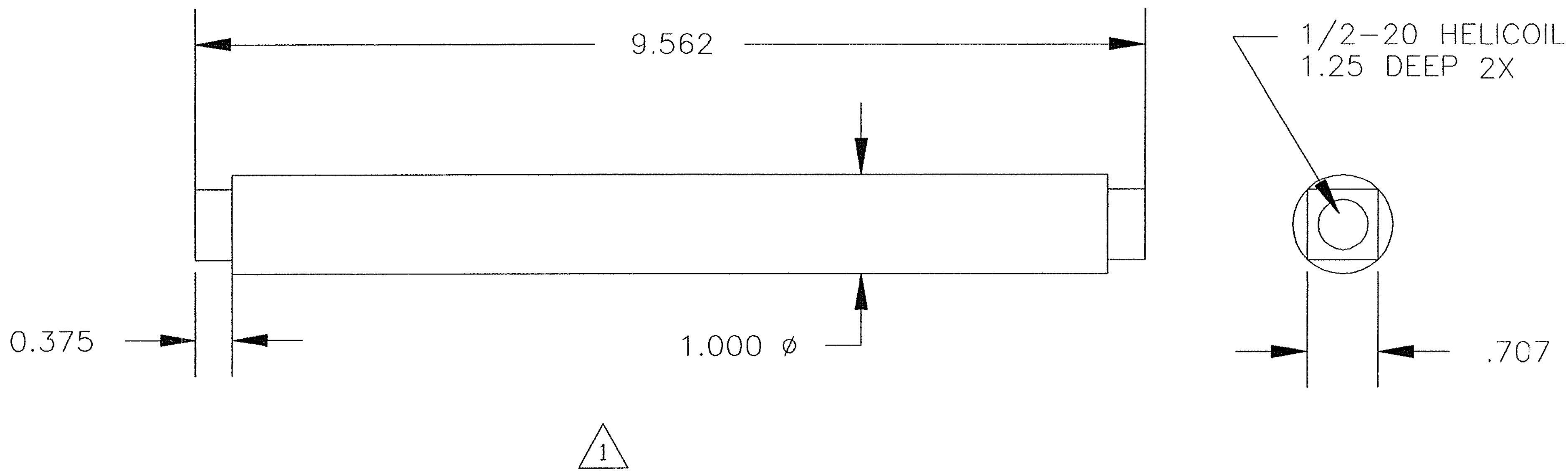
PART LIST

NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES

UNLESS OTHERWISE NOTED:
TOLERANCES
.XX ± .01 ANGLES ± 0.5°
.XXX ± .005
64

DESIGN DAB WAW	DATE 1/30/92	UNIVERSITY OF CALIFORNIA, DAVIS MECHANICAL ENGINEERING DEPARTMENT	
DRAWN KJM		TITLE LOWER LINKPIN BLOCK ROUTER ASSEMBLY	
APPRV DAB		QTY 1 SCALE 1:1	DRAWING NO. SHRP(APS)RM-A105
RELEASE DAB		SIZE B SHT	PROJECT SHRP PROGRAM

REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	1/30/92	KJM	DAB



NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES

1		ø 1.000x9.812	1040 Steel	1
ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD

PART LIST

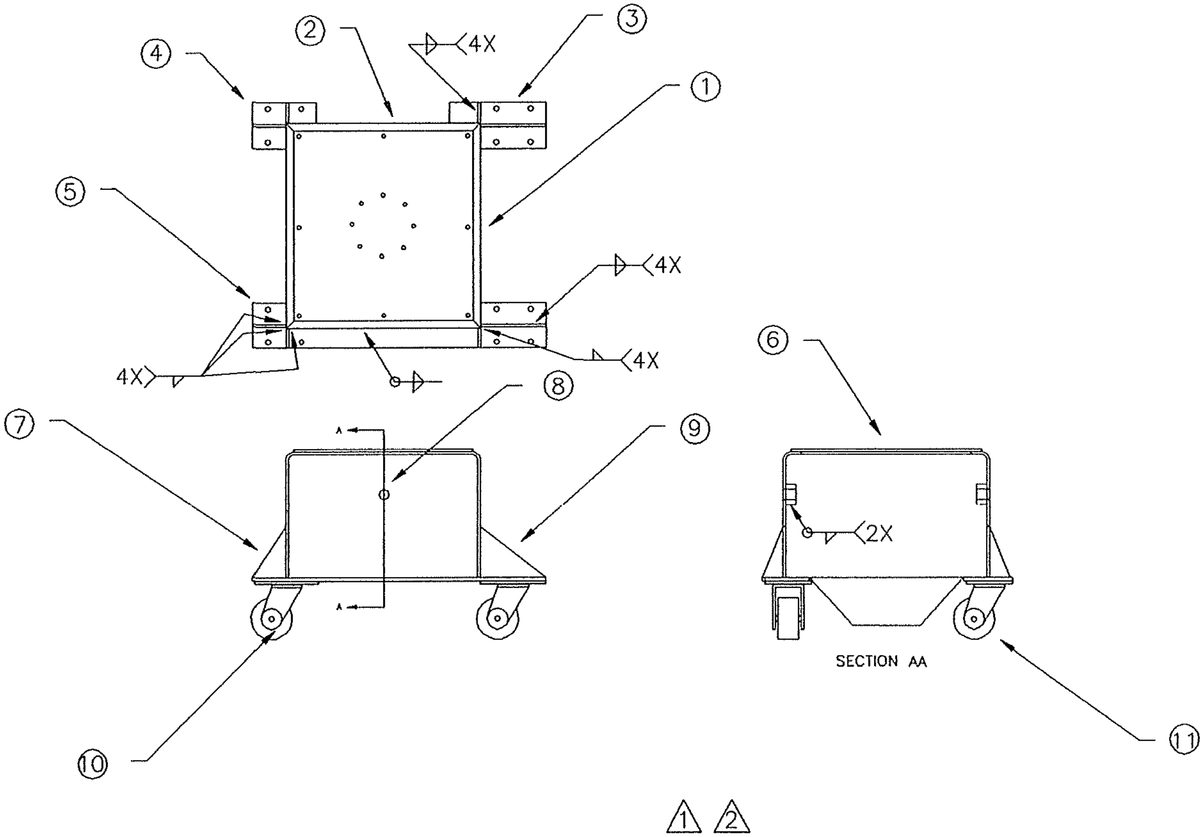
UNLESS OTHERWISE NOTED:
TOLERANCES
.XX ±.01
.XXX ±.005
ANGLES ±0.5°
64

DESIGN DAB WAW	DATE 1/30/92		
DRAWN KJM		QTY 1	DRAWING NO. SHRP(APS)RM-A106
APPRV DAB		SCALE 1:1	
RELEASE DAB		SIZE B / SHT	PROJECT SHRP PROGRAM

UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT

TITLE UPPER LINKPIN ROUTER ASSEMBLY

REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	1/30/92	KJM	DAB



11		CASTERS MCM-CARR 2494T81		4
10	RM-B102-2	BACK STEEL PLATE	1018 STEEL	1
9	RM-B103-6	FRONT STEEL GUSSET	1018 STEEL	1
8	RM-B103-5	STEEL BOSS	1018 STEEL	1
7	RM-B103-4	BACK STEEL GUSSET	1018 STEEL	1
6	RM-B101-2	STEEL PLATE	1018 STEEL	1
5	RM-B103-3	EXTENDED STEEL FOOT	1018 STEEL	1
4	RM-B103-2	BACK STEEL FOOT	1018 STEEL	1
3	RM-B103-1	FRONT STEEL FOOT	1018 STEEL	1
2	RM-B101-1	STEEL PLATE	1018 STEEL	2
1	RM-B102-1	FRONT STEEL PLATE	1018 STEEL	1
ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD

PART LIST

NOTES: UNLESS OTHERWISE SPECIFIED

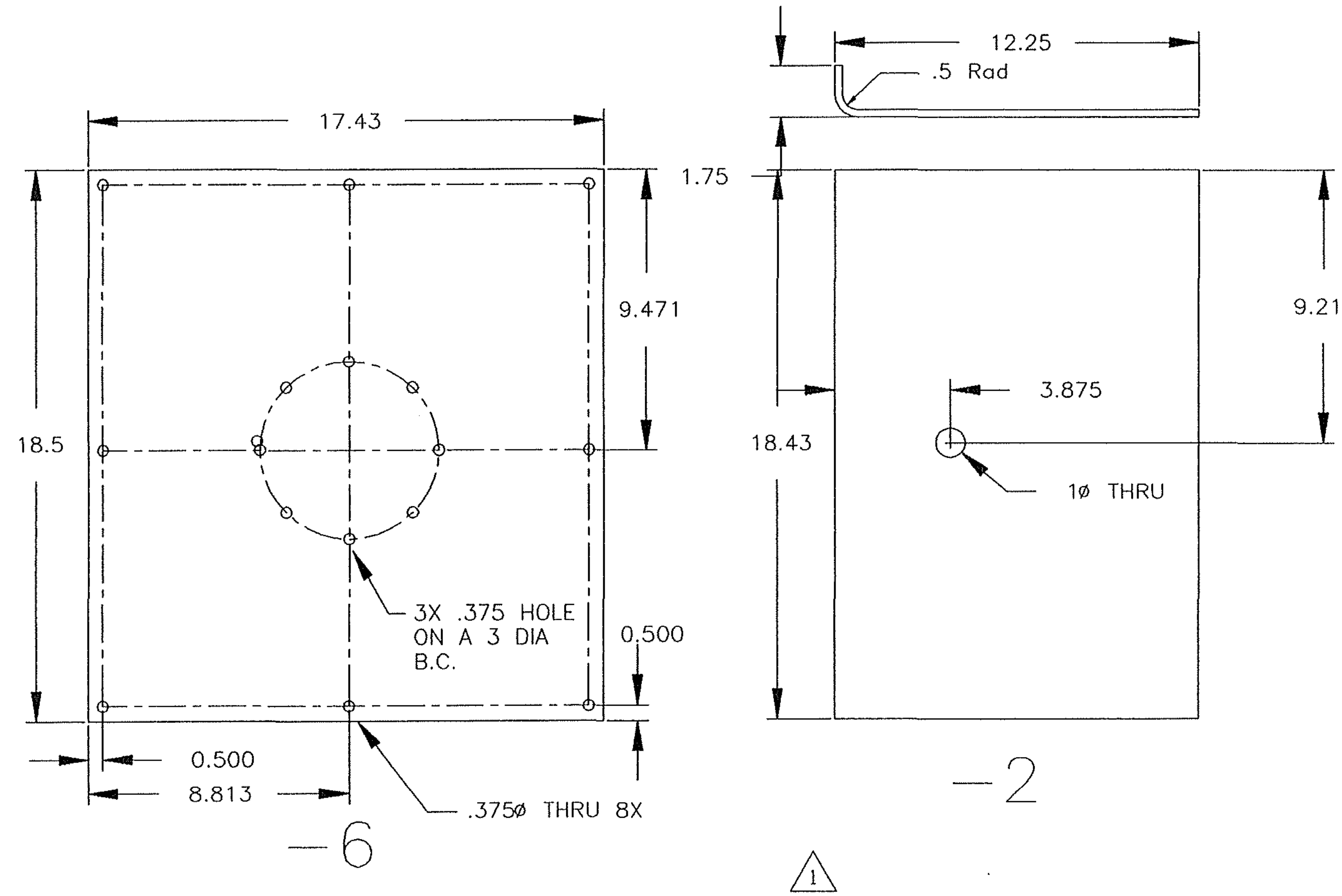
1) BREAK ALL SHARP EDGES
2) WELDS SHALL BE AS FOLLOWS:
   A. V–GROOVE WELDS SHALL BE 1/4 IN SIZE WITH 60°–90° GROOVE ANGLE. GRIND FLUSH.
   B. BEVEL GROOVE WELDS SHALL BE 3/16 IN SIZE WITH 45° GROOVE ANGLE.
   C. ALL FILLET WELDS SHALL BE 1/4 IN SIZE.

UNLESS OTHERWISE NOTED: TOLERANCES
.XX ± .01 ANGLES ±0.5°
.XXX ± .005
64

UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT

DESIGN DAB WAW	DATE 1/30/92	TITLE WHEEL SUPPORT FRAME ROUTER ASSEMBLY	
DRAWN KJM		QTY 1	DRAWING NO. SHRP(APS)RM-B100
APPRV DAB		SCALE 1:1	
RELEASE DAB		SIZE D / SHT	PROJECT SHRP PROGRAM

REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	1/30/92	KJM	DAB



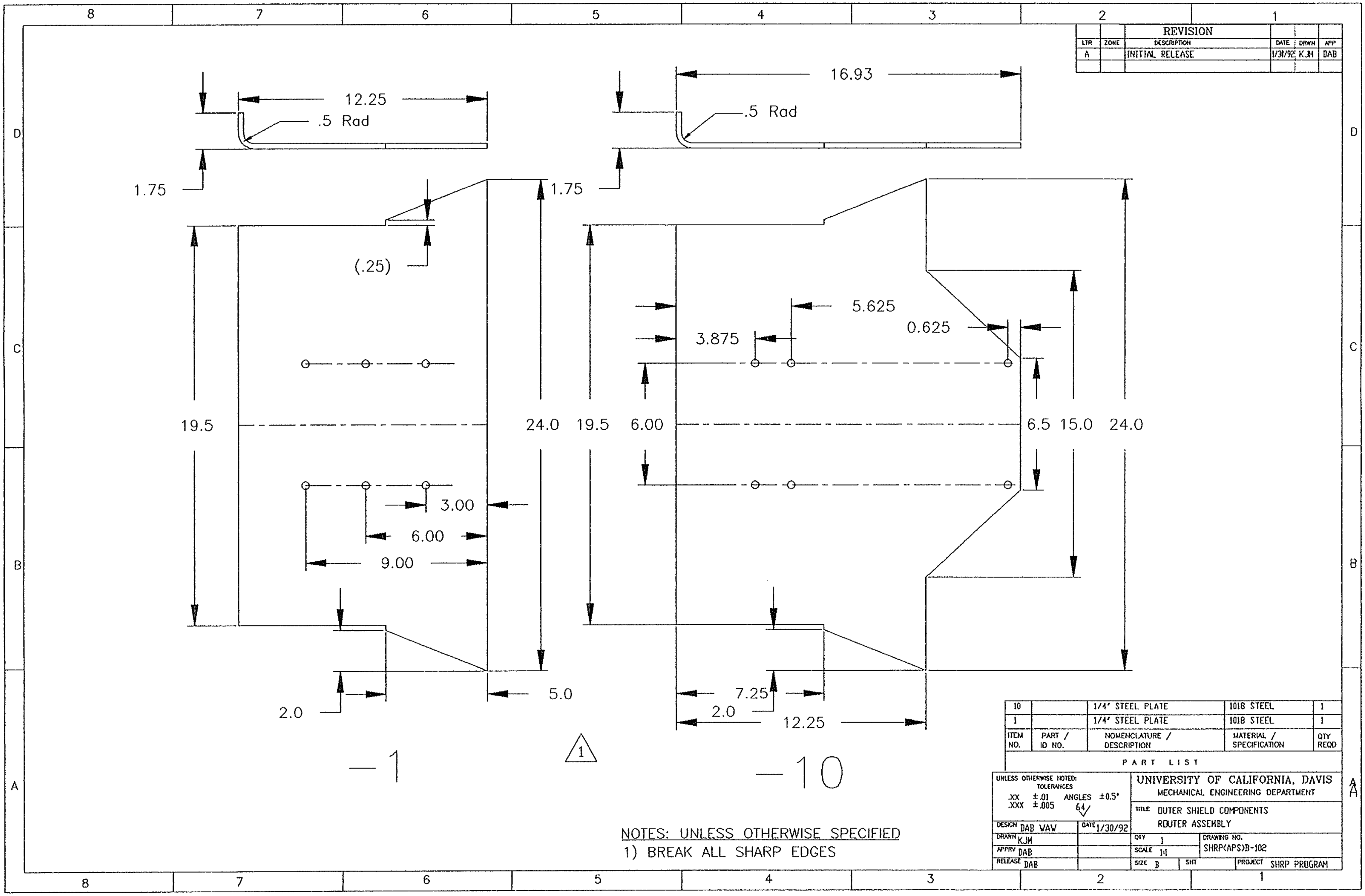
NOTES: UNLESS OTHERWISE SPECIFIED

1) BREAK ALL SHARP EDGES

6		1/4' STEEL PLATE	1018 STEEL	1
2		1/4' STEEL PLATE	1018 STEEL	2
ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD

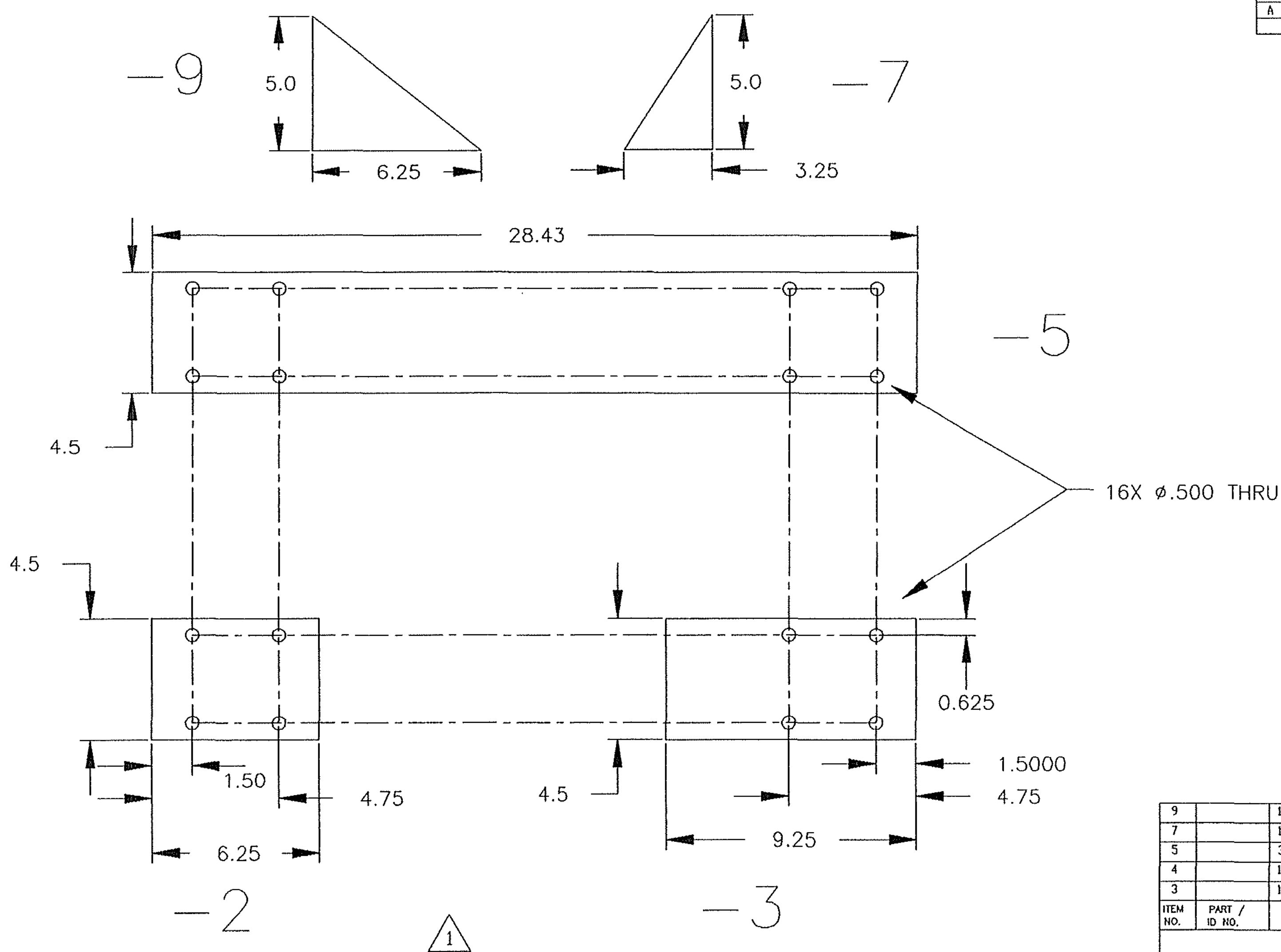
PART LIST

UNLESS OTHERWISE NOTED: TOLERANCES .XX ± .01 .XXX ± .005 ANGLES ±0.5° 64		UNIVERSITY OF CALIFORNIA, DAVIS MECHANICAL ENGINEERING DEPARTMENT	
DESIGN DAB WAW	DATE 1/30/92	TITLE OUTER SHIELD COMPONENTS ROUTER ASSEMBLY	
DRAWN KJM		QTY 1	DRAWING NO. SHRP(APS)RM-B101
APPRV DAB		SCALE 1:1	
RELEASE DAB		SIZE D	SHT	PROJECT SHRP PROGRAM



REVISION
LTR | ZONE | DESCRIPTION | DATE | DRWN | APP
A | INITIAL RELEASE | 1/31/92 | KJM | DAB
12.25
.5 Rad
1.75
(.25)
19.5
24.0
3.00
6.00
9.00
2.0
5.0
16.93
.5 Rad
1.75
19.5
6.00
3.875
5.625
0.625
6.5
15.0
24.0
7.25
2.0
12.25
1
-1
-10
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
10 | 1/4' STEEL PLATE | 1018 STEEL | 1
1 | 1/4' STEEL PLATE | 1018 STEEL | 1
ITEM NO. | PART / ID NO. | NOMENCLATURE / DESCRIPTION | MATERIAL / SPECIFICATION | QTY REQD
PART LIST
UNLESS OTHERWISE NOTED: TOLERANCES
.XX ±.01 ANGLES ±0.5°
.XXX ±.005
64
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
TITLE OUTER SHIELD COMPONENTS
ROUTER ASSEMBLY
DESIGN DAB WAW
DATE 1/30/92
DRAWN KJM
APPRV DAB
RELEASE DAB
QTY 1
SCALE 1:1
SIZE B
SHT
DRAWING NO. SHRP(APS)B-102
PROJECT SHRP PROGRAM

REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	1/31/92	KJM	DAB



NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES

ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
9		1/4' STEEL PLATE	1018 STEEL	2
7		1/4' STEEL PLATE	1018 STEEL	2
5		3/8' STEEL PLATE	1018 STEEL	1
4		1/4' STEEL PLATE	1018 STEEL	1
3		1/4' STEEL PLATE	1018 STEEL	1

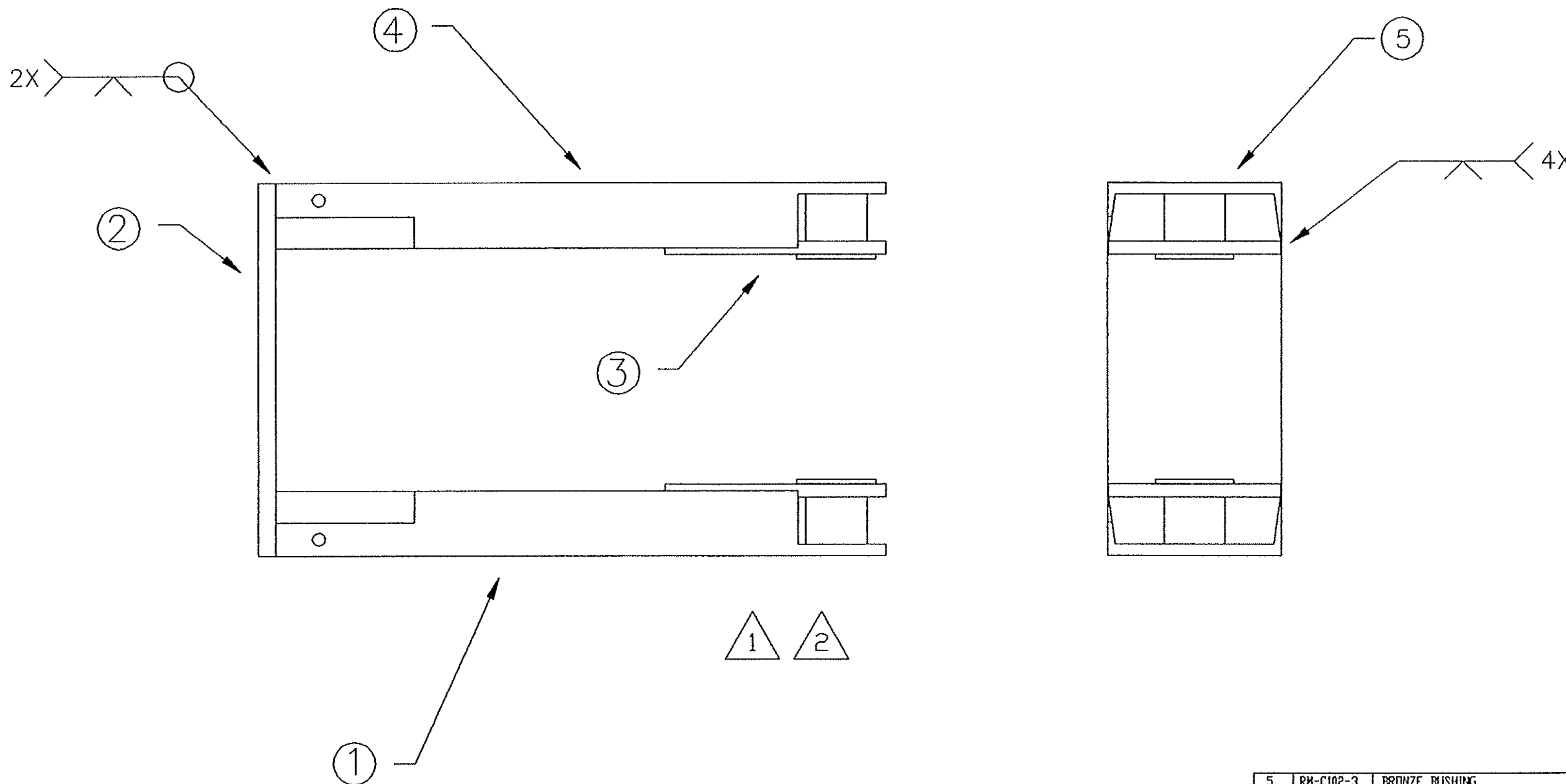
PART LIST

UNLESS OTHERWISE NOTED:
TOLERANCES
.XX ± .01 ANGLES ±0.5°
.XXX ± .005
64√

UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT

DESIGN DAB WAW	DATE 1/30/92	TITLE OUTER SHIELD COMPONENTS ROUTER ASSEMBLY	
DRAWN KJM		QTY 1	DRAWING NO. SHRP(APS)B-103
APPRV DAB		SCALE 1:1	
RELEASE DAB		SIZE D / SHT	PROJECT SHRP PROGRAM

REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	1/31/92	KJM	DAB



NOTES: UNLESS OTHERWISE SPECIFIED

1) BREAK ALL SHARP EDGES

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

ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
5	RM-C102-3	BRONZE BUSHING		2
4	RM-C101-2	CUTTER GUIDE PLATE	1018 STEEL	2
3	RM-C102-2	PLATE	1018 STEEL	2
2	RM-C102-1	BACK PLATE	1018 STEEL	1
1	RM-C101-1	CUTTER GUIDE PLATE	5" C-CHANNEL	2

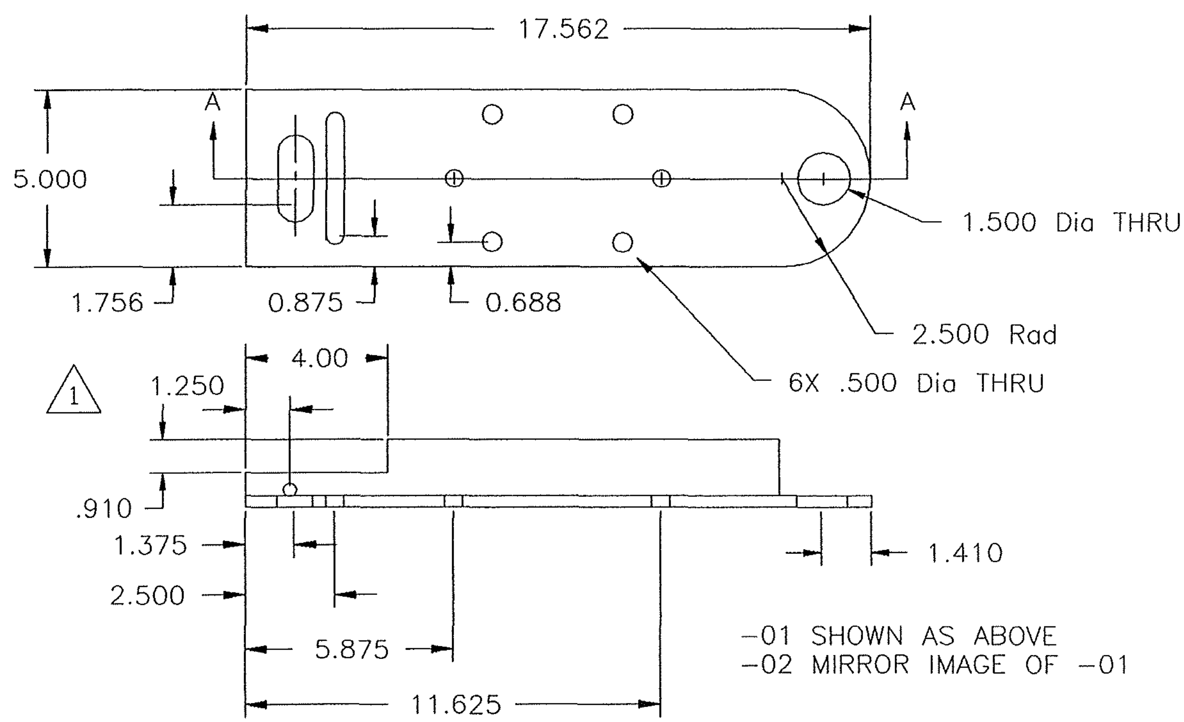
PART LIST

UNLESS OTHERWISE NOTED: TOLERANCES .XX ± .01 .XXX ± .005 ANGLES ± 0.5° 64√	UNIVERSITY OF CALIFORNIA, DAVIS MECHANICAL ENGINEERING DEPARTMENT
DESIGN DAB WAW — DATE 1/30/92	TITLE CUTTER GUIDE ASSEMBLY ROUTER ASSEMBLY
DRAWN KJM	QTY 1 — DRAWING NO. SHRP(APS)RM-C100
APPRV DAB	SCALE 1:1
RELEASE DAB	SIZE D — SHT — PROJECT SHRP PROGRAM

A

REVISION

LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	1/31/92	KJM	DAB



-01 SHOWN AS ABOVE
-02 MIRROR IMAGE OF -01

1

NOTES: UNLESS OTHERWISE SPECIFIED

1) BREAK ALL SHARP EDGES

ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
2		CUTTER GUIDE PLATE	5' C-CHANNEL	1
1		CUTTER GUIDE PLATE	5' C-CHANNEL	1

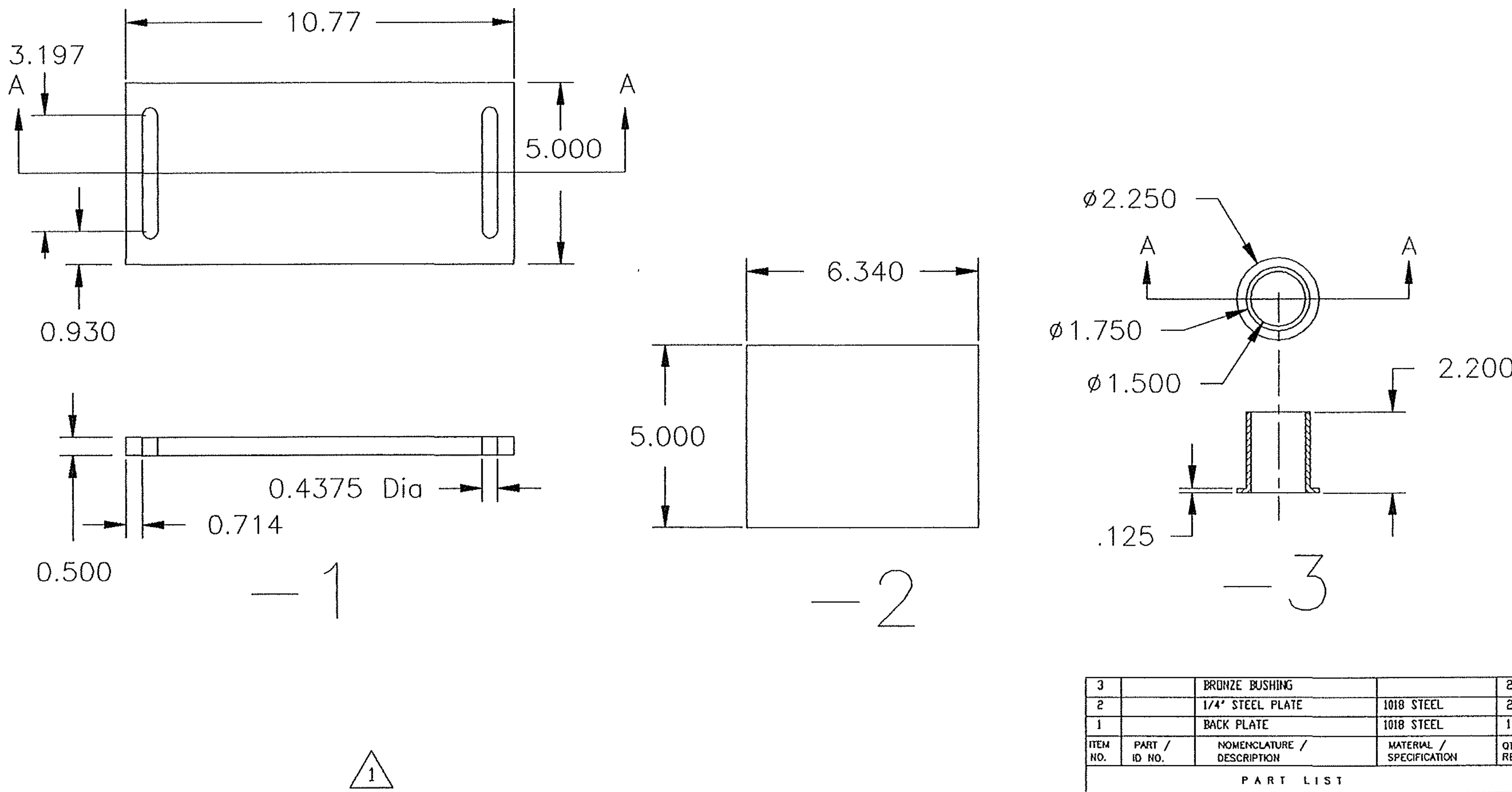
PART LIST

UNLESS OTHERWISE NOTED: TOLERANCES
.XX ±.01 ANGLES ±0.5°
.XXX ±.005
64

UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT

DESIGN DAB WAW	DATE 1/30/92	TITLE CUTTER GUIDE PLATE ROUTER ASSEMBLY	
DRAWN KJM		QTY 1	DRAWING NO. SHRP(APS)RH-C101
APPRV DAB		SCALE 1/1	
RELEASE DAB		SIZE D SHT	PROJECT SHRP PROGRAM

REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	1/31/92	KJM	DAB



NOTES: UNLESS OTHERWISE SPECIFIED

1) BREAK ALL SHARP EDGES

ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
3		BRONZE BUSHING		2
2		1/4' STEEL PLATE	1018 STEEL	2
1		BACK PLATE	1018 STEEL	1

PART LIST

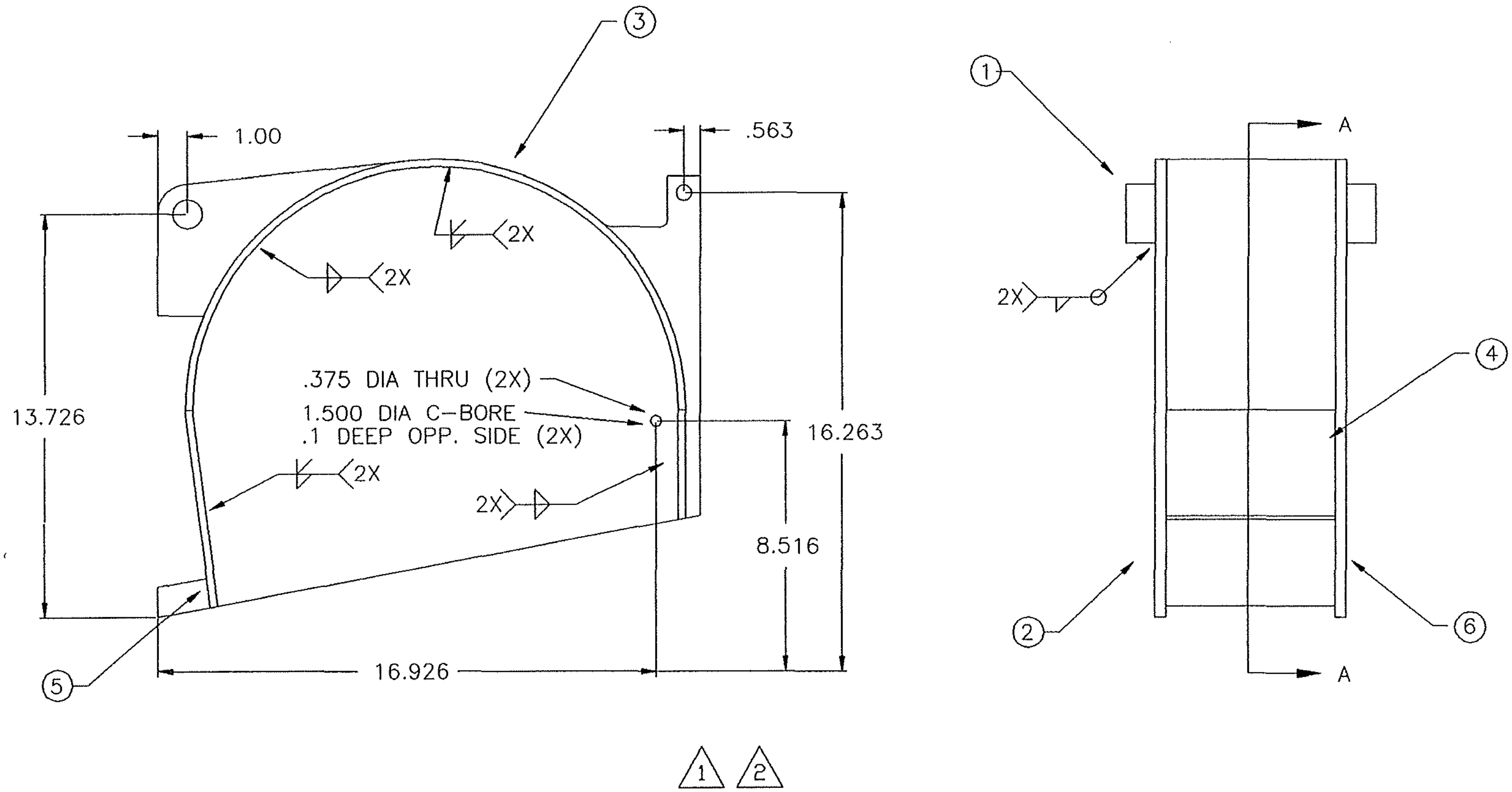
UNLESS OTHERWISE NOTED: TOLERANCES .XX ± .01 .XXX ± .005 ANGLES ±0.5° 64√

UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT

TITLE C-CHANNEL ASSEMBLY COMPONENTS ROUTER ASSEMBLY

DESIGN DAB WAW	DATE 1/30/92	QTY 1	DRAWING NO. SHRP(APS)RM-C102
DRAWN KJM		SCALE 1:1	
APPRV DAB		SIZE D	SHT
RELEASE DAB			PROJECT SHRP PROGRAM

REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	1/30/92	KJN	DAB



NOTES: UNLESS OTHERWISE SPECIFIED

1) BREAK ALL SHARP EDGES

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

ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
6	RN-D102-2	SIDE PLATE	1018 STEEL	1
5	RN-D101-3	STEEL PLATE	1018 STEEL	1
4	RN-D101-2	STEEL PLATE	1018 STEEL	1
3	RN-D101-4	CURVED UPPER PLATE	1018 STEEL	1
2	RN-D102-1	SIDE PLATE	1018 STEEL	1
1	RN-D101-1	UPPER PIN SETOFF	1018 STEEL	2

PART LIST

UNLESS OTHERWISE NOTED:
TOLERANCES
.XX ±.01 ANGLES ±0.5°
.XXX ±.005
64

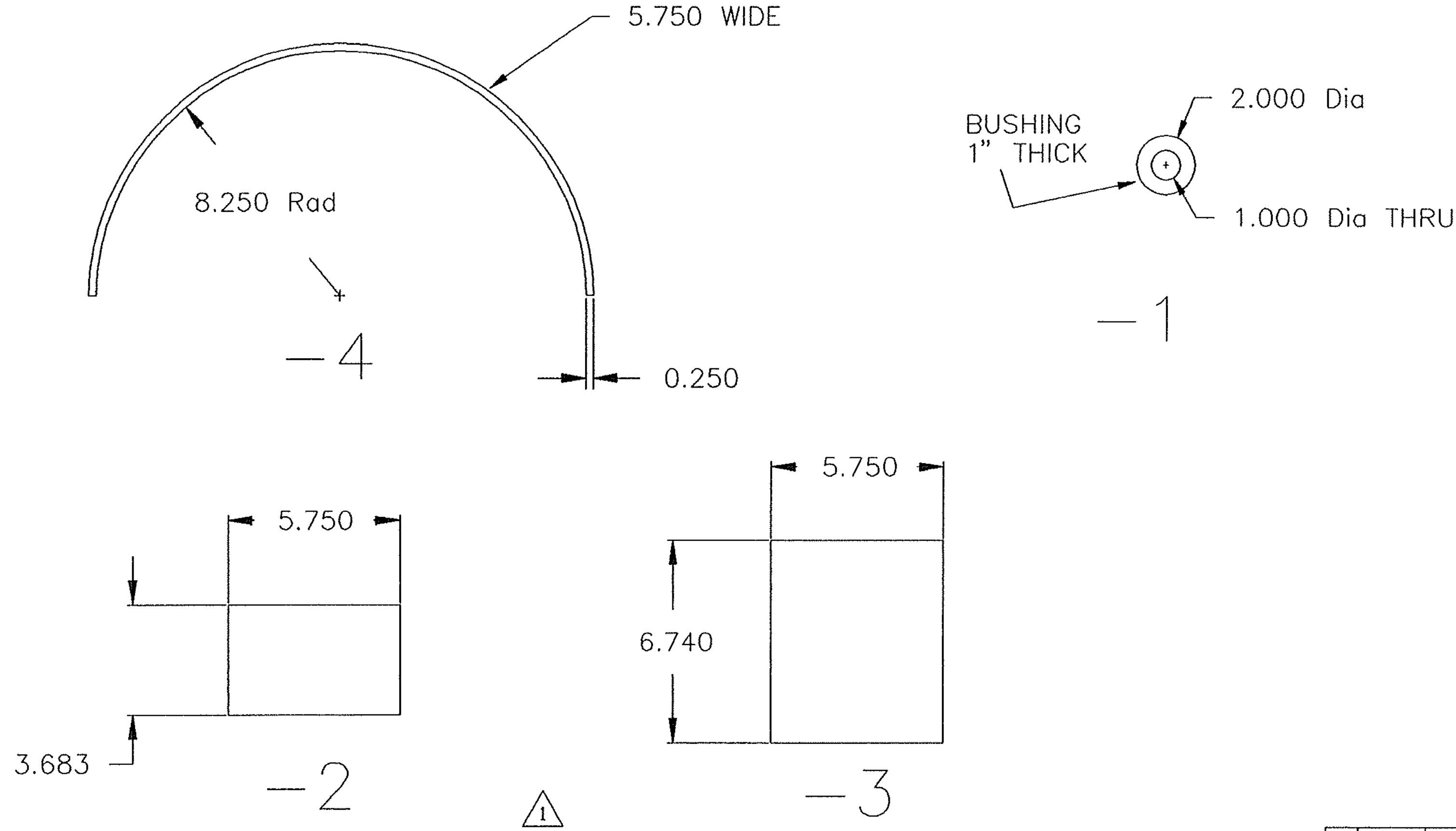
DESIGN DAB VAW DATE 1/30/92
DRAWN KJN
APPRV DAB
RELEASE DAB

UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT

TITLE INNER FRAME ASSEMBLY
ROUTER ASSEMBLY

QTY 1
SCALE 1:1
SIZE D
SHT
DRAWING NO. SHRP(APS)RN-D100
PROJECT SHRP PROGRAM

REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	1/30/92	KJH	DAB



NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES

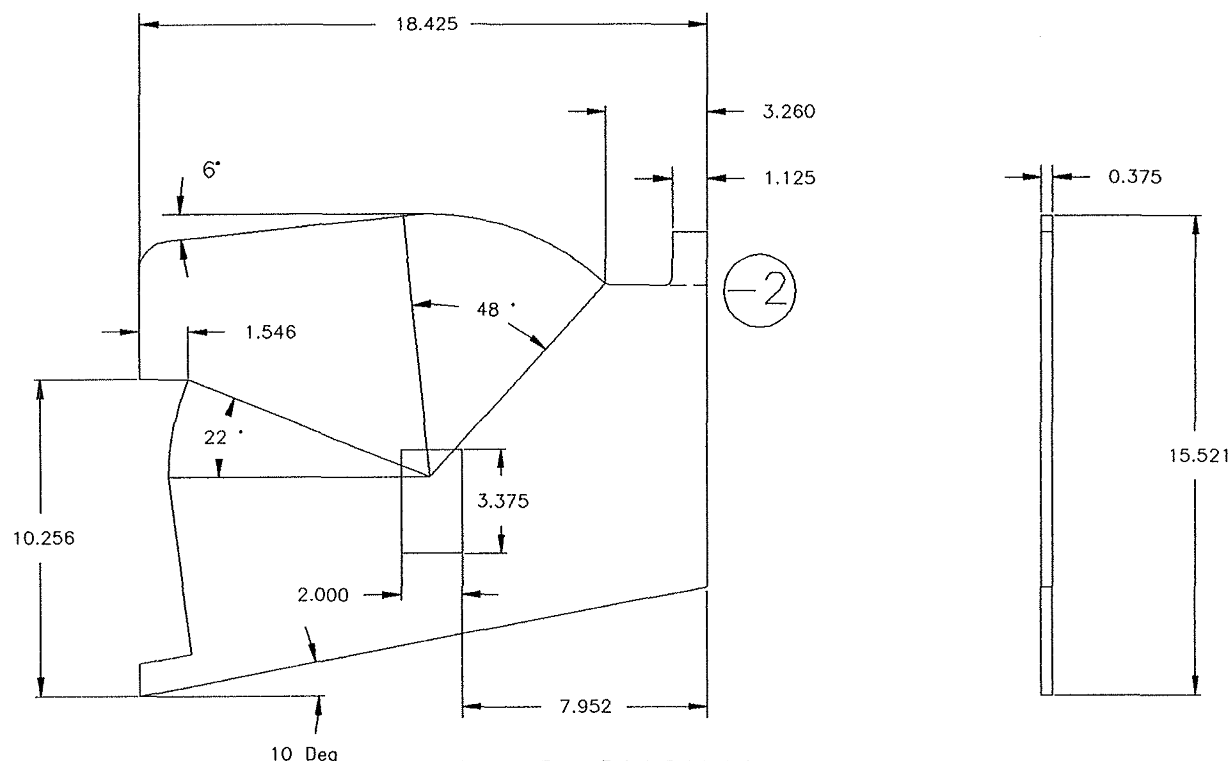
ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
4		1/4" STEEL PLATE	1018 STEEL	1
3		1/4" STEEL PLATE	1018 STEEL	1
2		1/4" STEEL PLATE	1018 STEEL	1
1		UPPER PIN SETOFF	1018 STEEL	2

PART LIST

UNLESS OTHERWISE NOTED: TOLERANCES .XX ±.01 .XXX ±.005 ANGLES ±0.5° 64		UNIVERSITY OF CALIFORNIA, DAVIS MECHANICAL ENGINEERING DEPARTMENT	
DESIGN DAB VAV	DATE 1/30/92	TITLE INNER ASSEMBLY PLATES ROUTER ASSEMBLY	
DRAWN KJH		QTY 1	DRAWING NO. SHRP(APS)RN-B101
APPRV DAB		SCALE 1:1	
RELEASE DAB		SIZE D / SHT	PROJECT SHRP PROGRAM

REVISION

LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	1/31/92	KJH	DAB



−1 AS SHOWN
−2 MIRROR IMAGE OF −1
EXCEPT FOR CUT ABOVE

1

NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES

ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
2		1/4' STEEL PLATE	1018 STEEL	1
1		1/4' STEEL PLATE	1018 STEEL	1

PART LIST

UNLESS OTHERWISE NOTED: TOLERANCES
.XX ±.01 ANGLES ±0.5°
.XXX ±.005 64

DESIGN DAB VAV DATE 1/30/92
DRAWN KJH
APPRV DAB
RELEASE DAB

UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT

TITLE SIDE PLATE
ROUTER ASSEMBLY

QTY 1
SCALE 1:1
SIZE D
SHT
DRAWING NO. SHRP(APS)RM-D102
PROJECT SHRP PROGRAM

E.2 - Heating/Cleaning/Debris Removal System

E.2.1 - General Specifications

1.0 INTRODUCTION

1.1 This document serves to provide detail specifications for the DEBRIS SEPARATOR, BLOWER, BURNER, and FUEL TRAIN/FLAME SAFEGUARD units to be provided by vendors and installed by UCD on the above mentioned crack sealing machine.

1.2 The heating/cleaning system shall be sold to UCD as components only and will be assembled by UCD. Section 8.0 contains a list of deliverables.

2.0 DEBRIS SEPARATOR

2.1 The unit shall provide enough suction to remove approximate 1/2" diameter chunks of asphalt concrete at no less than 400 standard cubic feet per minute of air flow.

2.2 Clean air shall be exhausted at approximately 8-10 micron filtration.

2.3 Debris shall be collected in no less than a 55 gallon drum that shall be mounted on wheels for easy emptying.

2.4 A vacuum relief valve shall be provided in case a clog occurs.

2.5 The unit shall incur a pressure loss of no more than 1 PSI @ 400 SCFM.

3.0 BLOWER SPECIFICATIONS

3.1 The blower shall move air at no less than 400 standard cubic feet per minute (SCFM) at no less than 5 PSI.

3.2 The blower shall be hydraulically driven and actuated electrically using 110 VAC solenoids.

3.3 Inlet and exit diameters shall be no less than 3" and no greater than 4".

3.4 Blower shall operate using hydraulic fluid supplied at 2000 PSI and pumped at up to 20 gallons per minute (GPM).

4.0 BURNER SPECIFICATIONS

4.1 The burner shall heat no less than 400 standard cubic feet per minute (SCFM) to no less than 1500°F.

4.2 The burner shall be able to accommodate a gage pressure at the burner exit of no less than 2 PSI.

4.3 The burner shall take no longer than 15 seconds to reach 90% of its steady state heat output.

4.4 Combustion air shall be provided to the burner inlet by UCD via a hydraulically powered 5 PSI, 400 SCFM centrifugal blower.

4.5 All necessary plumbing and insulation downstream of the burner nozzle exit shall be designed and purchased separately by UCD.

5.0 FUEL TRAIN AND FLAME SAFEGUARD SYSTEM SPECIFICATIONS

5.1 A standard control box/panel shall house all major electrical components and a wiring pin diagram shall be provided to UCD outlining connections to fuel train components.

5.2 All primary controls and switches shall also be mounted on the face of the box/panel in a "user friendly" manner. These shall include an easily accessible emergency shut off type switch. Other necessary meters, lights, etc... may be added provided they shall enhance the ease and safety of operation of the system.

5.3 Two 2-way, electrically actuated, 3" diameter valves shall be provided by the vendor. They shall be configured such that when one is open the other is closed. They shall provide a means of deflected flow from the pavement, upstream of the burner. A properly sized DPDT toggle switch located on the control box/panel face shall toggle these valves.

5.4 A 110VAC, 3A push button switch shall be added to the face of the control box/panel. This switch will serve as a means of turning on the blower solenoid provided by UCD.

5.5 When the air flow is switched to deflect flow from the burner, or DIVERT as it will be referred to herein, fuel flow to the burner should be cut off without turning off power to the blower.

5.6 A pressure differential circuit breaker in the blower airway shall protect crack sealing machine subsystems by shutting down the burner fuel flow *and* blower in proper succession should an obstruction in the inlet or exit of the heating system occur.

5.7 Fuel flow control shall occur via a 4-20 mA input from a UCD provided infrared pyrometer which will measure pavement surface temperature between 0 and 400°F. The fuel flow shall be automatically continuously adjusted by a PID type controller to attain a surface temperature of 250°F. The fuel flow control valve shall have a 95% response time of 0.5 seconds or less.

5.8 The specifications mentioned above should by no means bypass or override the standard and legally required flame safeguard system.

5.9 All necessary wiring and minor plumbing supplies shall be provided by UCD. They need not be quoted by the vendor but must be specified.

5.10 The heating system may be able to be operated in either the BLOW ONLY or HEAT mode.

6.0 <u>POWER SYSTEMS</u>

6.1 All electrical systems and subsystems shall operate using 110 VAC requiring no more than 3 kW of combined power.

6.2 All methane fuel used shall be standard commercially available liquid propane.

6.3 LP gas will be provided by UCD via 4-100 lb. vapor withdrawal tanks. The burner and fuel train system provided must be able to operate at maximum fuel flow given this fuel system.

6.4 All electrical systems shall have circuit breakers to protect other unrelated systems on the crack sealing machine. In the event of a power failure to any system, proper sequenced shut-down should automatically occur in the heating/cleaning system.

7.0 <u>PHYSICAL CONSTRAINTS</u>

7.1 All deliverables shall be able to withstand typical vehicle shock and vibration.

7.2 The control panel need NOT be NEMA 4 rated. It will only be operated in a closed room or dry weather day.

8.0 <u>DELIVERABLES</u> - shall meet all of the above and below specifications.

8.1 Debris Separator
- 8.1.1 Debris separator meeting Section 2 specifications
- 8.1.2 (2) 3" diameter vacuum hoses (30 feet total)
- 8.1.3 (1) custom fabricated router shroud (built-in router design)

8.2 Blower meeting Section 3 specifications

8.3 Burner
- 8.3.1 (1) Burner meeting Section 4 specifications
- 8.3.2 (1) Flame rod
- 8.3.3 (1) Spark ignitor
- 8.3.4 Complete set of manufacturer instructions and documentation.

8.4 Fuel train and flame safeguard system
- 8.4.1 (1) Control panel/box and flame safeguard system (see Section 5)
- 8.4.2 (1) PID digital process controller for fuel flow control.
- 8.4.3 (1) Fuel flow control valve.
- 8.4.4 Standard fuel train components necessary to ensure the safe, efficient operation of the above described system.
- 8.4.5 List of wiring and minor plumbing supplies (nipples, connectors, elbows, etc.). (All necessary wiring and minor plumbing supplies will be provided by UCD).
- 8.4.6 (2) 2-way, electrically actuated, 3" diameter valves for DIVERTER.
- 8.4.7 (1) DPDT switch for DIVERTER actuation mounted on control panel face.
- 8.4.8 (1) 110VAC, 3A push button switch mounted on control panel face.
- 8.4.9 (1) Pressure differential switch.
- 8.4.10 All necessary and standard regulators, filters, safety valves, etc.

E.2.1 - Manufacturer's Specifications

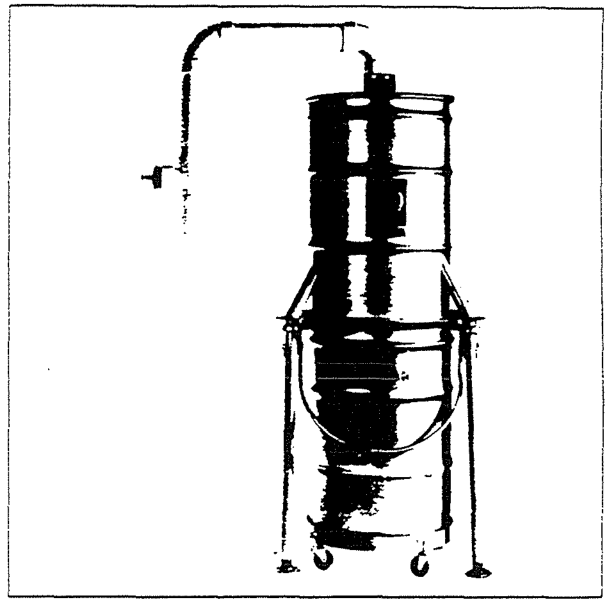
APPENDIX E - MANUFACTURE'S EQUIPMENT SPECIFICATIONS

EG&G ROTRON
Industrial Division

ROTRON IVM2000PF FLOOR MOUNT VACUUM UNIT

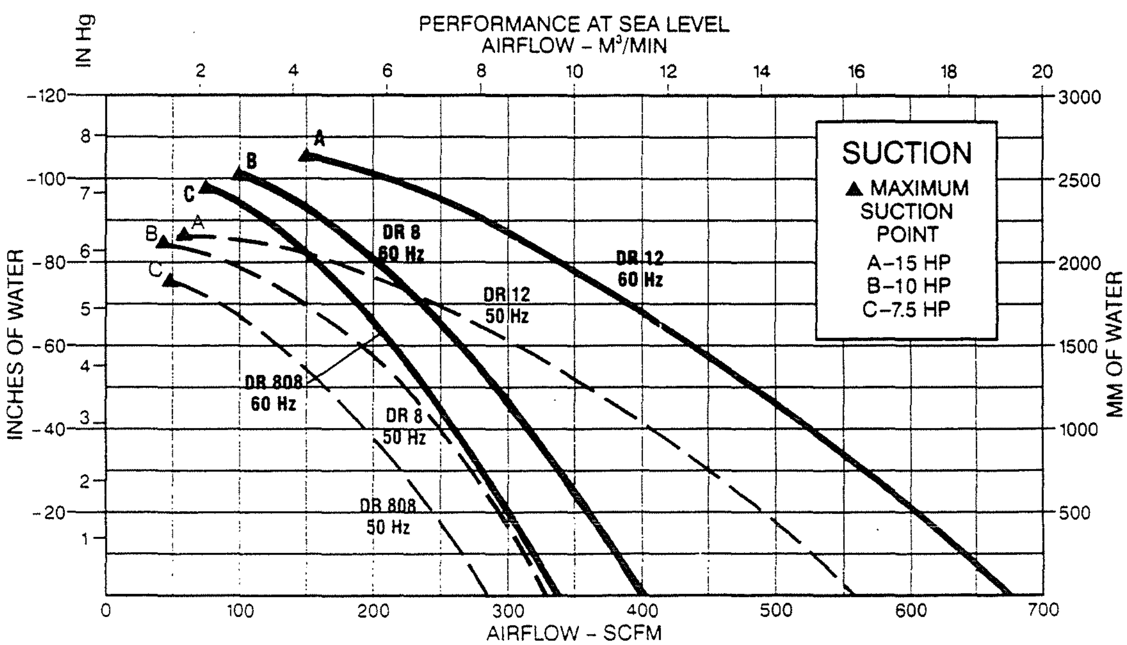
FEATURES

- Manufactured in the U.S.A.
- Dry Material Collection
- Epoxy Coated Steel Separator and Receiver
- Centrifugal Separation and Self-cleaning Permanent Filter
- Secondary 8-10 Micron Cartridge Filter
- Easy Access Filter
- Dolly-mounted Collection Canister
- Accepts Industry Standard Drums for Collection
- Blower-to-Separator Interconnecting Piping
- Brass Vacuum Relief Valve
- Continuous-duty Regenerative Blower
- Blower Construction–Cast Aluminum Housing, Impeller and Cover
- Noise Level Within OSHA Standards when Properly Piped and Muffled
- Capacity: 55 gallons (208 liters)/7.5 cu ft



OPTIONS

- **H**igh **E**fficiency **P**articulate **A**ir Filtration
- 575 Volt and Explosion-proof Motors
- Stainless Steel Receiver and Separator
- Surface Treatments or Plating
- Accessories Available



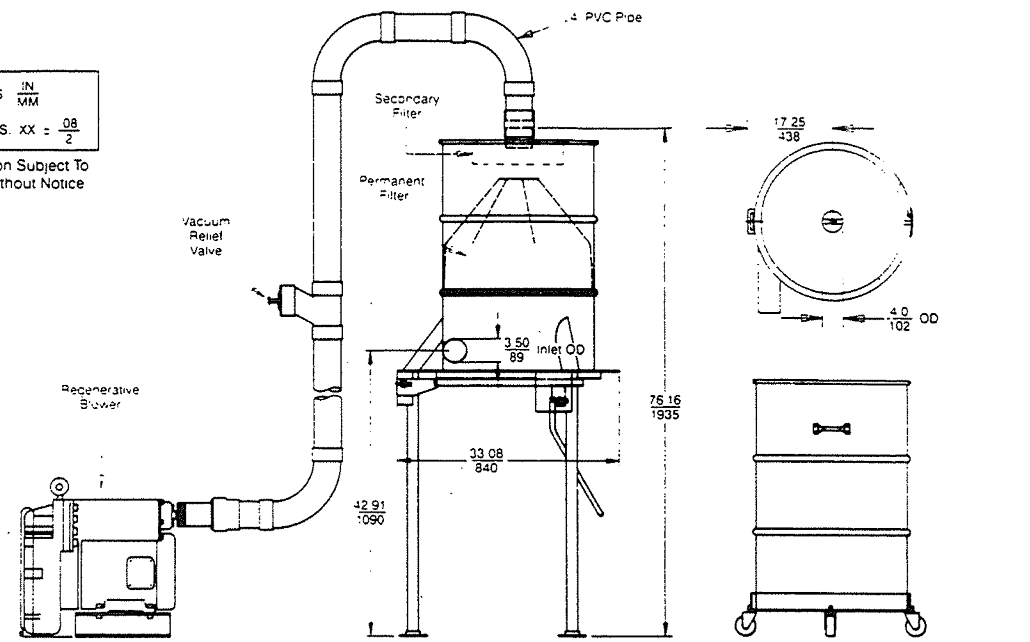
EG&G ROTRON
Industrial Division

EG&G ROTRON
Industrial Division
North Street
Saugerties, NY 12477
Tel 914/246 3407
Telefax 914/246 3802
Telex 981511

DIMENSIONS $\frac{IN}{MM}$

TOLERANCES. XX $\pm \frac{.08}{2}$

Specification Subject To Change Without Notice

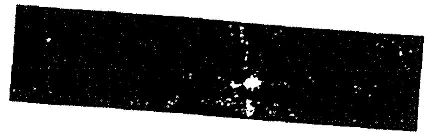


SPECIFICATIONS

Model		IVM2000PF 12BE72W	IVM2000PF 8BB72W	IVM2000PF 808AY72W	IVM2000PF
Part No.		037826	037825	038140	037959
Motor Type		TEFC	TEFC	TEFC	—
Motor Horsepower		15.0	10.0	7.5	—
Voltage[1]		230/460	230/460	230/460	—
Phase		3	3	3	—
Frequency[1] (Hz)		60	60	60	—
Recommended NEMA Starter		2/2	2/1	1/1	—
Total Shipping Weight–lbs (kg)		804 (364)	636 (288)	579 (262)	378 (171)
Max. # of Operators[2]	1.25" Hose Diameter	9	5	4	—
	1.5" Hose Diameter	6	3	2	—
	2.0" Hose Diameter	4	2	1	—
Blower Dimensions L x W x H	in.	24.3 x 19.6 x 25.4	24.1 x 18.6 x 23.9	22.6 x 18.7 x 21.1	—
	mm.	617 x 498 x 645	612 x 472 x 607	574 x 475 x 536	—
Blower Inlet Outlet Diameter		3" NPSC	2½" NPSC	2½" NPSC	—

1. All 3 phase motors are factory tested and certified to operate on [illegible] 460 VAC-3 ph-60 Hz and 220-240/380-415 VAC-3 ph-50 Hz. All 1 phase motors are factory tested and certified to operate on [illegible]
2. [illegible]

PAXTON Centrifugal Blowers



EFFICIENT

Paxton specializes in powerful but compact blowers for pressure and/or vacuum applications. If your requirements fall within the Paxton performance range, you probably won't find another blower competitive with Paxton's features.

The belt drive design allows the RM series to be driven with 1/2, 1, 2, 3, 5, 7-1/2, 10, 15 and 20 HP, Single or Three-Phase, TEFC or Explosion Proof, motors. We also regularly ship these units with complete engines or hydraulic motors. No special foundation or vibration isolation is required. Blowers may be mounted in any rotation - even upside down.

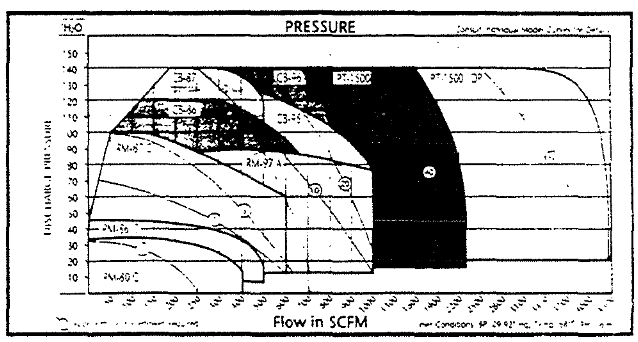
COMPACT

Most Paxton blowers take up less than one cubic foot of space and weigh less than 30 lbs, yet comfortably deliver over 1,000 CFM. Competitive blowers can weigh from 300 to 2,000 lbs, require heavy foundations, costly silencing equipment, more floor space, and present major problems in shipping and handling - all factors which represent unnecessary hidden costs. Paxton's compact design eliminates these unnecessary hidden costs.

USED ALL OVER THE WORLD

Paxton centrifugal blowers are performing vital roles for literally thousands of major food, metal, automotive, photographic, wood, aviation, disposal, and chemical companies around the world. Wherever noise, weight or space is a factor, you'll find Paxton Centrifugal Blowers.

A WIDE PERFORMANCE RANGE



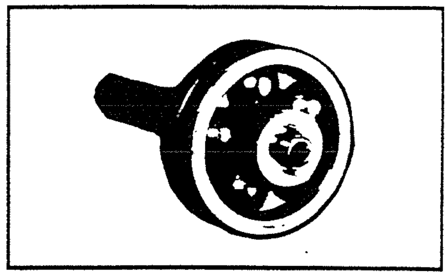
CALL OUR ENGINEERS

For costs and delivery information, to accurately specify optimum RPM, BHP and Accessories, or to help solve a problem, call or write our engineers with your requirements. Telephone (213) 450-4800 or FAX (213) 452-8093, 7:00 am to 3:30 pm Pacific Time.

PAXTON Centrifugal Blowers

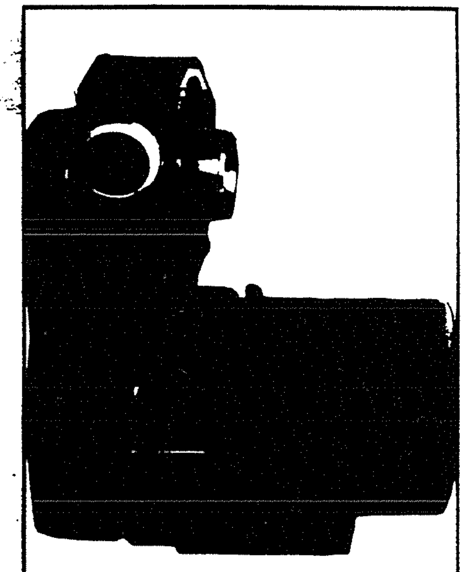
RELIABLE

Paxton CB models have a unique internal planetary ball drive that steps up input shaft speed without gears. Five matched grade chrome steel ball bearings within a raceway, machined to within ±.00005", steps up shaft speed quietly and without vibration. Reliable blower-motor set-ups are available with 1/2 to 100 BHP motors. Within their recommended performance ranges Paxton blowers produce efficiently, are very reliable, and are warranted for continuous unattended duty.



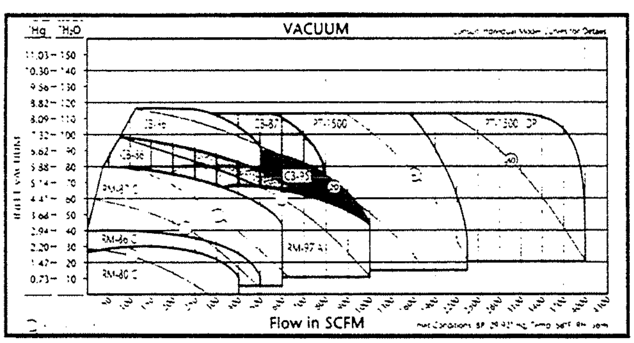
QUALITY

Blowers with gears and multiple impellers must be large and heavy to stand up. We've eliminated those restrictive elements from our blower design and have built a centrifugal blower out of aluminum and high-strength steels that is as strong as any other blower, no matter how large or heavy.
Each impeller and scroll are machined to a perfect fit. And, a complete, 100% operational, performance and vibration test is conducted on every blower prior to shipment.



HOT OR CORROSIVE GAS

Paxton blowers utilize a fluorocarbon seal that has been proven, under extreme conditions, to provide an oil-free gas stream over a wide range of gas conditions.
For special conditions we produce Paxton blowers in stainless steel, monel and hastelloy to withstand high temperatures or corrosive gases.



CALL
OUR ENG...
FOR
SPECIFICATIONS

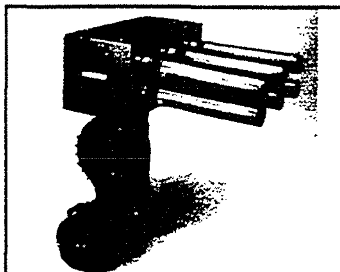
PAXTON CENTRIFUGAL BLOWERS, 929 Olympic Blvd., Santa Monica, CA

PAXTON
Centrifugal Blowers

[redacted]

LOW COST, EASY MAINTENANCE

The RM Series blowers are belt driven from the drive mechanism. The sealed bearing design and integral belt drive operate 15,000 - 20,000 hours between service. Should the blower fail it can be removed by one man in minutes and inexpensively shipped back to the factory for prompt, expert service. Many companies that use them extensively have a spare blower head assembly so that a unit can be replaced in a matter of minutes with virtually no down time.



A COMPLETE AIR KNIFE DRYER
Blower/Air Knife System is complete and self contained, ready to run.
- System is built to suit your needs.
- Ideal for conveyors 2 inches to 24 feet wide.
- Handles speeds 3 to 300 feet/minute.
- Reliable, quiet, compact and lightweight.
- Efficiently replaces most compressed air and multiple low pressure fan systems.
- Eliminates most heater banks.
- Great for PC boards, plastics, glass, metal strips, continuous plating, cable, bottles, cans and more.
- Quick delivery on standard units.

TYPICAL APPLICATIONS

DRYING/BLOW-OFF
- Printed circuit boards
- Steel, plastic, glass sheets
- Fruits, vegetables, other food products
- Plastic strand drier
- Dust removal - bearings, optic sensors, grinding & polishing
- Filter-belt dewatering systems

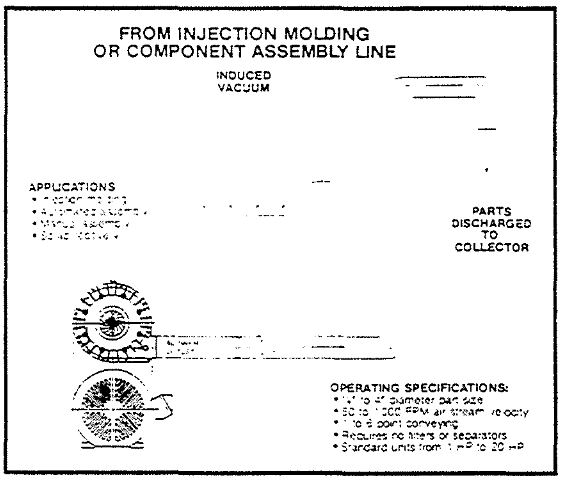
PROCESS AIR
- Flow bench testing
- Purge air
- Air curtains (furnaces, dusty environments)
- Air cushions (floating air pallets)
- Power take-off units (farm machinery)
- Air sampling (laboratory test equipment)
- Metal and plastic molds and extrusions

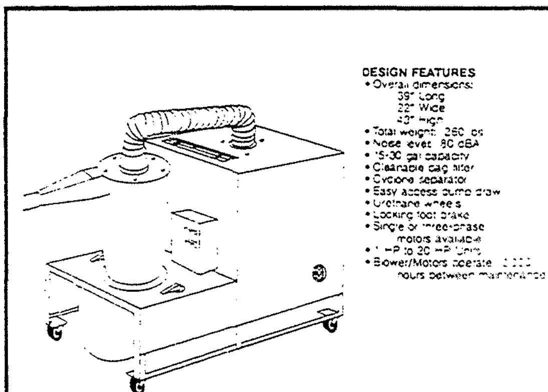
AERATION/AGITATION
- Plating tanks
- Large-scale film processing tanks
- Wastewater treatment tanks
- Fish ponds and other aquaculture tanks
- Investment casting (fluidizing sand beds)
- Fluidized resin (fiberglass, PVC powder, etc)

POLLUTION CONTROL AND COMBUSTIBLE GASES
- Exhaust and corrosive fumes – stainless steel, monel, hastelloy and other special blower materials available
- Vapor recovery (petroleum, chemical and other storage tanks)
- Exhaust tower/stack scrubbers and recyclers
- Exhaust emission analyzer systems
- Containment release blower systems (nuclear plants)
- Soil cleanup/fume recovery
- Landfill sites (methane gas recovery)
- Digester gas
- Combustion air

COOLING
- Supercomputer cooling
- Military aircraft ground support equipment, missile launchers, other mobile and airborne needs.
- Environmental test chambers

VACUUM/EXHAUST PROCESSES
- Complete portable vacuum systems
- Vacuum excavation - truck mounted
- Vacuum holding (packaging processes)
- Central vacuum (chips, dust, etc)
- Pneumatic conveying
- Air sampling (laboratory test equipment)





VACUUM CLEANER
WITH CYCLONE SEPARATOR
(UNIT SHOWN IS 3HP SYSTEM)

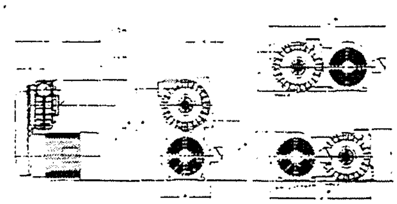
PAXTON Centrifugal Blowers

Paxton Centrifugal Blowers are performing vital roles for thousands of major food, metal, automotive, aviation, disposal and chemical companies, world-wide.

Paxton specializes in providing complete air knife, vacuum and conveying systems.

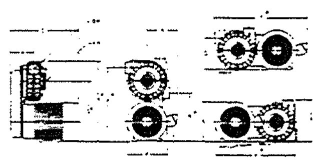
DIMENSIONS ARE IN INCHES. GENERAL TOLERANCE ± .06" EXCEPT WHERE SPECIFICED (* = .50" TOLERANCE). DH/EH = I.D. HOSE CONNECTIONS.

RM-80 SERIES



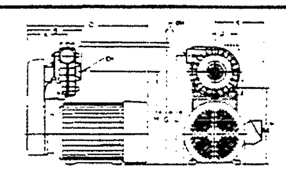
FRAME SIZE	H.P.	A	C	DH	EH	G*	H*	J*	K	P	Q	R*	S	T*	V*	X
145 TC	1.0/2.0/3.0	6.12	12.31	2.75	4.0	13	17.75	16	6.12	7.31	6.50	10	7.14	20.06	17.87	8.75
184 TC	5.0/7.5	6.12	16.43	2.75	4.0	14	18.75	17	7.03	9.56	7.50	11	9.28	20.75	19.00	9.75
213 TC	7.5	6.62	19.37	2.75	4.0	18	23.25	21	8.25	11.25	8.50	15	10.87	26.00	23.37	10.75
215 TC	10.0	6.62	20.87	2.75	4.0	18	23.25	21	8.25	11.25	8.50	15	10.87	26.00	23.37	10.75

RM-90 SERIES



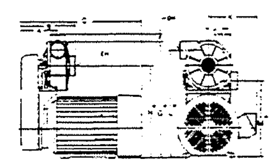
H.P.	A	C	DH	EH	G*	H*	J*	K	P	Q	R*	S	T*	V*	X
10.0	5.62	19.18	3.5	4.0	18.18	23.31	21.56	8.25	11.25	8.87	14.93	10.87	27.81	27.43	12.12
15.0	5.62	23.81	3.5	4.0	19.93	24.06	22.31	9.93	13.37	9.62	15.56	12.93	29.25	24.25	12.87

CB-80 SERIES



H.P.	A	B	C	DH	EH	F	G*	H*	J	K	L*	M*	N
[illegible]	[illegible]	0.5	22.6	2.75	4.0	0.5	22.8	18.0	3.0	7.75	21.0	15.0	13.3
15.0	6.0	0.5	23.6	2.75	4.0	0.5	23.8	19.0	3.0	10.0	22.0	16.0	13.3

CB-90 SERIES



H.P.	A	B	C	DH	EH	F	G*	H*	J	K	L*	M*	N
20.0	6.0	10.0	27.0	3.5	4.0	1.5	24.1	19.0	3.4	10.0	22.3	15.6	13.4

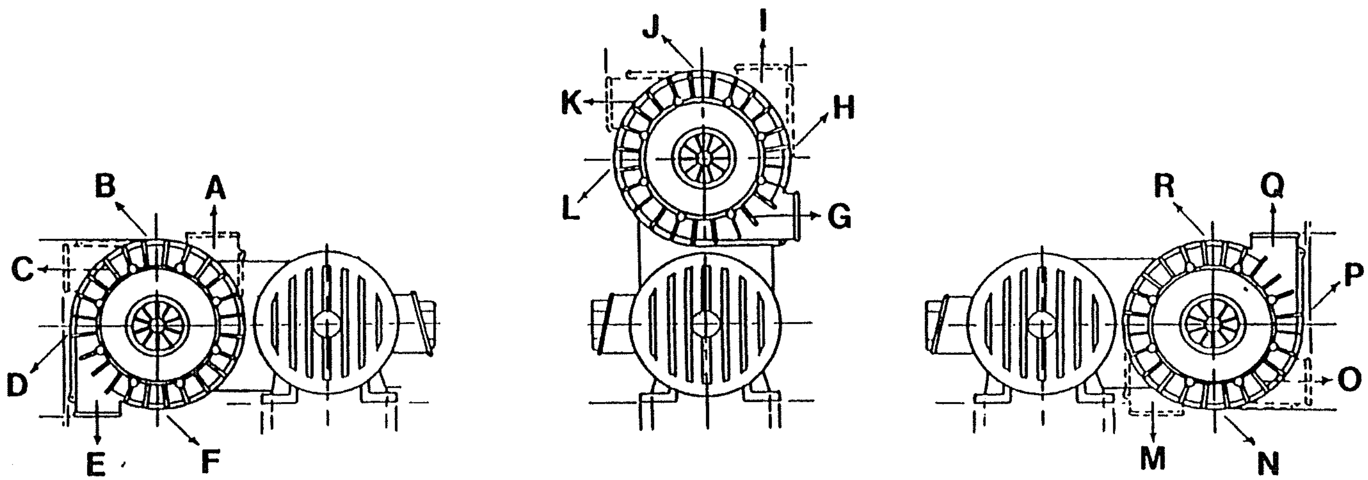
CALL OUR ENGINEERS ... **For costs and delivery information, to accurately specify optimum RPM, BHP and Accessories, or to help solve a problem, call or write our engineers with your requirements.**

Paxton Centrifugal Blowers, 929 Olympic Blvd., Santa Monica, CA 90404
Telephone (213) 450-4800 or FAX (213) ... 7:00 ...

PAXTON PRODUCTS INC.
929 OLYMPIC BLVD.
SANTA MONICA, CAL. 90404
(213) 394-2751

BLOWER OUTLET ORIENTATION

PAXTON MODELS RM / CB / PT SERIES



VIEW A VIEW B VIEW C

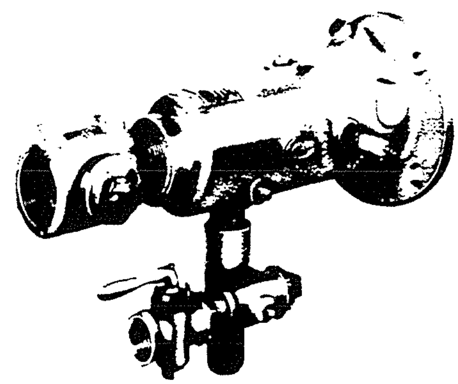
THIS DRAWING IS FOR GENERAL REFERENCE ONLY.
AVAILABILITY OF SPECIFIC ORIENTATION MAY BE LIMITED BY TYPE OF MOTOR ENCLOSURE AND JUNCTION BOX LOCATION.
AS CB & PT SERIES BLOWERS ARE BASE PLATE MOUNTED BLOWERS, THEY ARE NOT AVAILABLE IN ORIENTATION E.F.M.N. AND VIEW B.

8/20/84

H-44-3
Bulletin
9/83

ECLIPSE THERMAL BLAST AIR HEATERS

SERIES "TBH"



COMPLETE HEATER

Eclipse Thermal Blast Air Heaters are high temperature, high pressure, air heaters designed to produce 50 to 400 scfm of heated air with a temperature rise of 300° to 1600° F. at pressures up to 50 psi. They are suitable for a wide range of industrial heating and drying applications. These include: mold and core box heating, water dry-off, paper and fabric drying, plastic treating, food processing, air curtains, and aggregate drying.

OPERATION

Air piping upstream and downstream of the Thermal Blast Heater should be sized according to required air flow through the heater. See page 2 for recommended piping and transitions for various air flows. For normal operation, air is supplied to the burner at a constant pressure and volume, and gas flow only is controlled.

ADVANTAGES

• • • Nozzle-mixing design
• • • Single valve control
• • • Exceptional flame stability
• • • Broad range of discharge pressures
• • • Broad range of discharge temperatures
• • • Easy installation

IGNITION

Eclipse "TBH" heaters are furnished with an ignition plug which will light the burner anywhere within its operating range. The spark plug may be used in either of two openings provided on the heater (see Dimensions and Specifications, page 2).

FLAME MONITORING

Flame monitoring may be provided by using either a flame electrode or an ultra-violet scanner monitoring the flame. A tapped opening is provided on the heater for installing either flame rod or scanner (see Dimensions and Specifications, page 2).

DESIGN FEATURES

Eclipse "TBH" heaters have separate air and gas inlets and mixing takes place internally. No complex proportionating equipment is required. "TBH" heaters are designed to produce high discharge pressures with relatively low blower pressure. Air flows straight through the burner, minimizing pressure drops. The heater inlet is threaded and outlet is flanged for ease of installation.

ASSEMBLIES

Eclipse "TBH" heaters are available in either basic or complete assemblies. The *Basic Heater* consists of heater with ignition plus and peepsight. The *Complete Heater*, pictured above, includes the basic heater plus air butterfly valve, gas adjusting tee, gas cock, and necessary pipe nipples.

CAUTION: It is dangerous to use any fuel burning equipment unless it is equipped with suitable flame sensing device(s) and automatic fuel shut-off valve(s). Eclipse can supply such equipment or information on alternate sources.

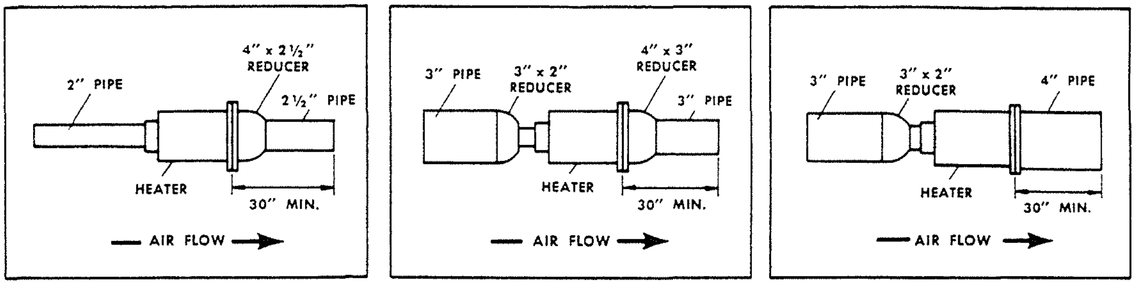
CAPACITIES

BURNER CATALOG NUMBER	SCFM HEATED AIR	MIN. GAS PRESS. IN "W.C. ABOVE DISCHARGE PRESS.	BTU/HR. 1600° F. TEMP. RISE*	BTU/HR. 800° F. TEMP. RISE*	BTU/HR. AT MIN. TEMP. RISE**	MINIMUM TEMP. RISE	MAXIMUM DISCHARGE PRESSURE*** IN "W.C. FOR VARIOUS BLOWER PRESSURES						
							8 oz.	12 oz.	16 oz.	20 oz.	24 oz.	32 oz.	48 oz.
84-10TBH	50	4.5	86,500	43,250	16,000	300° F	10	17	24	31	38	52	79
	100	5.5	173,000	86,500	32,000	300° F	8	15	22	29	36	50	77
	150	7.0	259,000	129,000	48,000	300° F	5	12	19	26	33	47	74
	200	9.5	345,000	172,500	64,000	300° F	--	8	15	22	29	43	70
84-14TBH	250	7.5	432,000	216,000	80,000	300° F	--	7	14	21	28	42	69
	300	9.0	518,000	259,000	110,000	340° F	--	3	10	16	23	38	65
	350	7.0	605,000	302,500	137,000	362° F	--	--	8	15	22	36	63
	400	8.5	692,000	396,000	166,000	384° F	--	--	3	10	17	31	58

*Inputs do not take into consideration manifold heat loss. Actual inputs willl be higher by amount of heat loss.
**Temperature rise does not take into consideration manifold heat loss. Actual rise will be somewhat less.
*** Delivery pressure based on 10' of pipe between blower and burner. Loss in extra pipe length must be subtracted from delivery pressure. Loss through bell reducer has been considered in above table.

ECLIPSE COMBUSTION
A DIVISION OF ECLIPSE, INC.
ROCKFORD, ILLINOIS 61103 (815) 877-3031
IN CANADA ECLIPSE FUEL ENGINEERING CO OF CANADA, LTD. DON MILLS, ONTARIO

PREFERRED PIPING & TRANSITIONS

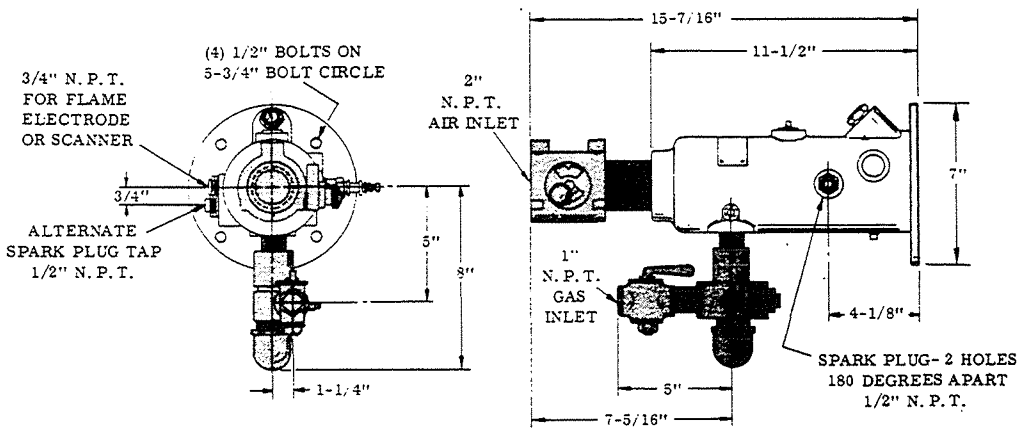


50 - 130 SCFM HEATED AIR

131 - 300 SCFM HEATED AIR

301 - 400 SCFM HEATED AIR

DIMENSIONS & SPECIFICATIONS



NOTE: Illustrates "Basic Heater."
Illustrates additional components included with "Complete Heater."

CATALOG NUMBER EXAMPLE

8 4 — 10 TBH

Air Inlet in ¼"
8 = 8/4 = 2

Gas Inlet in ¼"
4 = 4/4 = 1"

Gas Jet Dia. in 1/32"
10 = 10/32 = .076 Area Sq. In.

Thermal Blast Heater

Eclipse

ECLIPSE COMBUSTION
A DIVISION OF ECLIPSE, INC.
ROCKFORD, ILLINOIS 61103 (815) 877-3031
IN CANADA: ECLIPSE FUEL ENGINEERING CO. OF CANADA, LTD. DON MILLS, ONTARIO

Litho in U.S.A.

Thermalert ET noncontact temperature sensors for process monitoring and control

ET sensors measure temperature in film, paper and metal coaters, textiles, metal and print dryers, plastic, glass and metal forming and molding machines, food, glass and chemical processing equipment, and silicon wafers, magnetic media, and wave soldering devices

Noncontact temperature sensors offer significant advantages over contact devices in many OEM applications.
ET sensors accurately measure the temperature of inaccessible objects, moving materials and webs. They have faster response times than thermocouples for better control of process heaters and indexing. This gives you better control of process quality and allows you to optimize throughput and yield.

Rugged, reliable and repeatable
The ET series combines sensor and electronics in a single, rugged package. They're easy to install and simple to adjust. And ET sensors generally last longer and require far less service than contact devices.

ET sensors use digital logic circuitry to provide reliable, repeatable data over a wide temperature range.

Designed for continuous 24-hour operation, ET sensors are available in two basic configurations:

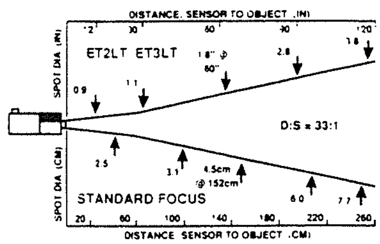
ET-II—Thermocouple Output
The ET-II provides simulated J, K, R, or S type thermocouple output for use with any display, recording or control device requiring thermocouple input.

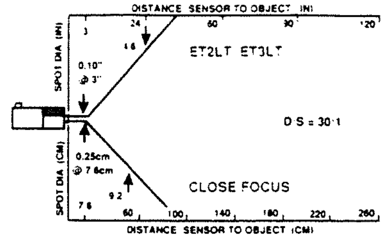
ET-III—Current Output
The ET-III provides a 4 to 20 mA current output for use with any display, recording or control device requiring a current input. The ET-III has four selectable temperature ranges.

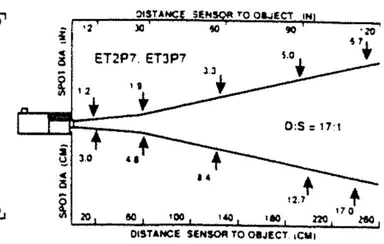
Models are available for measuring glass, plastics, and higher temperature targets. All models include a mounting nut, fixed bracket and interconnecting cable for easy installation.

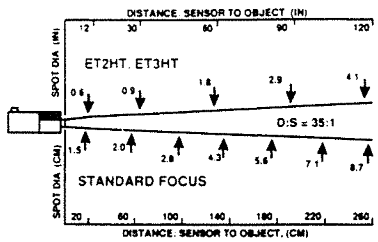
Both the ET-II and III can be customized to meet specific temperature applications.

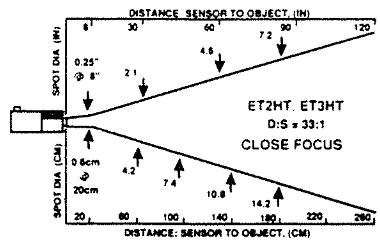
Raytek
Pioneering Infrared Technology

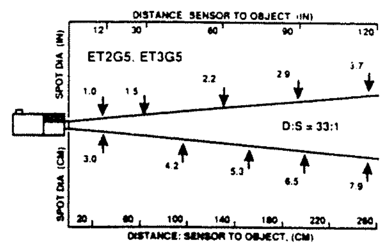












SPECIFICATIONS	ET2LT	ET3LT	ET2G5	ET3G5	ET2P7	ET3P7	ET2HT	ET3HT
Measurement ranges	**Type J** 0 to 1400 F (-18 to 760 C) **Type K** 32 to 1600 F (0 to 870 C)	F version / C version: 0 to 200 / -10 to 100; 200 to 400 / 100 to 200; 300 to 800 / 150 to 400; 400 to 1400 / 200 to 800 **(Range switchable)**	500 to 3000 F (260 to 1650 C)	1) 500 to 1500 F 2) 500 to 3000 F 3) 260 to 815 C 4) 260 to 1650 C **(Range switchable)**	50 to 650 F (10 to 360 C)	1) 50 to 350°F 2) 50 to 650°F 3) 10 to 110°C 4) 10 to 360°C **(Range switchable)**	1000 to 3000 F (500 to 1700 C)	1) 1000 to 2000 F 2) 1000 to 3000 F 3) 500 to 1100 C 4) 500 to 1650 C **(Range switchable)**
Data output	Type J, Type K Thermocouple 50 Ω impedance	4 to 20mA Max Loop Resistance 300 Ω	Type R Thermocouple 50 Ω impedance	4 to 20mA Max Loop Resistance 300 Ω	Type J Thermocouple 50 Ω impedance	4 to 20mA Max Loop Resistance 300 Ω	Type R Thermocouple 50 Ω impedance	4 to 20mA Max Loop Resistance 300 Ω
Spectral response	8 to 14 Microns (Low Temp.)		Nominal 5.2 Microns (Glass)		Nominal 7.9 Microns (Plastic)		Nominal 2.2 Microns (High Temp)	
Accuracy	±1% of Reading above 150 F (65 C), 2.5°F (1.4°C) or better, below 150 F (65°C)							
Repeatability	±0.5% of Reading ±1 digit F or °C							
Emissivity	0.10 to 1.0 digitally adjustable							
Response time	300 mSec (80 mSec option)						80 mSec standard	
Signal processing	Adjustable Peak Hold, Variable Averaging Filter							
Power	12 VAC nominal, 100 mA, 50 to 60 Hz							
Environmental rating	NEMA-4 (IEC529, IP65) with conduit & compression fitting							
Vibration	MIL STD 810D (IEC 68-2-6) 3G's, any axis, 11 to 200 Hz							
Shock	MIL STD 810D (IEC 68-2-27) 50G's, 11mSec, any axis							
Ambient operating range	32 to 120°F (0 to 50°C) without cooling; 32 to 350°F (0 to 177°C) with cooling							
Connection	Detachable 15 ft (4.5 m) cable standard							
Dimensions (L × Dia)	7.0 × 2.25 in (18 × 5.7 cm) Standard, 7.0 × 3.0 in (18 × 7.6cm) with cooling							
Weight	1.2 lbs (0.5 Kg) Standard, 1.7 lbs. (0.8 Kg) with cooling							
Options **(must be preordered)**	Water/air cooled housing (includes air purge collar), 50 ft (15 m) cable, 100 ft (30 m), 200 ft (60 m) cable; N.I.S.T. Calibration Certification, K, ST/C data output							
Accessories	Air purge collar, sighting viewer, right angle mirror, pipe adaptor, swivel bracket, 110/220 VAC to 12 VAC power supply							

Specifications subject to change without notice

®Registered Trademark of Raytek, Inc.™ Trademark of Raytek, Inc.

Raytek offers a full line of noncontact temperature measurement products for a wide range of applications. Both portable and online units are available. For additional information or a free product demonstration, contact Raytek at **(800) 227-8074** in the Continental U.S. or **(408) 458-1110** or your local Raytek representative.

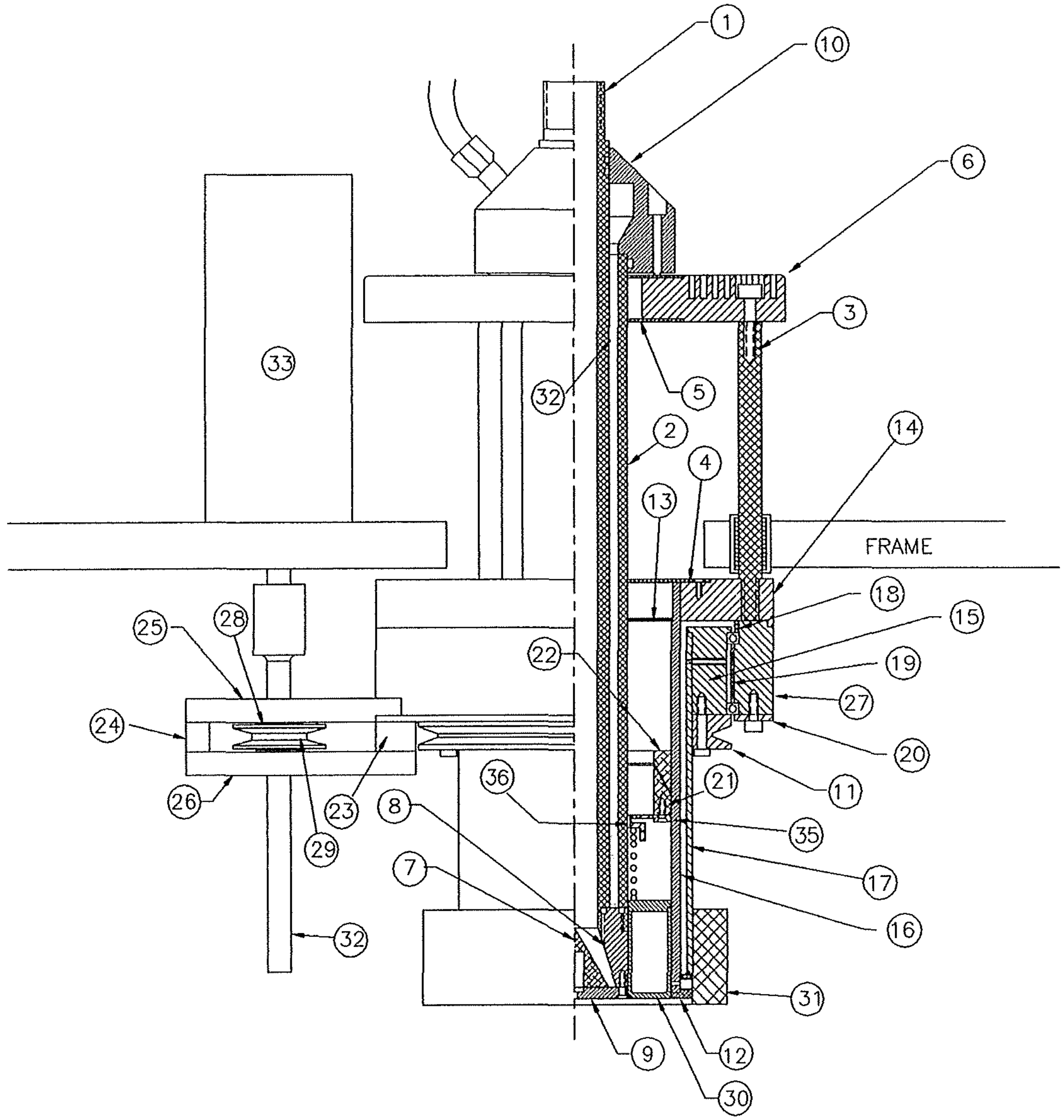
Raytek®

(800) 227-8074
1201 Shaffer Road, Box 1820,
Santa Cruz, CA 95061-1820
Phone (408) 458-1110 Telex 171890
FAX 408-458-1239

Pioneering Infrared Technology

E.3 - Sealant Applicator

LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	8/9/91	DAB	DAB
B		TENSIONER MODIFICATION	10/2/9	KJM	DAB
C		STRAIN GAUGE MODIFICATION	11/9/9	KJM	DAB

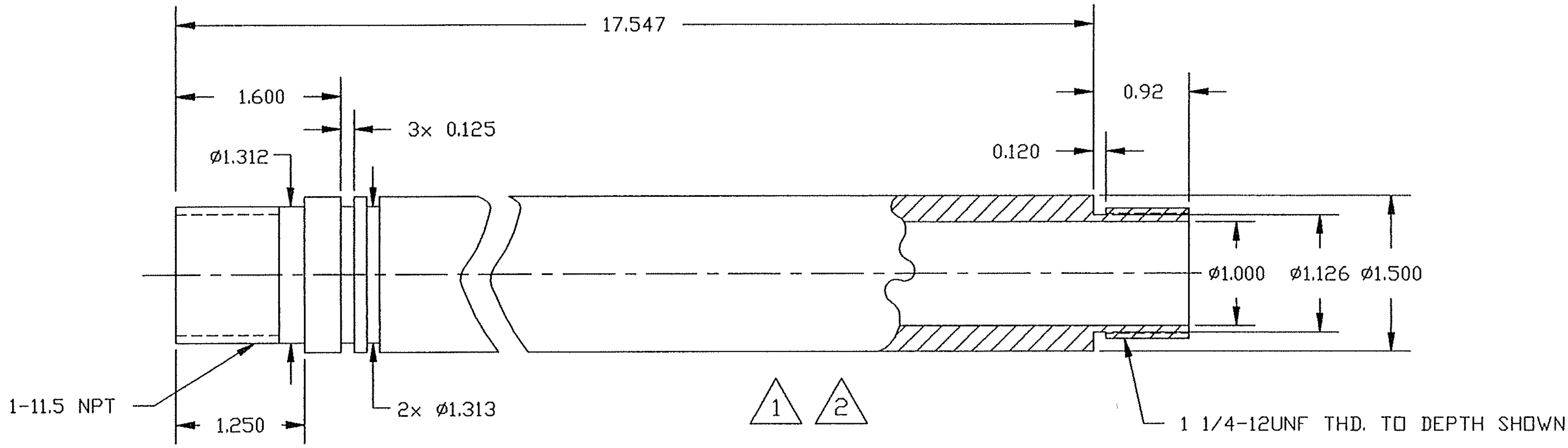


ITEM NO.	PART / ID NO. / NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
36	ITEM# A132	6061-T6	1
35	ITEM# A131	6061-T6	1
34	ITEM# A130	304 SS	2
33	DC MOTOR GRAINGER #4Z529		1
32	ITEM# A129	300 SERIES SS	1
31	RUBBER RING		1
30	ITEM# A200 SUB ASSY	6061-T6	1
29	ITEM# A128	6061-T6	1
28	ITEM# A127	OIL IMPREG BRONZE	2
27	ITEM# A126	6061-T6	1
26	ITEM# A125	6061-T6	1
25	ITEM# A124	6061-T6	1
24	ITEM# A123	6061-T6	1
23	ITEM# A122	6061-T6	1
22	ITEM# A121	6061-T6	1
21	ITEM# A120	6061-T6	1
20	ITEM# A119	6061-T6	1
19	ITEM# A118	1018 STEEL	1
18	ITEM# A117	1018 STEEL	1
17	ITEM# A116	300 SERIES SS	1
16	ITEM# A115	6061-T6	1
15	ITEM# A114	6061-T6	1
14	ITEM# A113	6061-T6	1
13	ITEM# A112	G-10 or 7	1
12	ITEM# A111	300 SERIES SS	1
11	ITEM# A110	6061-T6	1
10	ITEM# A109	6061-T6	1
9	ITEM# A108	6061-T6	1
8	ITEM# A107	6061-T6	1
7	ITEM# A106	6061-T6	1
6	ITEM# A105	6061-T6	1
5	ITEM# A104	G-10 or 7	2
4	ITEM# A103	G-10 or 7	1
3	ITEM# A102 THOMSON SHAFT MOD.		3
2	ITEM# A101	6061-T6	1
1	ITEM# A100	6061-T6	1

PART LIST

UNLESS OTHERWISE NOTED: TOLERANCES .XX ±.01 .XXX ±.005 ANGLES ±0.5° 64	UNIVERSITY OF CALIFORNIA, DAVIS MECHANICAL ENGINEERING DEPARTMENT
DESIGN DAB KJM DJD — DATE 8/9/91	TITLE SEALANT APPLICATOR ASSY
DRAWN DAB KJM DJD	QTY — DRAWING NO. SHRP(APS)SH-A
APPRV DAB	SCALE 1:1.25
RELEASE	SIZE D — SHT — PROJECT SHRP PROJECT

REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	08/01/91	WWN	DAB



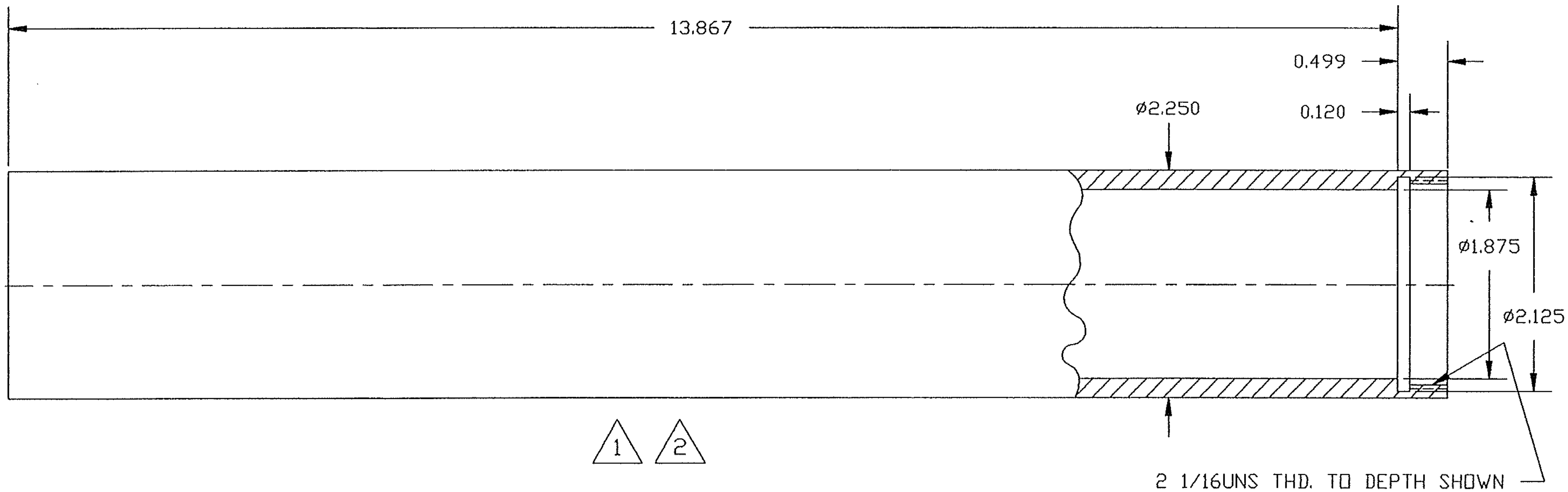
ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
1		TUBE ø1.5OD×1.0ID×18.467LONG	6061-T6 ALUMINUM	1

PART LIST

UNLESS OTHERWISE NOTED: TOLERANCES .XX ± .01 .XXX ± .005 ANGLES ±0.5° 64		UNIVERSITY OF CALIFORNIA, DAVIS MECHANICAL ENGINEERING DEPARTMENT	
		TITLE INSIDE PIPE SEALANT APPLICATOR	
DESIGN DAB & KJM	DATE 08/01/91		
DRAWN WN		QTY 1	DRAWING NO. SHRP(APS)SM-A100
APPRV DAB		SCALE 1:1	
RELEASE DAB		SIZE B / SHT	PROJECT SHRP PROJECT

NOTES: UNLESS OTHERWISE SPECIFIED
1. BREAK ALL SHARP EDGES.
2. HARD BLACK ANODIZE

		REVISION			
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	08/1/91	WWN	DAB



1		TUBE ø2.25OD×ø1.875ID×15LONG	6061-T6 ALUMINUM	1
ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD

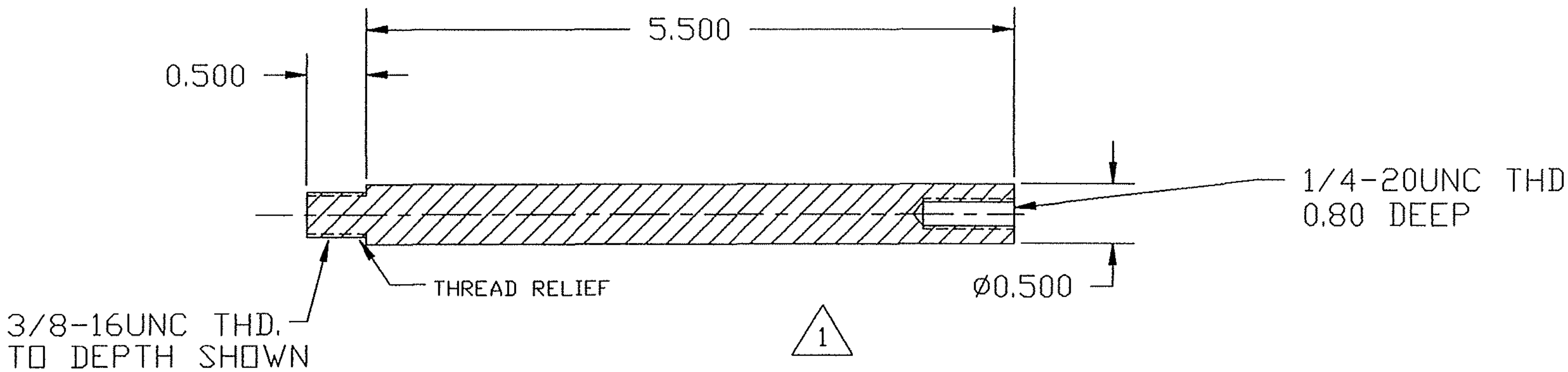
PART LIST

UNLESS OTHERWISE NOTED:
TOLERANCES
.XX ±.01 ANGLES ±0.5°
.XXX ±.005
64

DESIGN DAB & KJM	DATE 08/1/91	UNIVERSITY OF CALIFORNIA, DAVIS MECHANICAL ENGINEERING DEPARTMENT	
DRAWN WN		TITLE OUTSIDE PIPE SEALANT APPLICATOR	
APPRV DAB		QTY 1	DRAWING NO. SHRP(APS)SM-A101
RELEASE DAB		SCALE 1:1	
		SIZE B / SHT	PROJECT SHRP PROGRAM

NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
2) HARD BLACK ANODIZE

REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	08/01/91	WWN	DAB



1		Ø0.500x6.000	THOMSON SHAFT	3
ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD

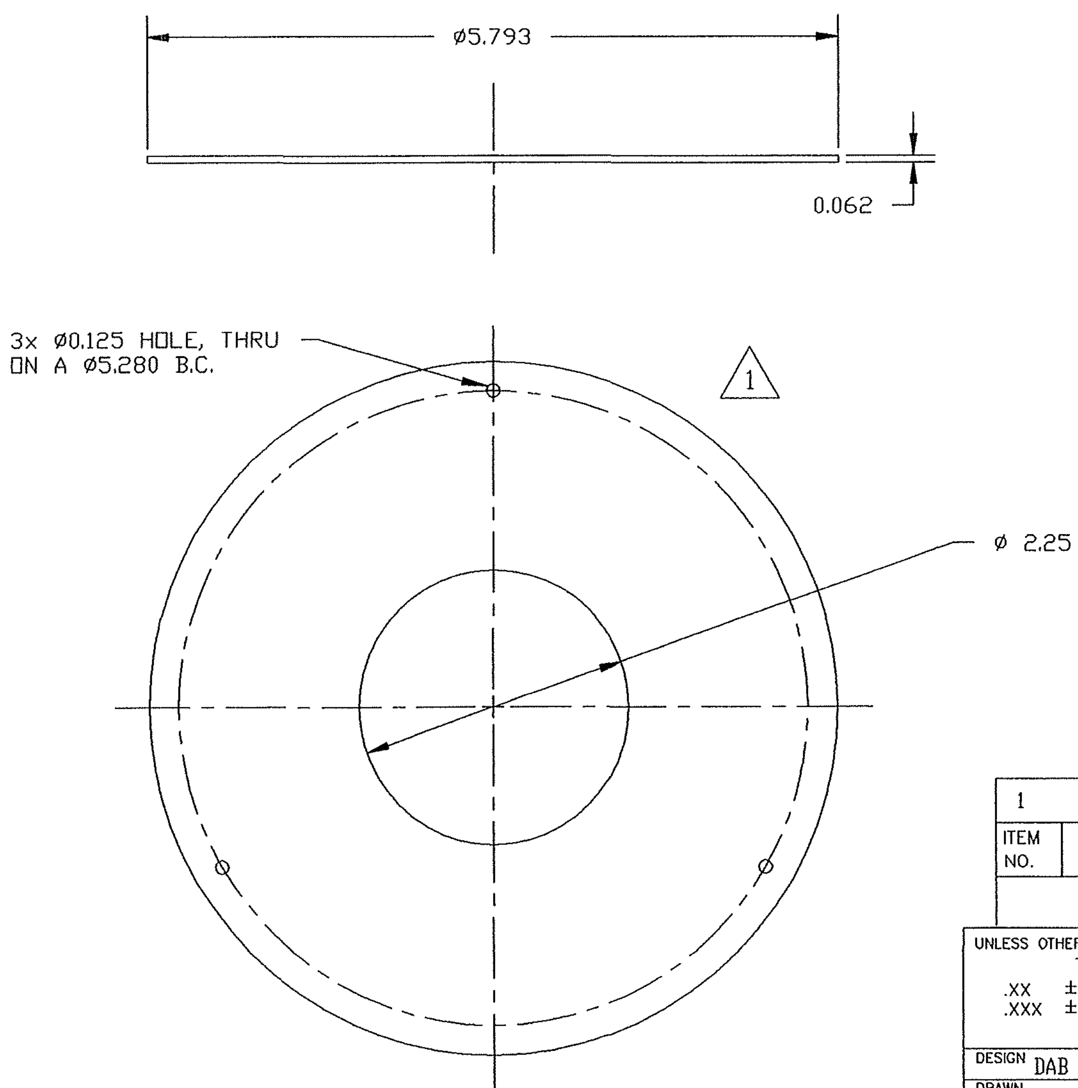
PART LIST

NOTES: UNLESS OTHERWISE SPECIFIED
1. BREAK ALL SHARP EDGES.

UNLESS OTHERWISE NOTED: TOLERANCES .XX ±.01 .XXX ±.005 ANGLES ±0.5° 64√		UNIVERSITY OF CALIFORNIA, DAVIS MECHANICAL ENGINEERING DEPARTMENT	
		TITLE STAND OFF SEALANT APPLICATOR	
DESIGN DAB & KJM	DATE 08/01/91		
DRAWN WN		QTY 3	DRAWING NO. SHRP(APS)SM-A102
APPRV DAB		SCALE 1:1	
RELEASE DAB		SIZE B	SHT / PROJECT SHRP PROJECT

LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	08/01/91	WWN	DAB

REVISION



NOTES: UNLESS OTHERWISE SPECIFIED
1. BREAK ALL SHARP EDGES.

ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
1		ø6.00x0.062	G-10 or G-7	1

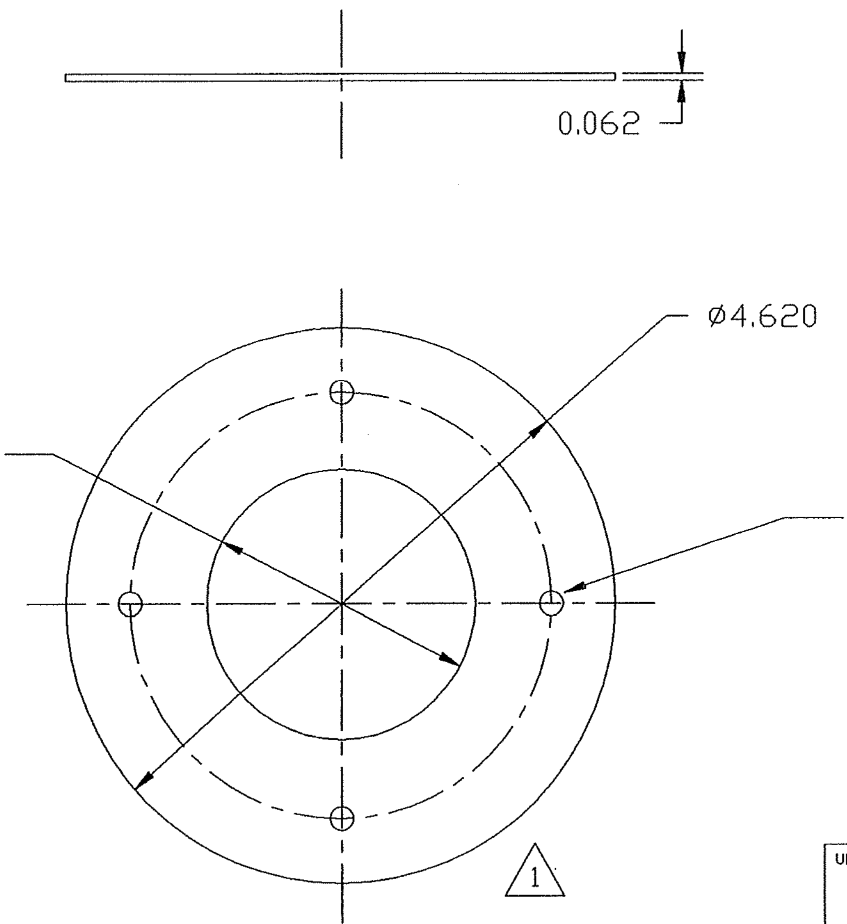
PART LIST

UNLESS OTHERWISE NOTED:
TOLERANCES
.XX ±.01 ANGLES ±0.5°
.XXX ±.005
64

UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT

TITLE INSULATING WASHER
SEALANT APPLICATOR

DESIGN DAB & KJM	DATE 08/01/91	QTY 1	DRAWING NO. SHRP(APS)SM-A103
DRAWN WN		SCALE 1:1	
APPRV DAB		SIZE B	SHT
RELEASE DAB		PROJECT SHRP PROJECT	



REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	08/01/91	WWN	DAB

NOTES: UNLESS OTHERWISE SPECIFIED
1. BREAK ALL SHARP EDGES.

1		Ø5.00x0.250	G-10 or G-7	2
ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD

PART LIST

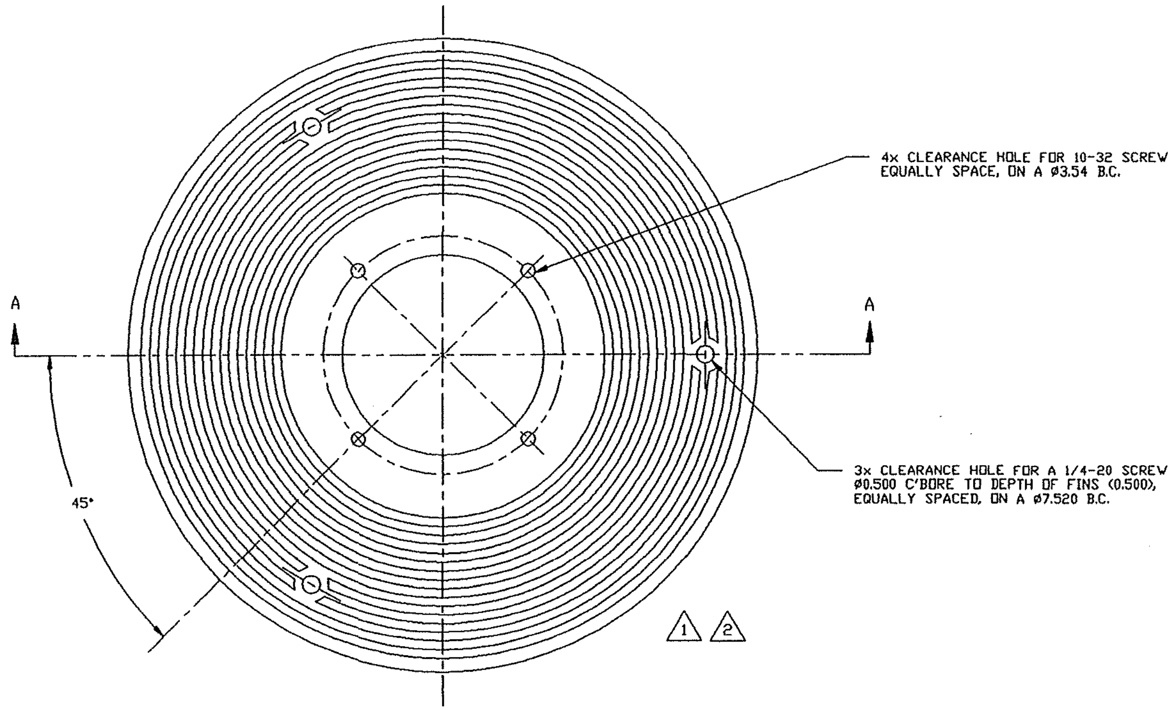
UNLESS OTHERWISE NOTED:
TOLERANCES
.XX ±.01 ANGLES ±0.5°
.XXX ±.005
64

UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT

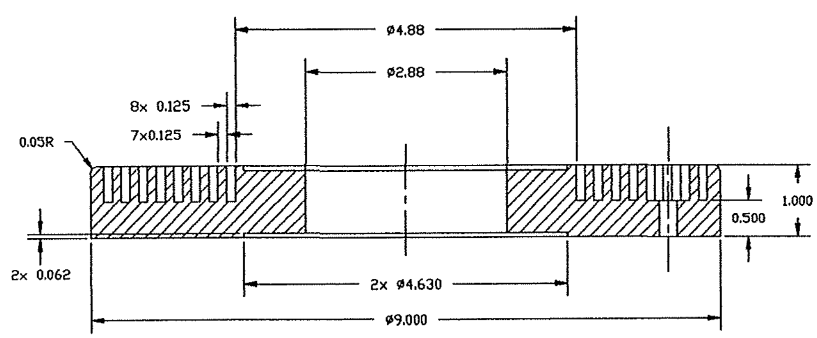
TITLE INSULATING WASHER

DESIGN DAB & KJM	DATE 08/01/91		
DRAWN W. NEDERBRAGT		QTY 2	DRAWING NO. SHRP(APS)SM-A104
APPRV DAB		SCALE 1:1	
RELEASE DAB		SIZE B	SHT	PROJECT AHMT PROGRAM

REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	08/01/91	WWN	DAB



NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
2) HARD BLACK ANODIZE



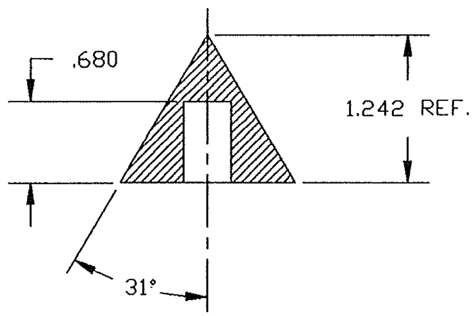
SECTION A-A

1		ø9.000 x 1.000	6061-T6 ALUMINUM	1
ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD

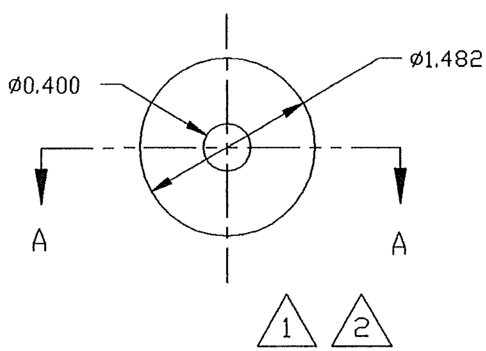
PART LIST

UNLESS OTHERWISE NOTED: TOLERANCES .XX ±.01 .XXX ±.005 ANGLES ±0.5° 64		UNIVERSITY OF CALIFORNIA, DAVIS MECHANICAL ENGINEERING DEPARTMENT	
DESIGN DAB & KJM	DATE 07/31/91	TITLE HEAT TRANSFER FINS SEALANT APPLICATOR	
DRAWN WN		QTY 1	DRAWING NO. SHRP(APS)SM-A105
APPRV DAB		SCALE 1:1	
RELEASE DAB		SIZE C / SHT	PROJECT SHRP PROJECT

REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	07/31/91	WWN	DAB



SECTION A-A



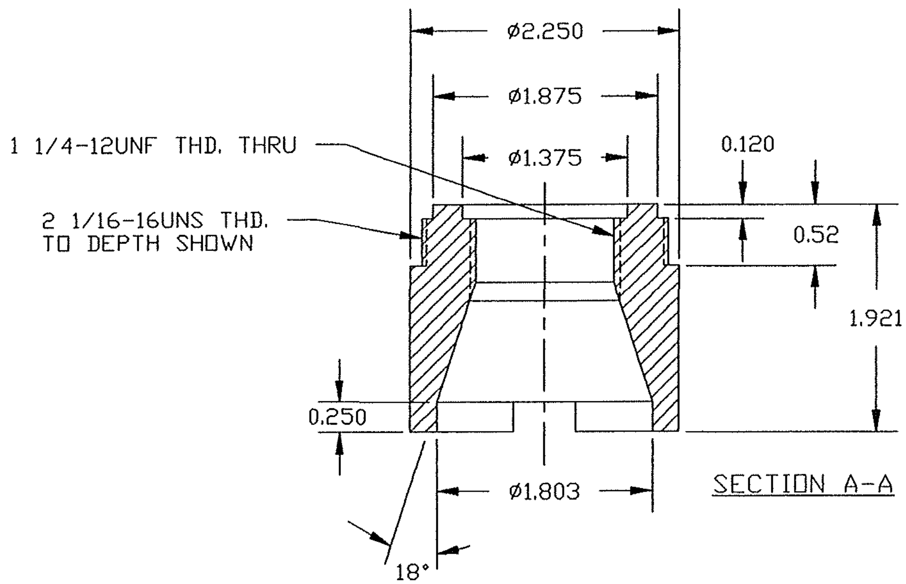
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
2) HARD BLACK ANODIZE

1		ø1.5x1.25	6061-T6 ALUMINUM	1
ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD

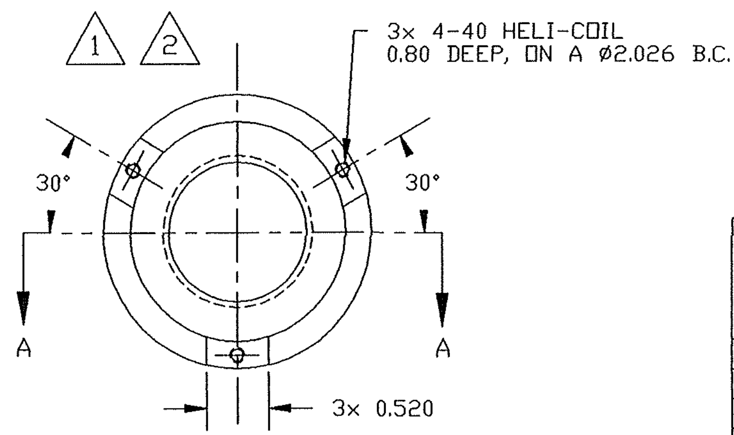
PART LIST

UNLESS OTHERWISE NOTED: TOLERANCES .XX ±.01 .XXX ±.005 ANGLES ±0.5° 64√		UNIVERSITY OF CALIFORNIA, DAVIS MECHANICAL ENGINEERING DEPARTMENT	
		TITLE CONE SEALANT APPLICATOR	
DESIGN KJM & DAB	DATE 07/31/91		
DRAWN WN		QTY 1	DRAWING NO. SHRP(APS)SM-A106
APPRV DAB		SCALE 1:1	
RELEASE DAB		SIZE B	SHT	PROJECT SHRP PROJECT

REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	07/31/91	WWN	DAB



SECTION A-A



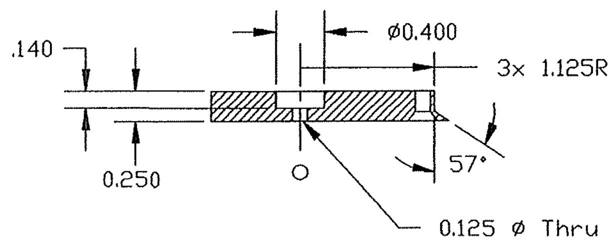
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
2) HARD BLACK ANODIZE (MASK 4-40 HOLES)

ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
1		Ø2.25x2.00	6061-T6 ALUMINUM	1

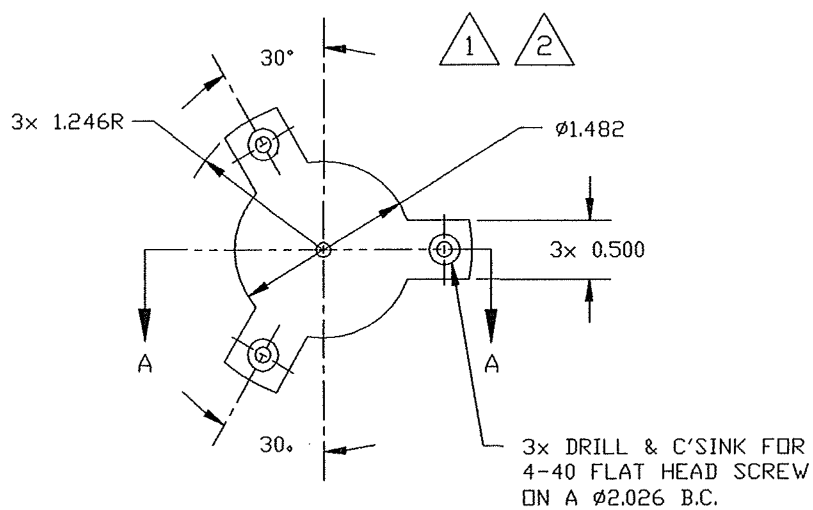
PART LIST

UNLESS OTHERWISE NOTED: TOLERANCES .XX ±.01 .XXX ±.005 ANGLES ±0.5° 64		UNIVERSITY OF CALIFORNIA, DAVIS MECHANICAL ENGINEERING DEPARTMENT	
DESIGN KJM & DAB	DATE 07/31/91	TITLE CONE-STOP SEALANT APPLICATOR	
DRAWN WN		QTY 1	DRAWING NO. SHRP(APS)SM-A107
APPRV DAB		SCALE 1:1	
RELEASE DAB		SIZE B SHT	PROJECT SHRP PROJECT

REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	07/31/91	WWN	DAB



SECTION A-A



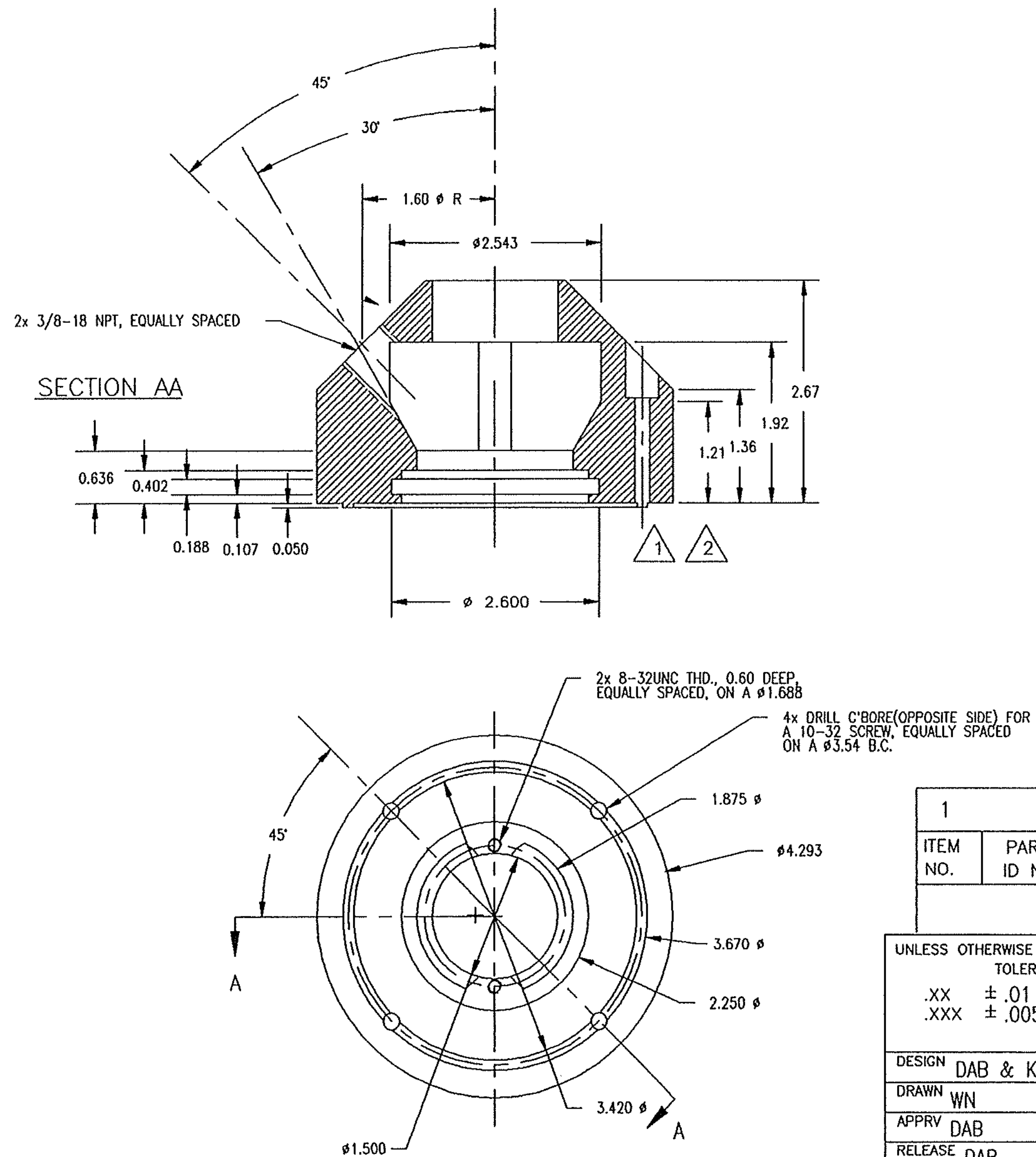
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
2) HARD BLACK ANODIZE (DO NOT MASK HOLES)

ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
1		Ø2.500x0.25	6061-T6 ALUMINUM	1

PART LIST

UNLESS OTHERWISE NOTED: TOLERANCES .XX ±.01 .XXX ±.005 ANGLES ±0.5° 64√	UNIVERSITY OF CALIFORNIA, DAVIS MECHANICAL ENGINEERING DEPARTMENT
DESIGN DAB & KJM — DATE 07/31/91	TITLE CONE SUPPORT/SPRING HOLDER SEALANT APPLICATOR
DRAWN WN	QTY 1 — DRAWING NO. SHRP(APS)SM-A108
APPRV DAB	SCALE 1:1
RELEASE DAB	SIZE B — SHT — PROJECT SHRP PROJECT

LTR	ZONE	REVISION DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	08/02/91	WWN	DAB



NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
2) HARD BLACK ANODIZE (MASK HOLES UNDER .3ø)

ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
1		ø4.293 x 2.72	6061-T6 ALUMINUM	1

PART LIST

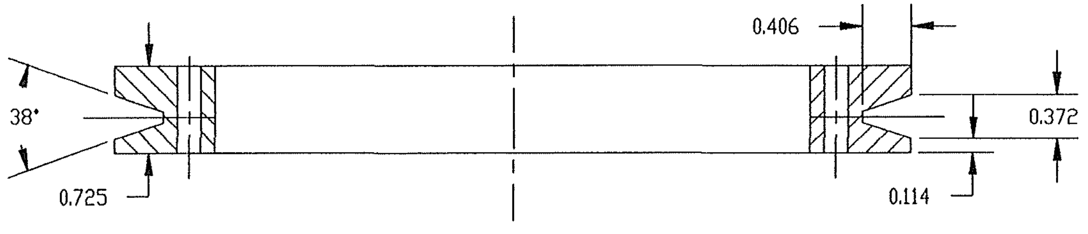
UNLESS OTHERWISE NOTED:
TOLERANCES
.XX ± .01 ANGLES ± 0.5°
.XXX ± .005
64

UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT

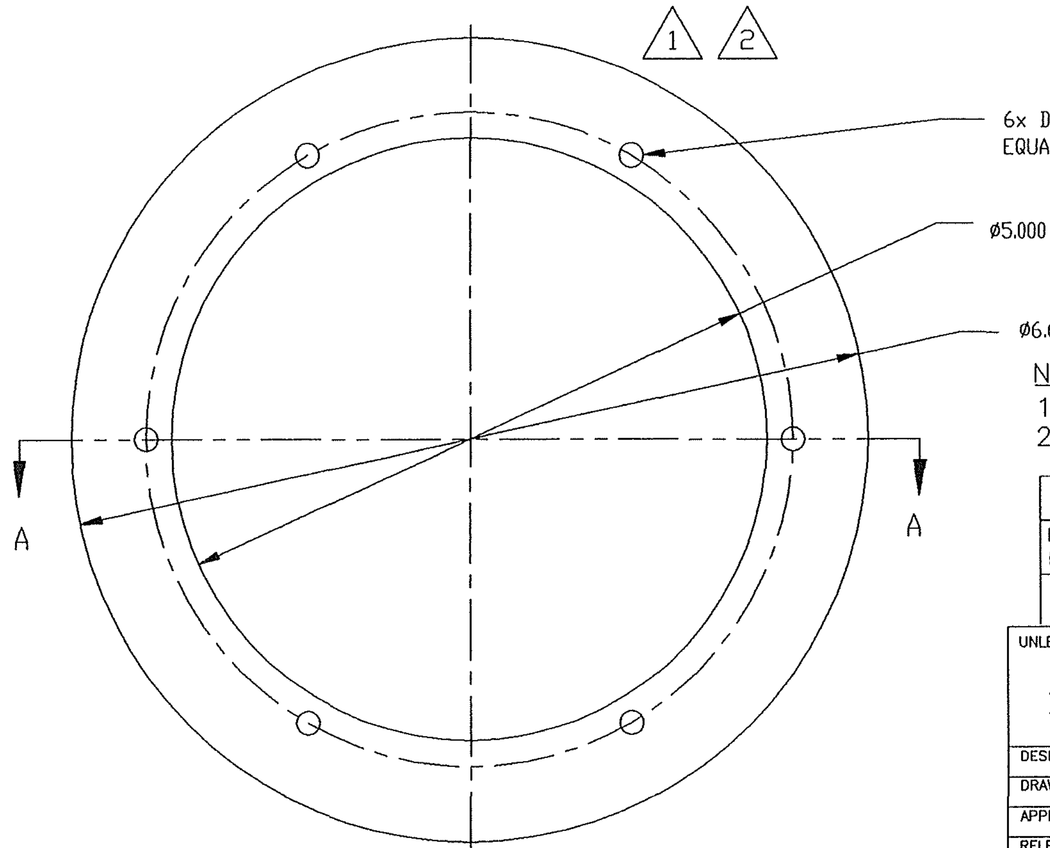
TITLE INLET FOR HOT OIL SEALANT APPLICATOR

DESIGN DAB & KJM	DATE 08/02/91	QTY 1	DRAWING NO. SHRP(APS)SM-A109
DRAWN WN		SCALE 1:1	
APPRV DAB			
RELEASE DAB		SIZE B SHT	PROJECT SHRP PROJECT

		REVISION			
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	08/02/91	WWN	DAB
B		THICKNESS CHG TO 0.725	9/12	KJM	KJM



SECTION A-A



NOTES: UNLESS OTHERWISE SPECIFIED

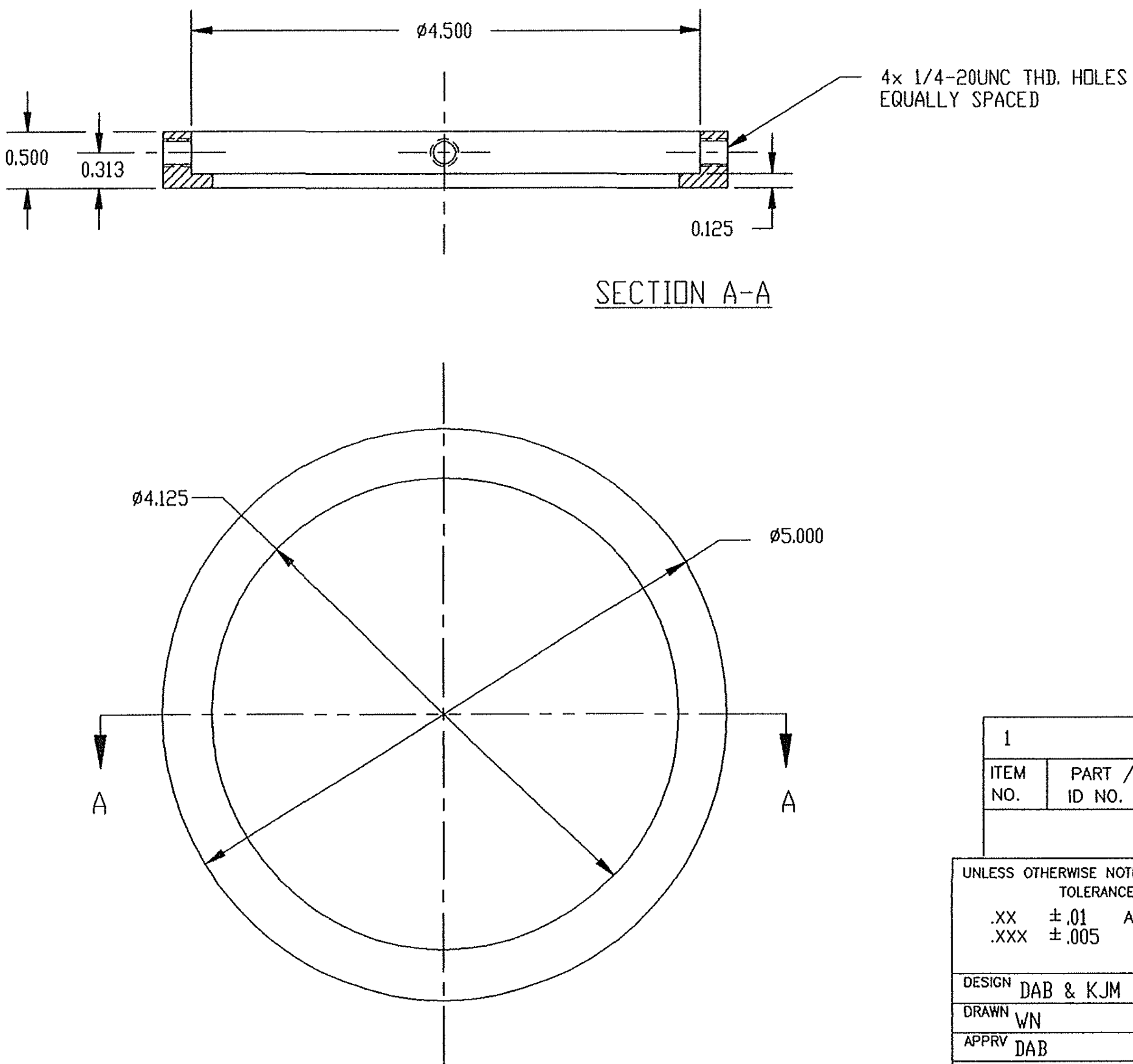
1) BREAK ALL SHARP EDGES
2) HARD BLACK ANODIZE (MASK HOLES UNDER ⌀0.50)

ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
1		⌀6.686 x .500	6061-T6 ALUMINUM	1

PART LIST

UNLESS OTHERWISE NOTED: TOLERANCES .XX ±.01 .XXX ±.005 ANGLES ±0.5° 64√	UNIVERSITY OF CALIFORNIA, DAVIS MECHANICAL ENGINEERING DEPARTMENT
DESIGN DAB & KJM — DATE 08/02/91	TITLE V-BELT PULLEY SEALANT APPLICATOR
DRAWN WN	QTY 1 — DRAWING NO. SHRP(APS)SM-A110
APPRV DAB	SCALE 1:1
RELEASE DAB	SIZE B — SHT — PROJECT SHRP PROJECT

REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	08/02/91	WWN	DAB



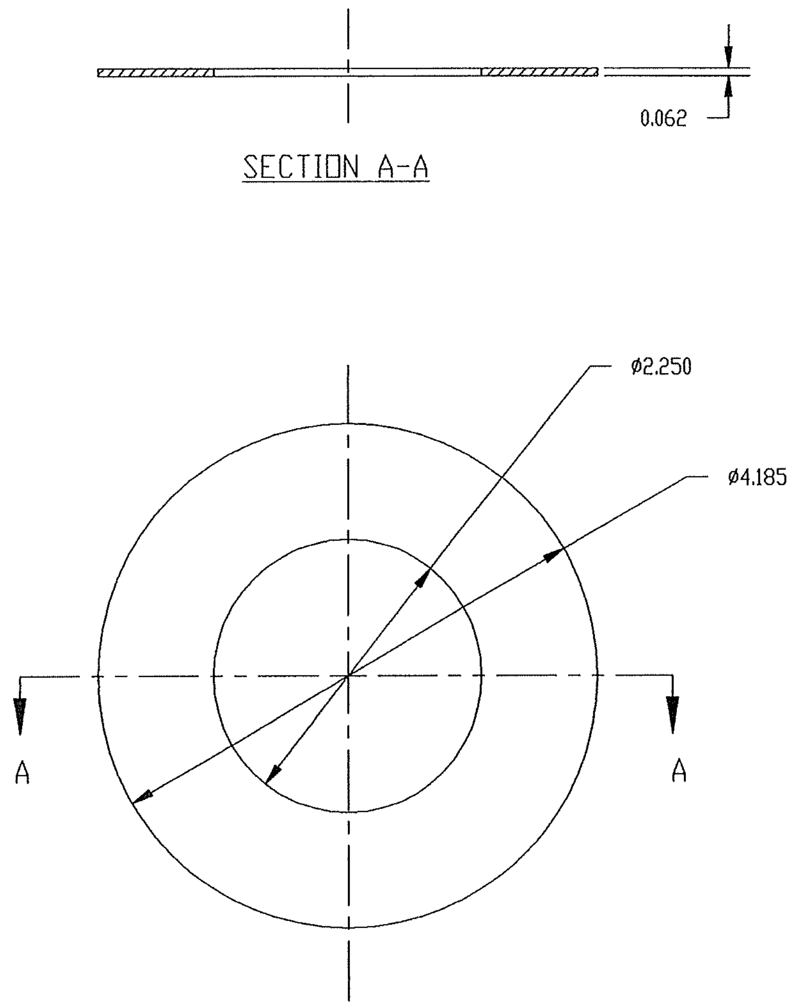
NOTES: UNLESS OTHERWISE SPECIFIED
1. BREAK ALL SHARP EDGES.

1		ø5.000 x .50	300 SERIES SS	1
ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD

PART LIST

UNLESS OTHERWISE NOTED: TOLERANCES .XX ±.01 .XXX ±.005 ANGLES ±0.5° 64√		UNIVERSITY OF CALIFORNIA, DAVIS MECHANICAL ENGINEERING DEPARTMENT	
		TITLE SPACER SEALANT APPLICATOR	
DESIGN DAB & KJM	DATE 08/02/91		
DRAWN WN		QTY 1	DRAWING NO. SHRP(APS)SM-A111
APPRV DAB		SCALE 1:1	
RELEASE DAB		SIZE B / SHT	PROJECT SHRP PROJECT

REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	08/02/91	WWN	DAB



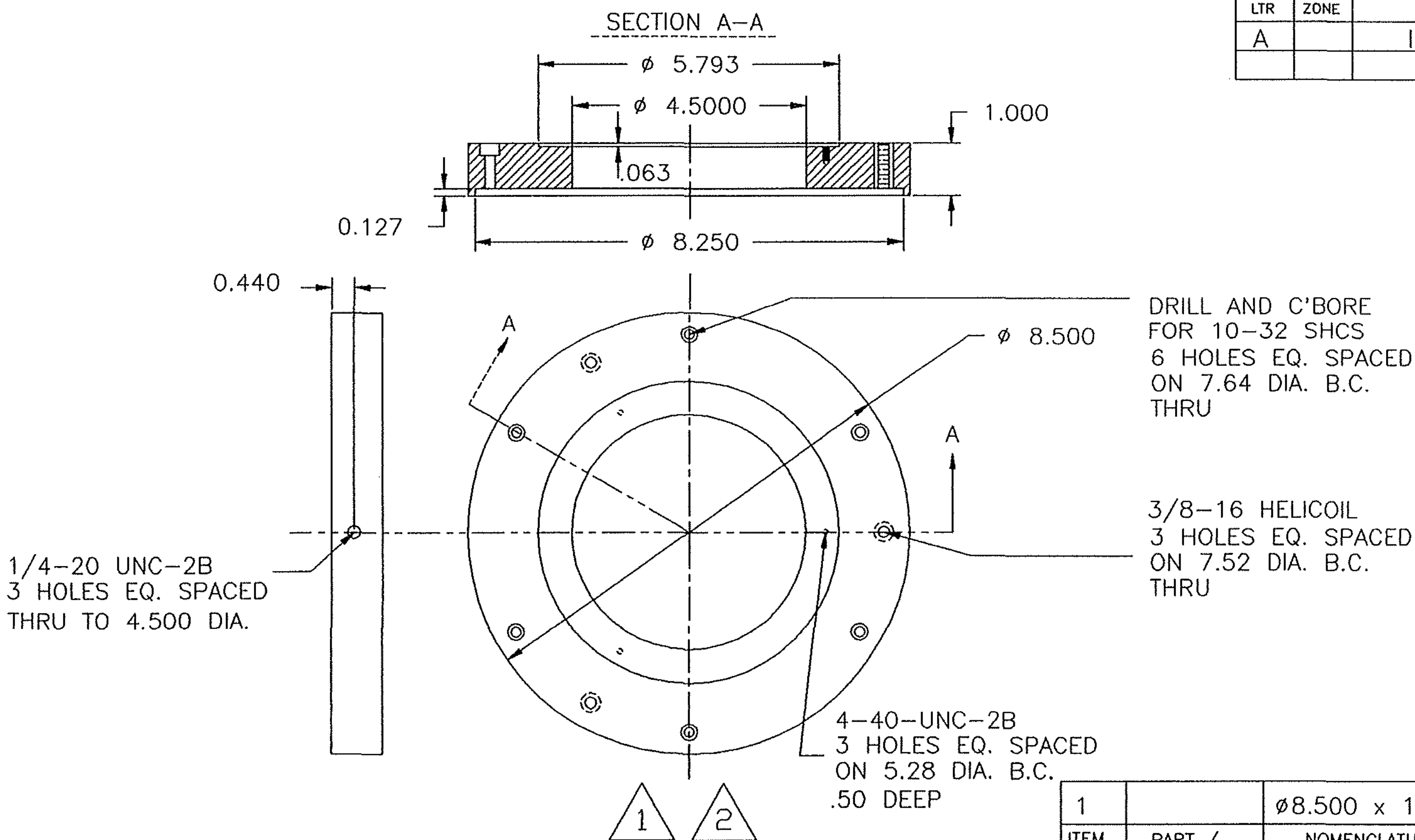
NOTES: UNLESS OTHERWISE SPECIFIED
1. BREAK ALL SHARP EDGES.

ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
1		ø4.185x0.062	G-10 or G-7	1

PART LIST

UNLESS OTHERWISE NOTED: TOLERANCES .XX ±.01 .XXX ±.005 ANGLES ±0.5° 64√		UNIVERSITY OF CALIFORNIA, DAVIS MECHANICAL ENGINEERING DEPARTMENT	
		TITLE WASHER SEALANT APPLICATOR	
DESIGN DAB & KJM	DATE 08/02/91		
DRAWN WWN		QTY 1	DRAWING NO. SHRP(APS)SM-A112
APPRV DAB		SCALE 1:1	
RELEASE DAB		SIZE B SHT	PROJECT SHRP PROJECT

REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	891	KJM	DAB

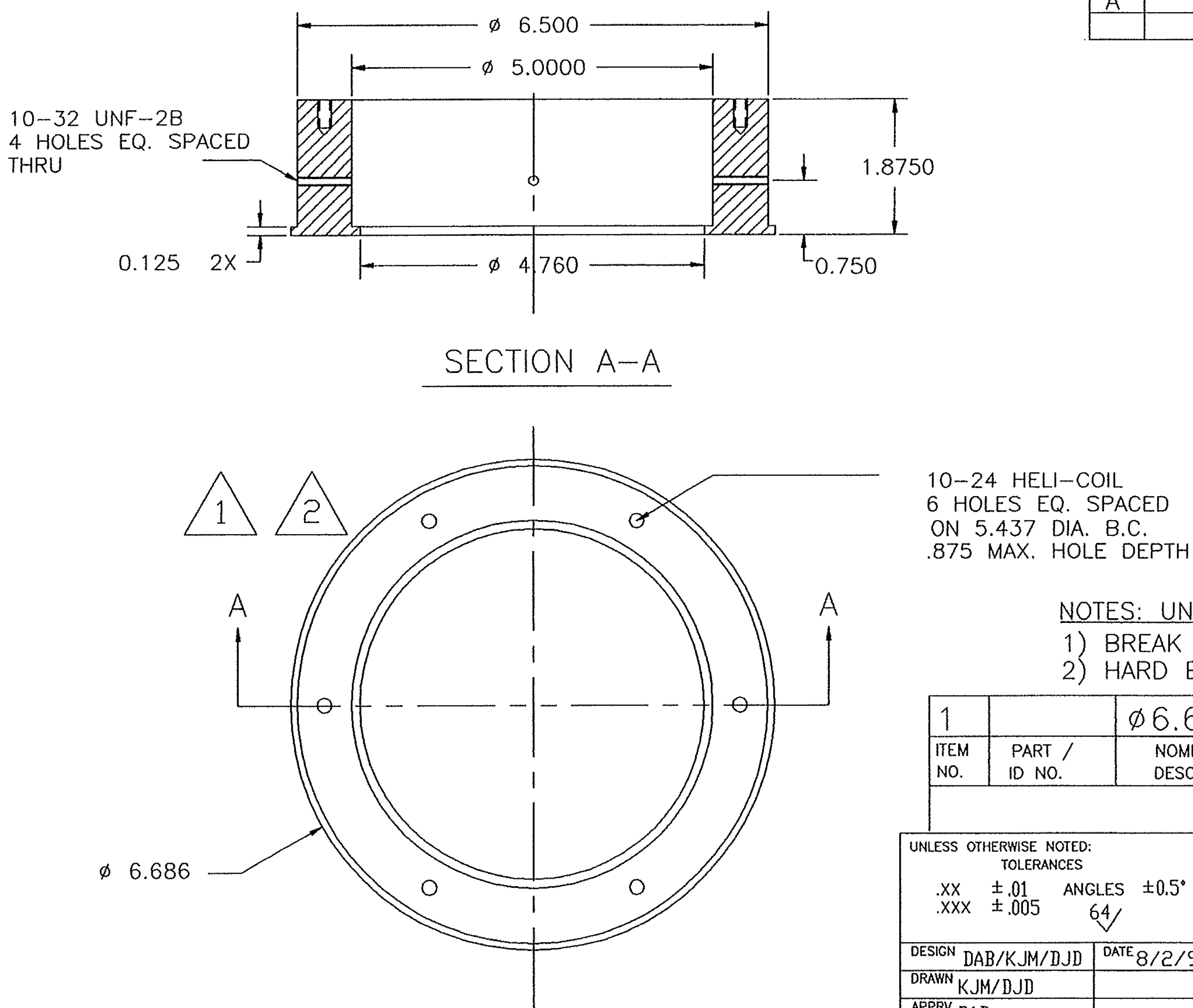


ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
1		ϕ8.500 x 1.000	6061–T6 ALUM	1

PART LIST

NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
2) HARD BLACK ANODIZE (MASK TAPPED HOLES)

UNLESS OTHERWISE NOTED: TOLERANCES .XX ±.01 .XXX ±.005 ANGLES ±0.5° 64/		UNIVERSITY OF CALIFORNIA, DAVIS MECHANICAL ENGINEERING DEPARTMENT	
		TITLE Top-Ring (of lower assembly)	
DESIGN DAB	DATE 8/2/91		
DRAWN DJD/KJM		QTY 1	DRAWING NO. SHRP(APS)SM-A113
APPRV DAB		SCALE 1:2.25	
RELEASE		SIZE B / SHT	PROJECT SHRP PROGRAM



REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	891	KJM	DAB

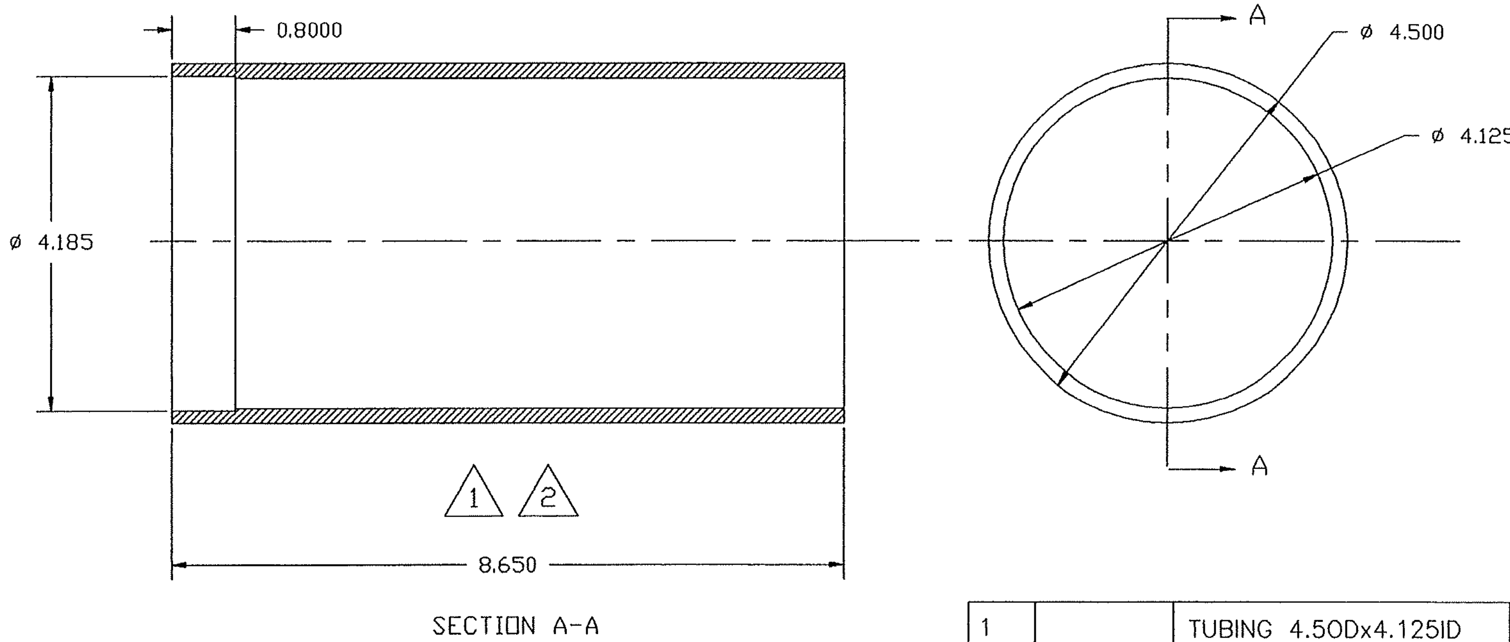
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
2) HARD BLACK ANODIZE (MASK TAPPED HOLES)

ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
1		Ø6.686 x 1.875	6061-T6	1

PART LIST

UNLESS OTHERWISE NOTED: TOLERANCES .XX ± .01 .XXX ± .005 ANGLES ±0.5° 64√	UNIVERSITY OF CALIFORNIA, DAVIS MECHANICAL ENGINEERING DEPARTMENT
	TITLE Rotation Block
DESIGN DAB/KJM/DJD	DATE 8/2/91
DRAWN KJM/DJD	QTY 1
APPRV DAB	SCALE 1:1.5
	DRAWING NO. SHRP(APS)SM-A114
RELEASE	SIZE B
SHT	PROJECT SHRP PROGRAM

REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	891	KJM	DAB



1		TUBING 4.50Dx4.125ID	6061-T6 ALUM.	1
ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD

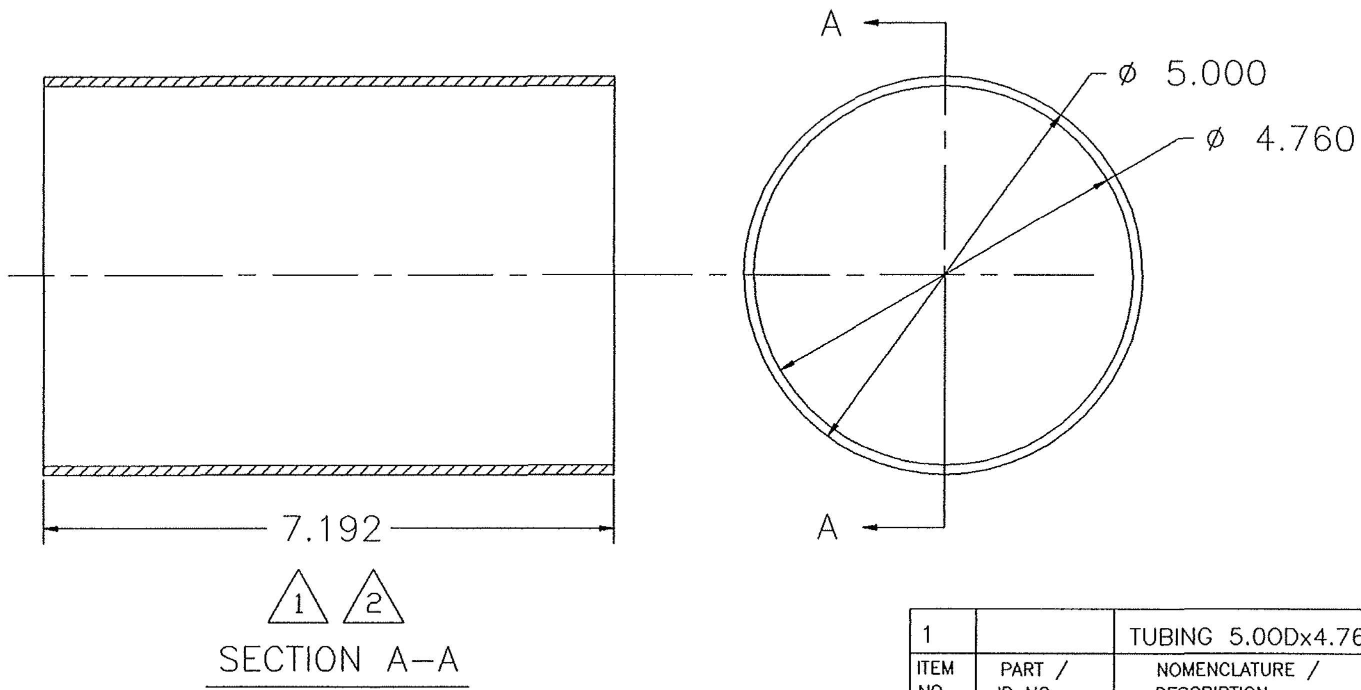
PART LIST

UNLESS OTHERWISE NOTED:
TOLERANCES
.XX ±.01 ANGLES ±0.5°
.XXX ±.005
64/

DESIGN DAB/KJM/DJD	DATE 8/2/91	UNIVERSITY OF CALIFORNIA, DAVIS MECHANICAL ENGINEERING DEPARTMENT	
		TITLE Outwall1	
DRAWN DJD/KJM		QTY 1	DRAWING NO. SHRP(APS)SM-A115
APPRV DAB		SCALE 1:1.5	
RELEASE		SIZE B	SHT	PROJECT SHRP PROGRAM

NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
2) HARD BLACK ANODIZE

LTR	ZONE	REVISION DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	891	KJM	DAB



ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
1		TUBING 5.0OD×4.76ID	304 SS	1

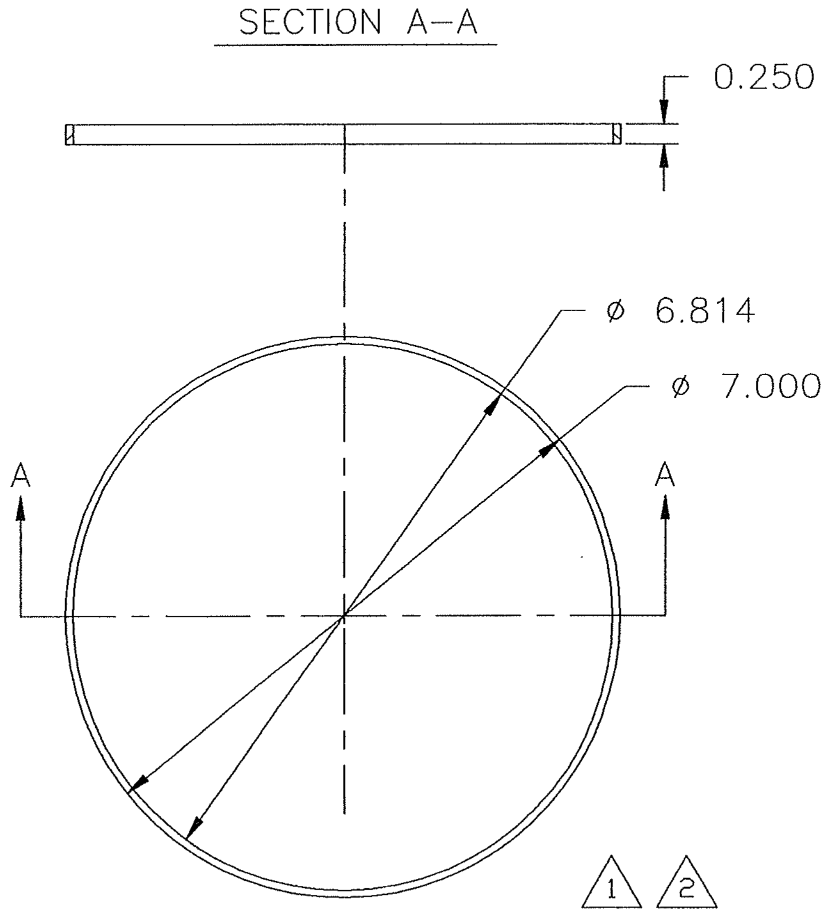
PART LIST

UNLESS OTHERWISE NOTED: TOLERANCES .XX ±.01 .XXX ±.005 ANGLES ±0.5° 64		UNIVERSITY OF CALIFORNIA, DAVIS MECHANICAL ENGINEERING DEPARTMENT	
		TITLE Outwall2	
DESIGN KJM/DAB	DATE 8/2/91		
DRAWN KJM/DJD		QTY 1	DRAWING NO. SHRP(APS)SM-A116
APPRV DAB		SCALE 1:1.5	
RELEASE		SIZE B SHT	PROJECT SHRP PROGRAM

NOTES: UNLESS OTHERWISE SPECIFIED

1) BREAK ALL SHARP EDGES
2) HAVE A NICE DAY!

REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	891	KJM	DAB



NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
2) ZINC COATING

ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
1		TUBING Ø7.0x.25	1018	1

PART LIST

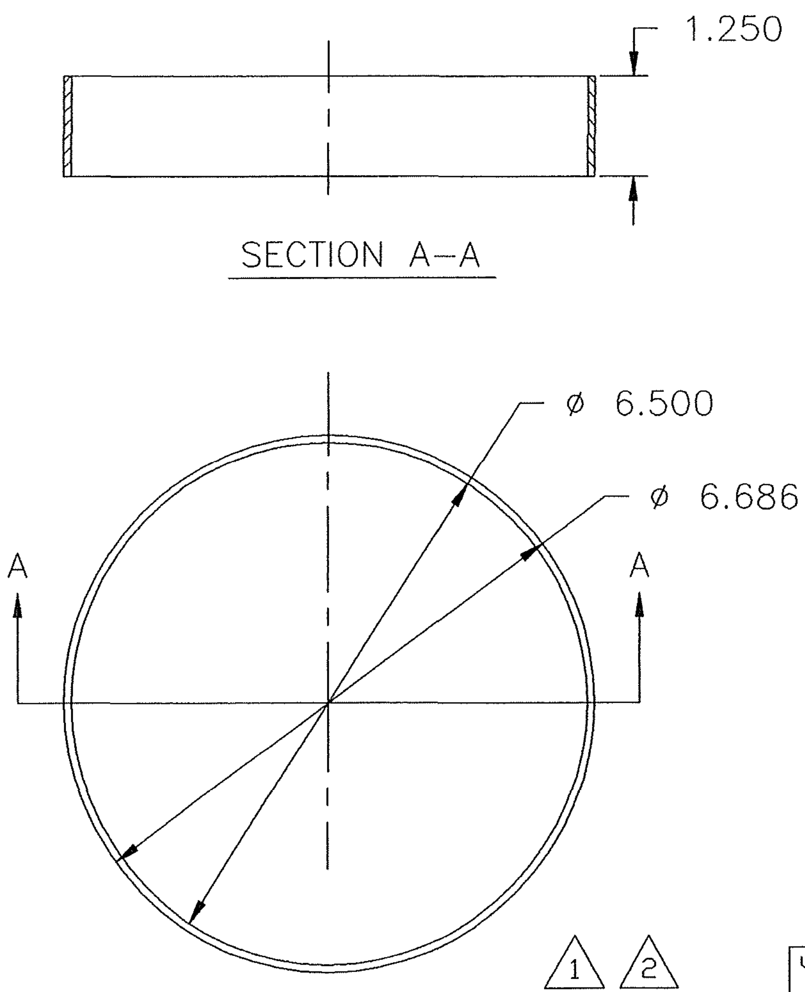
UNLESS OTHERWISE NOTED:
TOLERANCES
.XX ± .01 ANGLES ±0.5°
.XXX ± .005
64

UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT

TITLE Hoop1

DESIGN DAB	DATE 8/2/91		
DRAWN KJM		QTY 1	DRAWING NO. SHRP(APS)SM-A117
APPRV DAB		SCALE 1:1.5	
RELEASE		SIZE B	SHT	PROJECT SHRP PROGRAM

REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	891	KJM	DAB



NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
2) ZINC COATING

ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
1		TUBING 6.750Dx1.25LONG	1018STEEL	1

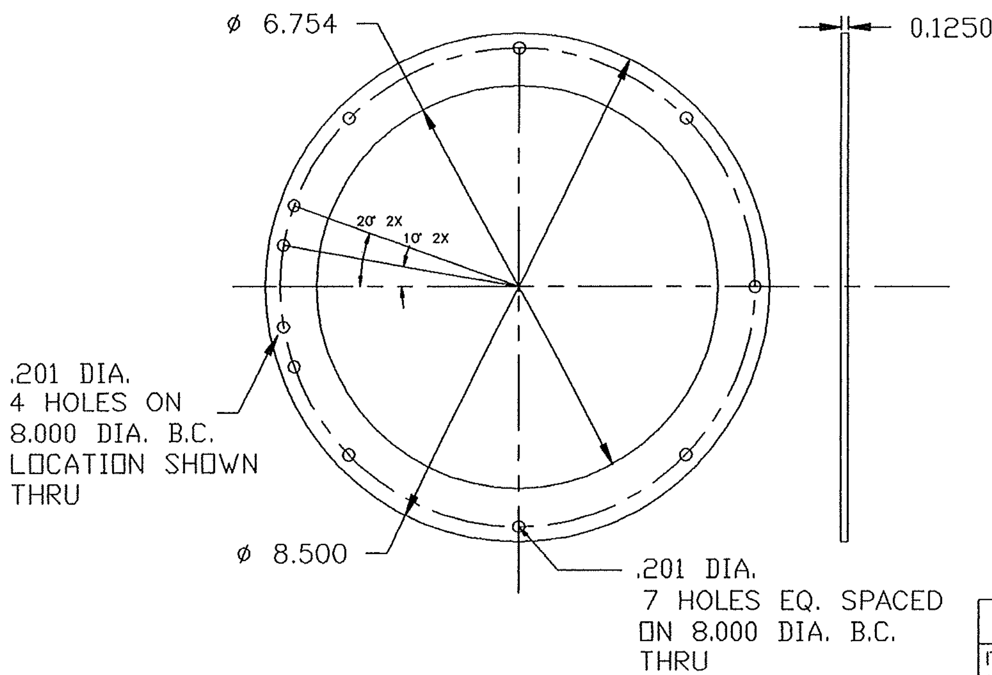
PART LIST

UNLESS OTHERWISE NOTED:
TOLERANCES
.XX ± .01 ANGLES ±0.5°
.XXX ± .005
64√

UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT

TITLE Hoop2

DESIGN DAB	DATE 8/2/91				
DRAWN KJM		QTY 1	DRAWING NO. SHRP(APS)SM-A118		
APPRV DAB		SCALE 1:1.5			
RELEASE		SIZE B	SHT	PROJECT SHRP PROGRAM	



LTR	ZONE	REVISION DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	891	DJD	DAB
B		HOLE PLACEMENT	991	KJM	DAB

NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
2) HARD BLACK ANODIZE

ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
1		8.50Dx6.865IDx.125	6061-T6 ALUM.	1

PART LIST

UNLESS OTHERWISE NOTED:
TOLERANCES
.XX ±.01 ANGLES ±0.5°
.XXX ±.005
64

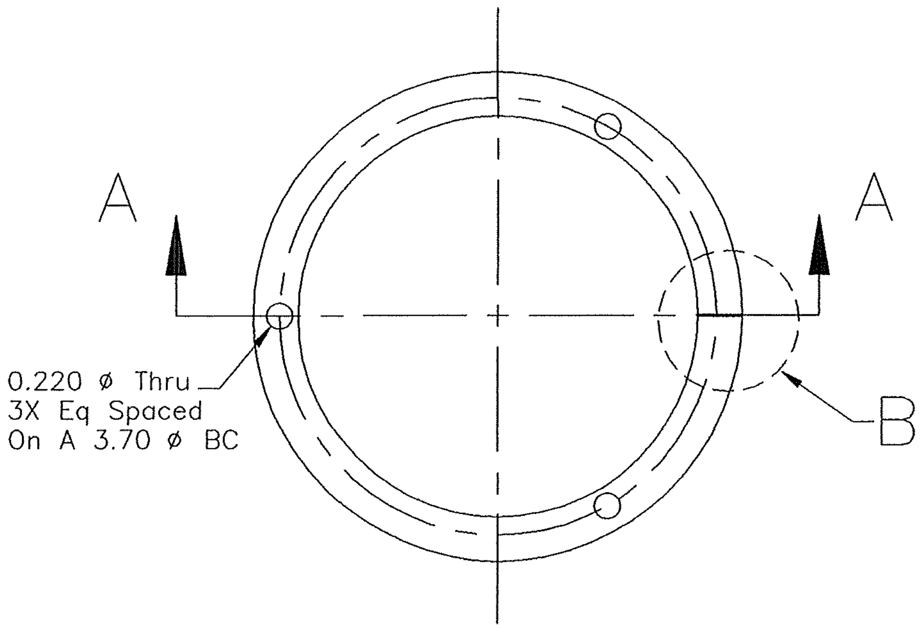
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT

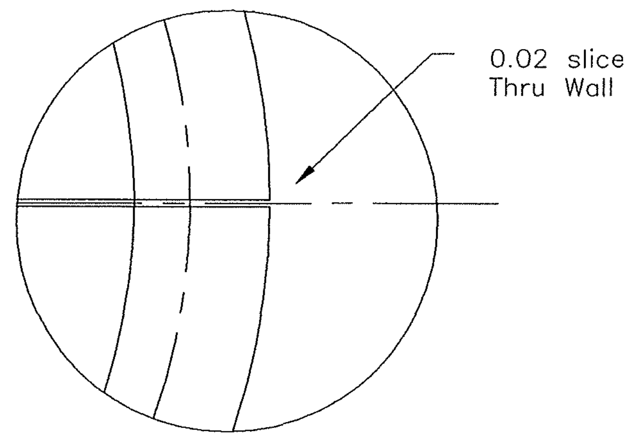
TITLE Inner Spacer

DESIGN DAB/DJD	DATE 8/5/91	QTY 1	DRAWING NO. SHRP(APS)SM-A119
DRAWN DJD		SCALE 1:1.5	
APPRV DAB		SIZE B	SHT
RELEASE		PROJECT SHRP PROGRAM	

LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	8/5/91	DAB	DAB

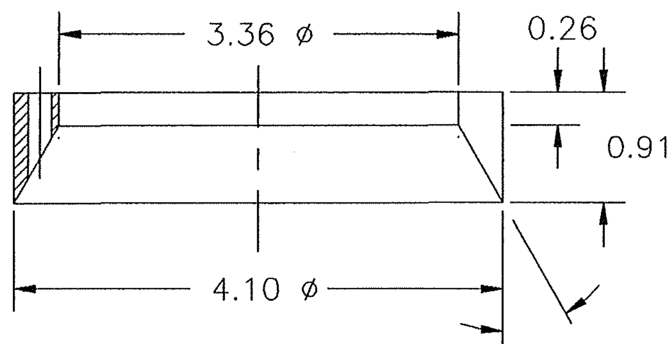
REVISION





DETAIL B
Scale 3:1

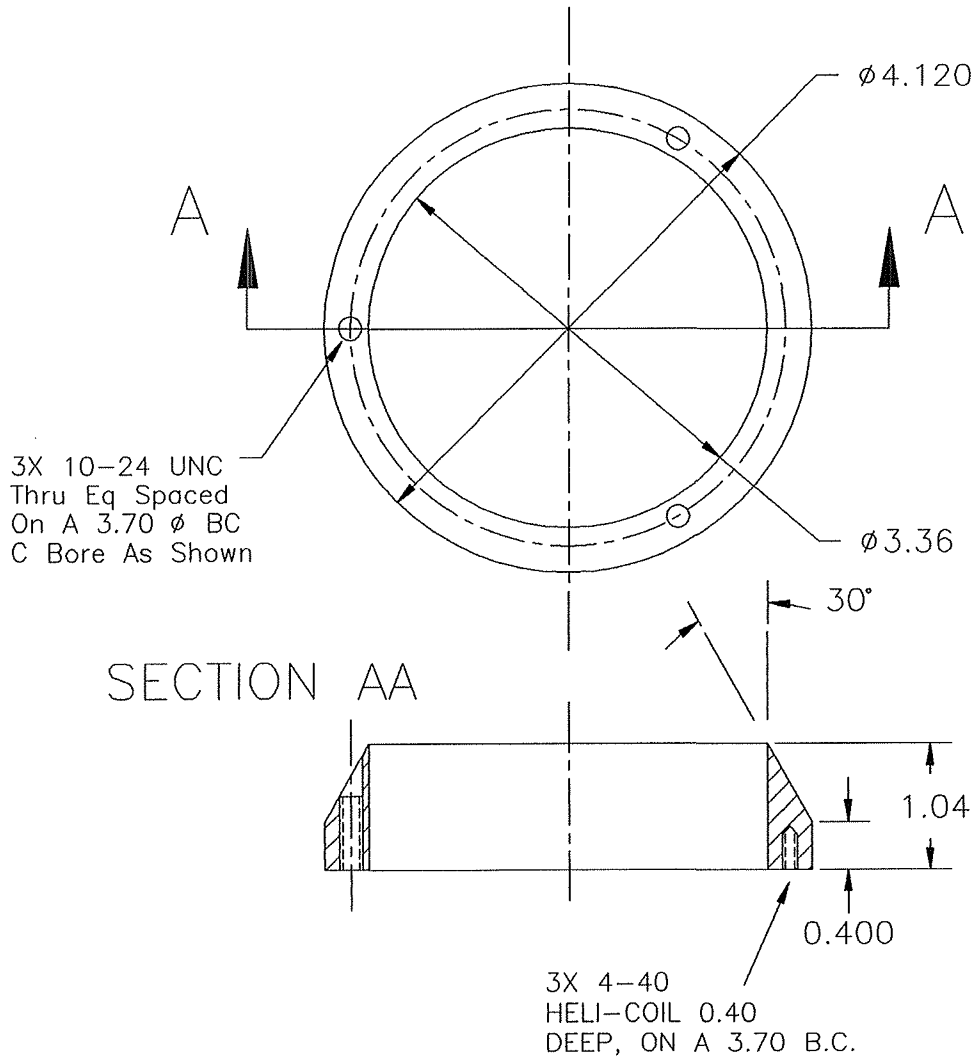
SECTION AA



ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
1		ø4.10X0.91	6061-T6	1

PART LIST

UNLESS OTHERWISE NOTED: TOLERANCES .XX ± .01 .XXX ± .005 ANGLES ± 0.5° 64√	UNIVERSITY OF CALIFORNIA, DAVIS MECHANICAL ENGINEERING DEPARTMENT
DESIGN DAB / DATE 8/2/91	TITLE STRAIN PLATE LOCK SEALANT APPLICATOR
DRAWN DAB	QTY / DRAWING NO. SHRP(APS)SM-A120
APPRV DAB	SCALE 1:1
RELEASE	SIZE B / SHT / PROJECT SHRP PROJECT



REVISION

LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	8/5/91	DAB	DAB
B		BOTTOM PLATE REMOVED	11/2/91	KJM	DAB

ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
1		ø4.12X1.04	6061-T6	1

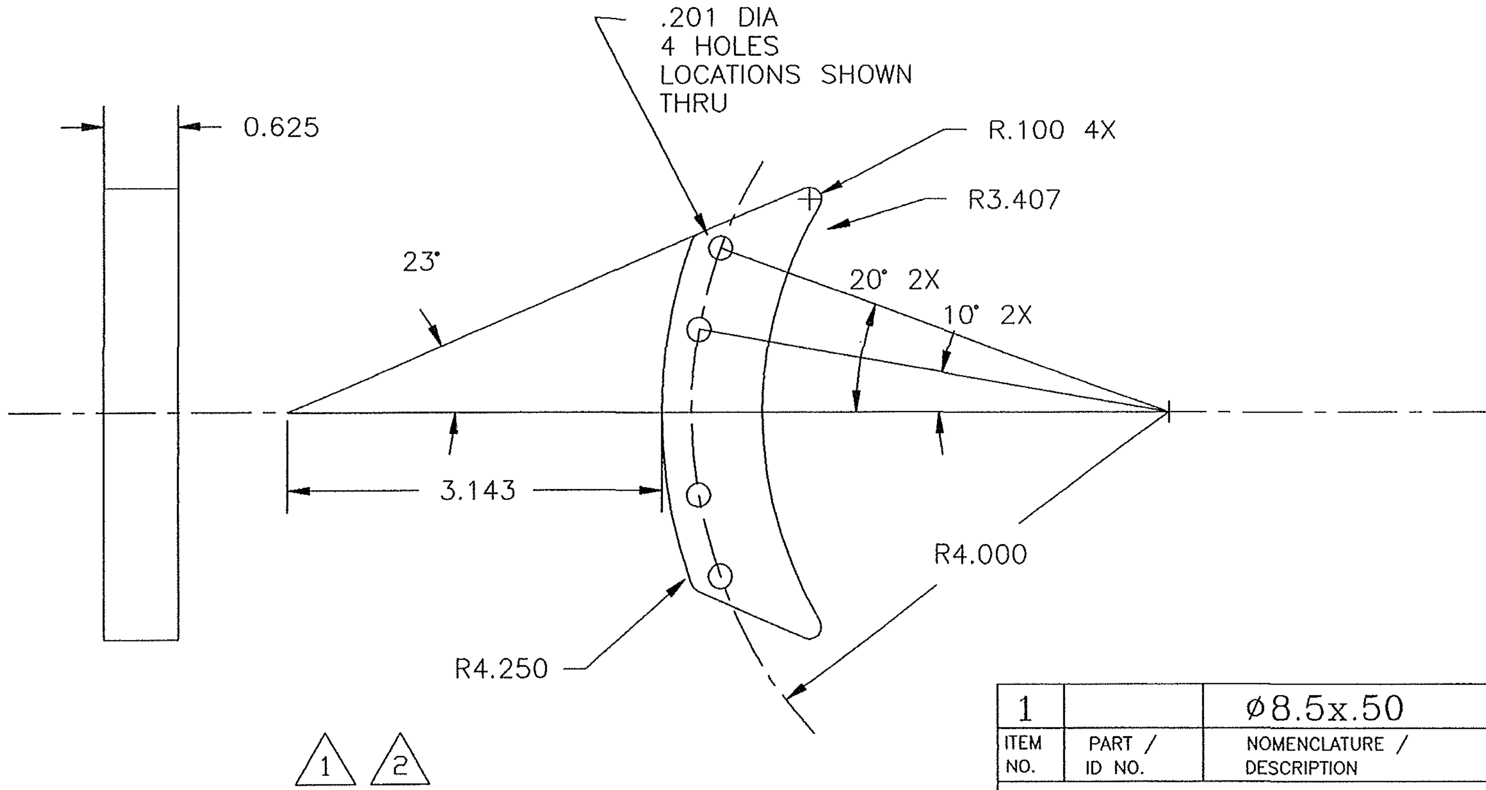
PART LIST

UNLESS OTHERWISE NOTED:
TOLERANCES
.XX ± .01 ANGLES ±0.5°
.XXX ± .005
64✓

UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT

DESIGN DAB	DATE 8/2/91	TITLE Strain Plate Holder Sealant Applicator	
DRAWN KJM		QTY 1	DRAWING NO. SHRP(APS)SM-A121
APPRV DAB		SCALE 1:1	
RELEASE		SIZE B / SHT	PROJECT SHRP PROJECT

REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	891	DJD	DAB
B		.625 THICK/SHORTENED	991	KJM	KJM



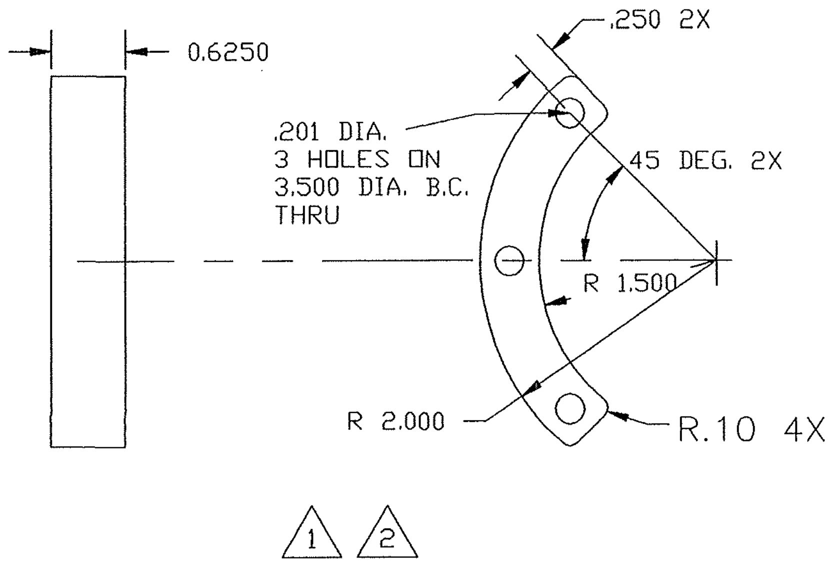
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
2) HARD BLACK ANODIZE

ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
1		Ø8.5x.50	6061-T6	1

PART LIST

UNLESS OTHERWISE NOTED: TOLERANCES .XX ±.01 .XXX ±.005 ANGLES ±0.5° 64√		UNIVERSITY OF CALIFORNIA, DAVIS MECHANICAL ENGINEERING DEPARTMENT	
		TITLE Inner Spacer 2	
DESIGN DJD	DATE 8/5/91		
DRAWN DJD		QTY 1	DRAWING NO. SHRP(APS)SM-A122
APPRV DAB		SCALE 1:1	
RELEASE		SIZE B	SHT / PROJECT SHRP PROGRAM

REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	891	DJD	DAB



NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
2) HARD BLACK ANODIZE

ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
1		ϕ4.0x.625	6061-T6	1

PART LIST

UNLESS OTHERWISE NOTED:
TOLERANCES
.XX ±.01 ANGLES ±0.5°
.XXX ±.005
64√

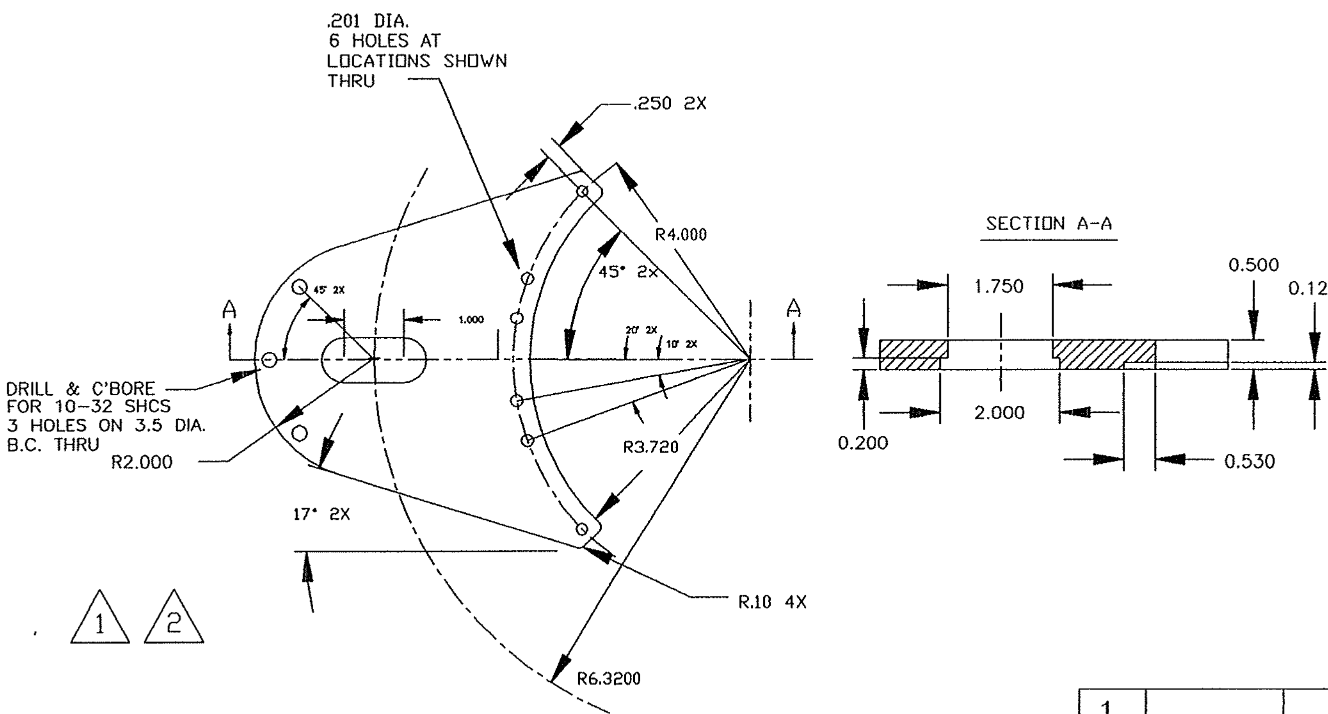
UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT

TITLE Outer Spacer

DESIGN DJD	DATE 8/5/91
DRAWN DJD	
APPRV DAB	
RELEASE	

QTY 1
SCALE 1:1
DRAWING NO. SHRP(APS)SM-A123
SIZE B
SHT
PROJECT SHRP PROGRAM

		REVISION			
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	891	DJD	DAB
B		HOLES/MILL PATH	991	KJM	KJM



NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES
2) HARD BLACK ANODIZE

ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
1		6.0x6.4x.25	6061-T6	1

PART LIST

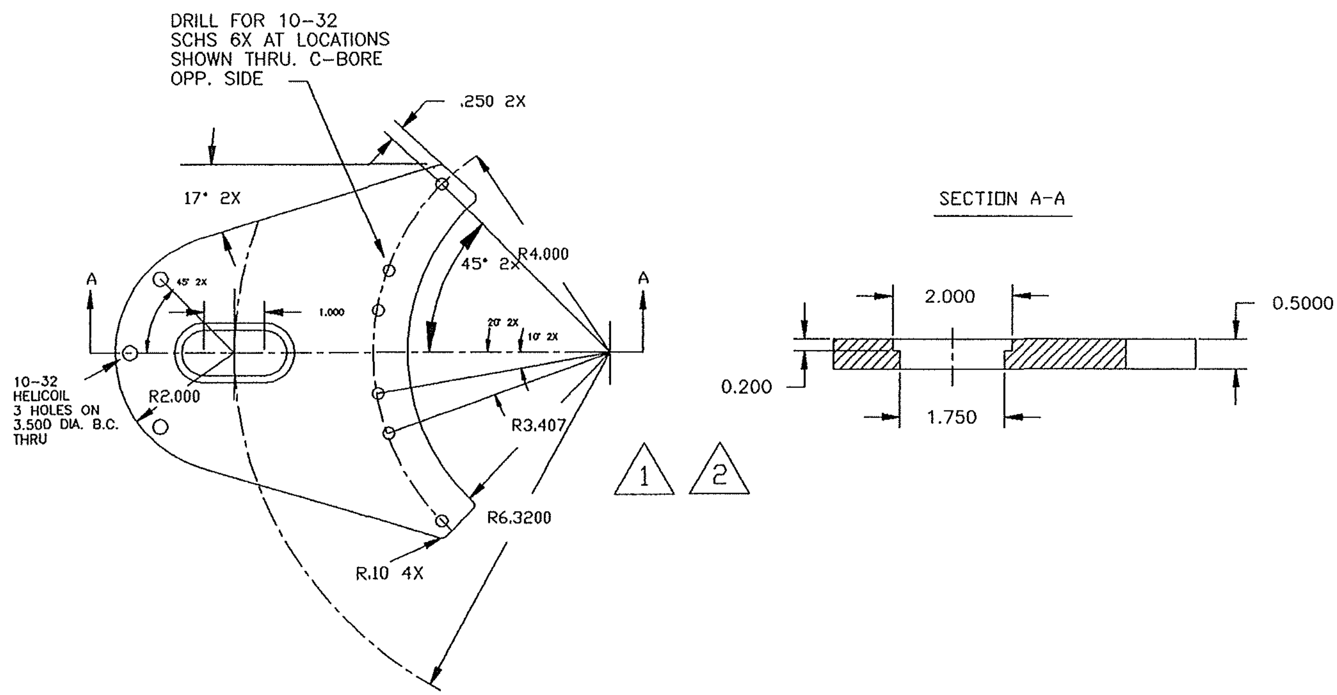
UNLESS OTHERWISE NOTED:
TOLERANCES
.XX ±.01 ANGLES ±0.5°
.XXX ±.005 64√

UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT

TITLE Top Holder

DESIGN DJD	DATE 8/5/91	QTY 1	DRAWING NO. SHRP(APS)SM-A124
DRAWN DJD		SCALE 1:2	
APPRV DAB		SIZE B	SHT
RELEASE		PROJECT SHRP PROGRAM	

REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	891	DJD	DAB
B		HOLES/MILL PATH	991	KJM	KJM



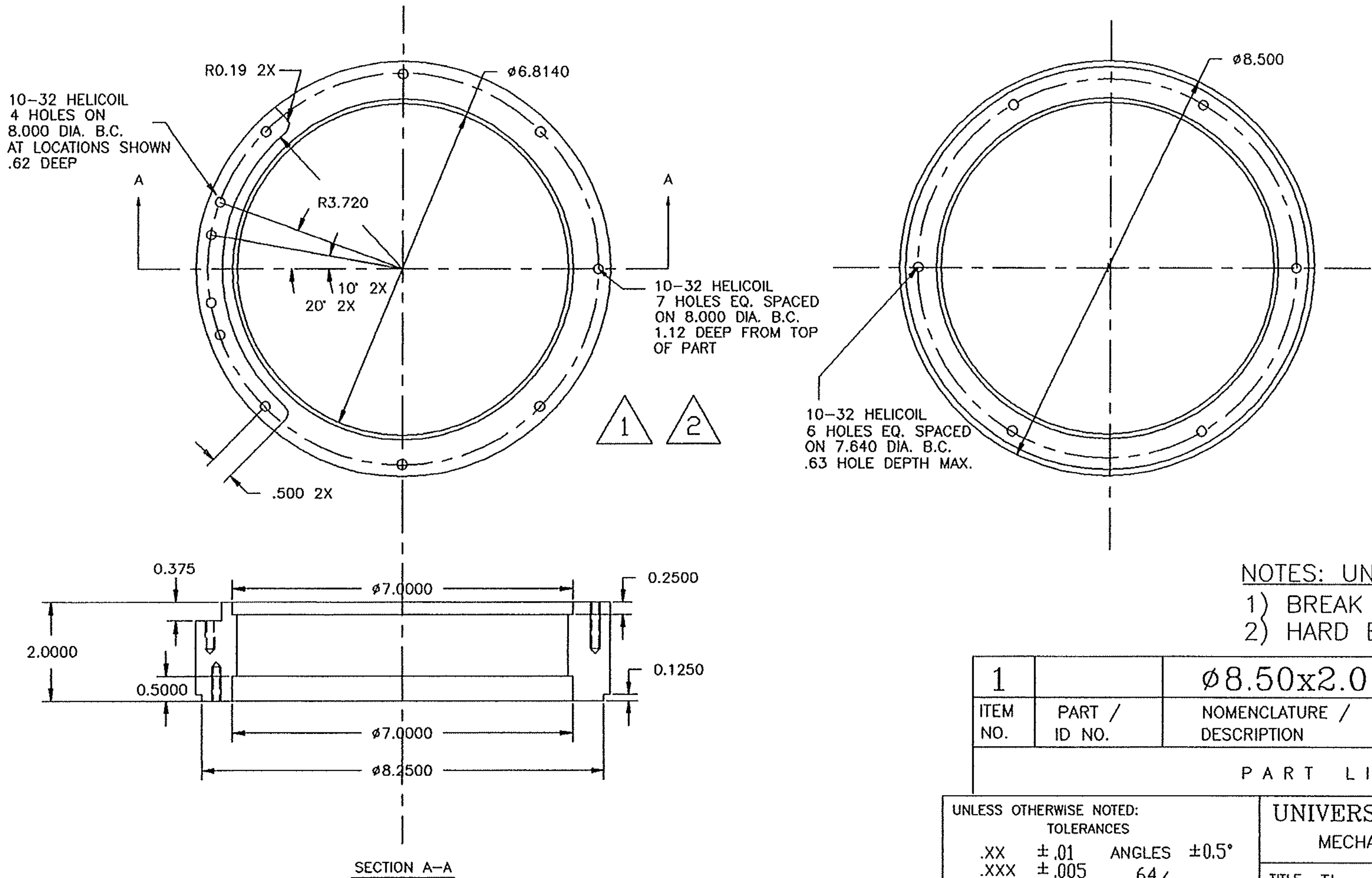
1		6.0x6.5x.50	6061-T6	1
ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD

PART LIST

UNLESS OTHERWISE NOTED: TOLERANCES .XX ±.01 ANGLES ±0.5° .XXX ±.005 64√	UNIVERSITY OF CALIFORNIA, DAVIS MECHANICAL ENGINEERING DEPARTMENT
DESIGN DJD / DATE 8/5/91	TITLE Bottom Holder
DRAWN DJD	QTY 1 / DRAWING NO. SHRP(APS)SM-A125
APPRV DAB	SCALE 1:2
RELEASE	SIZE B / SHT / PROJECT SHRP PROGRAM

NOTES: UNLESS OTHERWISE SPECIFIED

1) BREAK ALL SHARP EDGES
2) HARD BLACK ANODIZE



REVISION

LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	891	DJD	DAB
B		HOLE PLACEMENT	991	KJM	DAB

NOTES: UNLESS OTHERWISE SPECIFIED

1) BREAK ALL SHARP EDGES
2) HARD BLACK ANODIZE

ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
1		ø8.50x2.0	6061-T6	1

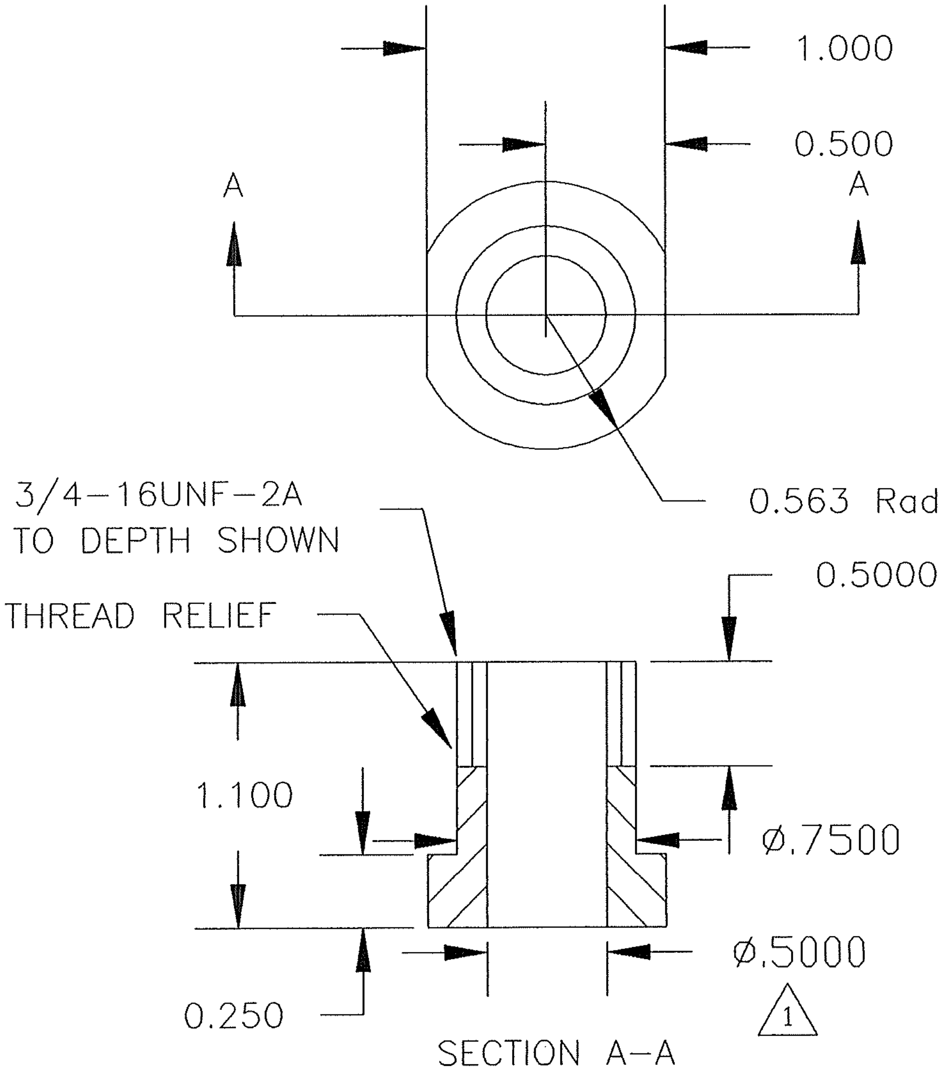
PART LIST

UNLESS OTHERWISE NOTED:
TOLERANCES
.XX ±.01 ANGLES ±0.5°
.XXX ±.005 64√

UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT

TITLE Thrust Holder

DESIGN DJD	DATE 8/5/91	QTY 1	DRAWING NO. SHRP(APS)SM-A126
DRAWN DJD		SCALE 1:2.25	
APPRV DAB		SIZE B	SHT
RELEASE			PROJECT SHRP PROGRAM



REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	891	DJD	DAB
B		THREADED	991	KJM	KJM
C		SHOULDER EXTENSION	1091	KJM	KJM
D		FLAT ADDED	1191	KJM	KJM

NOTES: UNLESS OTHERWISE SPECIFIED
1. BREAK ALL SHARP EDGES.

ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
1		ø1.00x.5425	OIL-IMPREGNATED BRONZE BUSHING	2

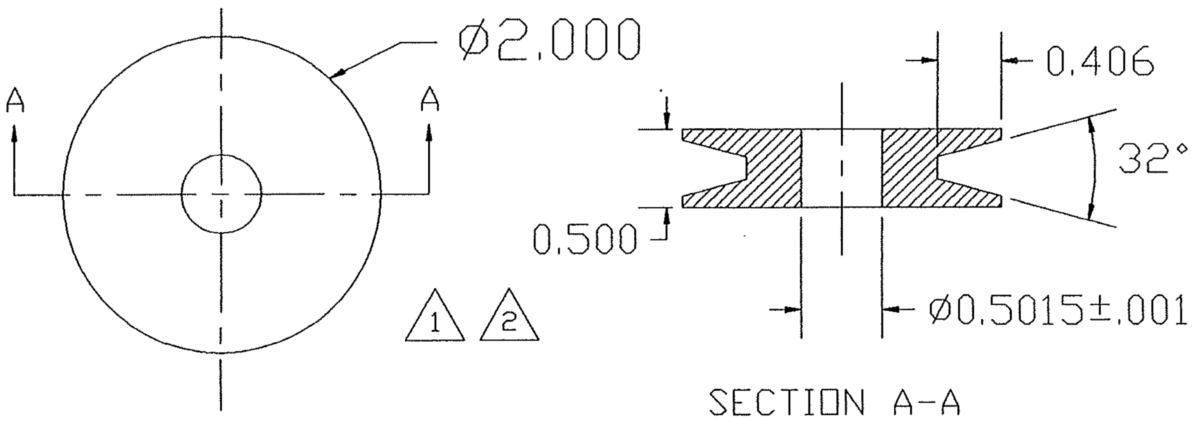
PART LIST

UNLESS OTHERWISE NOTED:
TOLERANCES
.XX ±.01 ANGLES ±0.5°
.XXX ±.005
64√

UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT

DESIGN DAB\DJD	DATE 8/5/91	TITLE Bushing	
DRAWN DJD		QTY 2	DRAWING NO. SHRP(APS)SM-A127
APPRV DAB		SCALE 1:5	
RELEASE		SIZE B / SHT	PROJECT SHRP PROGRAM

LTR	ZONE	REVISION DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	891	DJD	DAB



NOTES: UNLESS OTHERWISE SPECIFIED
1. BREAK ALL SHARP EDGES.

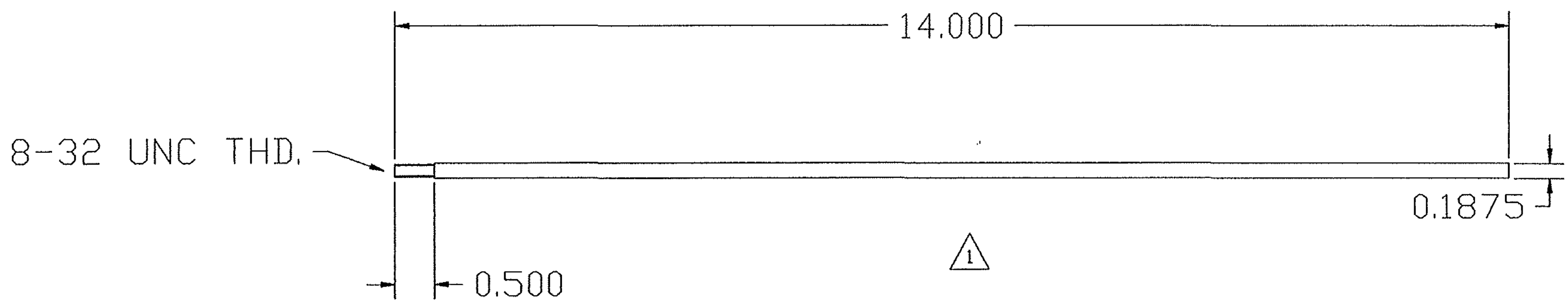
2) Hard Black Anodize
Mask All Holes Under 0.3 ø

ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
1		(APS)SM-A128	6061-T6	1

PART LIST

UNLESS OTHERWISE NOTED: TOLERANCES .XX ±.01 .XXX ±.005 ANGLES ±0.5° 64√	UNIVERSITY OF CALIFORNIA, DAVIS MECHANICAL ENGINEERING DEPARTMENT
DESIGN DJD, DATE 8/5/91	TITLE Motor Pulley
DRAWN DJD	QTY 1 / DRAWING NO. SHRP(APS)SM-A128
APPRV DAB	SCALE 1:.75
RELEASE	SIZE B / SHT / PROJECT SHRP PROGRAM

LTR	ZONE	REVISION DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	08/02/91	KJM	DAB



NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES

ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
1		ø.1875x14.000	300 SERIES SS	2

PART LIST

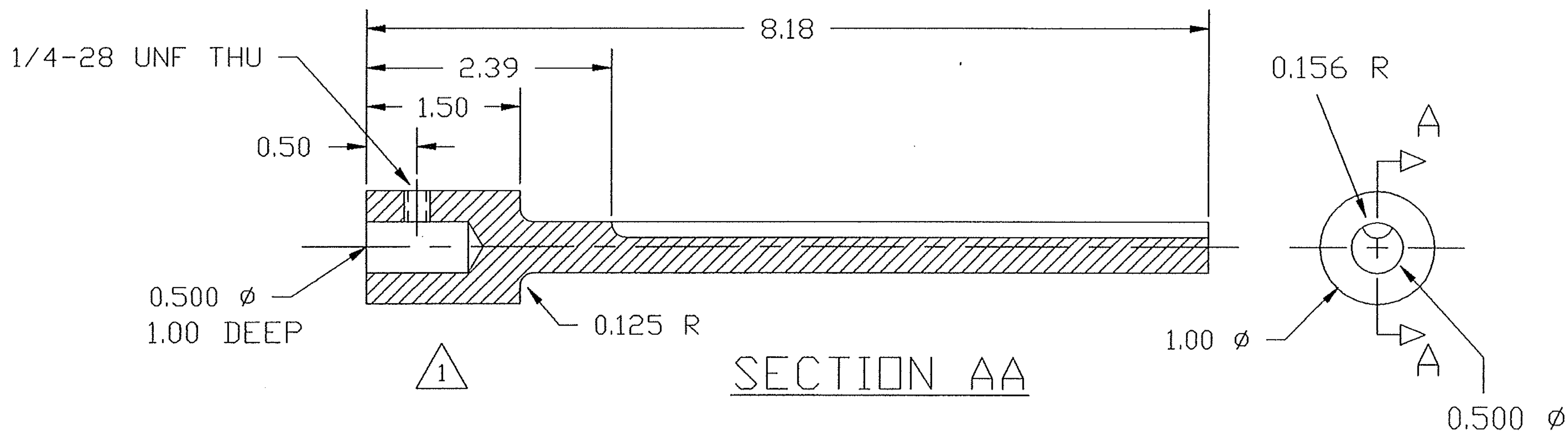
UNLESS OTHERWISE NOTED:
TOLERANCES
.XX ±.01 ANGLES ±0.5°
.XXX ±.005 64

UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT

TITLE DIVIDING BAR SEALANT APPLICATOR

DESIGN KJM	DATE 08/07/91	QTY 2	DRAWING NO. SHRP(APS)SM-A129
DRAWN KJM		SCALE 1:1	
APPRV DAB		SIZE B	SHT
RELEASE DAB			PROJECT SHRP PROJECT

LTR	ZONE	REVISION DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	891	DAB	DAB



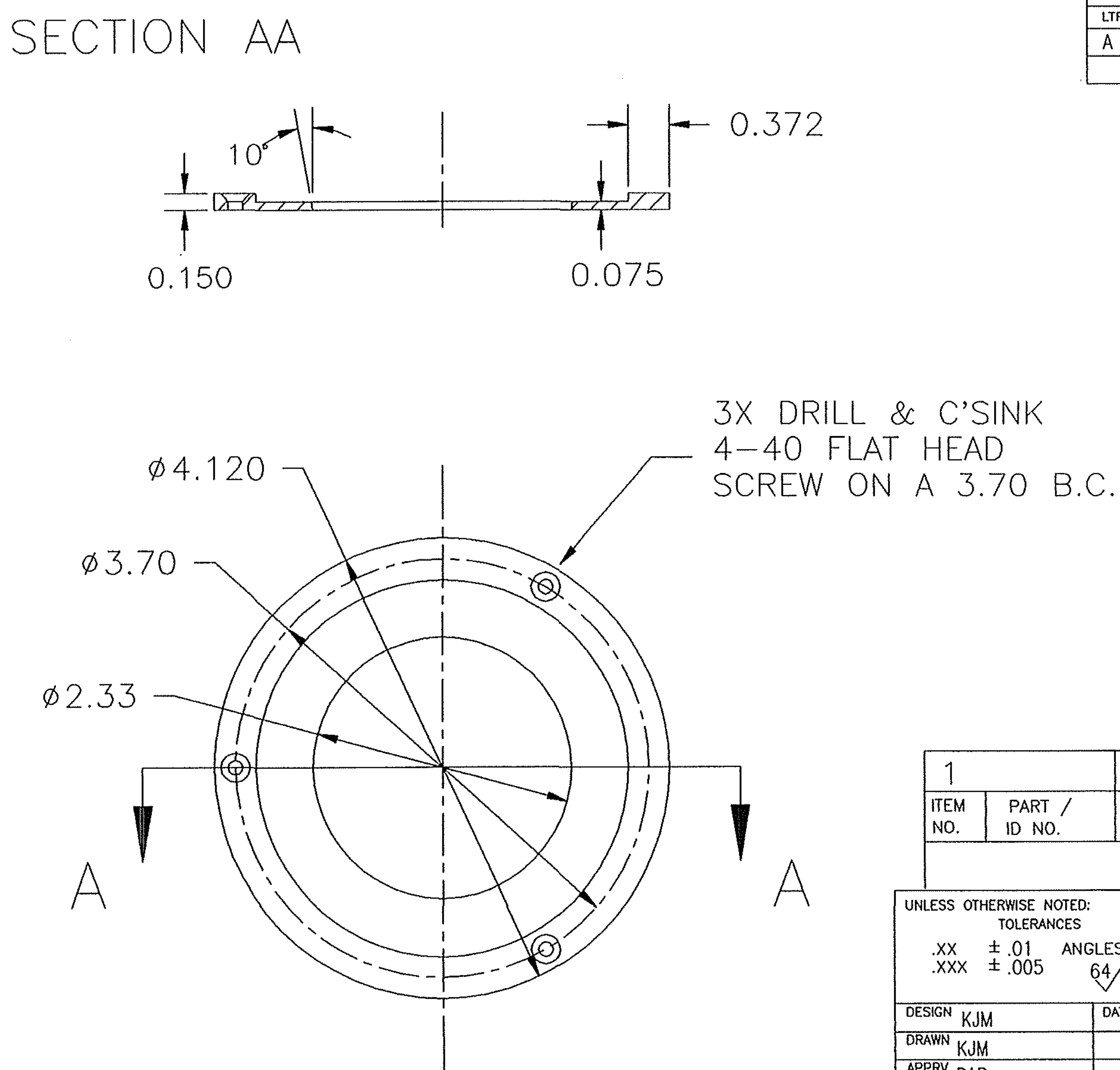
NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES

ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
1		ø1.00x8.18	304 SS	1

PART LIST

UNLESS OTHERWISE NOTED: TOLERANCES .XX ±.01 .XXX ±.005 ANGLES ±0.5° 64	UNIVERSITY OF CALIFORNIA, DAVIS MECHANICAL ENGINEERING DEPARTMENT
DESIGN DAB / DATE 8/9/91	TITLE Motor Adapter
DRAWN DAB	QTY 1 / DRAWING NO. SHRP(APS)SM-A130
APPRV DAB	SCALE 1:1
RELEASE	SIZE B / SHT / PROJECT SHRP PROGRAM

REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	11/2/91	KJM	DAB



ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
1		ø4.12 x 0.15	6061-T6	1

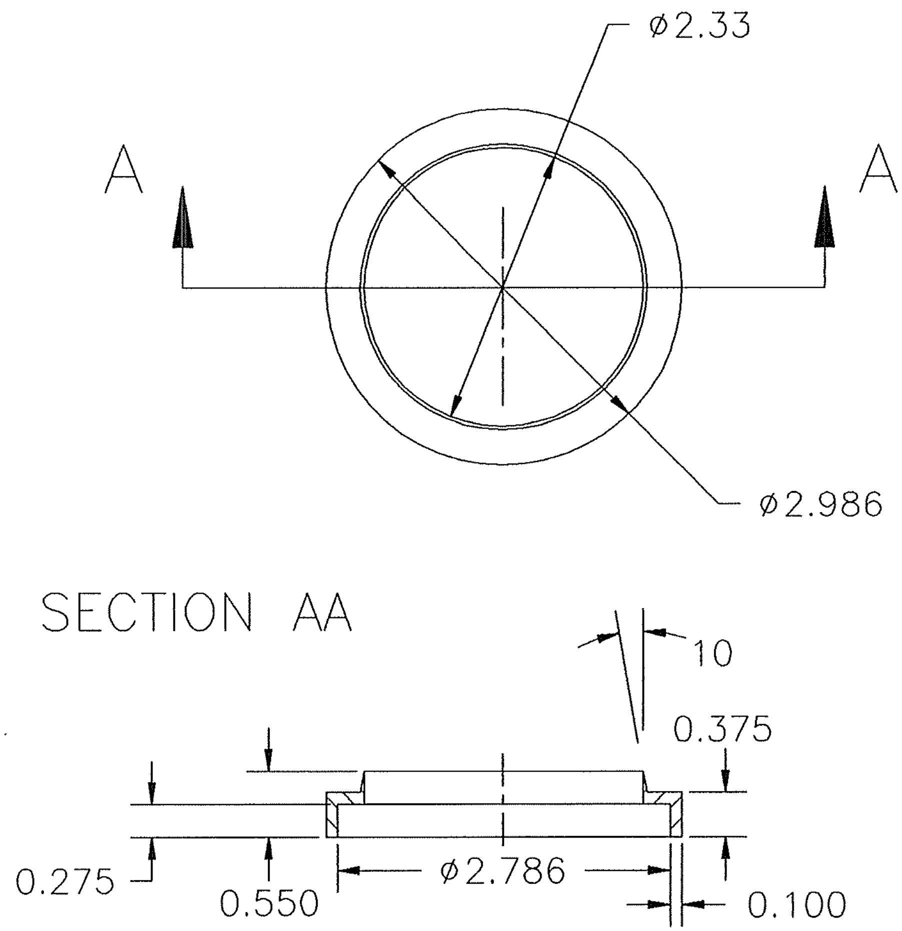
PART LIST

UNLESS OTHERWISE NOTED:
TOLERANCES
.XX ± .01 ANGLES ±0.5°
.XXX ± .005
64

UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT

DESIGN KJM	DATE 11/2/91	TITLE Strain Plate Sealant Applicator	
DRAWN KJM		QTY 1	DRAWING NO. SHRP(APS)SM-A131
APPRV DAB		SCALE 1:1	
RELEASE		SIZE B / SHT	PROJECT SHRP PROJECT

REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	11/2/91	KJM	DAB



ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
1		⌀2.986 X 0.55	6061-T6	1

PART LIST

UNLESS OTHERWISE NOTED:
TOLERANCES
.XX ± .01 ANGLES ±0.5°
.XXX ± .005 64√

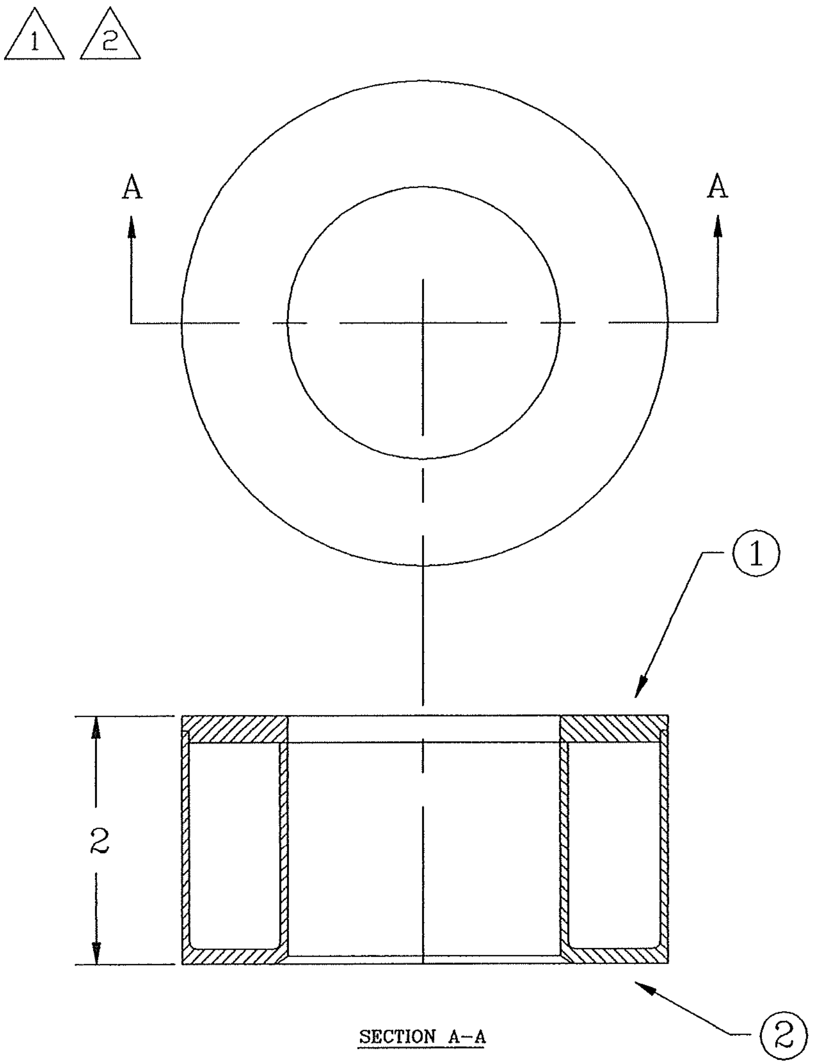
DESIGN KJM	DATE 11/2/91		
DRAWN KJM			
APPRV DAB			
RELEASE			

UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT

TITLE Spring Capture Sealant Applicator

QTY 1	DRAWING NO. SHRP(APS)SM-A132	
SCALE 1:1		
SIZE B	SHT	PROJECT SHRP PROJECT

REVISION					
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	8/91	KJM	DAB



SECTION A-A

NOTES: UNLESS OTHERWISE SPECIFIED

1) HARD BLACK ANODIZE
MASK ALL HOLES UNDER 0.3 DIA

2) SHRINK FIT ITEM 1 INTO 2
.0005/.0007 AFTER PLATING

ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
2		(APS)SM-A202	6061-T6	1
1		(APS)SM-A201	6061-T6	1

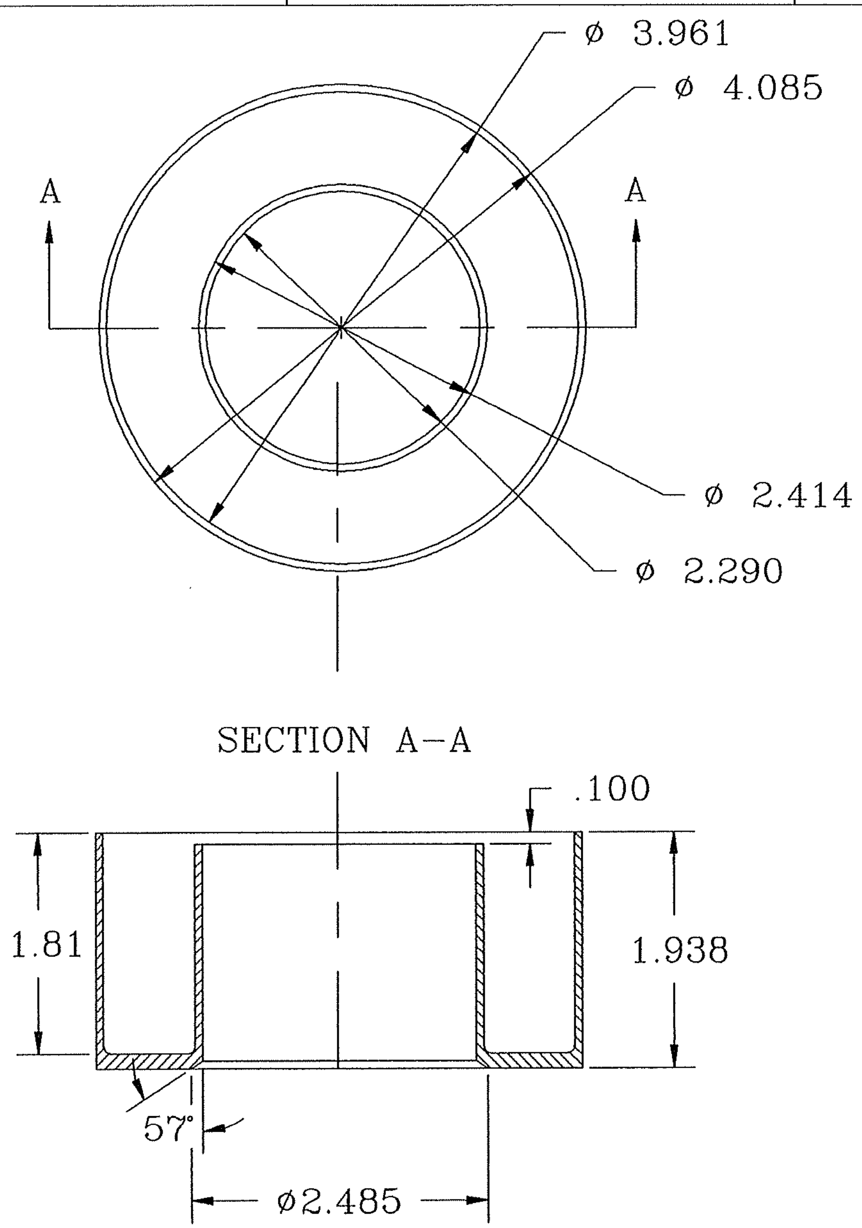
P A R T   L I S T

UNLESS OTHERWISE NOTED:
TOLERANCES
.XX ± .01   ANGLES ±0.5°
.XXX ± .005
64

UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT

TITLE Floater

DESIGN DAB	DATE 8/1/91	QTY 1	DRAWING NO. SHRP(APS)SM-A200
DRAWN KJM		SCALE 1:1	
APPRV DAB		SIZE B	SHT
RELEASE			PROJECT SHRP PROGRAM



LTR	ZONE	REVISION DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	8/91	KJM	DAB

NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES

ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
1		ϕ4.085x1.938	6061–T6	1

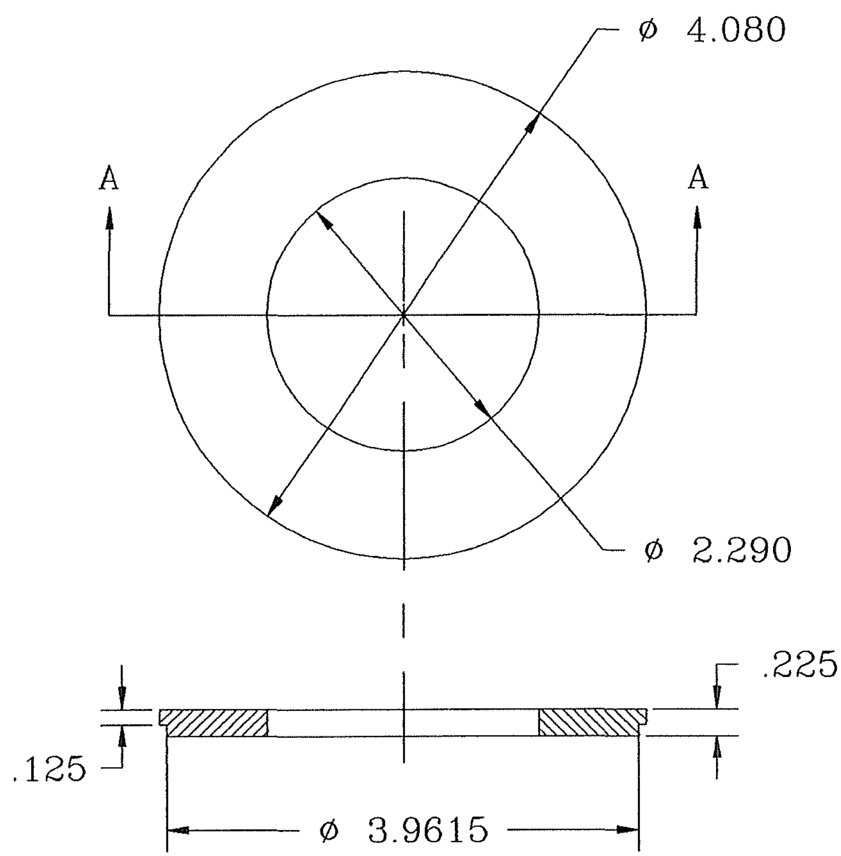
PART LIST

UNLESS OTHERWISE NOTED:
TOLERANCES
.XX ±.01
.XXX ±.005
ANGLES ±0.5°
64

UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT

DESIGN DAB	DATE 8/1/91	TITLE Floater-A	
DRAWN KJM		QTY 1	DRAWING NO. SHRP(APS)SM-A201
APPRV DAB		SCALE 1:1	
RELEASE		SIZE B	SHT	PROJECT SHRP PROGRAM

REVISION						
LTR	ZONE	DESCRIPTION	DATE	DRWN	APP
A		INITIAL RELEASE	8/91	KJM	DAB



SECTION A–A

NOTES: UNLESS OTHERWISE SPECIFIED
1) BREAK ALL SHARP EDGES

ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
1		ø4.080x.225	6061–T6	1

PART LIST

UNLESS OTHERWISE NOTED:
TOLERANCES
.XX ±.01 ANGLES ±0.5°
.XXX ±.005 64√

UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT

TITLE Floater-B

DESIGN DAB	DATE 8/1/91		
DRAWN KJM		QTY 1	DRAWING NO. SHRP(APS)SM-A202
APPRV DAB		SCALE 1:1	
RELEASE		SIZE B	SHT	PROJECT SHRP PROGRAM