DESIGN OF A TWO AXIS PRECISION GIMBAL

by

JAMES THORNE

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ABSTRACT

A two axis gimbal of 1 arc minute pointing and tracking accuracy was designed and constructed to be integrated into the engineering model (EM) of the Middeck Active Control Experiment (MACE). An A.B. Jones computational bearing analysis program and CAEDS finite element analysis were used in the design of the gimbal structure in order to meet a structural frequency bandwidth of 140 Hz. A tolerance study was performed on the design, and geometric tolerancing was used to insure proper alignment and assembly. A test plan was formulated to determine the performance of the completed gimbal, and a controls simulation was initiated in order to validate proper operation of the gimbal and optimize its performance by aiding in the design of a controller.

The MACE project is designed to study the behavior of structures that utilize active control to modify their dynamics and whose structural characteristics change between the 1-g and 0-g environments. MACE is a scaled down version of a large space structure, consisting of passive and active structural elements, an inertial platform, and two rate gyroscope payloads which are each manipulated using a two axis gimbal. The MACE EM serves as a development model for the flight hardware as well as a ground unit for the actual mission.

The performance requirements for the gimbals were scaled based on actual spacecraft, such as the Earth Observing System (EOS), which have multiple pointing payloads on a large structural bus. The gimbals will serve both as disturbance elements, exciting resonant frequencies in the MACE bus allowing actual performance problems to be analyzed and observed, and as measurements of the ability of active control to improve their performance. The MACE project will yield valuable control structures interaction (CSI) data which will be used in the design of future spacecraft which will require use of CSI technology to meet their mission objectives.

Thesis Supervisor: Dr. Edward F. Crawley
Title: Professor of Aeronautical and Astronautical Engineering

Dedicated to Ma and Pop.

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1.0 OVERVIEW

The Middeck Active Control Experiment (MACE) is designed to study the behavior of structures that utilize active control to modify their dynamics and whose structural characteristics change between the 1-g and 0-g environments. Active control involves measuring the dynamics of a system during its operation, in this case the vibration of a structure as its payload tracks to a position, and using that information to increase the system performance. MACE consists of a scaled down version of a large space structure such as the space station. Scaling the dynamics of a large space structure down to a article approximately 1.5 m in length, allows the flight experiment to be stowed along with control electronics in a shuttle middeck locker. This is very advantageous in terms of cost, design time and complexity over larger full scale experiments that would be performed in the cargo bay of the shuttle The MACE project will provide NASA with the capability and facility to conduct closed-loop experiments on structures inside the space shuttle middeck. These experiments will yield valuable scientific data which can be used by NASA in the design of future spacecraft that will require the use of Controlled Structures Technology (CST) to meet their mission objectives. The MACE Engineering Model (EM), which is presently being constructed, will demonstrate the feasibility of the MACE project as well as providing a ground unit for the actual shuttle launch. The MACE EM will also serve as a CST testbed for future research in the Space Engineering Research Center (SERC) at MIT.

The MACE EM test platform will consist of passive and active structural elements, an inertial platform, and two pointing and tracking payloads, see Figure 1-1. This modular structure is joined together using multidirectional nodes which allow the structure to be be configured in several orientations shown in figures 1-2, 1-3 and 1-4. This enables a number of structural control cases to be examined.

Since the engineering model will be in 1-g, suspension of the bus is required; this is acheived with a zero-g suspension system from CSA Engineering Inc. The suspension system consists of three pneumatic actuators, which support the weight of the test article and electronic closed loop control, which provides a low frequency restoring force. This frequency is low enough as to not interact with the resonant modes of the MACE bus.

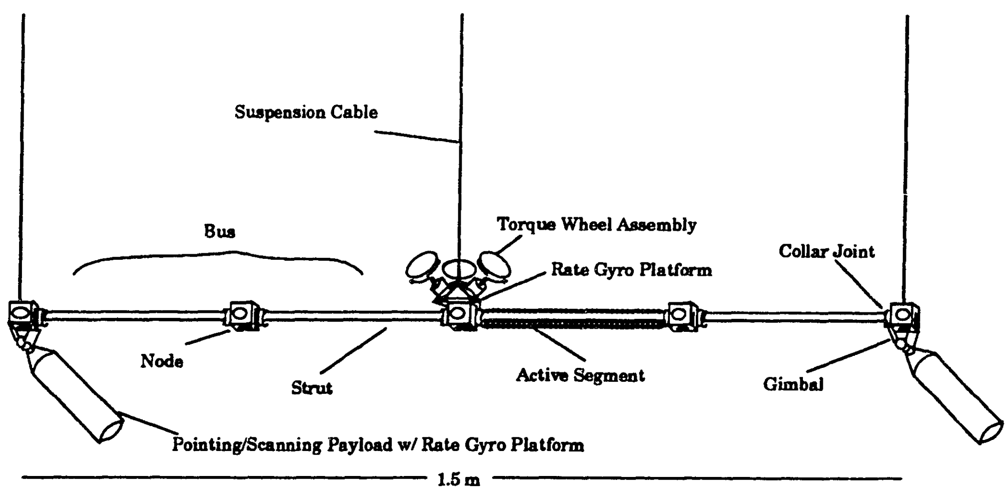


Figure 1-1 MACE engineering model platform.

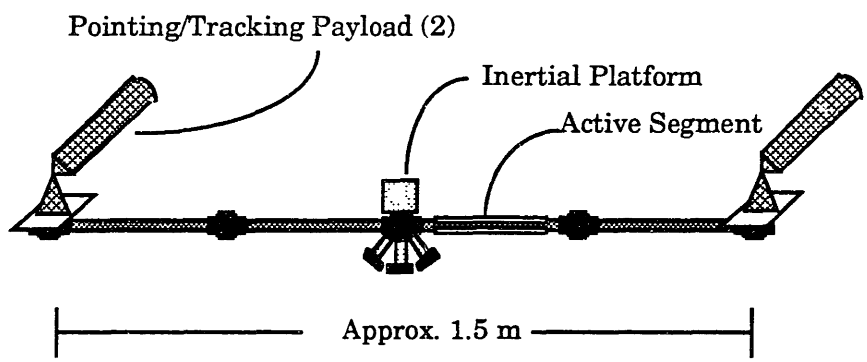


Figure 1-2 Standard MACE configuration.

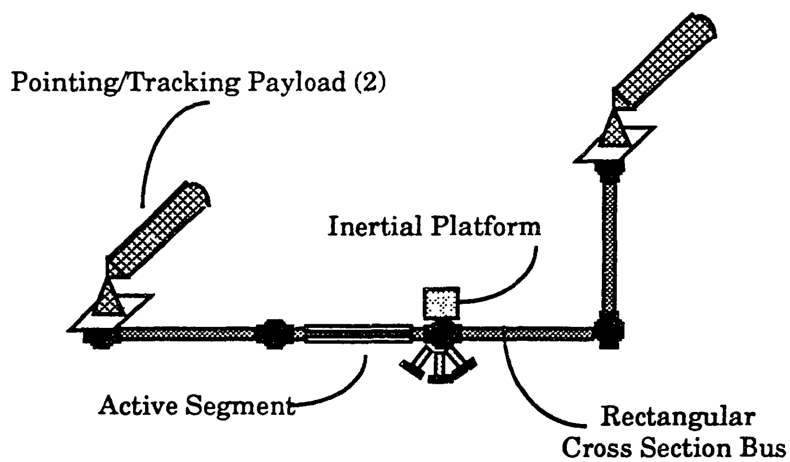


Figure 1-3 Three dimensional MACE configuration.

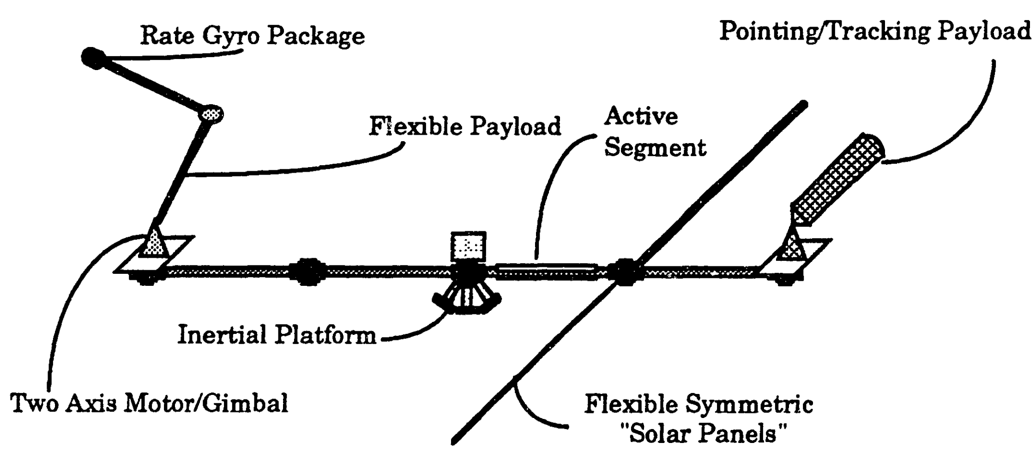


Figure 1-4 MACE configuration with flexible appendages.

2.0 FUNCTIONAL REQUIREMENTS

Attached on either end of the EM bus are the pointing and tracking payloads which are manipulated by two dual axis gimbals. The gimbals interface to a strut connection node on the MACE structural bus, and point a five pound payload comprised of dead weight and a rate gyroscope package The gimbals serve both as disturbance sources, and as actuators for the payloads. The desired physical and performance requirements for the gimbals are (per axis):

Weight	approx. 10 lbs
Slew Range:	+/- 60°
Slew Speed:	50°/sec
Acceleration:	125°/sec/sec
Pointing Accuracy:	1 arcmin
Pointing Stability	30 arcsec
Max. allowable Jitter	15 arcsec
Tracking Accuracy:	1 arcmin
Pointing Bandwidth:	1-15 Hz
Structural Bandwidth:	140 Hz

These performance parameters were determined by a multiple scaling of actual parameters of spacecraft which have multiple pointing and tracking payloads on a large structural bus. The parameters were scaled such that mass was scaled by 1/1000, distances scaled by 1/10 and both time (frequency) and rotation (strain) were scaled by unity. The advantage of this scaling is that it facilitates the interpretation of MACE performance results (angular position error and stability of the payload), since rotation and rotation rates were unchanged from those of the actual spacecraft.

The missions used for the multiple scaling analysis were the Geosynchronous Platform (GEO), a NASA candidate mission, the Space Infrared Telescope Facility (SIRTF), and the Earth Observing System, EOS-A and EOS-B, a series of six satellites scheduled for launch in 1998. The EOS platforms have a number of gimbaled payloads which scan the earths surface from a polar orbit.

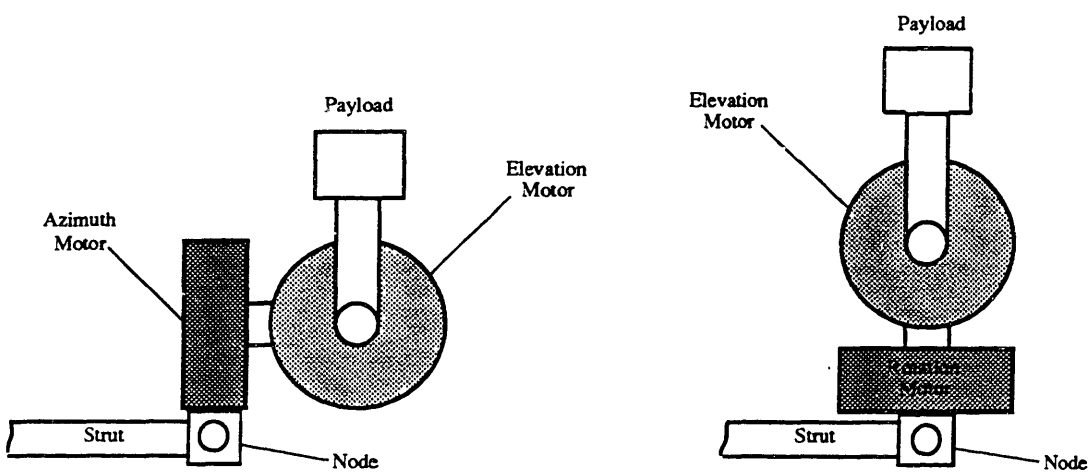
Several requirements were derived from this type of spacecraft which scan the earth from a low earth orbit (LEO) of approximately 300 km, since this yields the most extreme, or stringent performance requirement. For example, in a low earth orbit the earth subtends 120° of view from horizon to horizon, hence the 120° slew range requirement. The speed and acceleration requirements were determined by calculating the scanning rate needed to perform an entire scan of the earth on each orbit. Pointing accuracy, stability, jitter and tracking accuracy were scaled from the performance objectives of the actual missions in order to simulate as closely as possible the "real world" problems encountered by these spacecraft. The pointing bandwidth was specified in order to excite the first nine structural frequency modes of the MACE bus. The structural bandwidth was specified to be approximately one decade above these first nine modes in order to prevent structural interaction between the gimbal structure and the MACE bus.

3.0 DESIGN

3.1 General Gimbal Configuration

Two types of general gimbal configurations were initially considered; elevation/azimuth, and rotation/elevation. These two configurations differ in the relative positioning of the axis of rotation of the drive motors relative to the payload, see Figure 3-1. In an azimuth/elevation configuration, shown in Figure 3-1, the axis of rotation of the drive motors are in a horizontal plane relative to the payload. In a rotation/elevation configuration the axis of rotation of the drive motors are in a vertical plane relative to the payload.

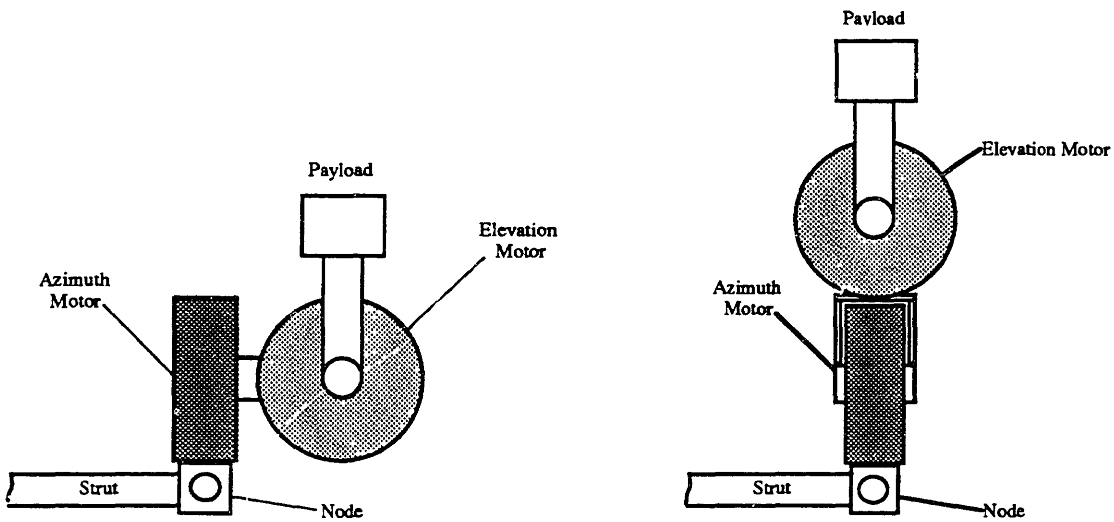
The rotation/elevation configuration was deemed unacceptable because this configuration has the potential for "gimbal lock"; that is, there is a singularity in its operation at the vertical position (more than one combination of elevation and rotation result in a vertical payload) which is difficult to control.



Azimuth/elevation   Rotation/elevation

Figure 3-1 Rotation/elevation and azimuth/elevation gimbal configurations.

Two types of elevation/azimuth configurations shown in Figure 3-2 were then considered; pivot centered (coplaner) and articulated (non-coplaner). The pivot centered configuration was chosen for several reasons; two of the most important being its smaller size and equal loading of the drive motors.



Coplaner Configuration Non-coplaner Configuration

Figure 3-2 Coplaner and non-coplaner elevation/azimuth gimbal configurations.

3.2 Main Component Selection

Major components were selected once the general design configuration was chosen, since the physical aspects of these components would drive the detailed final design. Also availability and lead time (approximately 8 weeks for the motors) were an issue in obtaining these components in order to complete the gimbal on schedule. Component specifications may be seen in Appendix B.

3.2.1 Motors

Unhoused, brushless, samarium cobalt, DC torque motors from Inland Motor Company (model RBE 03000-B50) were chosen as torque sources for the gimbal.

Unhoused motors were chosen since they are considerably smaller and lighter than housed motors and can be integrated directly into the design. Unhoused motors also allow for the specification of bearings which effect gimbal performance.

Brushless type motors, which achieve commutation electronically through the use of hall effect sensors, were chosen over brush type motors for several reasons. Mechanical drag is eliminated in a brushless motor since there are no brushes contacting the rotor, this also leads to a longer operational life since there are no brushes to wear. The armature windings in a brushless motor are on the stator, rather than the rotor as in a brush type motor, this allows for better heat dissipation since the armature windings are in contact with the structure of the gimbal.

Samarium cobalt, or rare earth type, magnets were used instead of ordinary ferrite magnets for their superior magnetic characteristics which allow for the motor to be lighter for the same torque output. Also, since the gimbal requires a relatively high torque at relatively low speeds, torque, or pancake type, motors were chosen. Torque motors have more poles than a standard motor of the same power rating, which enables the motor to produce considerably higher torques.

The motors were sized for continuous operation at the maximum load, when the payload was oriented at 60°. Heat dissipation, not stall torque, at this condition is the limiting factor. Using manufacturer values for the motor TPR, temperature rise per watt of power, and K_m, the motor constant which relates output torque to power input, the power required for the motor was determined.

3.2.2 Amplifiers

Two current control amplifiers (model BCL021810-A00) manufactured by Inland Motor Co. were selected to provide commutation and supply power to the two brushless torque motors. These amplifiers receive command signals from the host computer, and produce a current which is directly proportional to the input voltage. The amplifier power level was matched to the motor torque requirements by the motor manufacturer by determining the peak values of current and voltage encountered during motor operation.

3.2.3 Encoders

Rotary encoders generate an output which represents the rotational shaft position. This output is used to determine the position of the payload relative to the bus structure and as an input to the controller for the gimbal. Canon U.S.A Corp.laser rotary encoders (model R1-0) were chosen for the gimbal position sensors.

There are two main types of rotary encoders, incremental encoders which measure incremental position from an initialized zero position and absolute encoders which measure absolute rotational displacement without the need for an initialization routine. Incremental encoders were chosen since they are, in general, lighter, smaller and less expensive for the same resolution than absolute encoders. Laser type incremental encoders were chosen since they can achieve a greater resolution than that of ordinary L.E.D. incremental encoders.

Most incremental encoders generate two signals to resolve position, usually denoted channel A and channel B, which generate N square wave pulses per revolution. A Z phase channel of 1 pulse per revolution is also produced, which is used for initialization purposes. The output pulses of channel A and channel B are shifted by a quarter cycle as shown in Figure 3-3.

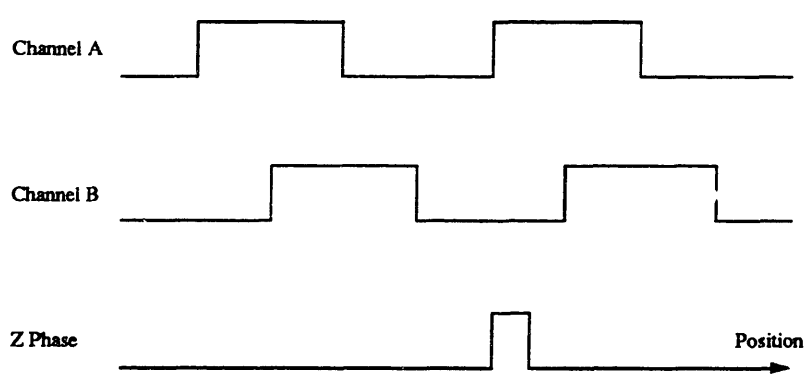


Figure 3-3 Incremental encoder output signals.

This shift enables the controller to determine the direction of rotation by registering which channel "goes up" in voltage first. This shift also increases the resolution of the encoder by dividing the pulse cycle into four quarters, called a quadrature count. Therefore an encoder with N pulses per revolution can actually resolve 4N quadrature counts per revolution.

The resolution of the encoder is chosen such that the position quantization is less than that of the required accuracy, in this case 1 arcmin. Higher resolution also results in smooth operation during slow slewing speeds since the rate of position feedback to the controller is higher. High resolution, however, may limit the maximum speed of the motor if the frequency output of the encoder is higher than the maximum frequency the controller is capable of registering. In this case the controller frequency range was not known, thus the encoder resolution was chosen such that it would just meet the accuracy quantization requirement.

3.3 Major Configuration Design Option

Two types of elevation/azimuth coplaner gimbal design were considered; end-supported and cantilevered (shown in Figure 3-4). These two designs differ by the placement of the bearings relative to the applied load. The cantilever design was advantageous in that it had fewer parts, was easier to assemble and easier to produce due to less stringent tolerance requirements, all of which would result in a quicker and less expensive unit production.

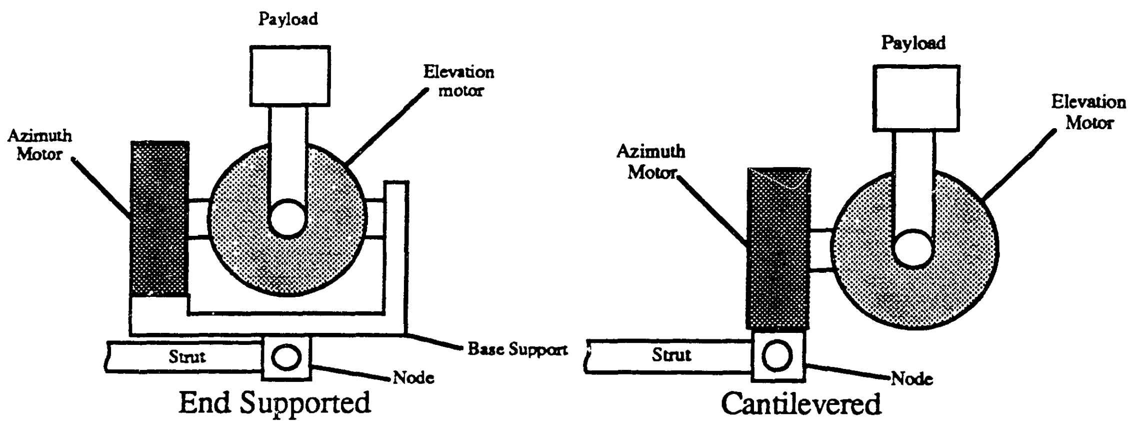


Figure 3-4 End supported and cantilevered elevation/azimuth gimbal configuration.

However, it was desired to keep the first resonant structural frequency of the gimbal at least one decade above the structural frequencies being examined in the MACE bus to keep structural interaction between the bus and the gimbal to a minimum. This corresponded to a desired first resonant structural mode of the gimbal to be 140 Hz or greater. It was not clear if the cantilever design would be stiff enough structurally to meet this requirement since the cantilever design was not as structurally efficient as the end supported design; that is, for an equivalent mass the structure of the cantilever design would be less rigid and consequently have a lower first resonant frequency than the end supported design. Also, it was evident that the bearings would yield a lower equivalent stiffness in a cantilever load configuration, than in a axially loaded configuration.

It was evident that a bearing analysis was required in order to determine the feasibility of the cantilevered design. The bearings were the limiting element in the structure, since the structure could be made stiffer through redesign whereas the bearings could not. By assuming that the structure was perfectly rigid and analyzing the bearings as a structural element it would be possible to determine their first resonant frequency.

3.3.1 Bearing Structural Frequency Analysis

Parameters of arbitrary bearings which applied to the loading case were used to obtain a first order approximation of the first resonant frequency of the bearing. The steps in the bearing structural analysis were as follows:

1. Estimated the worst case load on the bearings, for cantilever and end supported cases due to slewing of a five lb payload at a radius, r, relative to the axial pivot, at the maximum acceleration rate of 125°/sec/sec. This estimate was obtained by using the configurations of the payload mass relative to the bearings shown in figures 3-5 and 3-6. Using relations 3-1 thru 3-5, the axial force, F_{axial}, and the radial force, F_{radial} were determined..Where a_t and a_r are the tangential and radial accelerations due to the desired slewing acceleration, α, and slewing velocity, ω.

$$a_t = \alpha r \quad (3\text{-}1)$$

$$a_r = \omega^2 r \quad (3\text{-}2)$$

$$F_{axial} = ma_t \quad (3\text{-}3)$$

$$F_{radial} = ma_r + mg \quad (3\text{-}4)$$

$$M = (F_{radial})\ell \quad (3\text{-}5)$$

The moment, M, present on the bearings was determined by multiplying the radial force by the offset, ℓ. In the end supported case, since the mass is centered between the bearings,there is no applied moment

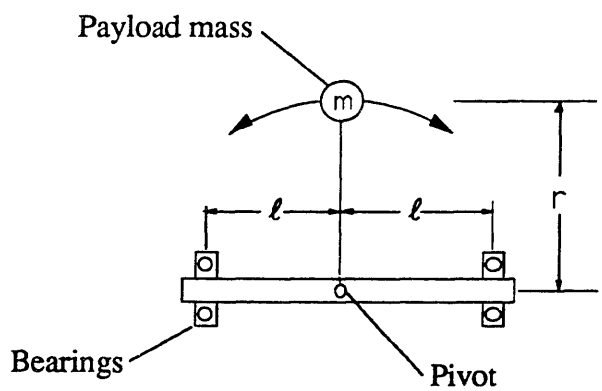


Figure 3-5 Load case for end supported configuration.

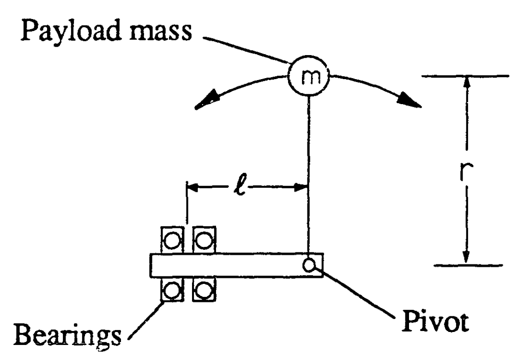


Figure 3-6 Load case for cantilever configuration.

2. A computational bearing analysis program (see Appendix C for explanation and detailed results) using the results of the dynamic loading analysis was employed to determine an equivalent elastic modulus, E, for the bearings.

3. Used the value of E obtained from the computational program along with the bearing configurations shown in figures 3-7 and 3-8 to determine the equivalent stiffness, Keq, for the cantilever and end supported designs.

For the analysis the bearings were modeled as springs with stiffness 1/E. Also a perfectly rigid support was assumed in order to isolate the stiffness of the bearings from the flexibility of the gimbal structure. Applying a force balance to the configurations equations 3-6 through 3-10 were obtained.

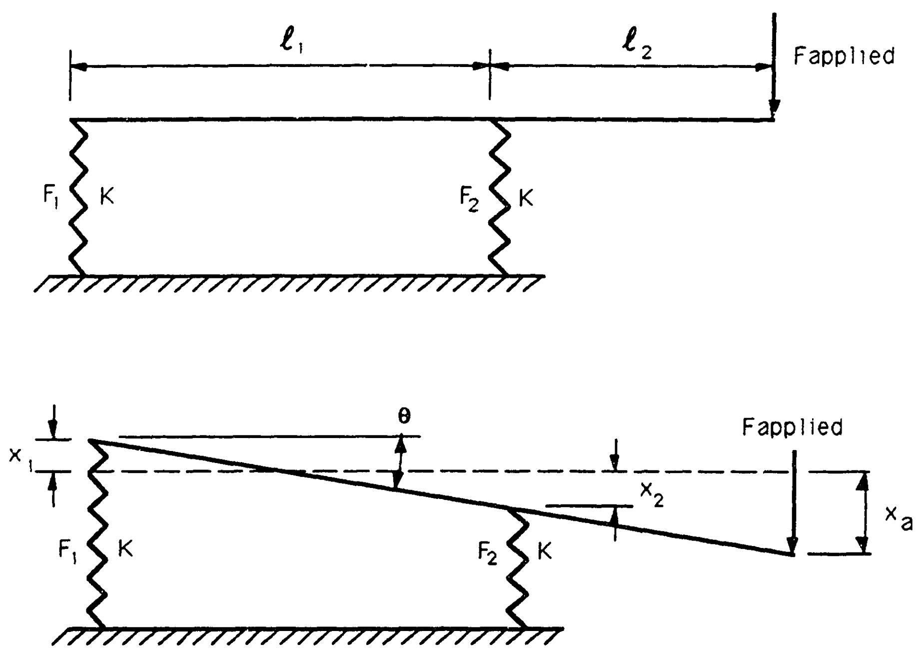


Figure 3-7 Cantilever bearing load schematic.

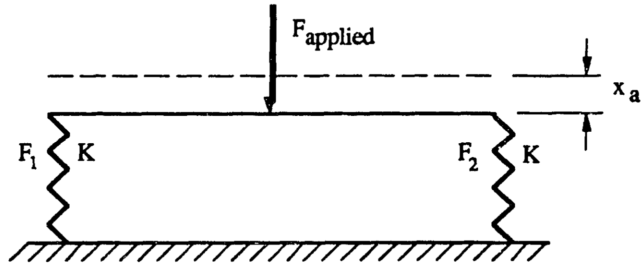


Figure 3-8 End supported bearing load schematic.

$$\sum Fy = F_1 + F_2 = kx_1 + kx_2 = Fapplied \tag{3-6}$$

$$\sum Fx = 0 \tag{3-7}$$

$$\sum Ma = F_2(\ell_1) - Fapplied(\ell_1 + \ell_2) \tag{3-8}$$

$$\tan\theta = \frac{|x_1| + |x_2|}{\ell_1} \tag{3-9}$$

$$Keq = \frac{Fapplied}{xa} \tag{3-10}$$

Where:	$F1$	= load on bearing 1
	$F2$	= load on bearing 2
	k	= 1/E = structural stiffness of individual bearings
	$x1$	= displacement of bearing 1
	$x2$	= displacement of bearing 2
	$\ell 1$	= distance between bearings
	$\ell 2$	= cantilever load offset
	Fapplied	= 1 lb representative applied load
	x_a	= applied displacement

4. Used the equivalent stiffness, K_{eq}, obtained from step 3 ,the mass of the payload, m, and equation 3-11 to obtain a first order approximation of the first resonant frequency of the bearings, ω_n.

$$\omega n = \sqrt{\frac{Keq}{m}} \tag{3-11}$$

From this analysis a first resonant frequency of 44 Hz was obtained for the cantilever design. Since this frequency was well below the 140 Hz requirement , the cantilever design was deemed unacceptable. A first resonant frequency of 571 Hz was obtained for the end supported design which was clearly over the desired frequency of 140 Hz. However, this result was obtained assuming a perfectly rigid structure, consequently the structure was now the limiting element in satisfying the structural frequency requirement.

3.4 Bearing Selection

Once the bearing configuration was finalized actual bearings were selected for size, weight and type requirements. The A.B. Jones software was used to determine the optimal value for the bearing preload, which is achieved with a preload wave spring, which is compressed against either the inner or outer bearing race. Bearing preload must be adequate to keep the bearing races from separating during operation, but also be kept to a minimum since bearing friction increases with axial preload. The bearing analysis also yielded theoretical radial and axial stiffness values which were later used for the finite element model.

3.5 Machined Part Design

Now that all components were specified and the general configuration determined the details of the machined parts could be designed. As with any design there were many considerations and objectives taken into account for each part of the assembly including size and weight, ease of manufacture (which involves time and cost), structural frequency, and assembly with tolerance constraints. These objectives for the general design drove the details of the gimbal part specifications. Since the gimbals would be used in an engineering model, it was advantageous that the gimbal assembly be designed such that disassembly would be possible. Also throughout the design an effort was made to keep machining operations to a minimum and use standards such as ANSI thread and hole sizes wherever possible.

In order to meet the general design objectives many trade-offs and compromises were made in order to satisfy the requirements as closely as possible. The longitudinal slew range was limited to 80°, due to the size of the torque motors and restrictions upon the size, weight and structural frequency of the entire gimbal assembly. Also the desired weight of the gimbal was exceeded primarily due to the size of the motors required to achieve the desired performance and desire to keep machining time and cost to a minimum..

Many additional features were added to the design which were not specified but were obvious that they would be beneficial to the functionality of the gimbal. Hard stops were incorporated into the gimbal which limited rotation to 120° in the transverse direction and 80° in the longitudinal direction to prevent damage to the encoders and wire harness. Stage locks were also integrated into the design, allowing shoulder bolts to be bolted through either stage, locking their rotational motion. This allows the gimbals to be transported safely, and enables it to be used as a fixed mass, or unidirectional excitation source on the structural bus.

3.5.1 Motor Housings and Rotors

The motor housings were designed following manufacturer recommendations in order to assure concentricity of the stator and rotor to .002" (see Appendix A - drawings 101 and 106). Unlike a brush-type DC motor, the stator for a brushless motor contains the armature windings, thus there are no through holes for mounting, as a result of this the stator must be axially clamped. This is accomplished by machining a "pocket" approximately 0.10" less than the width of the stator, see Figure 3-10. An externally bolted ring clamps down on the protruding part of the stator, holding it in place. The dimensions and tolerances for the stator housing and clamp ring were specified by the manufacturer.

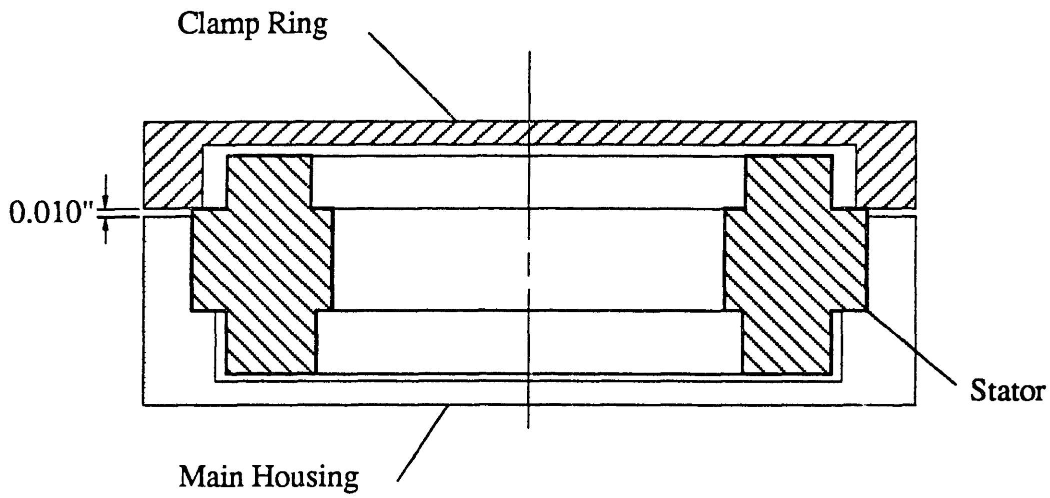


Figure 3-9 Cross section schematic of motor housing.

The rotor for the motor must also be affixed onto the shaft of the assembly the motor is to rotate. There are four possible ways to affix the rotor to the shaft. Bonding the rotor to the shaft is the most common method or a shrink fit can be used. However, both of these methods do not allow for disassembly. Press fitting the rotor is also possible though discouraged since it often results in damage to the rotor. The fourth method, clamping the rotor to the shaft, was chosen since it allows for disassembly and does not require special assembly techniques.

3.5.2 Bearing Housings

The bearing housings were designed as per manufacturer specifications for a sliding fit which allows for expansion and contraction of the gimbal due to temperature changes, see Appendix A - assembly drawing 100. A sliding fit also allows for disassembly and adjustment of bearing preload by adjusting the amount of compression of the preload springs using shim stock.

Concentricity of bearing races on the same shaft is essential for long life and smooth operation. Due to the configuration of the gimbal it was required to mount the bearings in separate parts of the assembly, this presented a problem due to possible tolerance build up between the two parts which would cause misalignment of the bearings. This problem was solved by specifying subassemblies during machining. The two parts containing the bearing mounts were machined to completion except for the bearing mounts, these were "roughed out" to a dimension smaller than that required. The two parts were pinned together in a subassembly (see Appendix A - drawings 123 and 124), then both bearing mounts bored to the correct diameter at the same time, thus ensuring concentricity.

3.5.3 Encoder Mountings

The axial locating shoulders for the encoders were designed using manufacturer ISO (International Standards Organization) specifications, see Appendix A - drawings 105 and 110. The laser encoder shafts, being extremely sensitive to radial and axial loads, must be aligned concentric with the shaft rotation as closely as possible. However, the encoder chosen could only withstand 0.4 kg of radial load and 1.0 kg of axial load, this would require shaft misalignment of 2 μm or less if the encoders were rigidly attached to the gimbal. In order to avoid this stringent tolerance requirement the encoder shafts were attached using flexible couplings, this not only compensates for the radial and axial loads due to misalignment, but also allows for thermal expansion to occur without damage to the encoder.

3.5.4 Structural Analysis of Payload and End Support Structures

A finite element model was developed using CAEDS analysis software to determine the structural frequencies of two parts which were suspected to be structurally limiting in the gimbal assembly. As was the case with the bearings, it was desired that the structural bandwidth of the gimbal be 140 Hz or higher to keep the structural modes approximately one decade above the resonant frequencies of the flexible MACE bus.

The base support (see appendix A - MACE 119) was analyzed by modeling the second stage as a lumped mass connected to the base support by a bearing at either end. The bearings were modeled by an annulus attached radially to spring elements using the radial and axial stiffness values obtained from the bearing analysis.

An undeformed FEA model of the base support, bearings and second stage mass is shown in Figure 3-10. The first three modes for the base support with 0.125" thick stiffening ribs are shown in Figures 3-11, 3-12 and 3-13.Since the first resonant mode of 119.4 Hz was below the desired bandwidth of 140 Hz, the base support was modified by doubling the thickness of the stiffening ribs to 0.25" .The desired bandwidth was achieved with this modification with the first resonant mode shown in figure 3-14 being 141.8 Hz. The next two structural modes of 146.8 Hz and 281.2 Hz for the modified base support with 0.25" ribs are shown in figures 3-15 and 3-16.

Due to time constraints the second stage was modeled independent of the base support model, though it was clear that interaction between the two stages could lower the structural bandwidth. The payload support (see appendix A - drawings 111,112 and 113) was modeled in the second stage since it was determined to be the limiting element. The analysis yielded a first resonant frequency, shown in Figure 3-18, of 146.4 Hz, thus the payload support met the structural bandwidth requirement without modification. The next two modes of 243.3 Hz and 574.3 Hz are shown in figures 3-19 and 3-20.

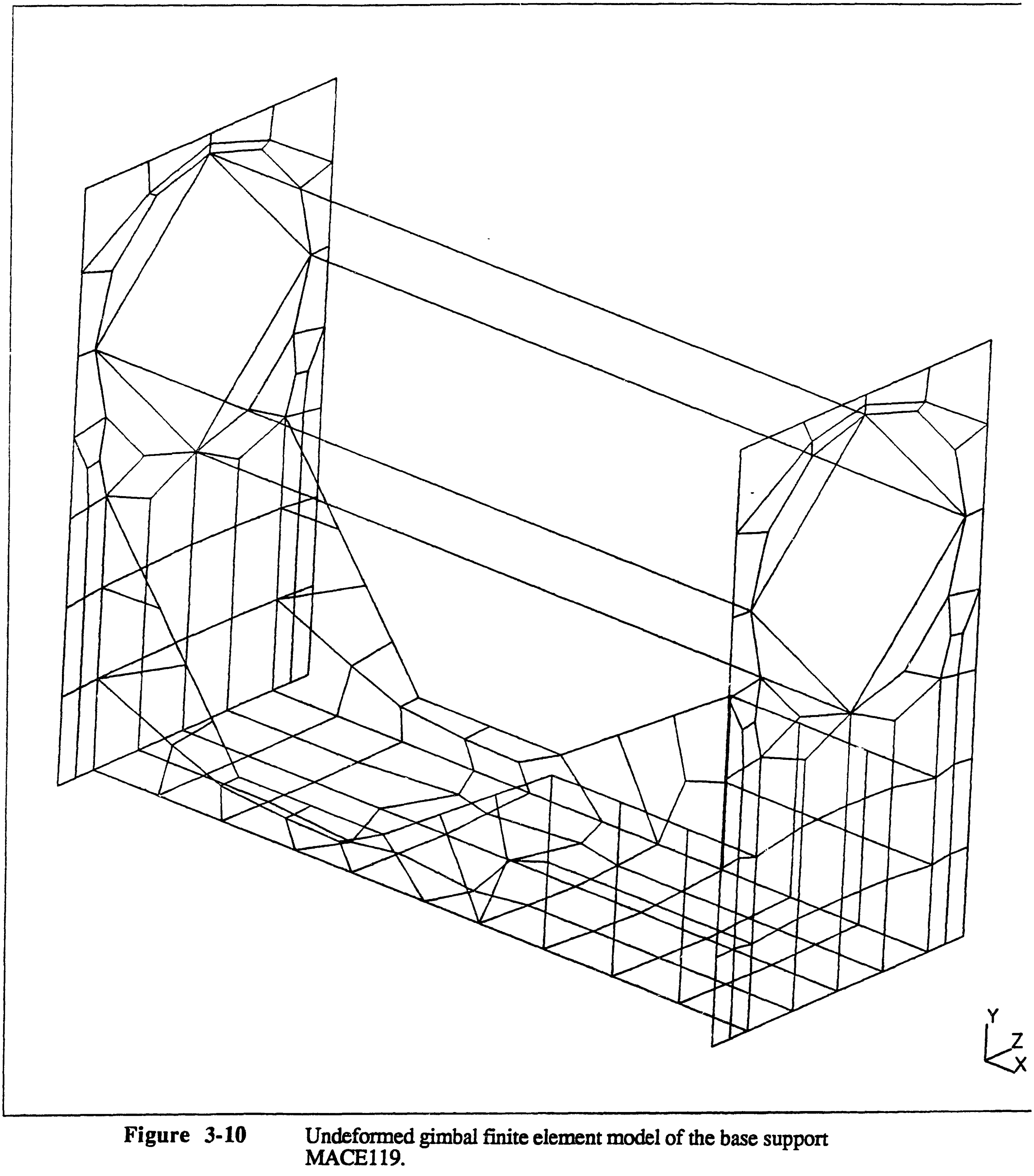


Figure 3-10 Undeformed gimbal finite element model of the base support MACE119.

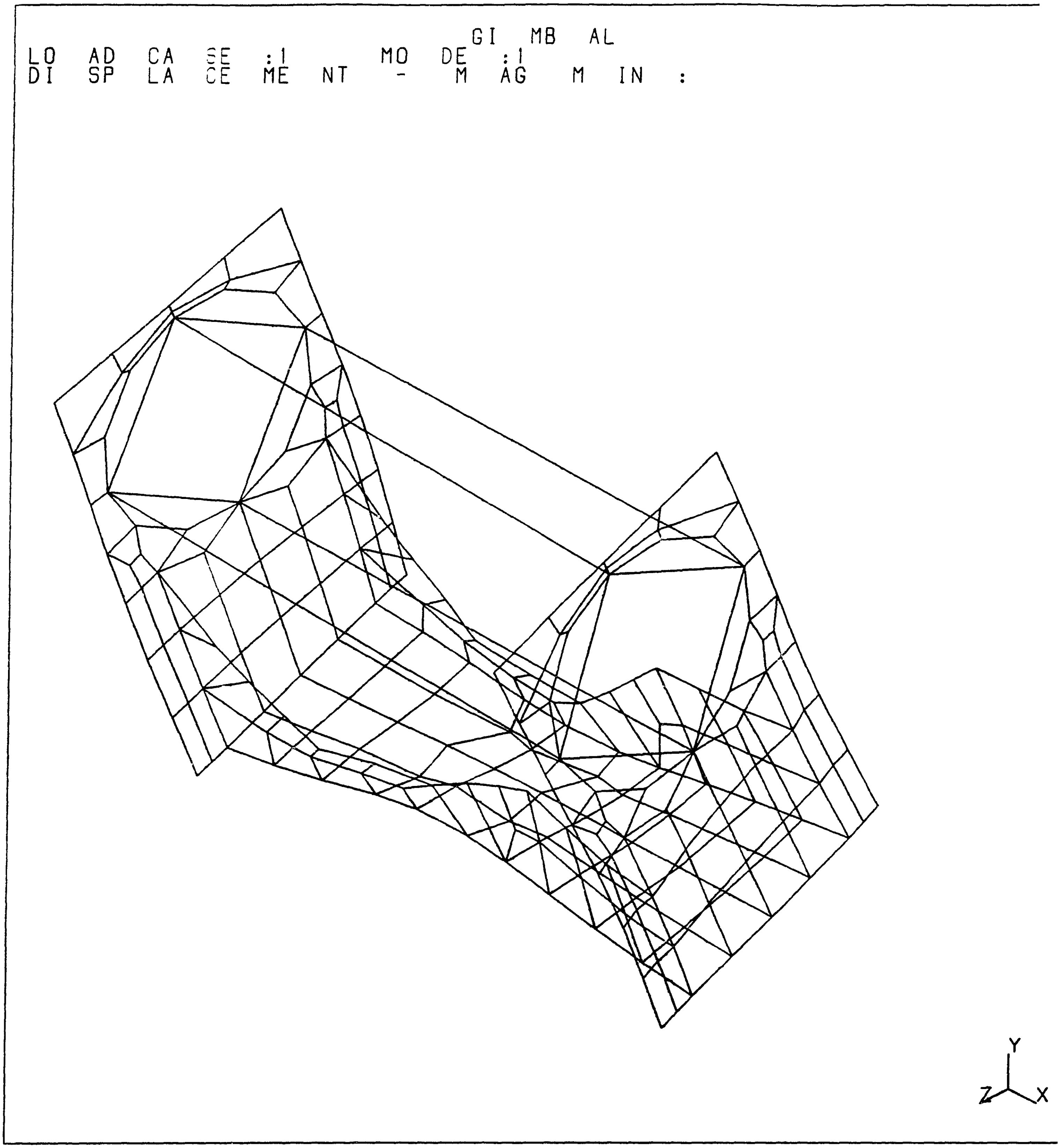


Figure 3-11 First frequency mode of 119.4 Hz for base support model with .125" thick stiffening ribs.

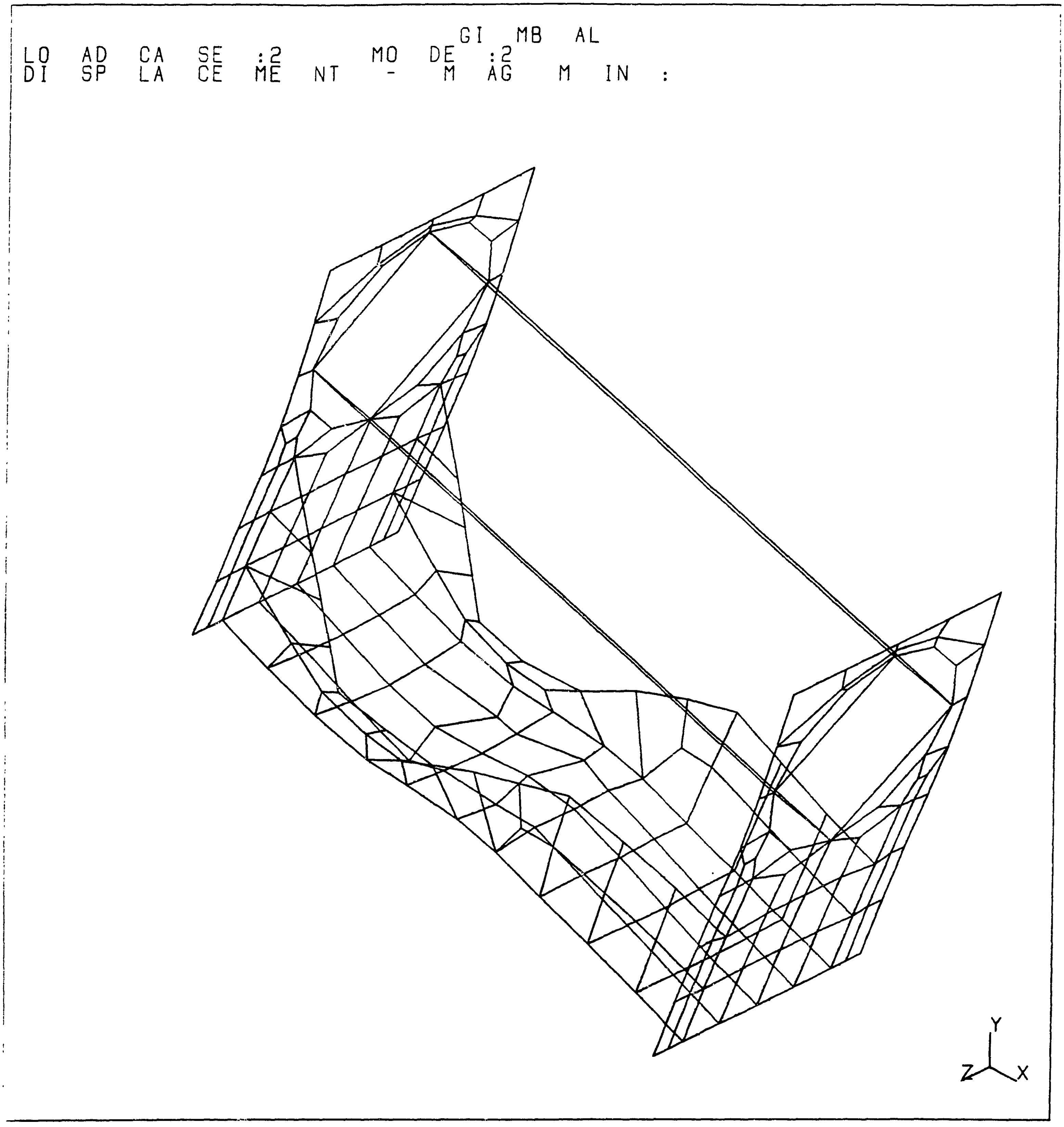


Figure 3-12 Second frequency mode of 120.3 Hz for base support model with .125" thick stiffening ribs.

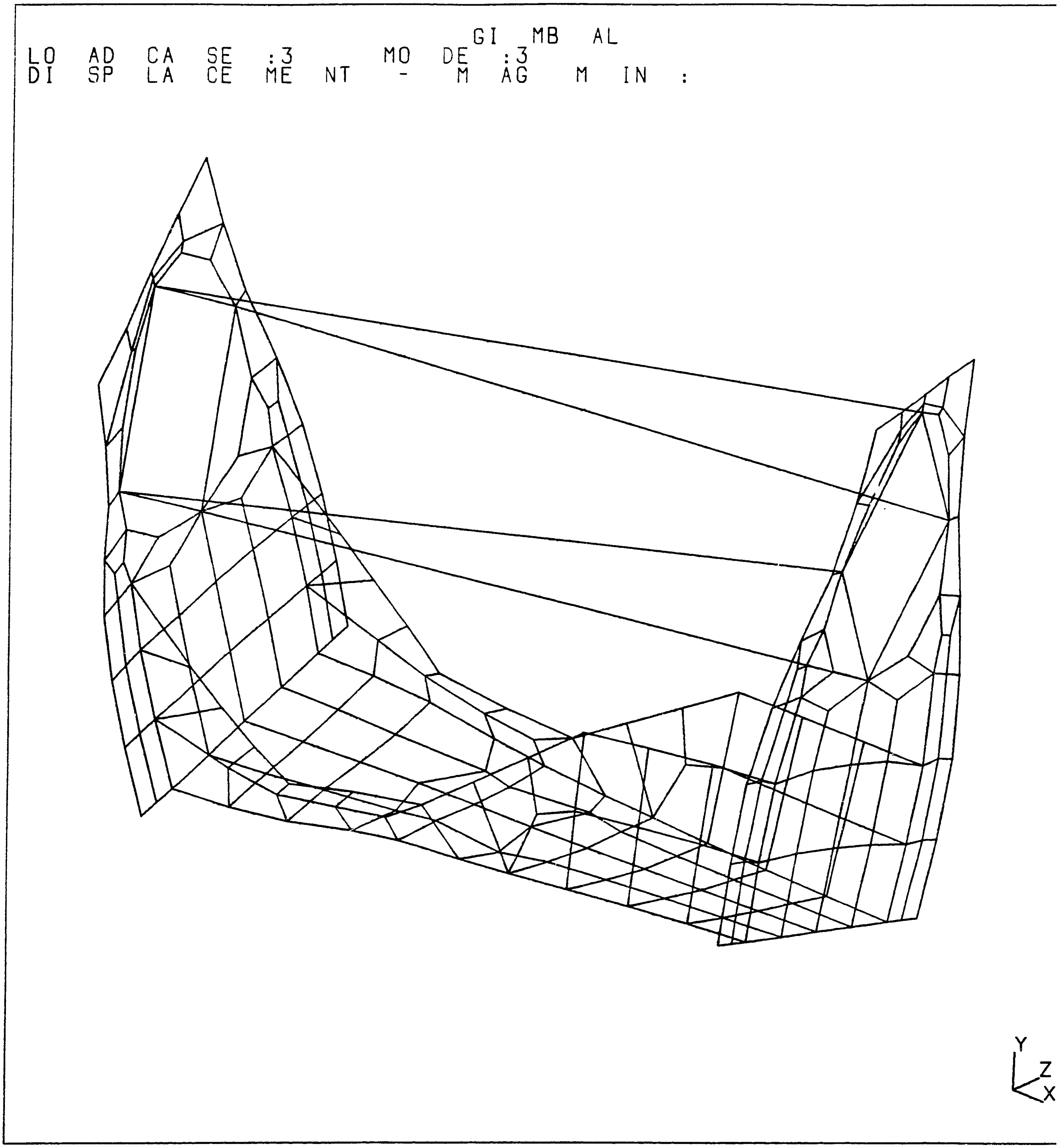


Figure 3-13 Third frequency mode of 262.9 Hz for base support model with .125" thick stiffening ribs.

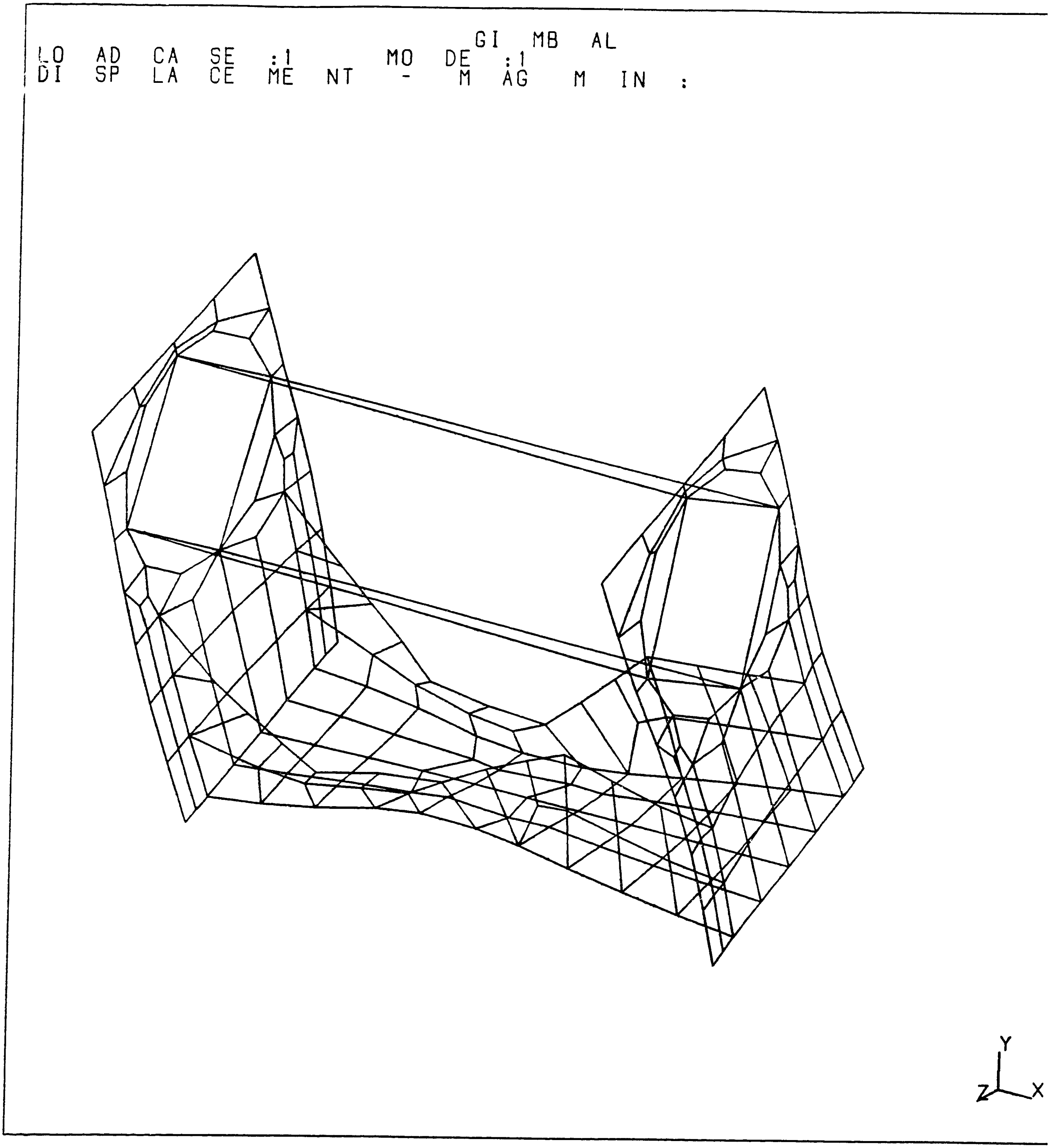


Figure 3-14 First frequency mode of 141.8 Hz for base support model with .25" thick stiffening ribs.

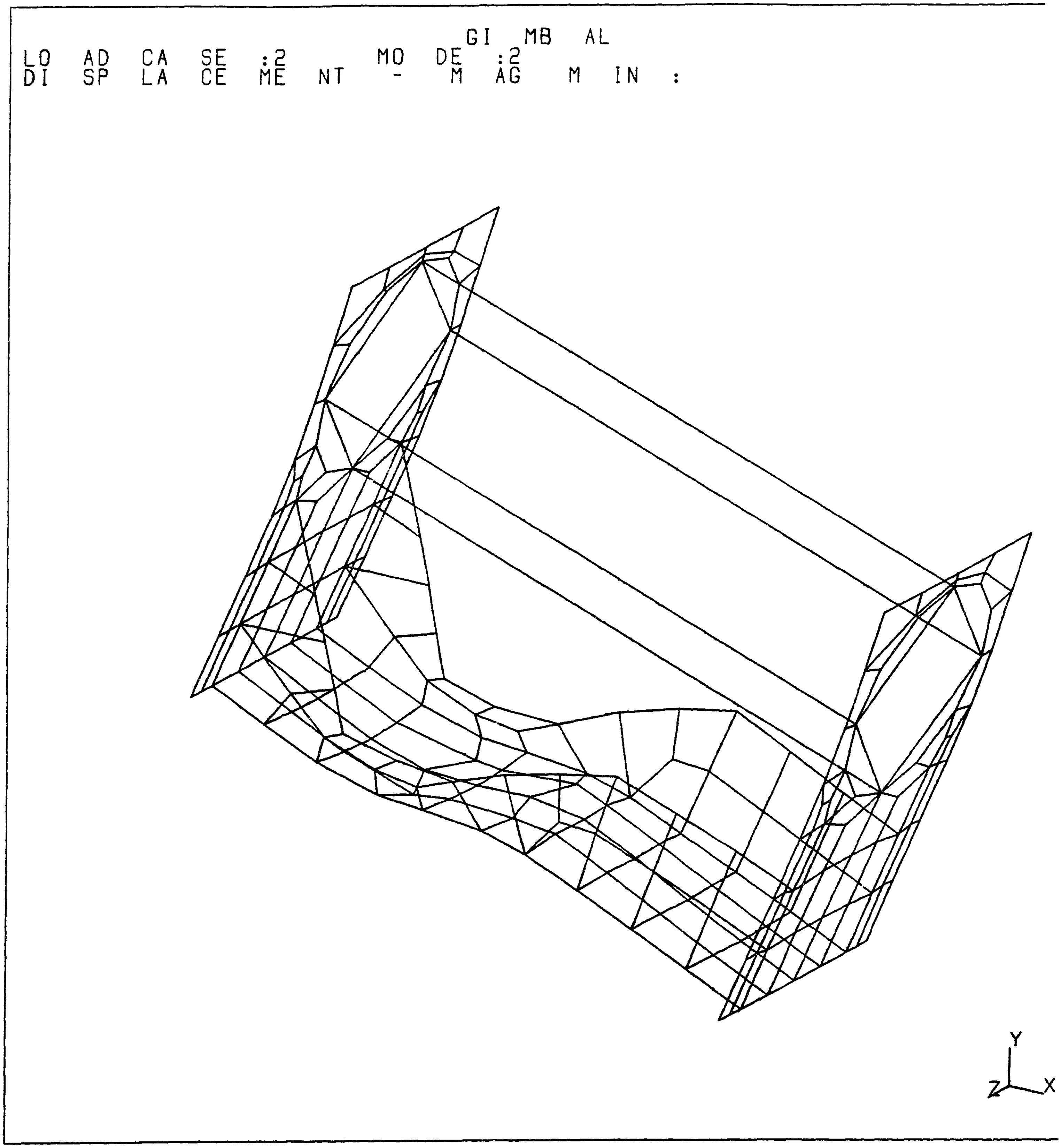


Figure 3-15 Second frequency mode of 146.8 Hz for base support model with .25" thick stiffening ribs.

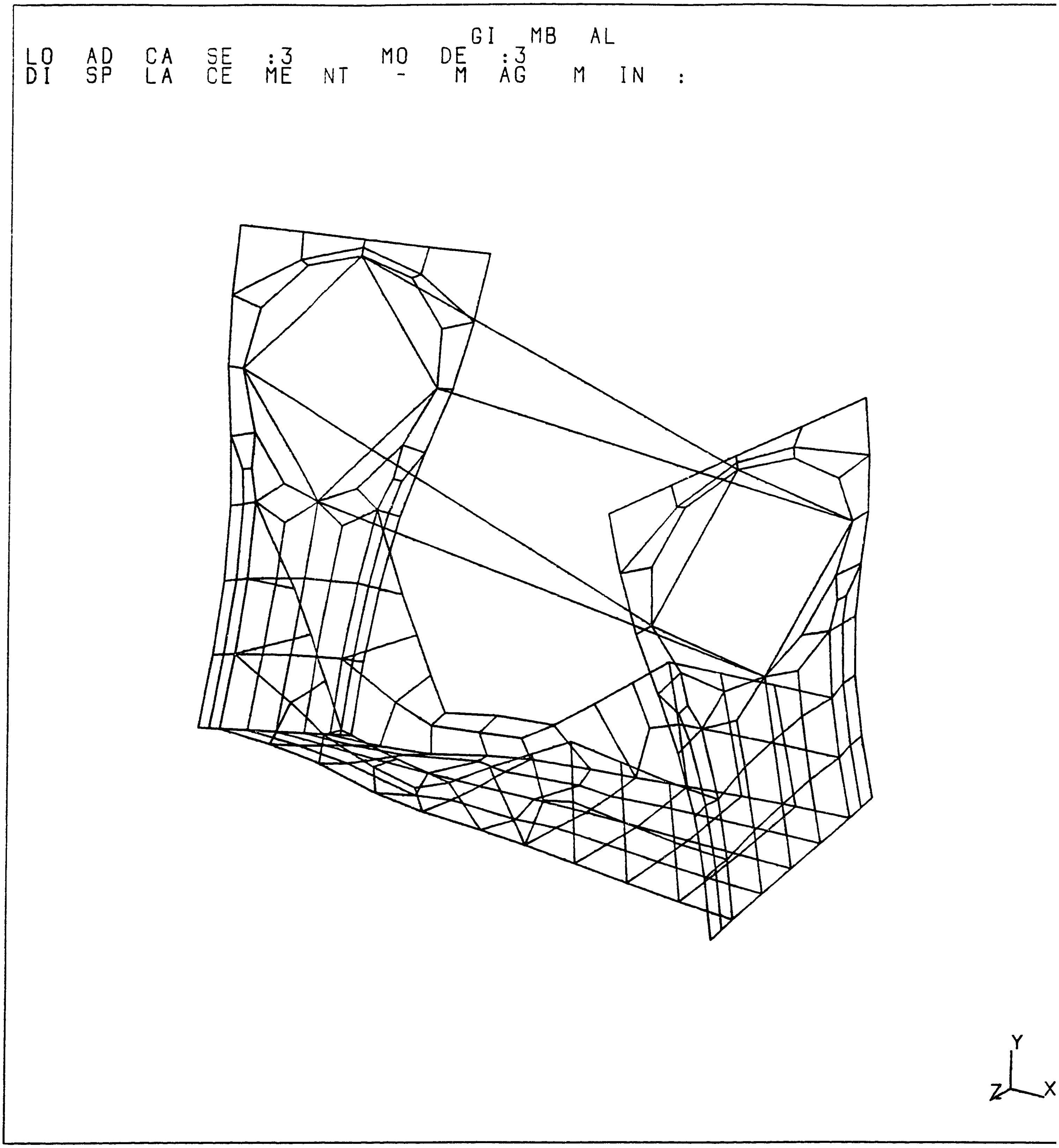


Figure 3-16 Third frequency mode of 281.2 Hz for base support model with .25" thick stiffening ribs.

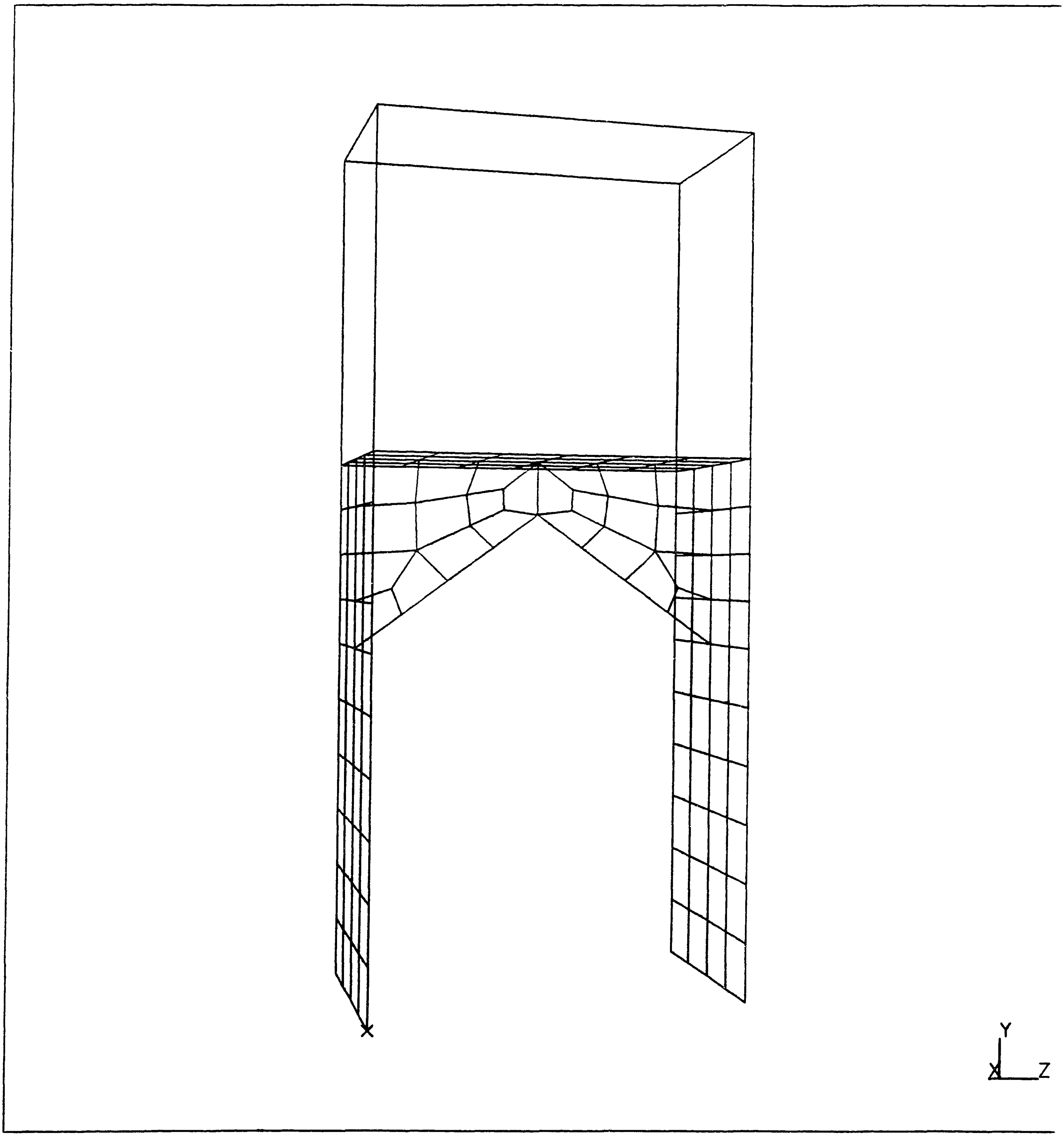


Figure 3-17 Undeformed finite element model of payload support.

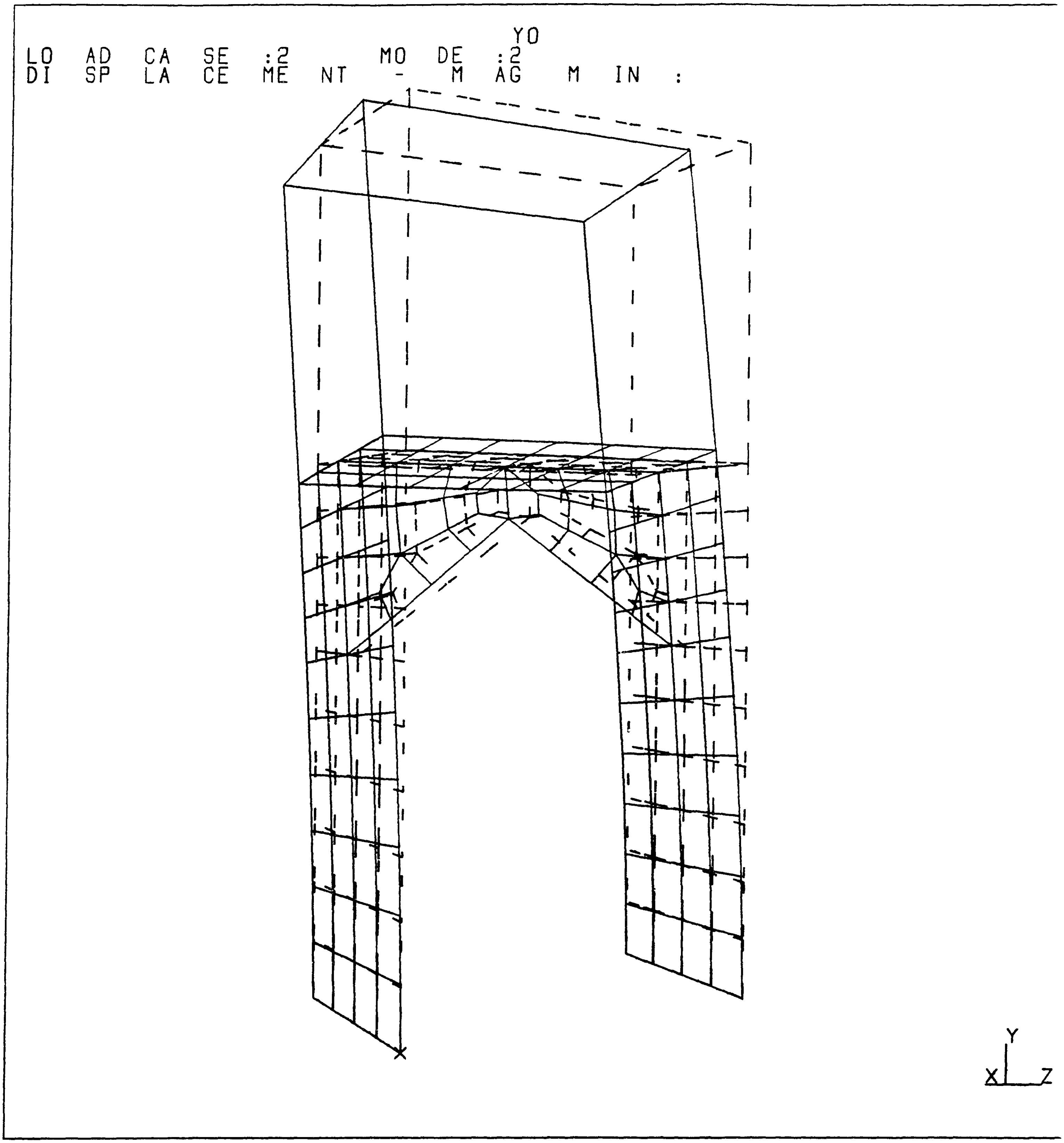


Figure 3-18 First frequency mode of 146.4 Hz for payload support.

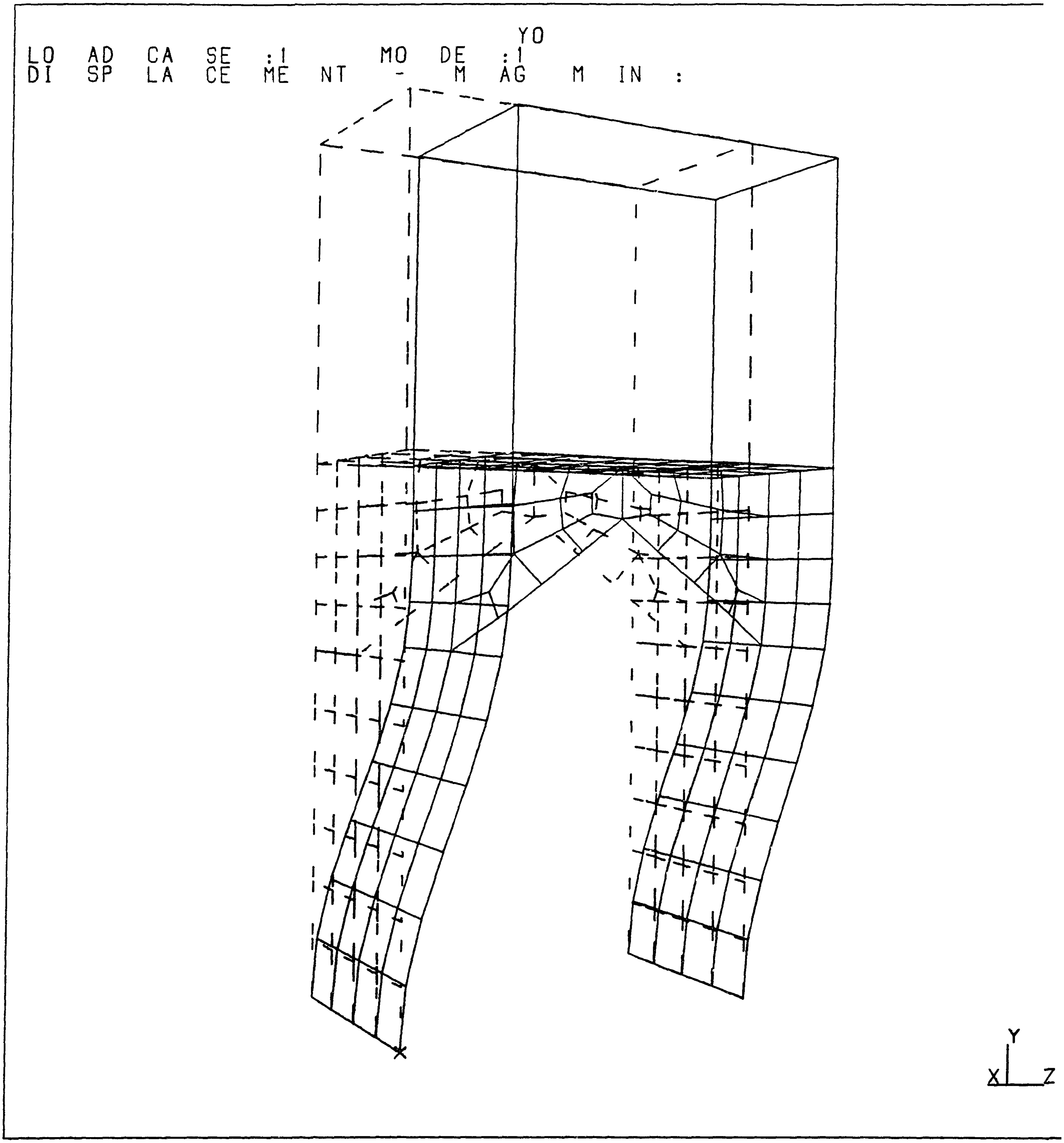


Figure 3-19 Second frequency mode of 243.3 Hz for payload support.

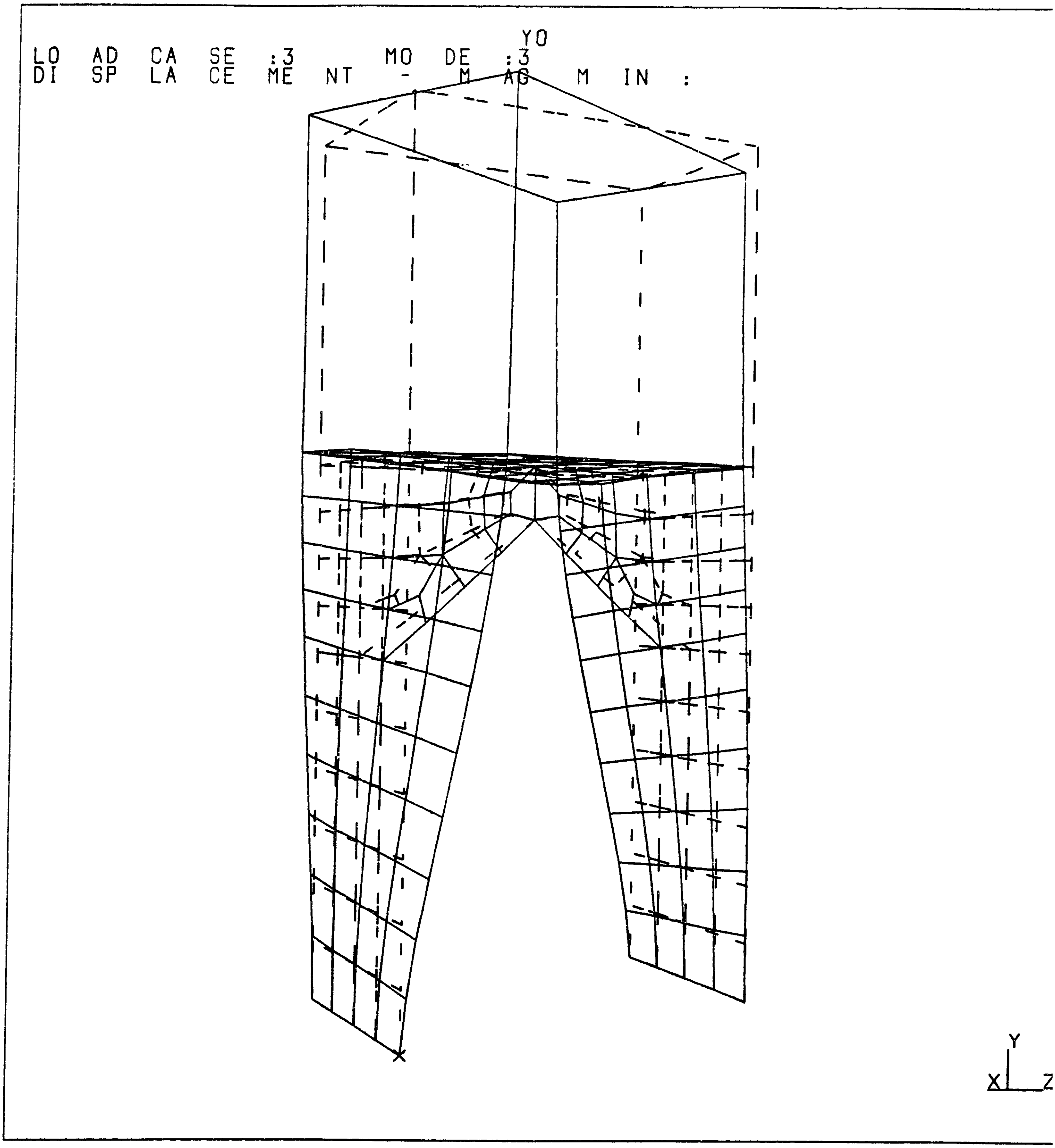


Figure 3-20 Third frequency mode of 574.3 Hz for payload support.

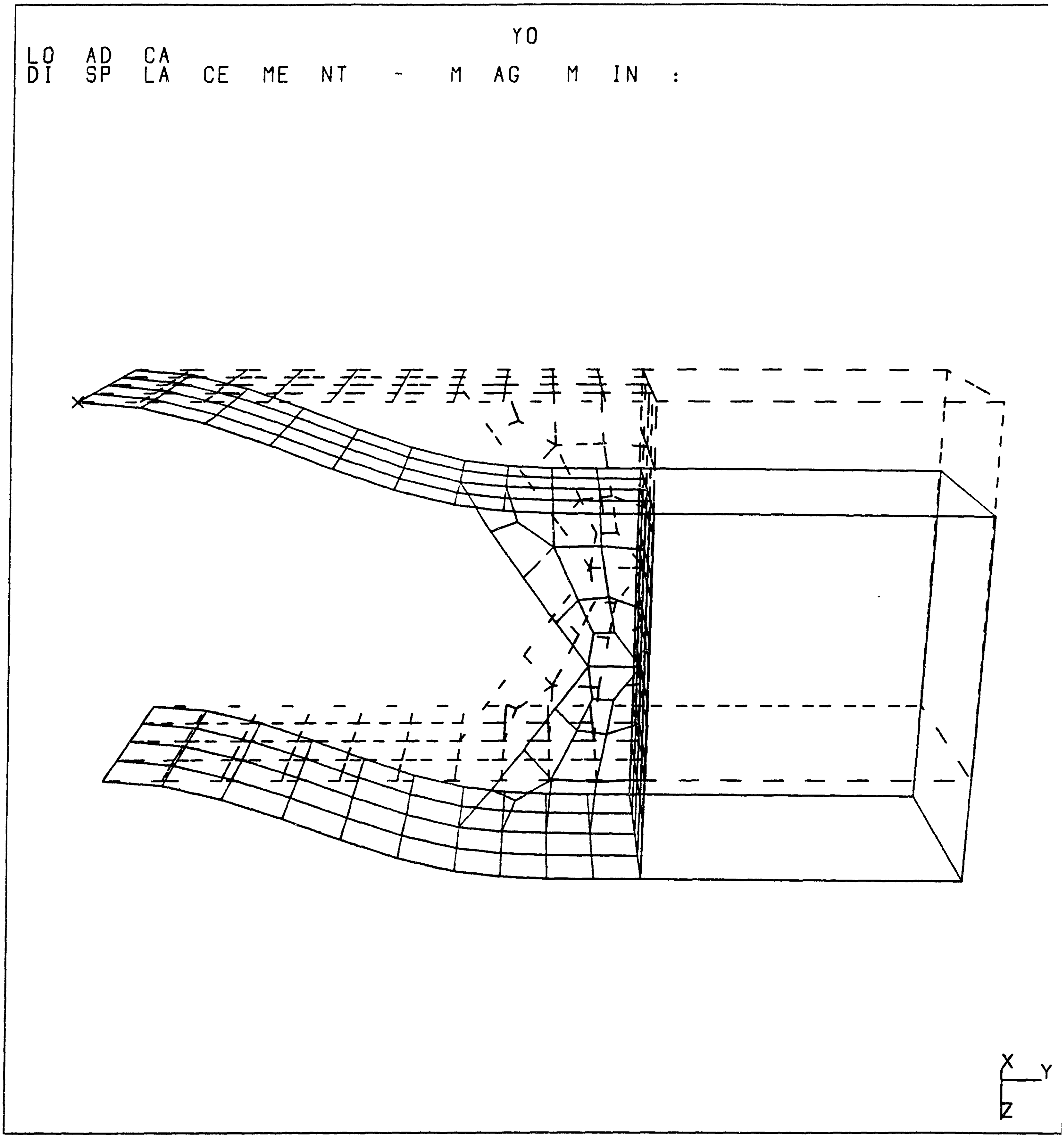


Figure 3-21 Static deflection of 4.6×10^{-3} in. due to worst case dynamic load.

The finite element model for the payload support was also used to determine the deflection due to the worst case dynamic load encountered by the payload support during operation. This result, shown in Figure 3-21, was used to assure adequate clearance between the payload support and the secondary motor housing during operation of the gimbal..

3.5.5 Tolerance Study

A tolerance study was performed to insure proper alignment and assembly of the finished machined parts. Tolerance buildup was examined in areas such as the motor rotors and spacers which had critical alignment requirements and multiple parts that were located with respect to each other. In order to determine tolerance requirements for these assemblies, an arbitrary tolerance was used for the parts and the worst case computed, where all parts were at the maximum or minimum value of the tolerance range. If in the worst case the tolerance build up was unacceptable, that is the parts would not fit or align, then the tolerance was "tightened". Since stringent tolerance requirements correspond to higher production costs, tolerances were chosen to be as "loose" as possible and still meet assembly requirements.

Geometric tolerancing was used throughout the design of the individual parts, as well as for the bearing housing subassemblies shown in Appendix A. Geometric tolerancing involves specifying the maximum allowable variations of a form or its position from a perfect geometry indicated on the drawing. Tolerances may also be locationally referenced to one or more datums, which specify such characteristics as concentricity, parallelism and perpendicularity. Typical geometric forms and locational symbols used in the drawings are shown in Figure 3-22. Supplementary symbols and notations used in the drawings, as well as examples of feature control symbols with datum references are shown in figures 3-23 and 3-24.

○	Roundness	⊥	Perpendicularity	∅	Diameter
—	Straightness	◎	Concentricity	Ⓜ	Maximum material condition
⏥	Flatness	//	Parallelism	BC	Bolt circle
⌭	Cylindricity	⌖	True position		

Figure 3-22 Geometric forms and locational symbols used in geometric tolerancing.

◎ | A | ∅0.050	Concentric to datum A within 0.050 inches
// | A | 0.010	Parallel to datum A within 0.010 inches
⌖ | A | ∅0.050 Ⓜ	Diameter true position to datum A within 0.050 inches at maximum material condition.
1.500 BC	1.500 inch bolt circle

Figure 3-23 Examples of feature control symbols with datum references.

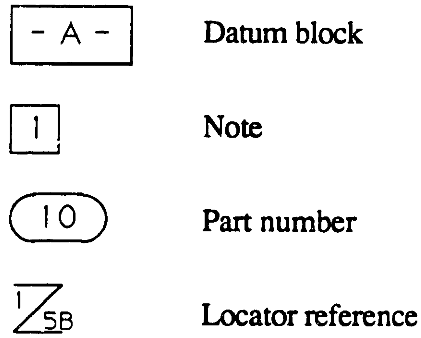


Figure 3-24 Supplementary symbols and notation used in part and assembly drawings.

3.6 Wire Harness Management

For general wire harness routing, tie wraps and integral clamps were used to affix the wires to the gimbal housing. An interesting feature of the wire harness is its ability to pass through the rotary motion of the second stage.

Since the second stage of the gimbal rotates relative to the primary stage, the wires from the second stage motor and encoder of the second stage must have a means of being routed to the stationary primary stage. Devices such as slip rings and other rotary couplings can accomplish this rotary coupling, however these have electronic noise associated with them and are impractical for a large number of wires. A twist-flex arrangement shown in Figure 3-25 (see also Appendix A - page 5 of assembly drawing 100) was chosen for its simplicity and performance. This arrangement allows the second stage to rotate relative to the primary stage as this "fountain" of wires expands and contracts.

Though it is important that the disturbance torque due to the harness is small, it is more important that it be constant, or linear, throughout the slewing range of 120°. Though there is hysterisis type torque associated with the twist flex harness it was designed to stay within the linear region of the hysterisis curve by making the wires bend as little as possible. This is achieved by routing the wires into a fountain type arrangement and then affixing the ends of the fountain to the stationary motor clamp ring of the primary stage.

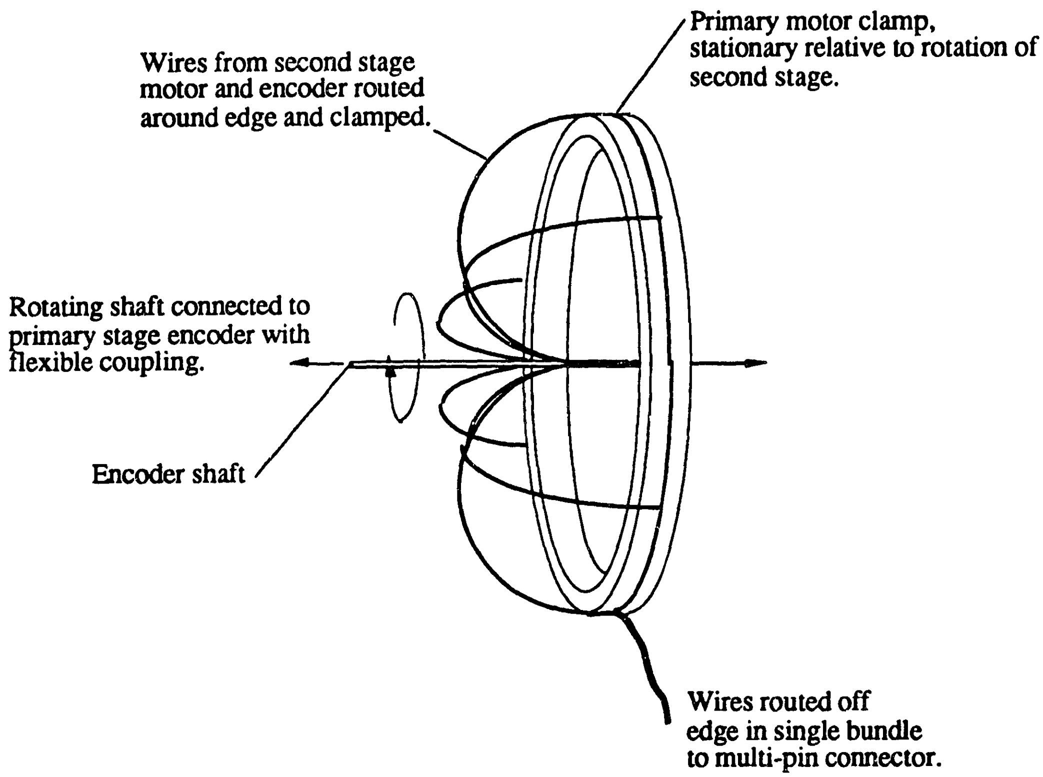


Figure 3-25 Schematic of gimbal wire harness management.

4.0 Gimbal Control and Simulation

The gimbal will be operated and controlled by real time digital computer, which will receive position feed back from the rotary encoders. A general outline of this configuration is shown in Figure 4-1.

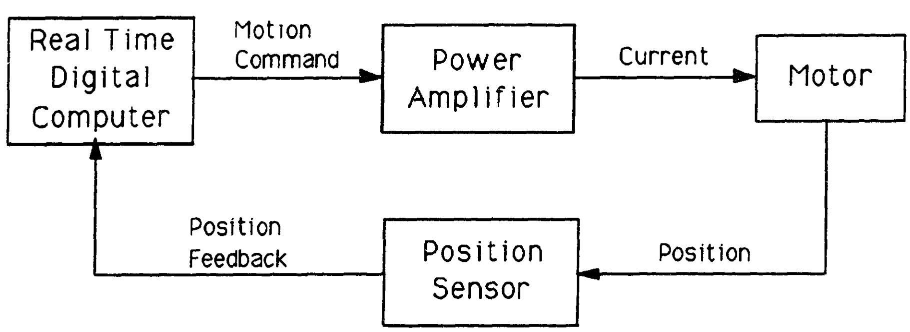


Figure 4-1 General elements in the gimbal control system.

A computational analysis of the gimbal system was initiated using SIMLAB, a control simulation package. Still under development, this analysis will aid in the design of a control model that will be used to program the real time computer to obtain optimal performance from the gimbal. The results of the analysis will also be used to verify the proper operation of the gimbal. Figure 4-2 shows a more detailed schematic of one stage of the preliminary gimbal system model. The cogging torque, damping and back emf of the motors was modeled theoretically, as was the quantization of the encoders, bearing friction and wire harness wind-up torque. Many of these effects were non-linear and at present the validity of the linearization of the SIMLAB model is still questionable. However, preliminary open and closed loop tracking bandwidth bode plots were produced using the linearization algorithm which indicate the gimbal response meets the 15 Hz tracking bandwidth requirement. The phase and magnitude bode plots for the open and closed loop tracking responses for one stage of the gimbal are shown in figures 4-3 and 4-4.

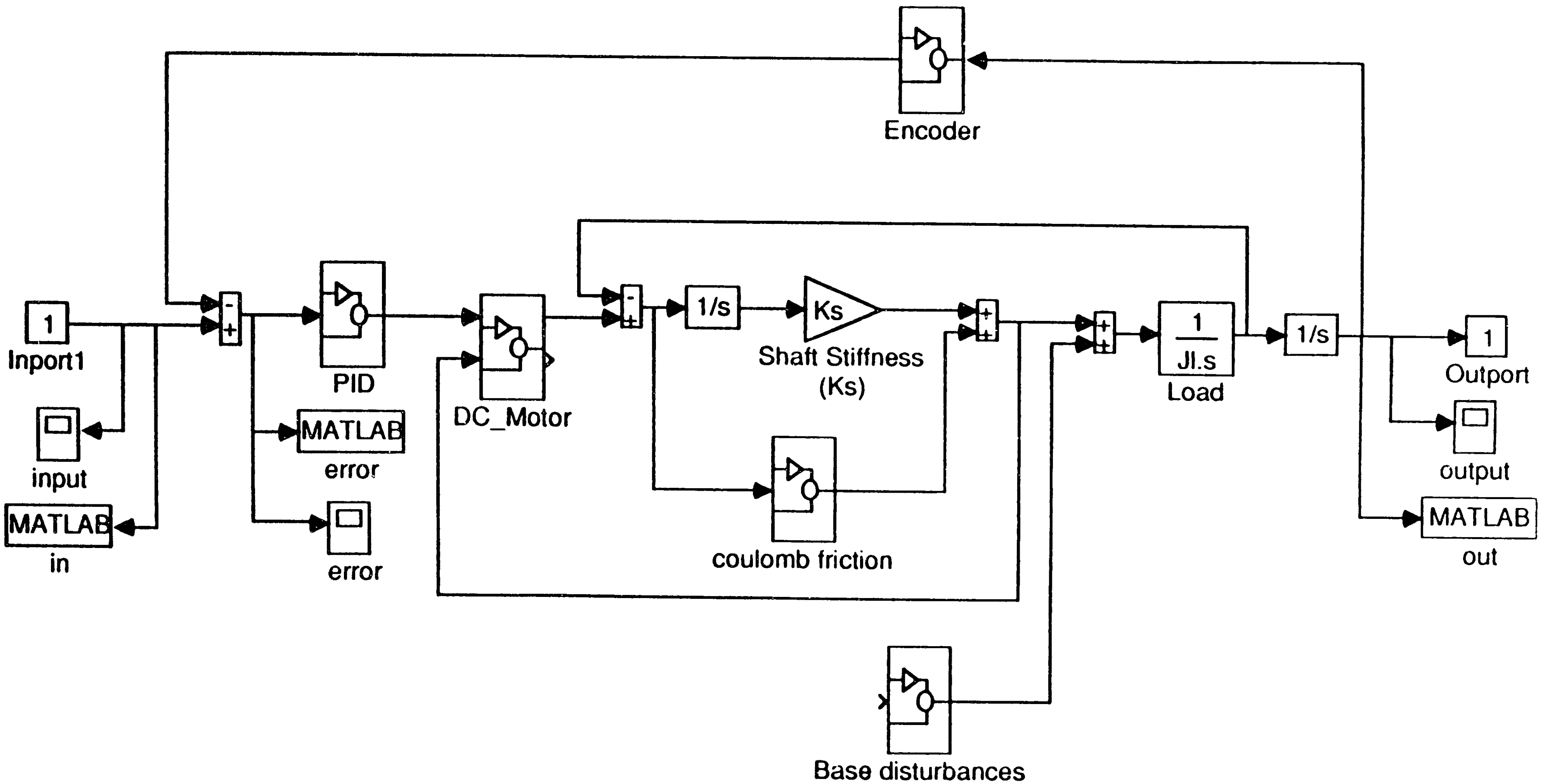


Figure 4-2 Gimbal SIMLAB control schematic for single gimbal stage.

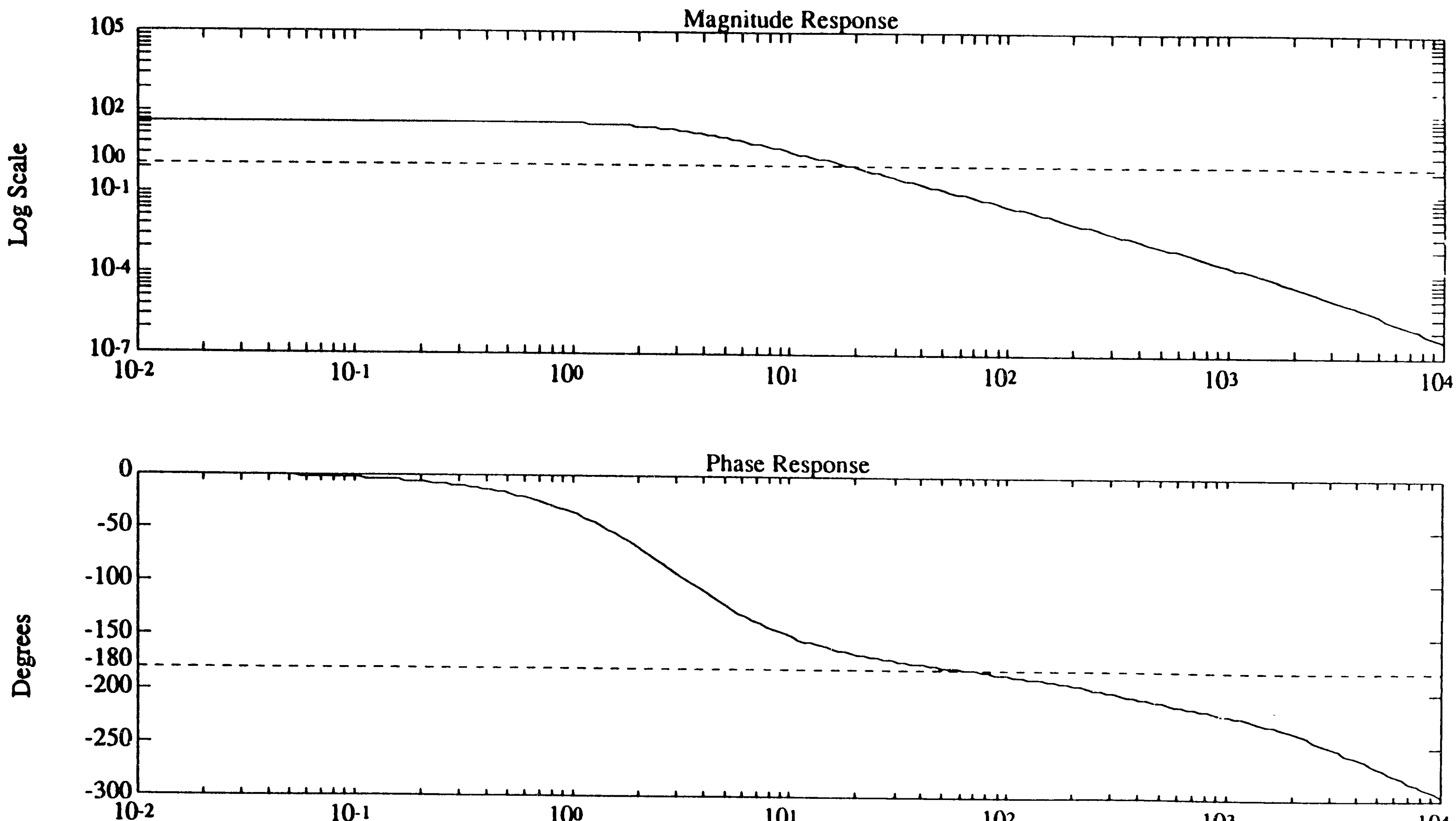


Figure 4-3 Open loop bode plot for SIMLAB control model.

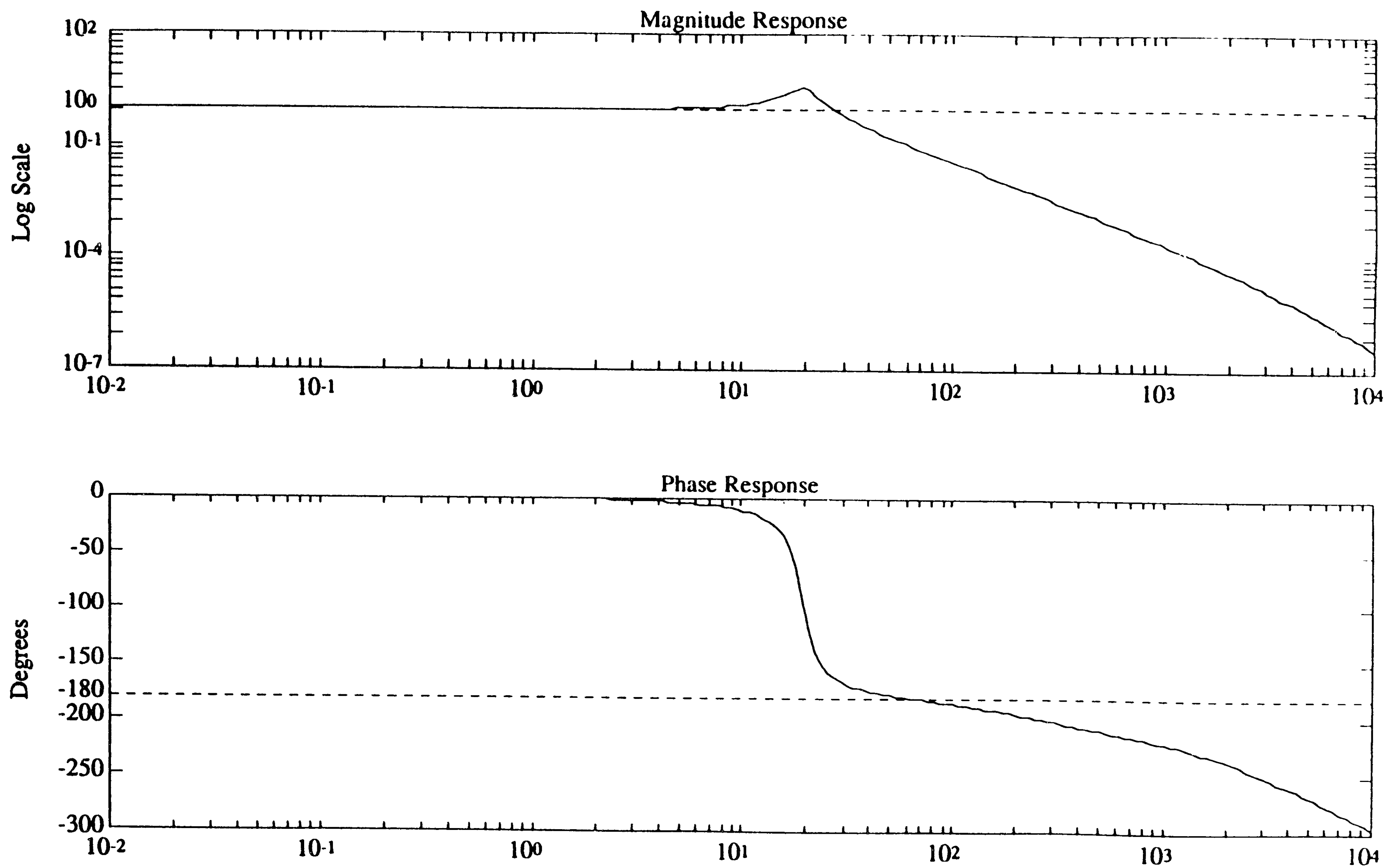


Figure 4-4 Closed loop bode plot for SIMLAB control model.

5.0 TESTING

A test plan was developed to be implemented both during the assembly of the gimbal and after it has been integrated into the MACE EM.

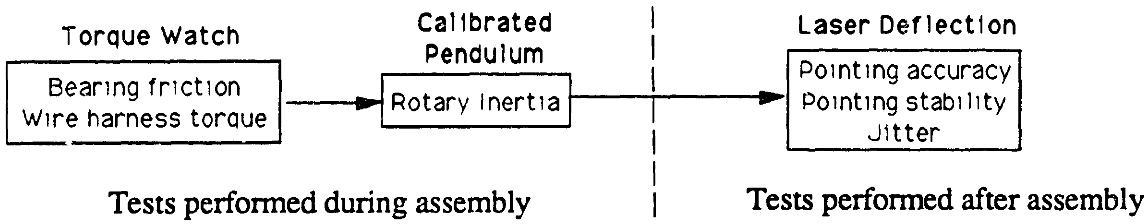


Figure 5-1 Gimbal parameter test plan.

5.1 Bearing Friction - Torque Watch Test

A torque watch will be used to test the bearing friction and wire harness wind-up torque. A torque watch is a manually operated device which is connected to a rotating element and registers the maximum torque as the element is rotated. This test will be implemented during the assembly of the gimbal when it is possible to measure the bearings independent of the other torque parameters such as motor cogging torque.

5.2 Rotary Inertia - Calibrated Pendulum Test

The test apparatus shown in Figure 5-2 will be used to determine the rotary inertia of each of the gimbal stages. The pendulum will first be calibrated by allowing it to swing independent of the gimbal and measuring its swing frequency by timing the period.The rotary inertia of the primary and secondary stage will then be determined by connecting the pendulum to each stage, measuring the new period and using equation 5-1.

$$f_n = \frac{1}{2\pi}\sqrt{\frac{(W)(L)}{I_p + I_g}} \tag{5-1}$$

Where f_n is the natural frequency, W is the total weight of the pendulum, L is the effective arm length to the weight, I_p is the inertia of the pendulum and I_g is the inertia of the gimbal stage being measured.The natural frequency, f_n, is obtained by measuring the damped natural frequency, f_d, using the bearing damping, ζ, obtained from the torque watch and using equation 5-2.

$$f_d = f_n\sqrt{1-\zeta^2} \tag{5-2}$$

5.3 Pointing - Laser Deflection Apparatus

A laser deflection apparatus shown in Figure 5-3 will be used to determine the pointing parameters of the gimbal. By commanding the gimbal to a position and using laser to reflect off a mirror mounted on the payload it will be possible to determine the pointing parameters by placing a target at a relatively far distance away and recording the movement of the laser on the target either by hand or by using photo sensitive paper or film. Definitions of pointing accuracy, jitter and pointing stability are those specified by General Electric for the design of space systems.

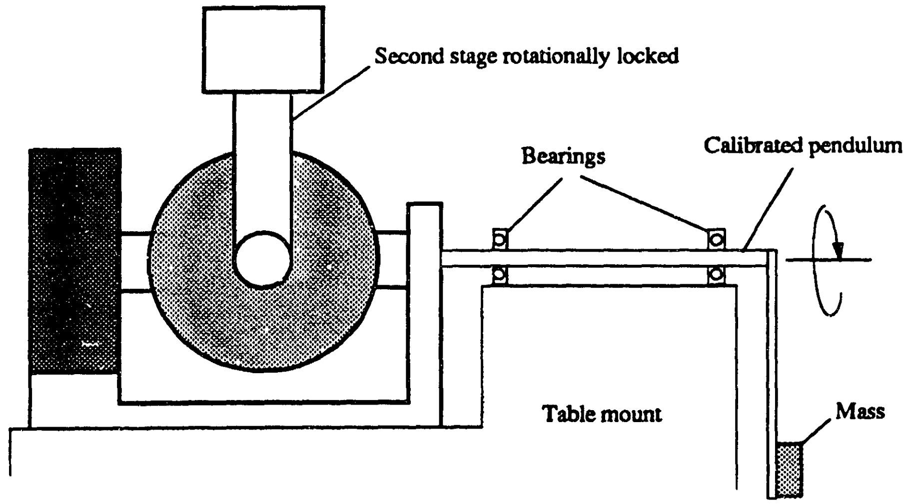


Figure 5-2 Calibrated pendulum test apparatus.

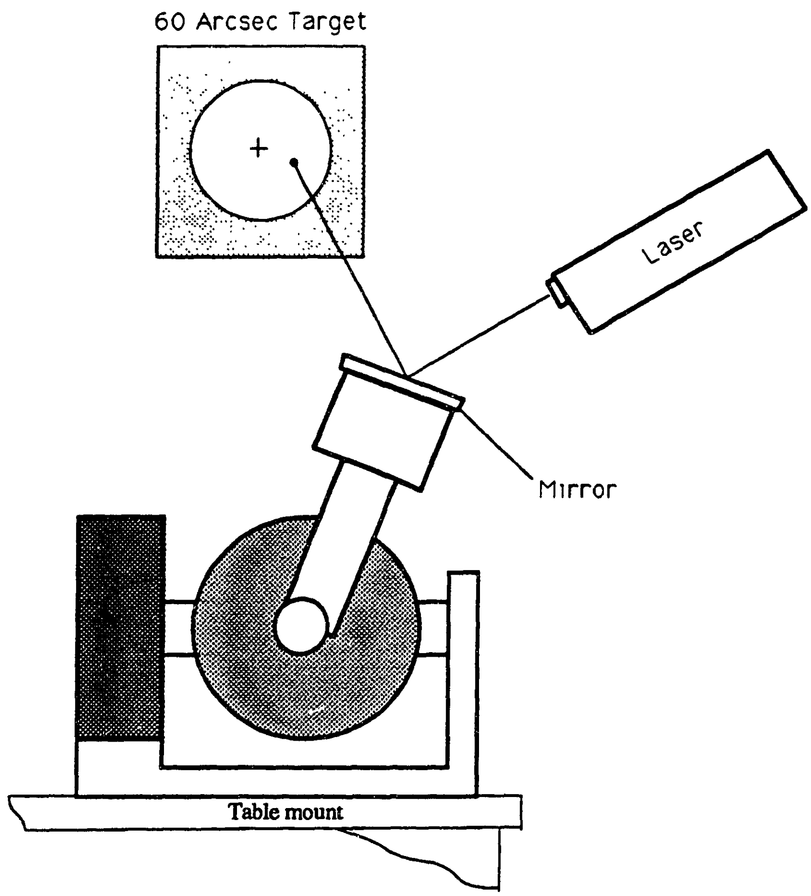


Figure 5-3 Laser deflection test apparatus.

5.4.1 Pointing Accuracy

Using the laser deflection analysis the pointing accuracy can be determined. Pointing accuracy is defined as: the total angle between the actual pointing direction and the desired direction. Graphic representations of this requirement are shown in figures 5-3 and 5-4.

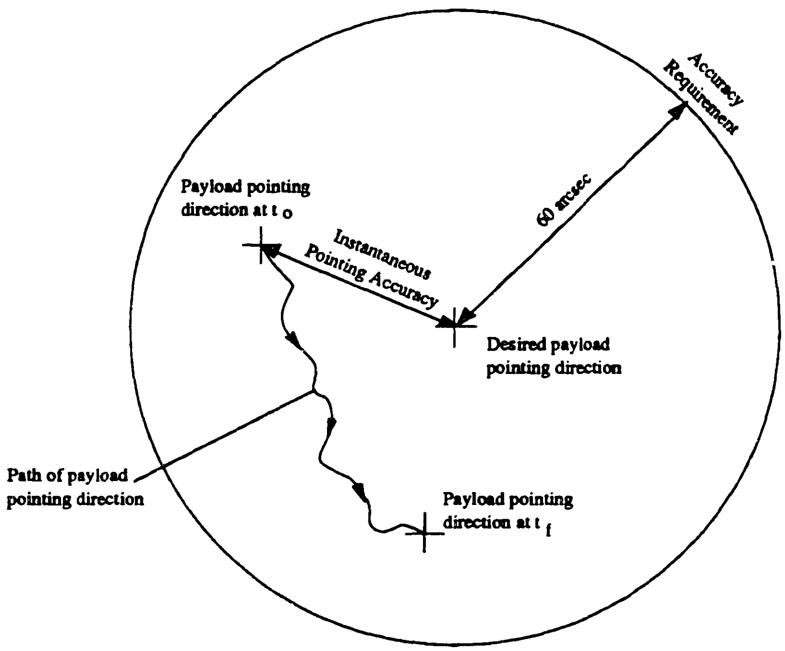


Figure 5-4 Pointing accuracy requirement satisfied.

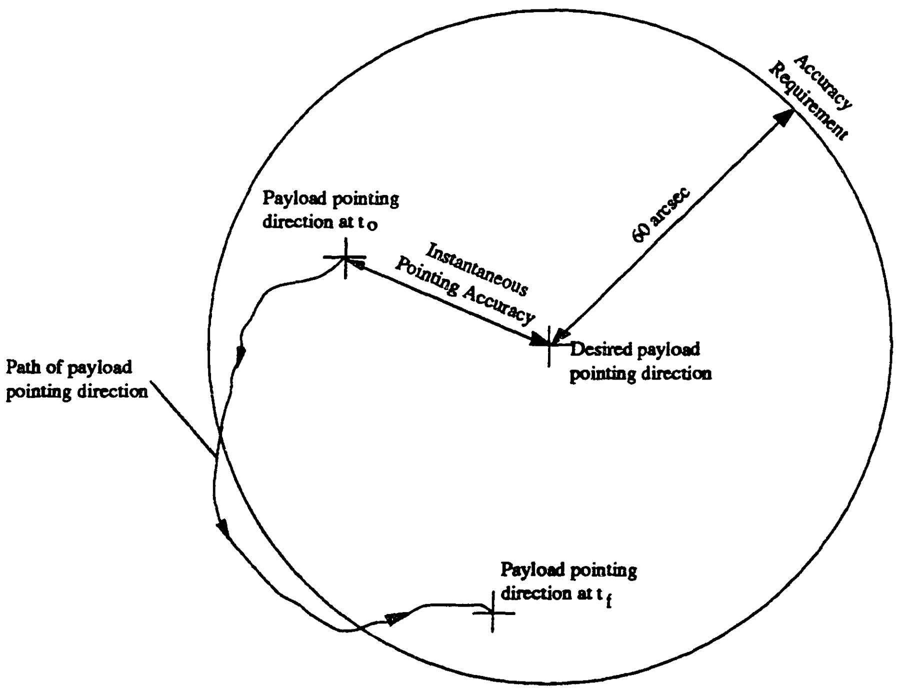


Figure 5-5 Pointing accuracy requirement not satisfied.

5.4.2 Pointing Jitter

Using the laser deflection analysis the jitter of the gimbal can be determined. Jitter is defined as: the peak to peak variation of the total angle between the actual pointing direction and the desired pointing direction over a 1 second interval. Graphic representations of this requirement are shown in figures 5-5 and 5-6.

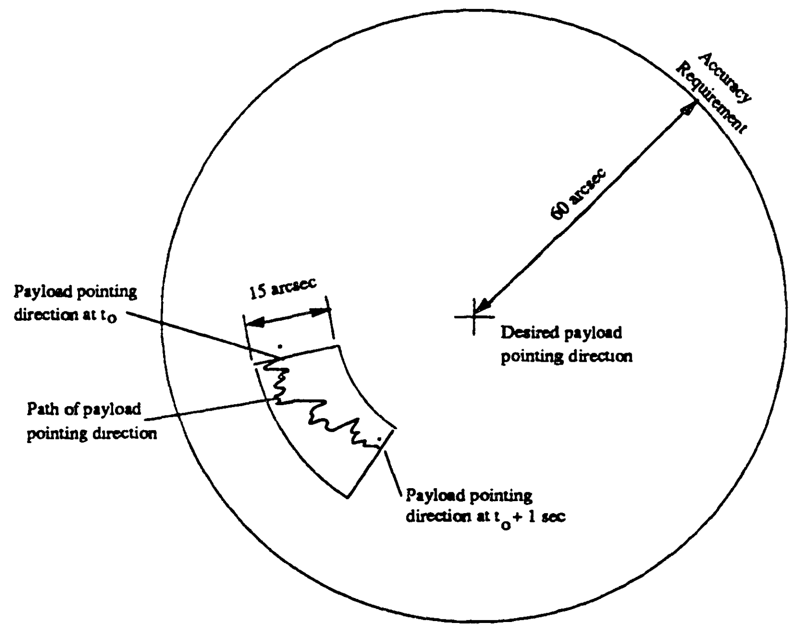


Figure 5-6 Jitter requirement satisfied.

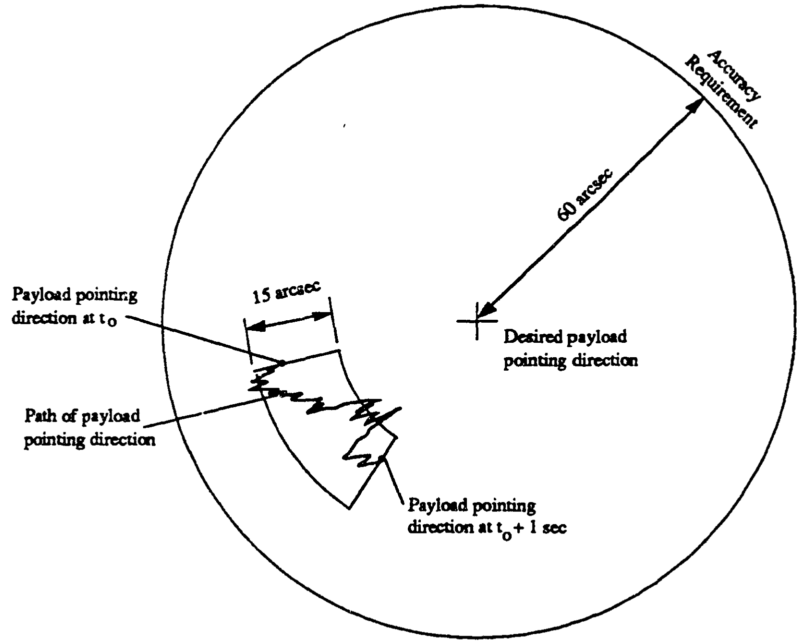


Figure 5-7 Jitter requirement not satisfied.

5.4.3 Pointing Stability

Using the laser deflection analysis the pointing stability of the gimbal can be determined. Pointing stability is defined as: the peak to peak variation of total angle between the actual pointing direction and the desired pointing direction over an 1800 second interval. Graphic representations of this requirement are shown in figures 5-7 and 5-8.

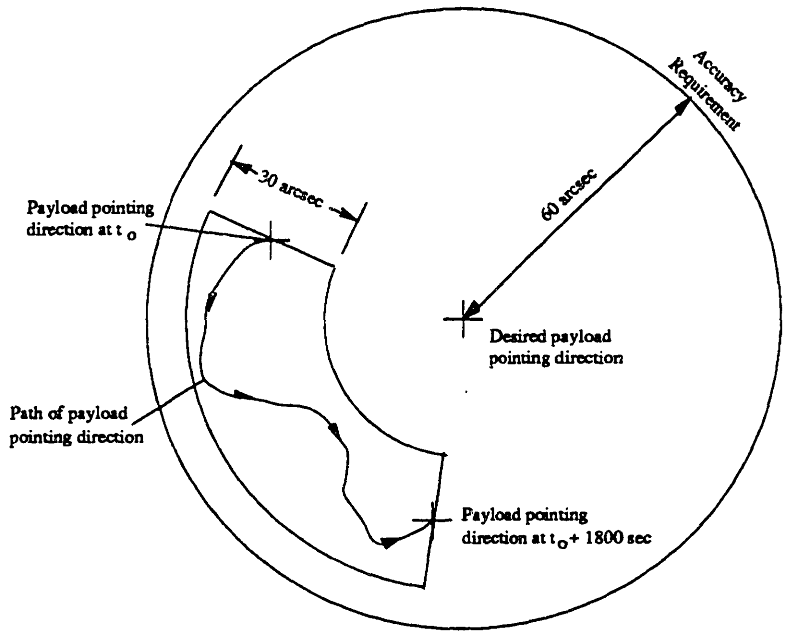


Figure 5-8 Pointing stability requirement satisfied.

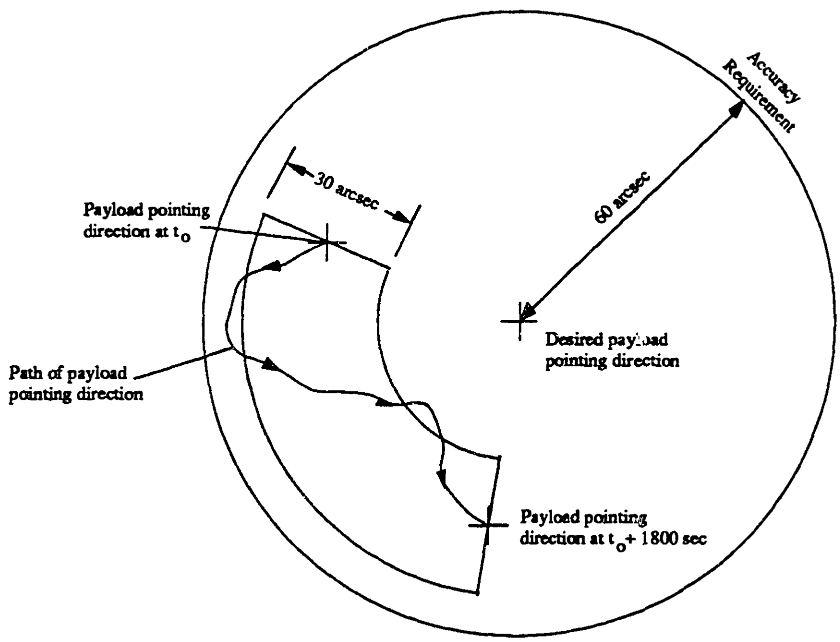


Figure 5-9 Pointing stability requirement not satisfied.

6.0 CONCLUSIONS AND RECOMMENDATIONS

Few modifications of the engineering model gimbal are presently evident, since the performance specifications have yet to be determined by testing. The engineering drawings are presently being revised as the gimbal is assembled and tested; these drawings should be used for production of subsequent units. Drawing revisions include tolerance adjustments to allow for ease of assembly and proper bearing and component alignments, and minor drawing, text and dimensioning errors. Gimbal weight could be reduced slightly, by milling out areas of excess material; however, this would increase machining costs and the total weight reduction would be small compared to the total weight of the gimbal. The number of wires routed from the gimbal may be reduced by combining ground wires of the encoder channels and possibly the motors; however this may lead to noise in the encoder output.

Additional features, however, could be added to the EM gimbal which possibly would prevent damage from occuring during operation. A thermocouple safety switch could be integrated into the motor housings which would protect the motors from being damaged due to excess heat.The output of this thermocouple could be routed to the computer, or it could be a passive fuse type protector. A"wind-up" or soft stop could also be used instead of the present "hard" stops; this would prevent possible shock damage to the encoders or to the gimbal structure when the gimbal is commanded to exceed its slew range. Small limit switches could also be used to limit the slew range.

Many possible modifications could be employed in the gimbals for the actual flight hardware. The motor size can be decreased since the torque requirements are greatly reduced in zero gravity. Also thermal dissipation will not be a problem since the motors will need minimal torque to hold a position at any angle. The motor amplifiers will also be reduced in size and weight and will require less power, all of which are very desirable for the flight article. Brush type motors should be investigated, since this would eliminate the need for electronic commutation, which in turn would reduce power requirements and the number of wires to be routed from the bus. These positive aspects of brush type motors may outweigh the negative aspects such as wear characteristics, assembly difficulties and friction.

The cantilever gimbal configuration may be also be possible for the flight article since only dynamic loads will be present on the bearings; however, bearing and finite element analysis would again be required to determine if the structural frequency requirement will be satisfied. By reducing the motor size and employing the cantilever gimbal configuration it should be possible to achieve the full 120° of slew range in both axis.

Different encoders may also be required for the flight article, as the present encoders may not tolerate launching loads. Also, since the unit will be stored in a locker and will be floating in the middeck, a protective cover for the encoders should be integrated into the gimbal structure to protect them from accidental impact.

APPENDIX A

Part and Assembly Drawings

An engineering drawing list (EDL) is presented for the MACE part drawings. Part and assembly drawings are identified by drawing number, located in the lower right hand corner.

MIT MACE GIMBAL EM																	ENGINEERING DRAWING LIST				
INDENTURE																	TITLE	PARTS NEEDED	DRAWING		SUPPLIER / REMARKS
*	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16			COMP	RELEASE	
		M	A	C	E	1	0	0									GIMBAL ASSEMBLY		8/10/90	8/13/90	6061 - T6 Al CHAMP
			M	A	C	E	1	0	1								PRIMARY MOTOR HOUSING	1	8/10/90	8/13/90	6061 - T6 Al CHAMP
			M	A	C	E	1	0	2								BEARING CLAMP RING	1	8/10/90	8/13/90	6061 - T6 Al CHAMP
			M	A	C	E	1	0	3								2.5" BEARING O.D. SPACER	3	8/10/90	8/13/90	6061 - T6 Al CHAMP
			M	A	C	E	1	0	4								WIRE HARNESS/ MOTOR CLAMP RING	1	8/10/90	8/13/90	6061 - T6 Al CHAMP
			M	A	C	E	1	0	5								PRIMARY ENCODER HOUSING	1	8/10/90	8/13/90	6061 - T6 Al CHAMP
			M	A	C	E	1	0	6								SECONDARY MOTOR HOUSING	1	8/10/90	8/13/90	6061 - T6 Al CHAMP
				M	A	C	E	1	2	4							SCNDARY MTR HSING SUB-ASSEMBLY		8/10/90	8/13/90	6061 - T6 Al CHAMP
			M	A	C	E	1	0	7								PRIMARY ROTOR CLAMP RING	1	8/10/90	8/13/90	6061 - T6 Al CHAMP
			M	A	C	E	1	0	8								PRIMARY ROTOR SPACER	1	8/10/90	8/13/90	6061 - T6 Al CHAMP
			M	A	C	E	1	0	9								SECONDARY MOTOR CLAMP RING	1	8/10/90	8/13/90	6061 - T6 Al CHAMP
			M	A	C	E	1	1	0								SECONDARY ENCODER HOUSING	1	8/10/90	8/13/90	6061 - T6 Al CHAMP
			M	A	C	E	1	1	1								PIVOT TOP PLATE	1	8/10/90	8/13/90	6061 - T6 Al CHAMP
			M	A	C	E	1	1	2								PIVOT ENCODER PLATE	1	8/10/90	8/13/90	6061 - T6 Al CHAMP
			M	A	C	E	1	1	3								PIVOT BEARING PLATE	1	8/10/90	8/13/90	6061 - T6 Al CHAMP
			M	A	C	E	1	1	4								SECONDARY ROTOR	1	8/10/90	8/13/90	6061 - T6 Al CHAMP
			M	A	C	E	1	1	5								SECONDARY ROTOR SPACER 'A'	1	8/10/90	8/13/90	6061 - T6 Al CHAMP
			M	A	C	E	1	1	6								SECONDARY ROTOR SPACER 'B'	1	8/10/90	8/13/90	6061 - T6 Al CHAMP
			M	A	C	E	1	1	7								2.0" BEARING O.D. SPACER	1	8/10/90	8/13/90	6061 - T6 Al CHAMP
			M	A	C	E	1	1	8								2.0" BEARING I.D. SPACER	1	8/10/90	8/13/90	6061 - T6 Al CHAMP
			M	A	C	E	1	1	9								BASE PLATE	1	8/10/90	8/13/90	6061 - T6 Al CHAMP
				M	A	C	E	1	2	3							BASE/MTR HSING SUB -ASSEMBLY		8/10/90	8/13/90	6061 - T6 Al CHAMP
			M	A	C	E	1	2	0								END BEARING CLAMP RING	1	8/10/90	8/13/90	6061 - T6 Al CHAMP
			M	A	C	E	1	2	1								2.0" BEARING I.D. SPACER	1	8/10/90	8/13/90	6061 - T6 Al CHAMP
			M	A	C	E	1	2	2								STOP PLATE	1	8/10/90	8/13/90	6061 - T6 Al CHAMP

NOTES:

1. VENDOR: HELICAL PRODUCTS COMPANY INC. 901 W. McCOY LANE - P.O. BOX 1069 - SANTA MARIA, CALIFORNIA 93456 (805) 928-3851
2. VENDOR: SMALLEY STEEL RING COMPANY, 385 ALICE STREET □ WHEELING, ILLINOIS 60090 □ (312) 537-7600
3. VENDOR: KAYDON CORPORATION 2860 McCRACKEN ST □ MUSKEGON, MICHIGAN 49443 □ (616) 755-3741
4. VENDOR: CANON U.S.A., INC. COMPONENTS DIVISION ONE CANON PLAZA □ LAKE SUCCESS, NEW YORK 11042-9979 □ (516) 488-6700
5. VENDOR: INLAND MOTOR COMPANY KOLLMORGEN CORP., 4020 E. INLAND ROAD □ SIERRA VISTA, ARIZONA 85635 □ (602) 459-1150
6. VENDOR: THE [illegible] COMPANY INC. [illegible] COMMERCIAL AVENUE □ SUNNYVALE, CA 94086 □ (408) 735-1850
7. PART NOT SHOWN IN MACE100. LISTED IN COMPLETE PARTS LIST ONLY. (SEE MACE111 FOR CALLOUT)

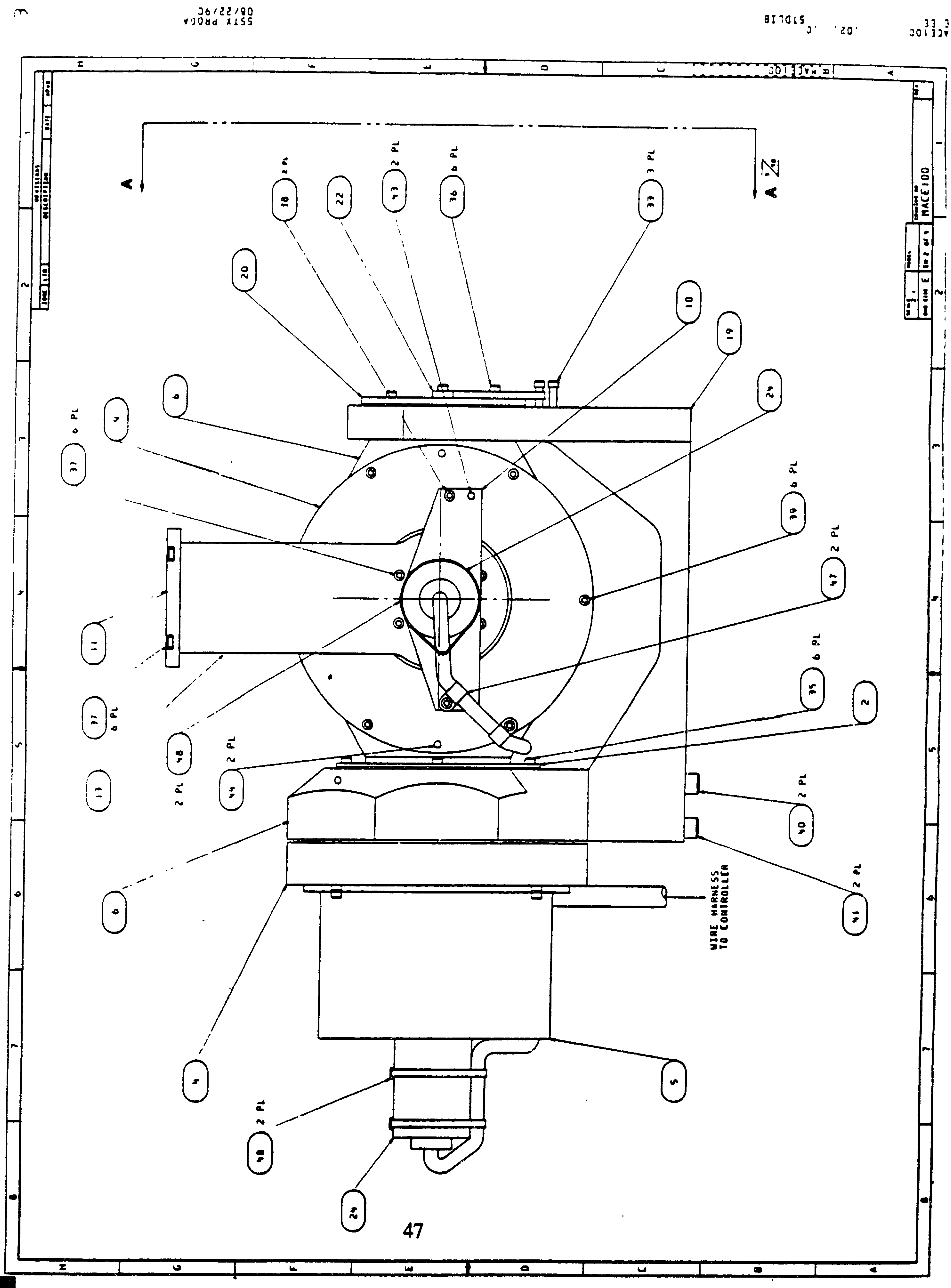
NOTE	ITEM NO	PART NUMBER	DESCRIPTION	QTY REQD
	60			
	59			
	58			
	57			
	56			
	55			
	54			
	53			
6	52	[illegible]	#4 X .625 X .25 Al SPACER	3
7, 6	51	[illegible]	1/4-20 HELIINSERT	4
6	50	[illegible]	4" ADJUSTABLE HOSE CLAMP	1
	49		RUBBER CUSHION STRIP	1
6	48		5" TIE WRAP	6
6	47		.125 ADEL CLAMP	2
6	46	[illegible]	M2.5 6mm ENCODER SCREW	6
	45	6061-T6	Ø 1/8" Al ENCODER ROD	2
6	44	12R100DOWS	.125 X 1.00 DOWEL PIN	2
6	43	12R750DOWS	.125 X .75 DOWEL PIN	4
6	42	0625ROLS	.0625 X .250 ROLL PIN	1
6	41	25C200SHCS	1/4-20 UNC-2A X 2.00 BOLT	2
6	40	25C250SHCS	1/4-20 UNC-2A X 2.50 BOLT	2
6	39	4C150SHCS	#4-40 UNC-2A X 1.50 BOLT	10
6	38	4C100SHCS	#4-40 UNC-2A X 1.00 BOLT	6
6	37	4C75SHCS	#4-40 UNC-2A X .750 BOLT	10
6	36	4C625SHCS	#4-40 UNC-2A X .625 BOLT	6
6	35	4C50SHCS	#4-40 UNC-2A X .500 BOLT	12
6	34	4C25SHCS	#4-40 UNC-2A X .250 BOLT	4
6	33	[illegible]	#4-40 X .375 SOLDER BOLT	3
6	32	4C1125SHCS	#4-40 UNC-2A X 1.125 BOLT	3

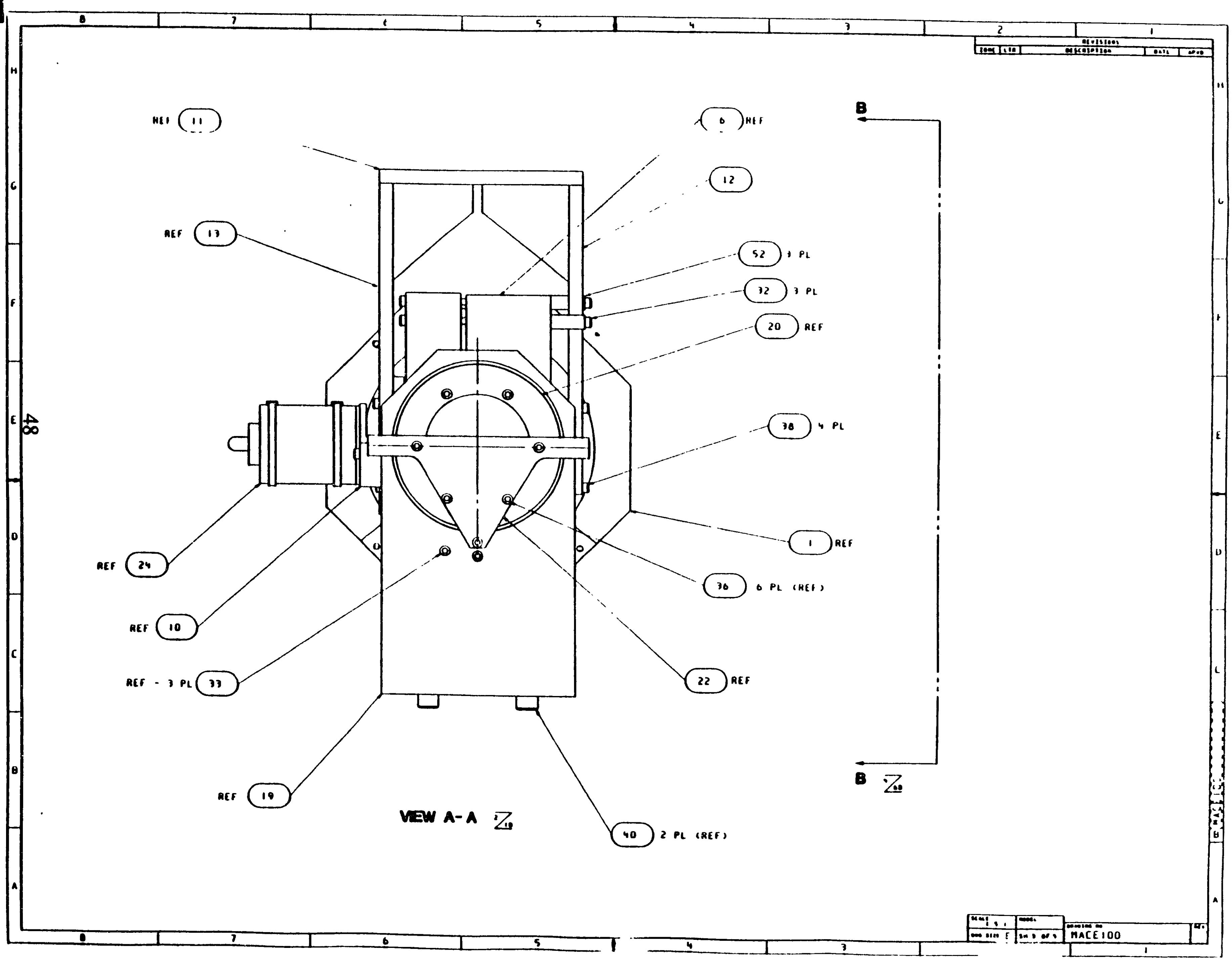
NOTE	ITEM NO	PART NUMBER	DESCRIPTION	QTY REQD
1	31	[illegible]	FLEXIBLE ENCODER COUPLING	2
2	30	[illegible]	2.0" SHIM STOCK	1
2	29	[illegible]	2.0" WAVE SPRING	1
2	28	[illegible]	2.5" SHIM STOCK	1
2	27	[illegible]	2.5" WAVE SPRING	1
3	26	K0020CP0	2.0" THIN WALL BEARING	1
3	25	K0025CP0	2.5" THIN WALL BEARING	3
4	24	R10	LASER ROTARY ENCODER	2
5	23	[illegible]	BRUSHLESS DC MOTOR	2
	22	122-001	STOP PLATE	1
	21	121-001	2.5 BEARING ID SPACER	1
	20	120-001	END BEARING CLAMP RING	1
	19	119-001	BASE PLATE	1
	18	118-001	2.0 BEARING ID SPACER	1
	17	117-001	2.0 BEARING OD SPACER	1
	16	116-001	SECONDARY ROTOR SPACER B	1
	15	115-001	SECONDARY ROTOR SPACER A	1
	14	114-001	SECONDARY STAGE ROTOR	1
	13	113-001	PIVOT BEARING PLATE	1
	12	112-001	PIVOT ENCODER PLATE	1
	11	111-001	PIVOT TOP PLATE	1
	10	110-001	SECONDARY ENCODER HOUSING	1
	9	109-001	SECONDARY MOTOR COVER	1
	8	108-00	PRIMARY ROTOR SPACER	1
	7	107-001	PRIMARY ROTOR CLAMP	1
	6	106-001	SECONDARY MOTOR HOUSING	1
	5	105-001	PRIMARY ENCODER HOUSING	1
	4	104-001	PRIMARY MOTOR COVER	1
	3	103-001	2.5 BEARING OD SPACER	3
	2	102-001	PRIMARY BEARING CLAMP	2
	1	101-001	PRIMARY MOTOR HOUSING	1

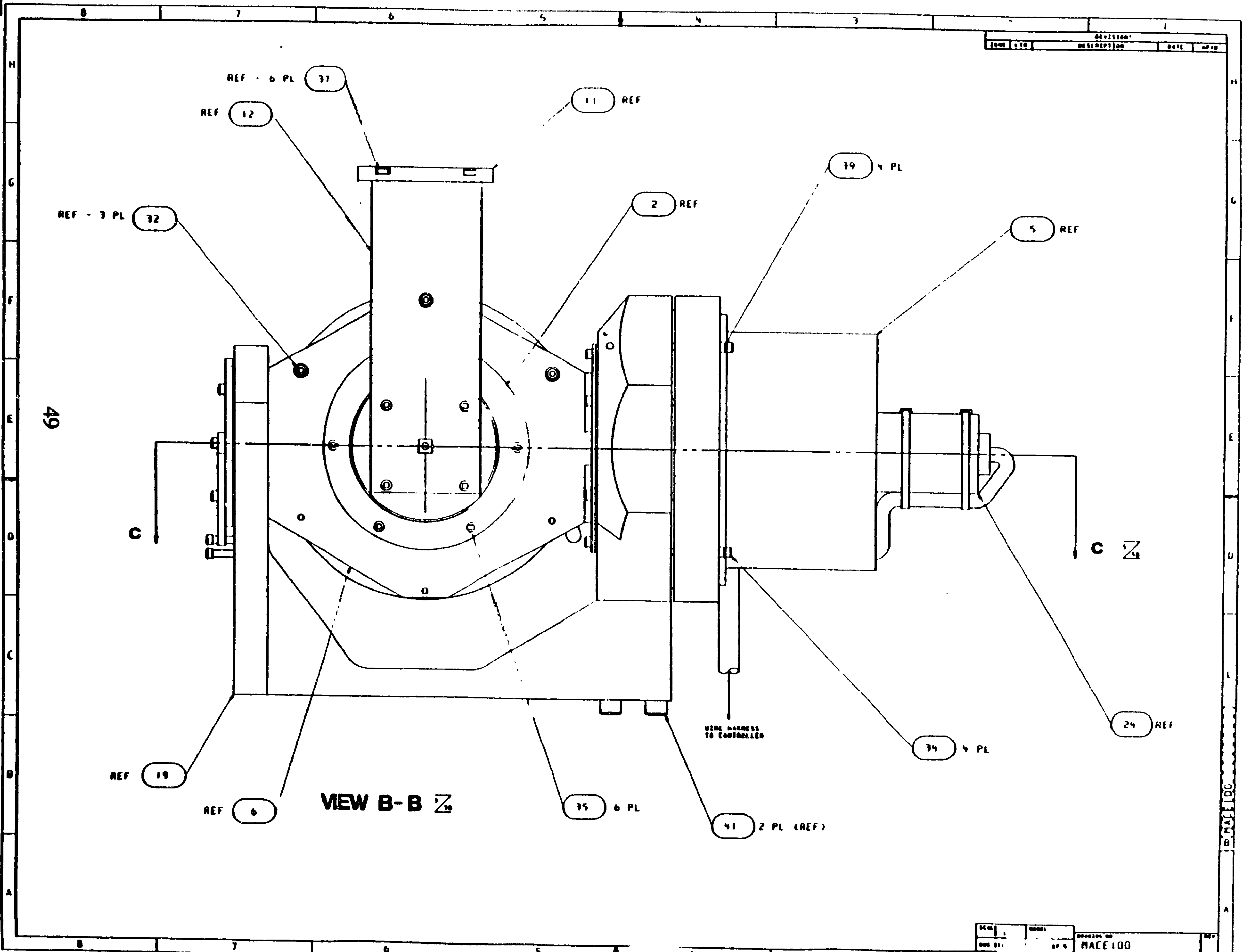
TITLE: MACE EM GIMBAL ASSEMBLY

MIT SPACE ENGINEERING RESEARCH CENTER

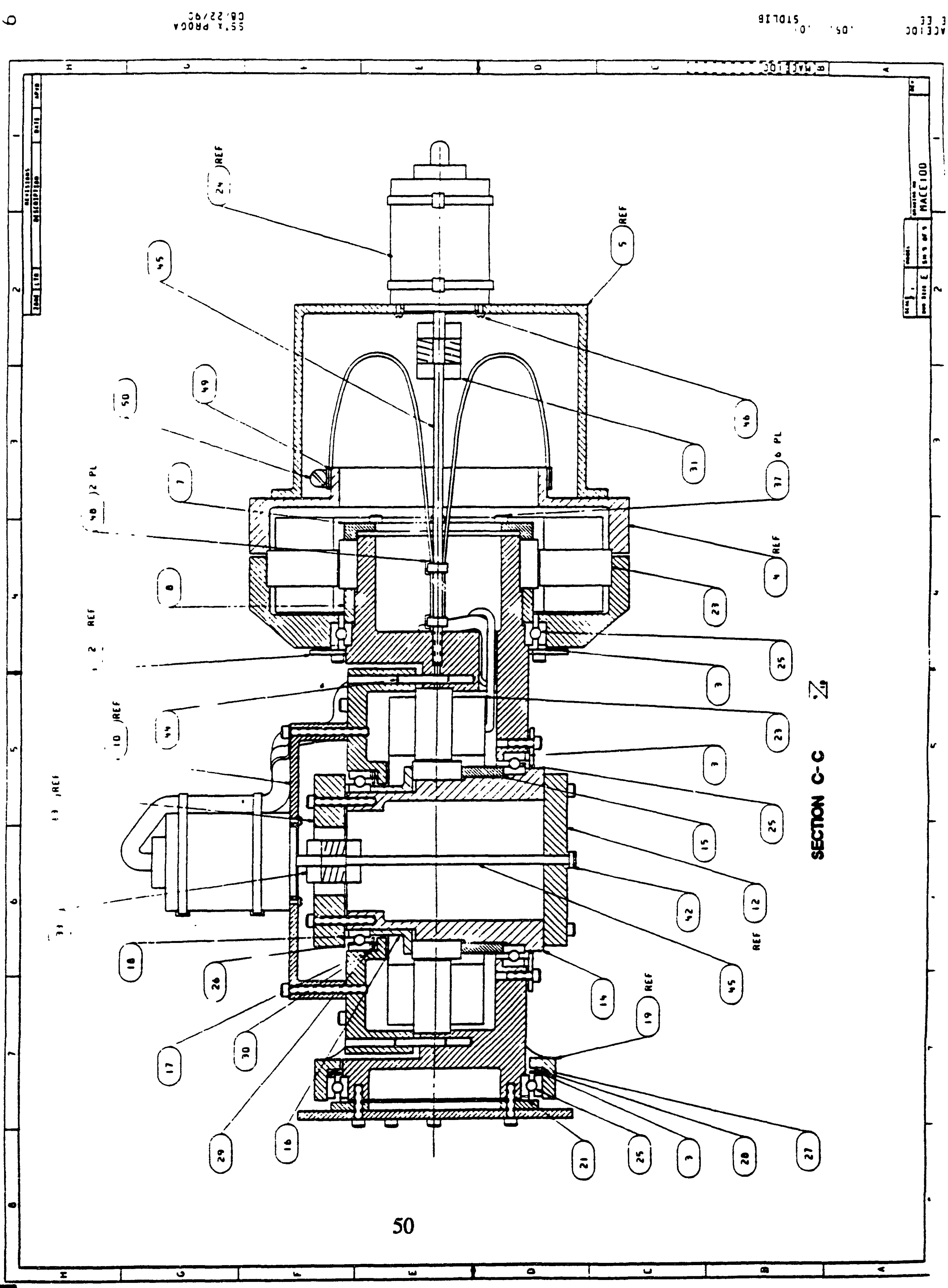
DWG NO MACE100 — SIZE E — REV 1

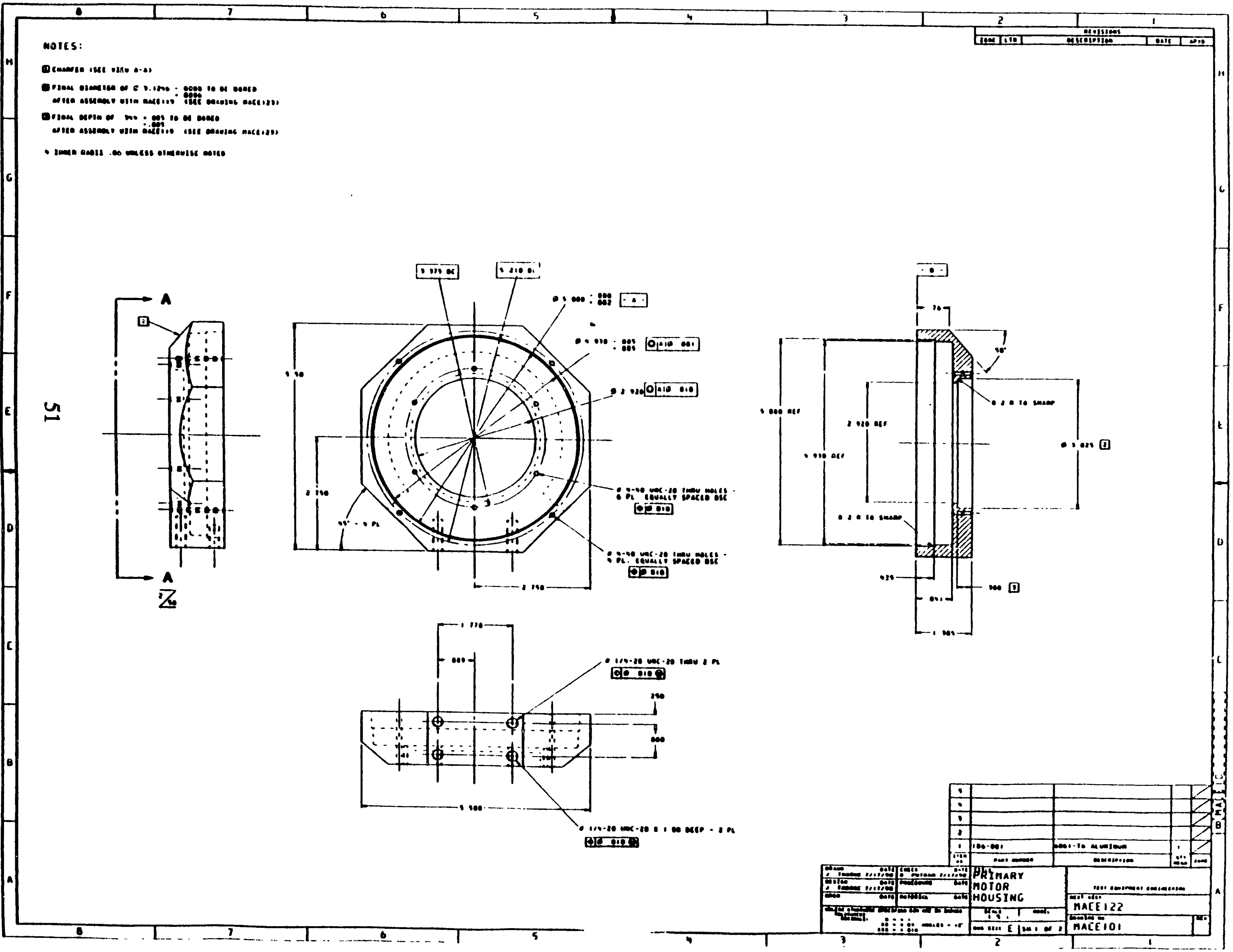

A
A
WIRE HARNESS TO CONTROLLER
MACE100

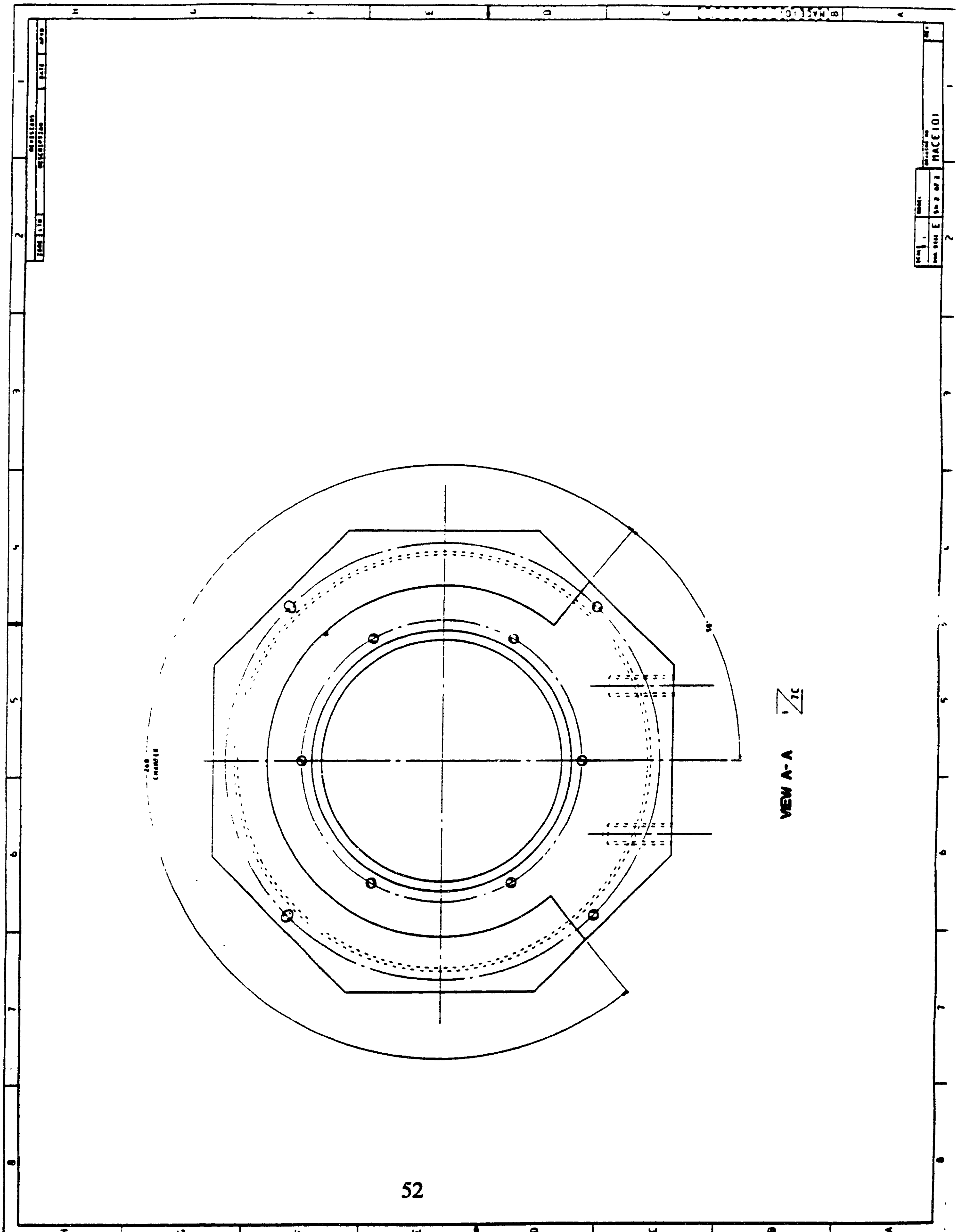

REF 11
REF 13
REF 24
REF 10
REF - 3 PL 33
REF 19
VIEW A-A
40 2 PL (REF)
6 REF
12
52 3 PL
32 3 PL
20 REF
38 4 PL
1 REF
36 6 PL (REF)
22 REF
B
B
MACE100

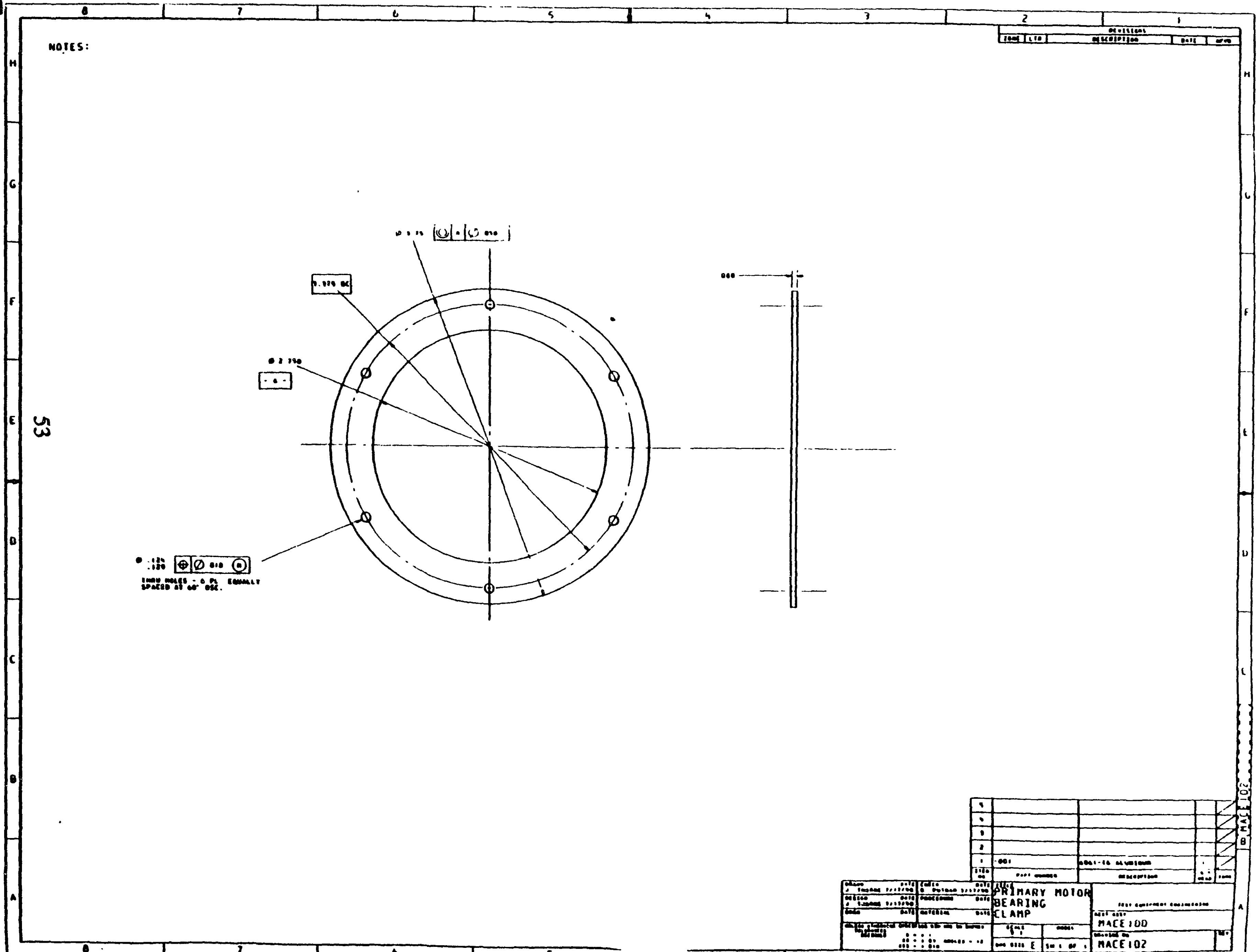

REF - 6 PL 37
REF 12
11 REF
REF - 3 PL 32
39 4 PL
2 REF
5 REF
C
C
WIRE HARNESS TO CONTROLLER
24 REF
34 4 PL
REF 19
REF 6
35 6 PL
41 2 PL (REF)
MACE100
SSTX PROGA
08/22/90
STDLIB

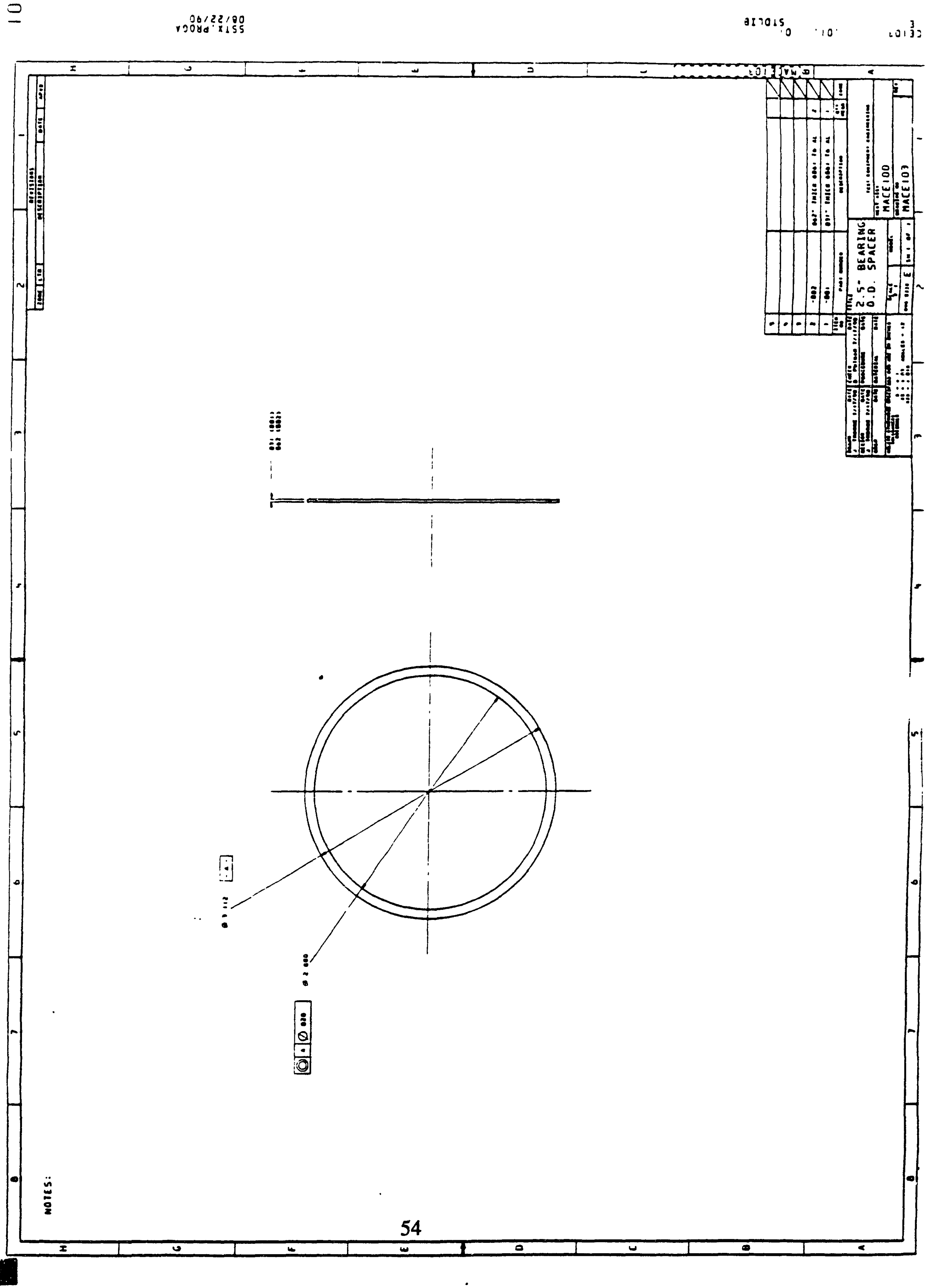
VIEW B-B

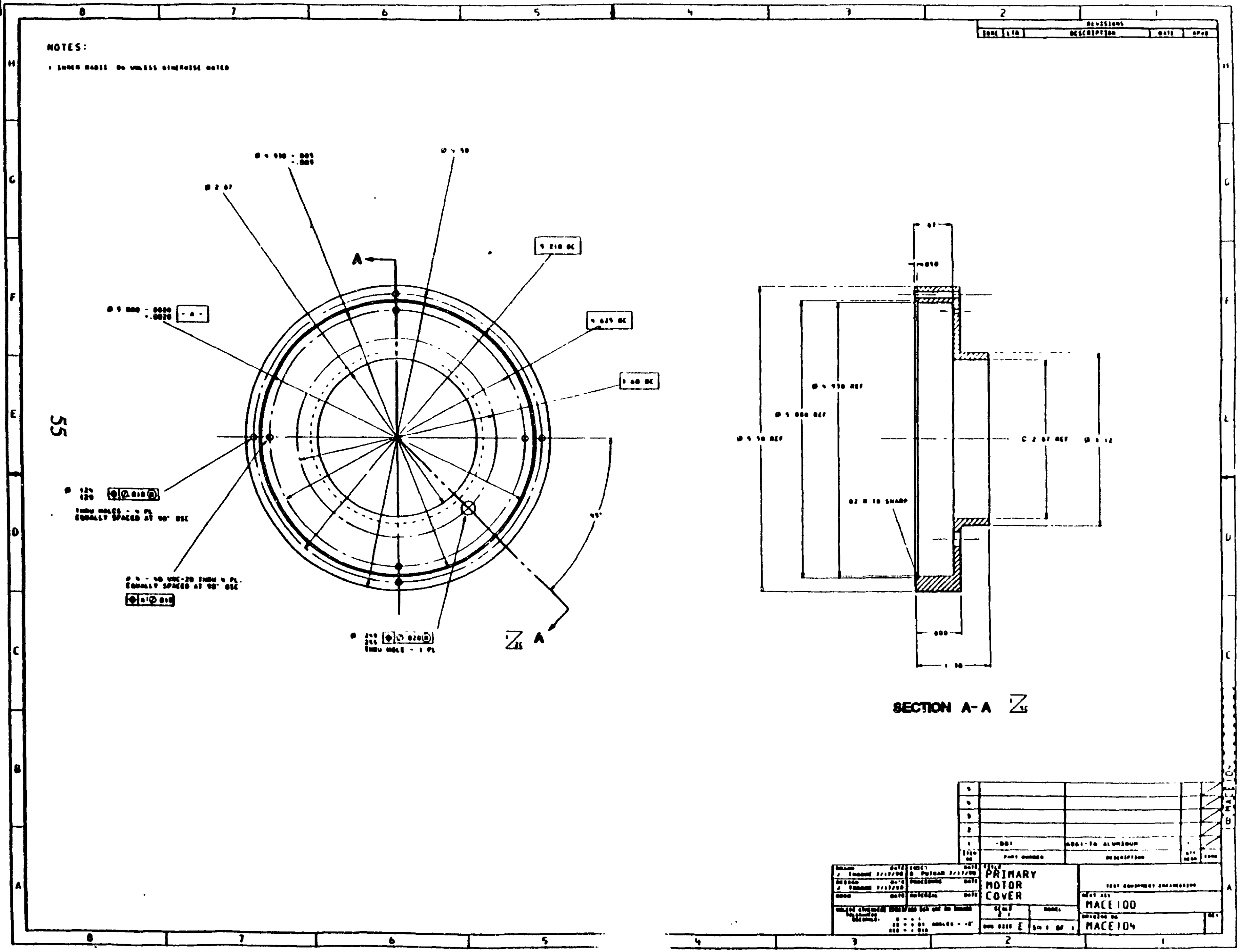

SECTION C-C
MACE100

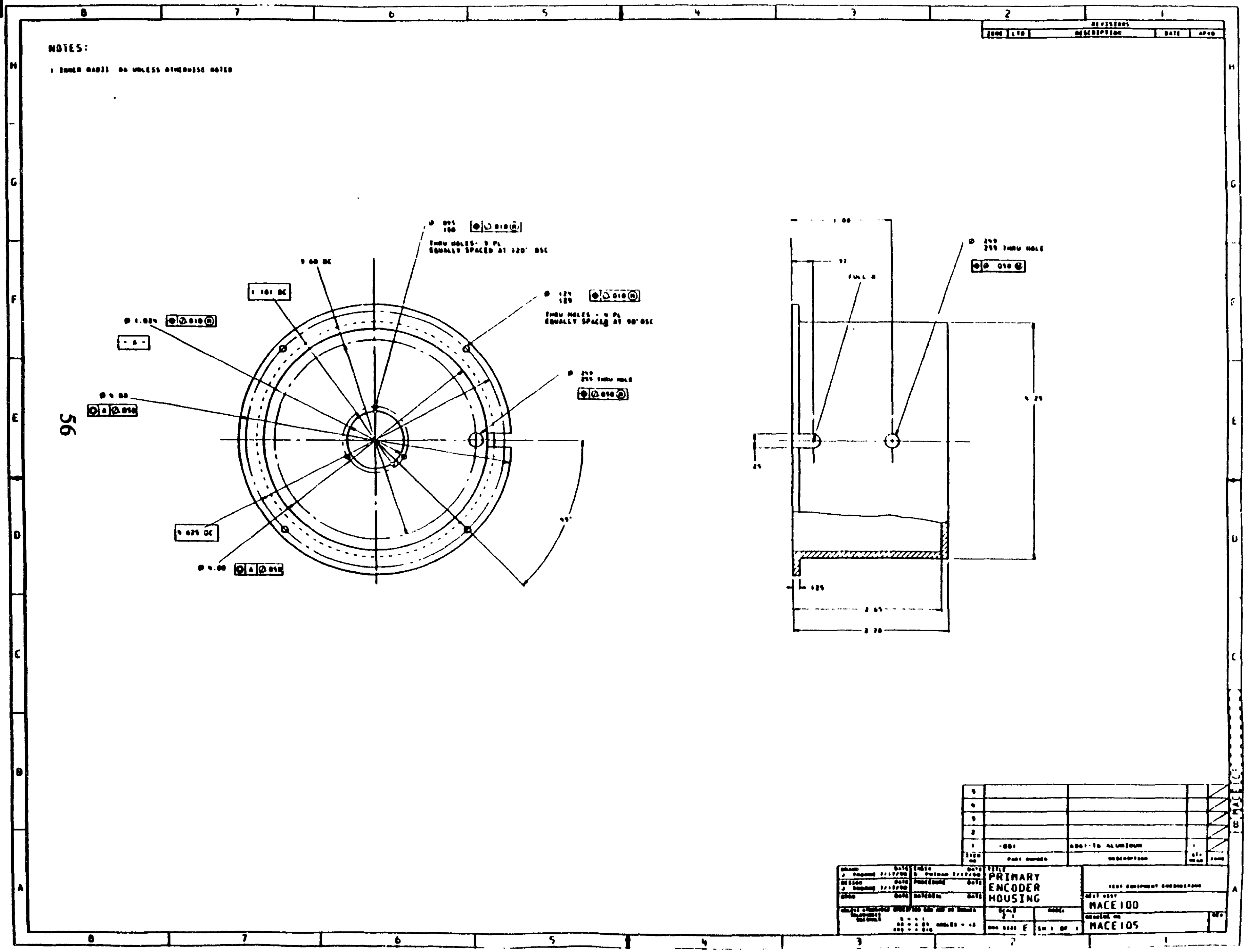

NOTES:
A
A
PRIMARY
MOTOR
HOUSING
MACE122
MACE101


VIEW A-A
MACE101


NOTES:
PRIMARY MOTOR
BEARING
CLAMP
MACE100
MACE102
SSTX PROGA
08/22/90
STDLIB

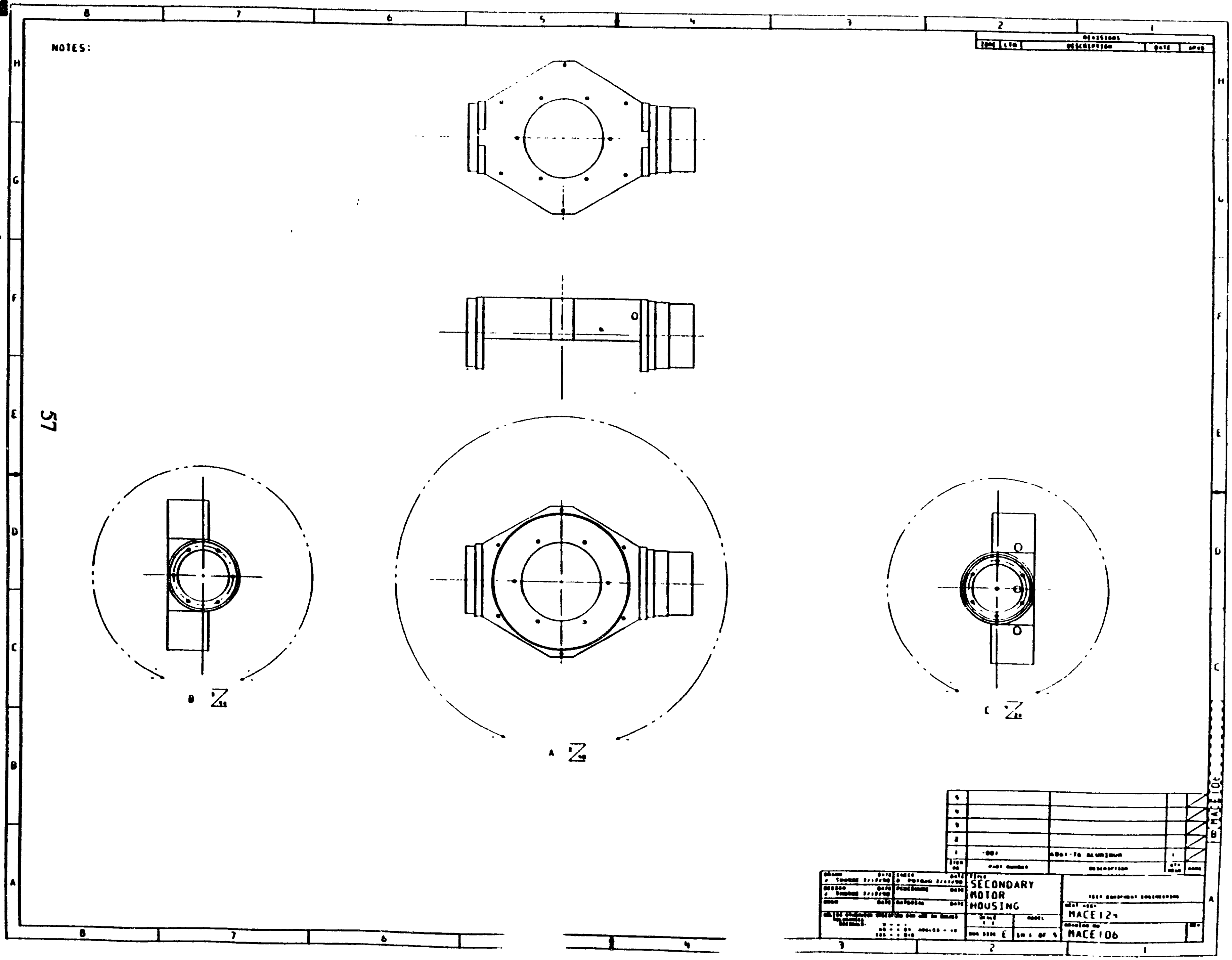

2.5" BEARING
O.D. SPACER
MACE100
MACE103
NOTES:


NOTES:
SECTION A-A
PRIMARY
MOTOR
COVER
MACE100
MACE104

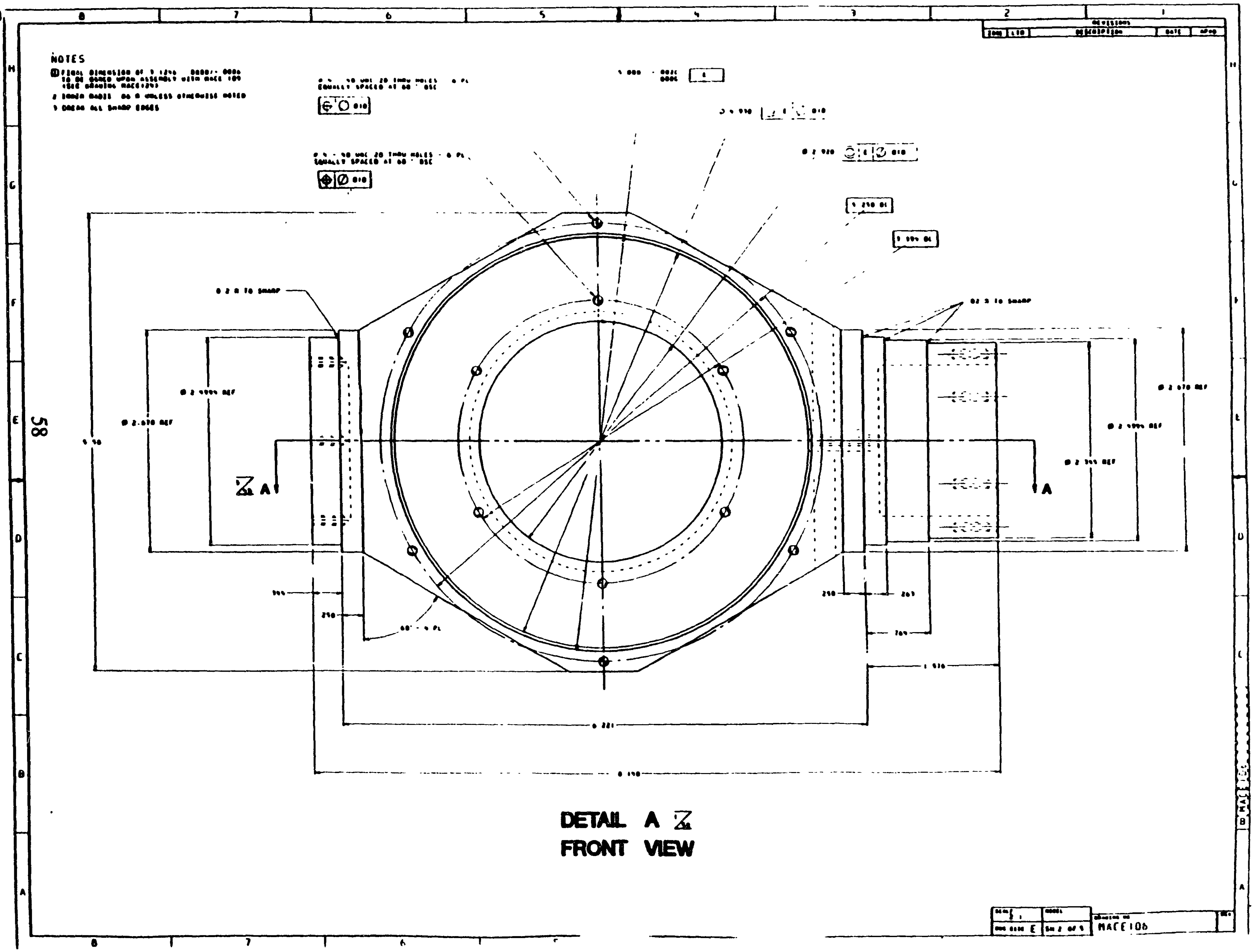


SSTX PROGA
08/22/90

STDLIB

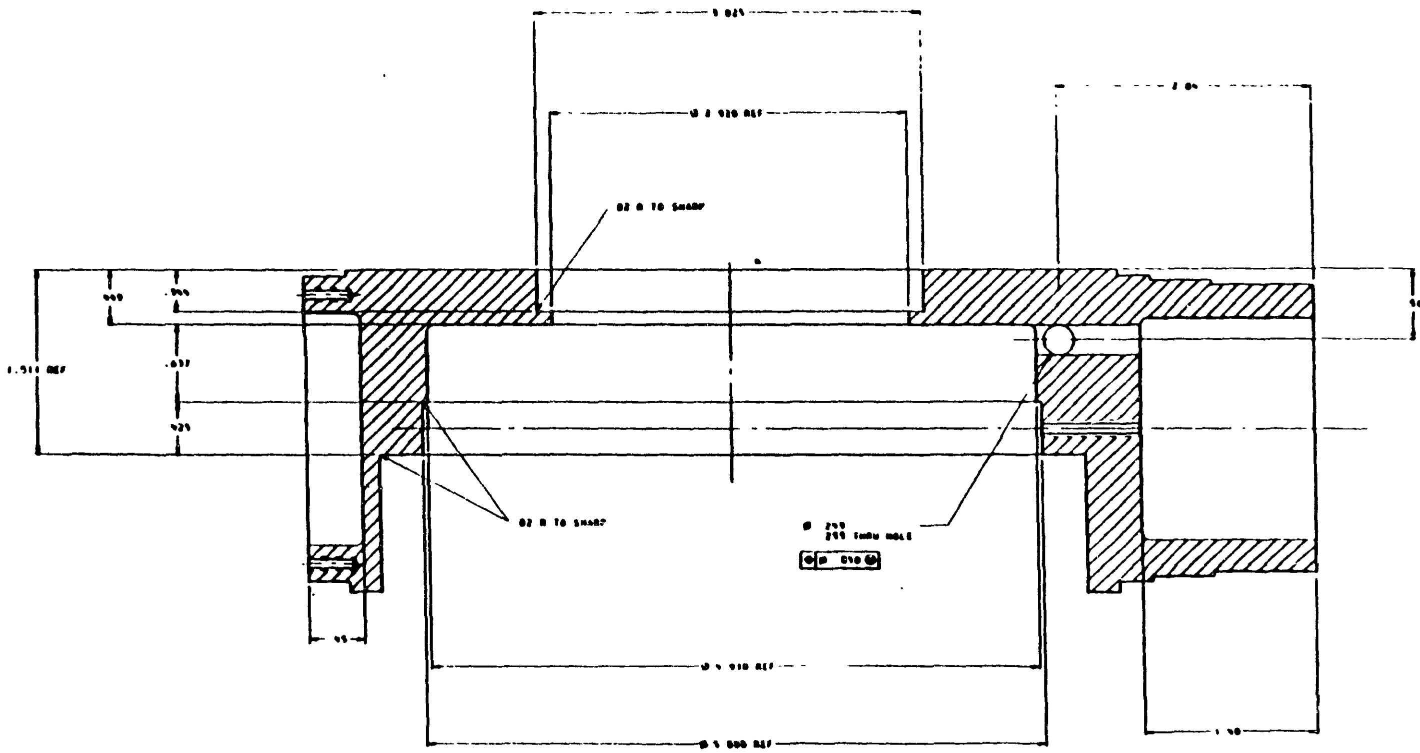

NOTES:
A
B
C
SECONDARY
MOTOR
HOUSING
MACE124
MACE106
STDLIB

14



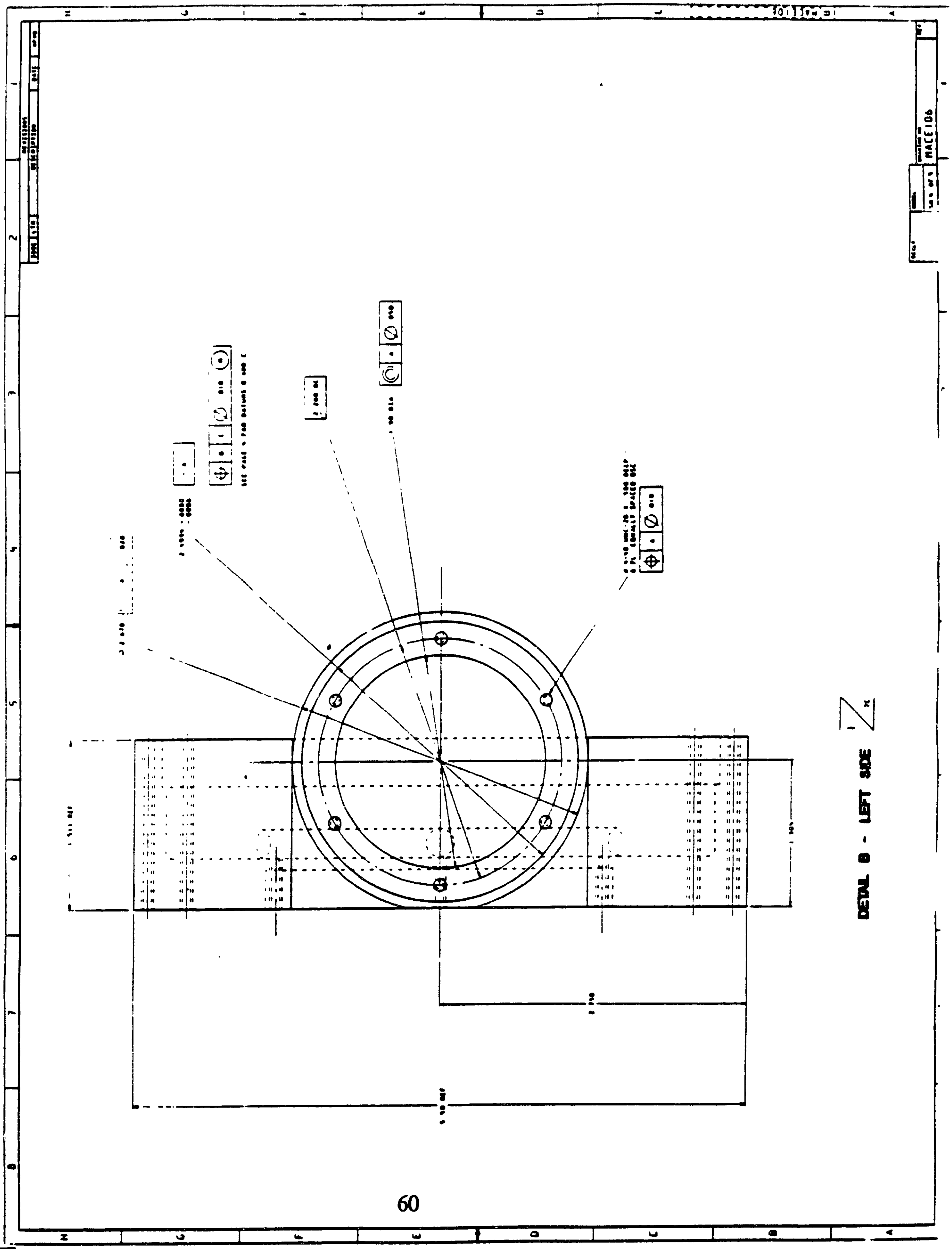
NOTES.

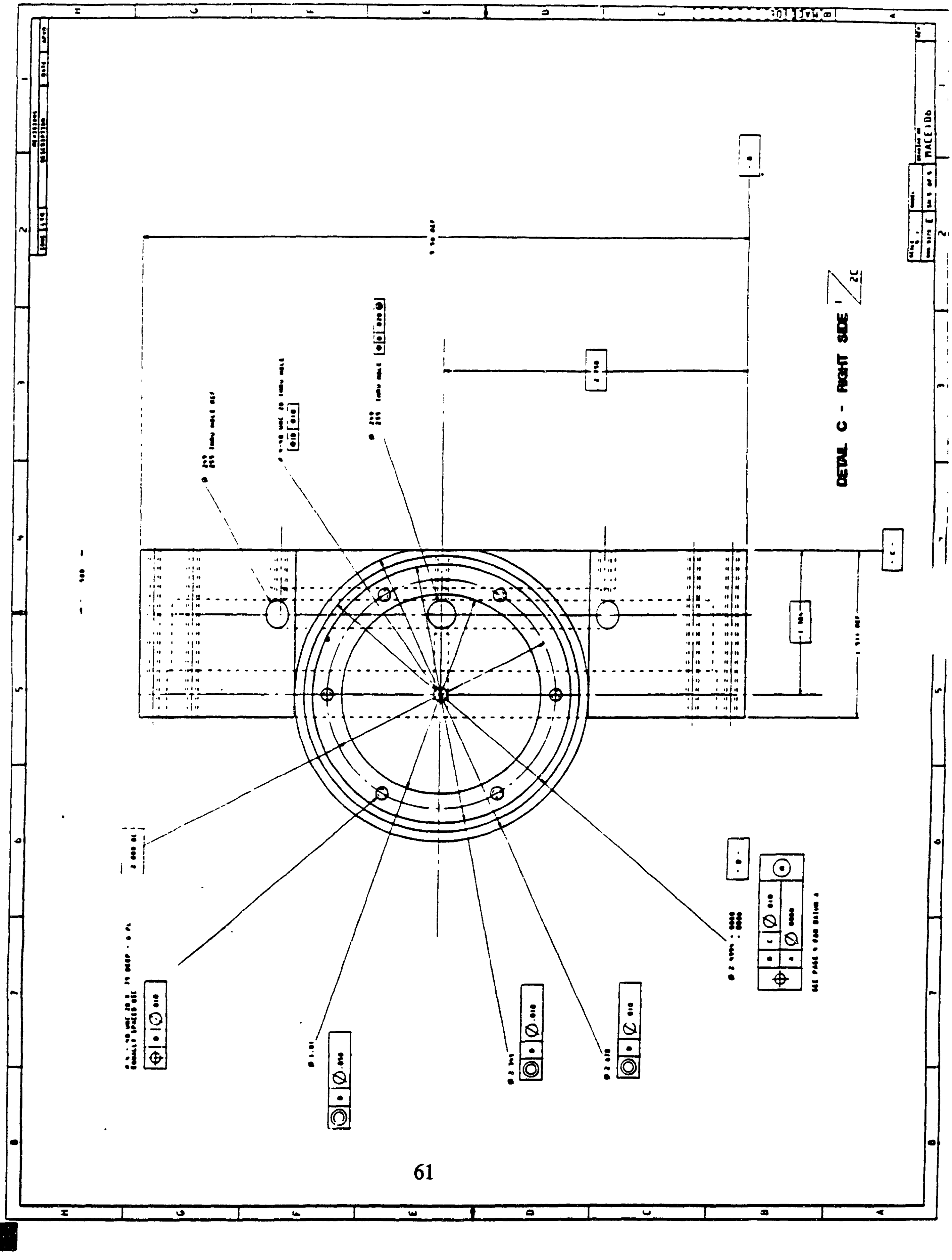
1. FINAL DIMENSION OF 5.1240 - .0000/+.0010 TO BE BORED UPON ASSEMBLY WITH MACE107 (SEE DRAWING MACE120)
2. INNER RADII .06 UNLESS OTHERWISE NOTED
3. BREAK ALL SHARP EDGES

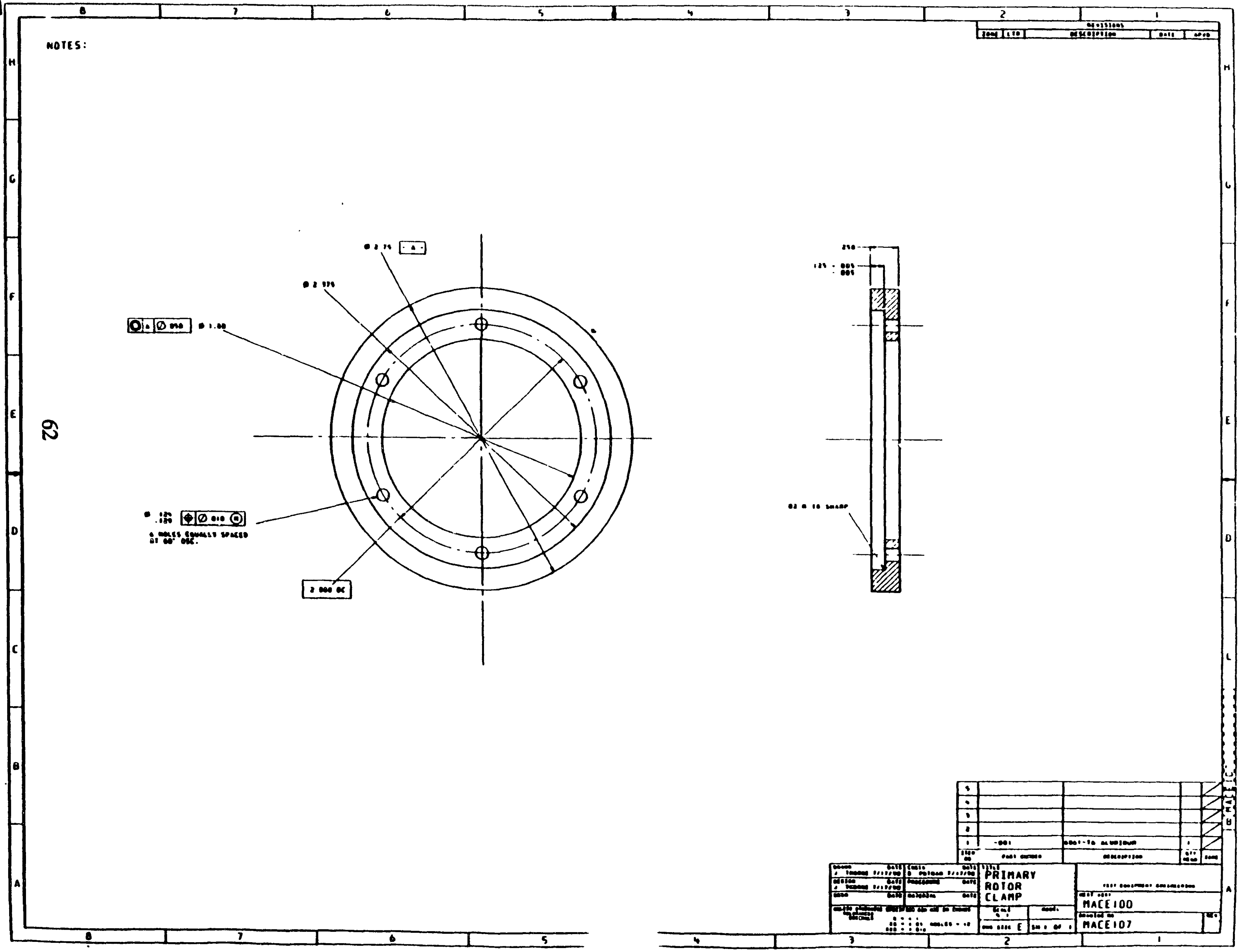


SECTION A-A

MACE106


DETAIL B - LEFT SIDE


DETAIL C - RIGHT SIDE


NOTES:
PRIMARY
ROTOR
CLAMP
MACE100
MACE107
6 HOLES EQUALLY SPACED
2.000 DC
SSTX.PROGA
06/22/90
STDLIB
MACE107

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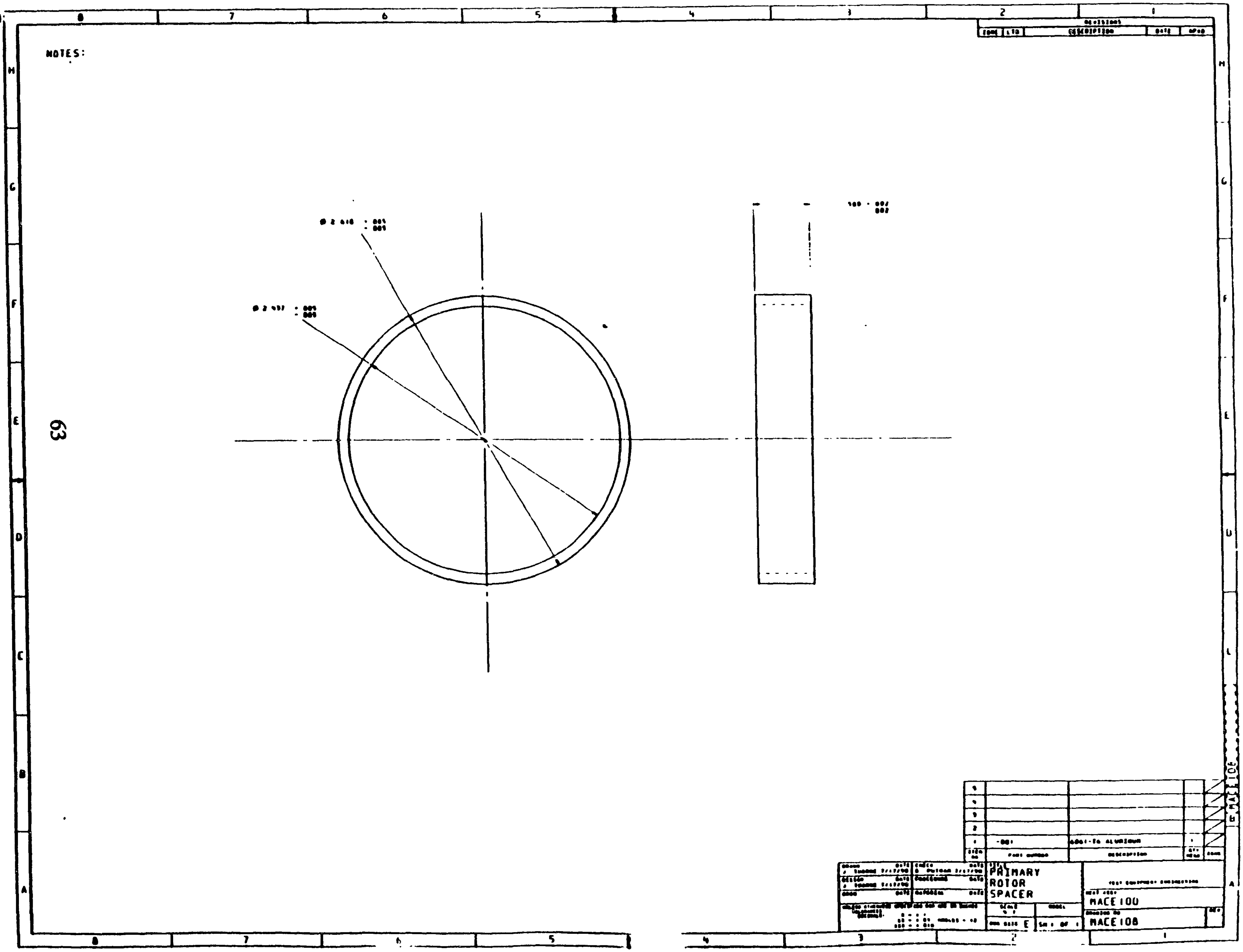
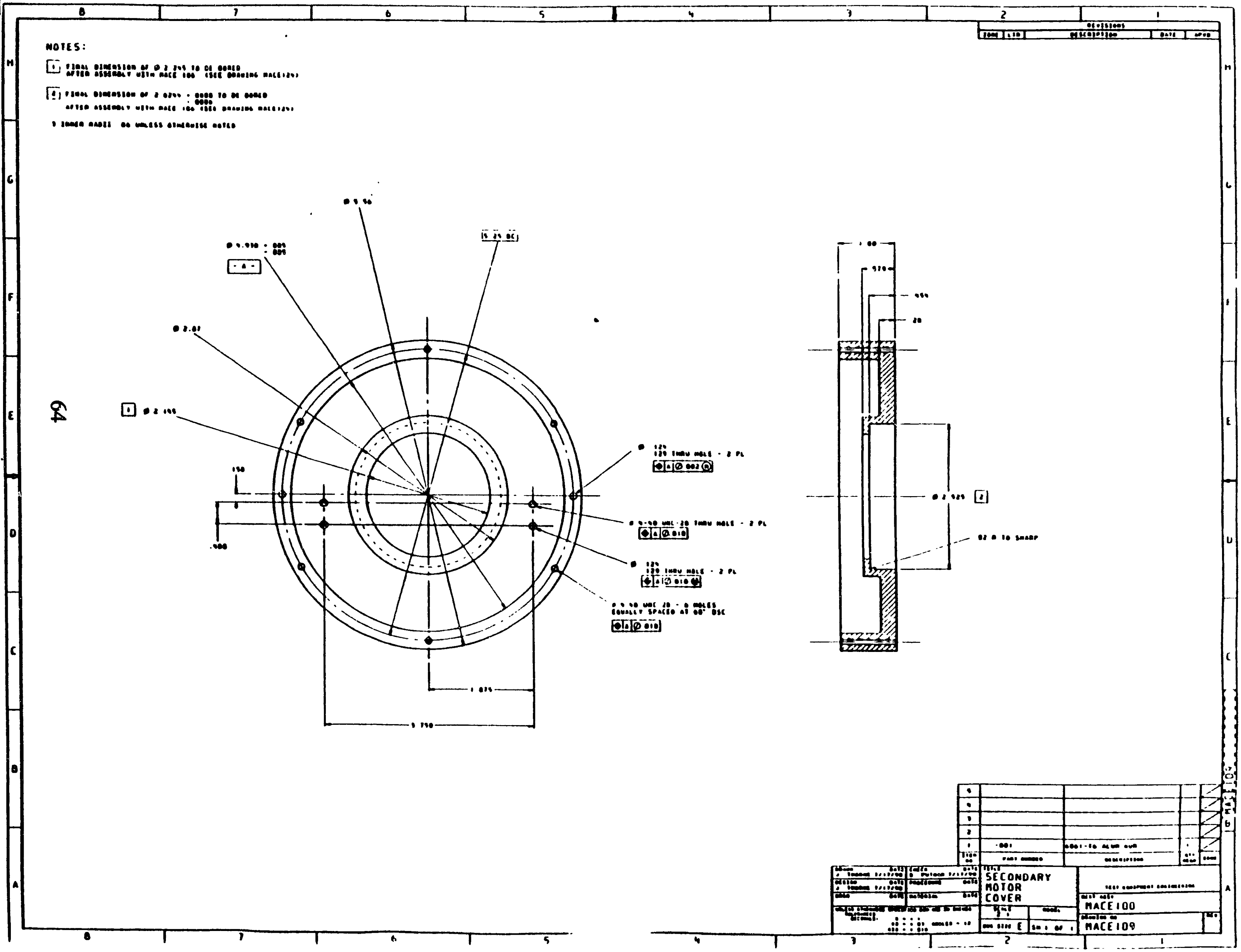
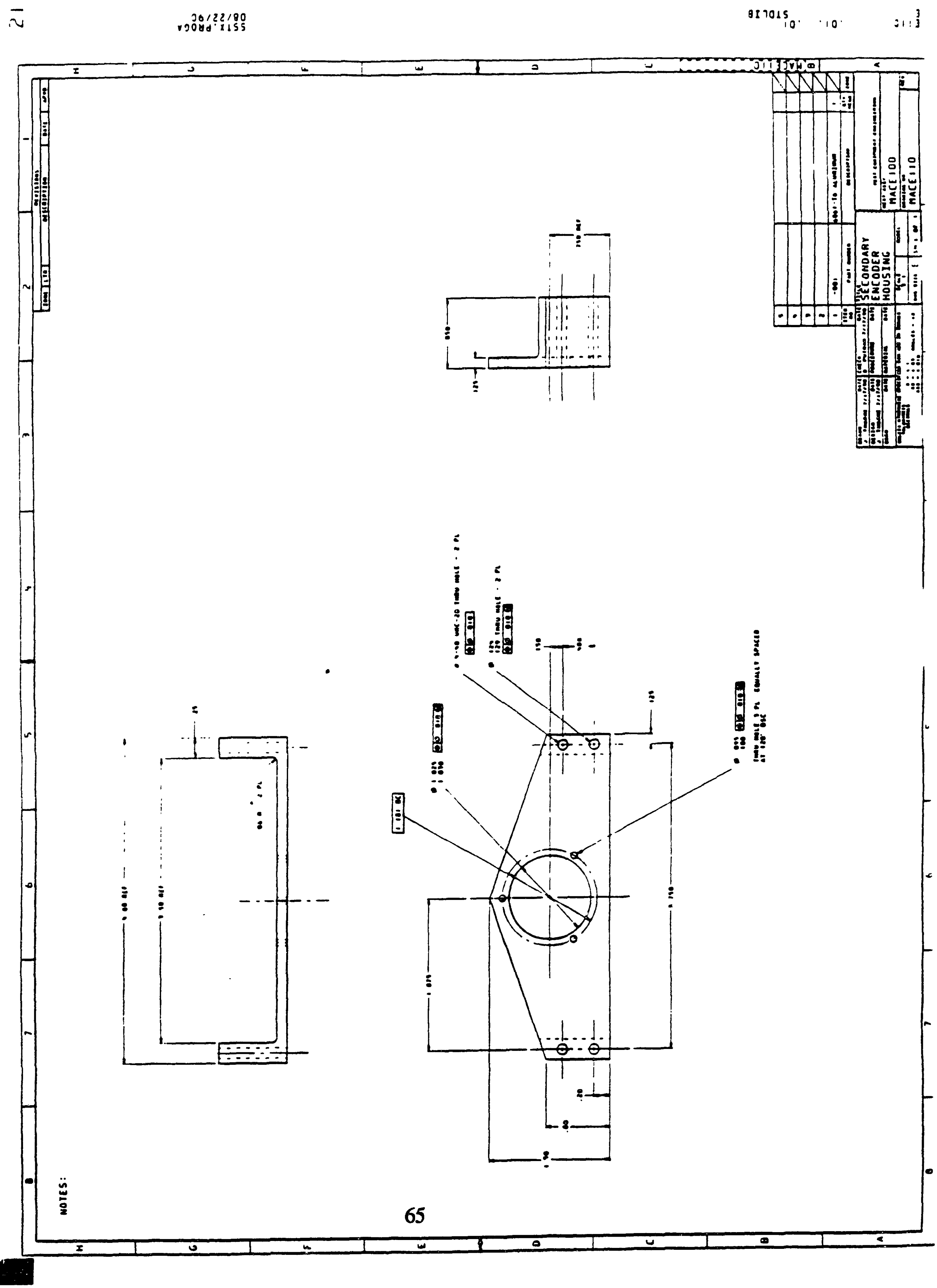
SST1 PROGA
08/22/90

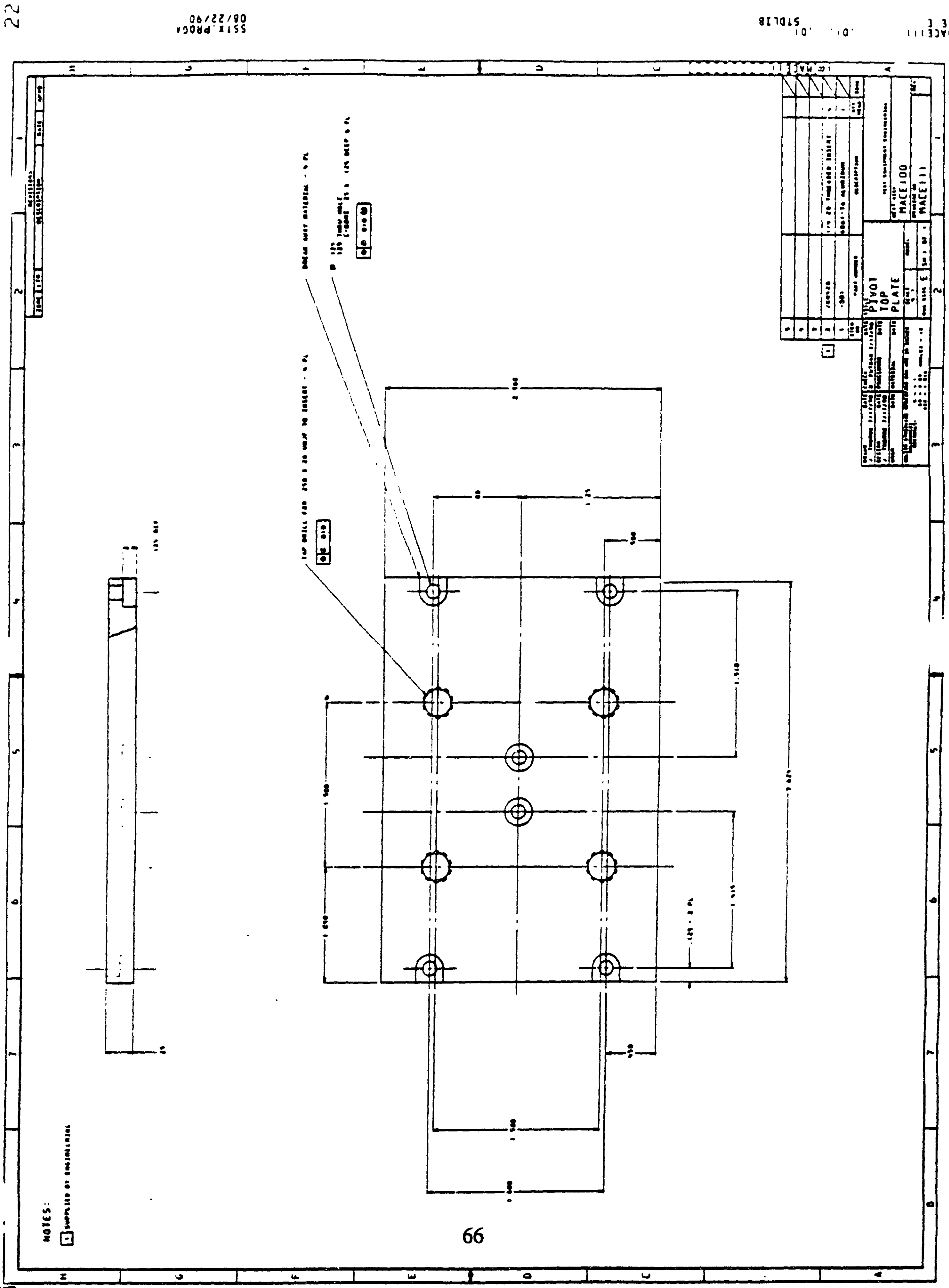


STDLIB

MACE108


NOTES:
SECONDARY
MOTOR
COVER
MACE100
MACE109


SECONDARY
ENCODER
HOUSING
MACE100
MACE110
NOTES:


PIVOT
TOP
PLATE
MACE100
MACE111
NOTES:
SUPPLIED BY ENGINEERING
SSTX.PROGA
06/22/90
STDLIB

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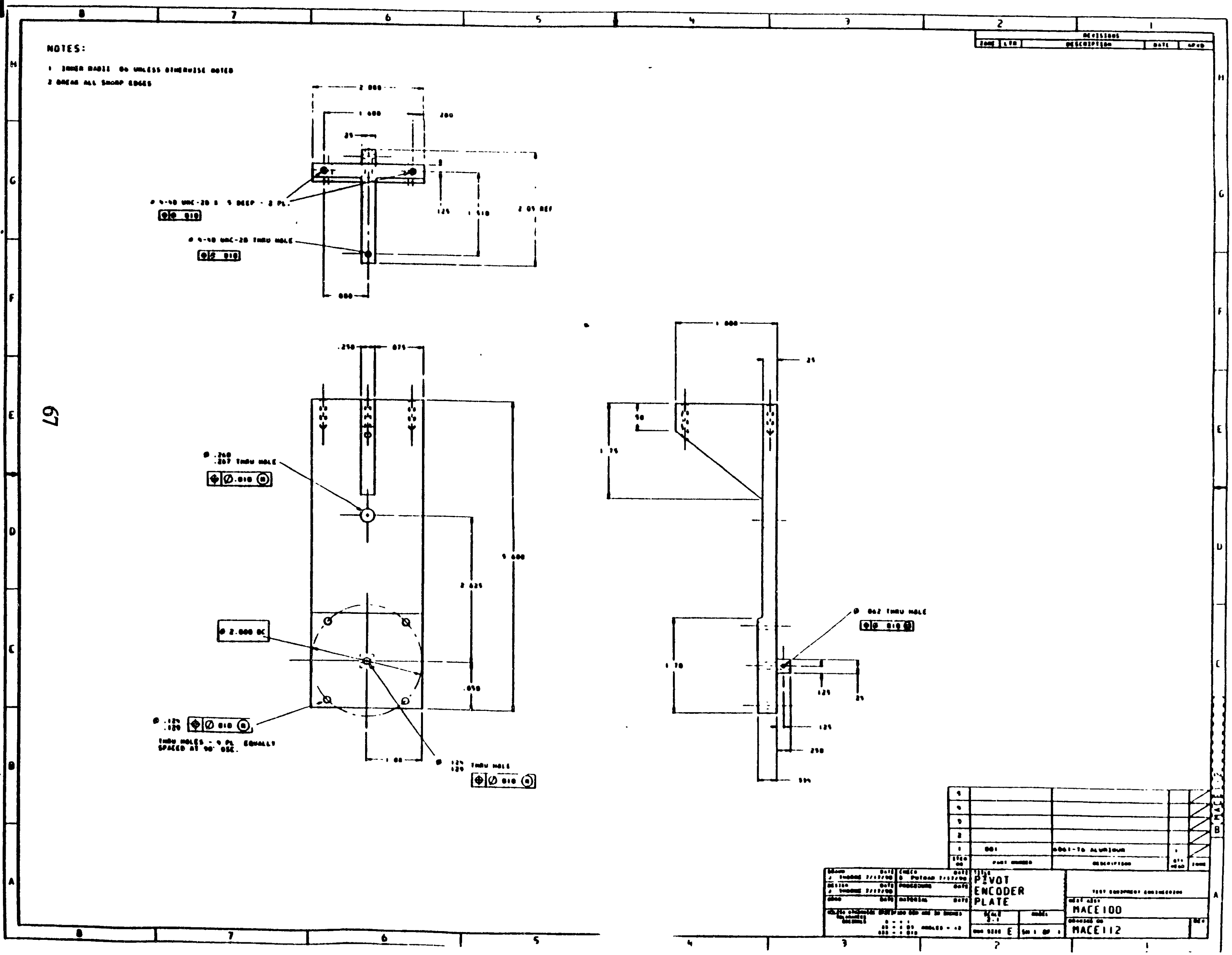
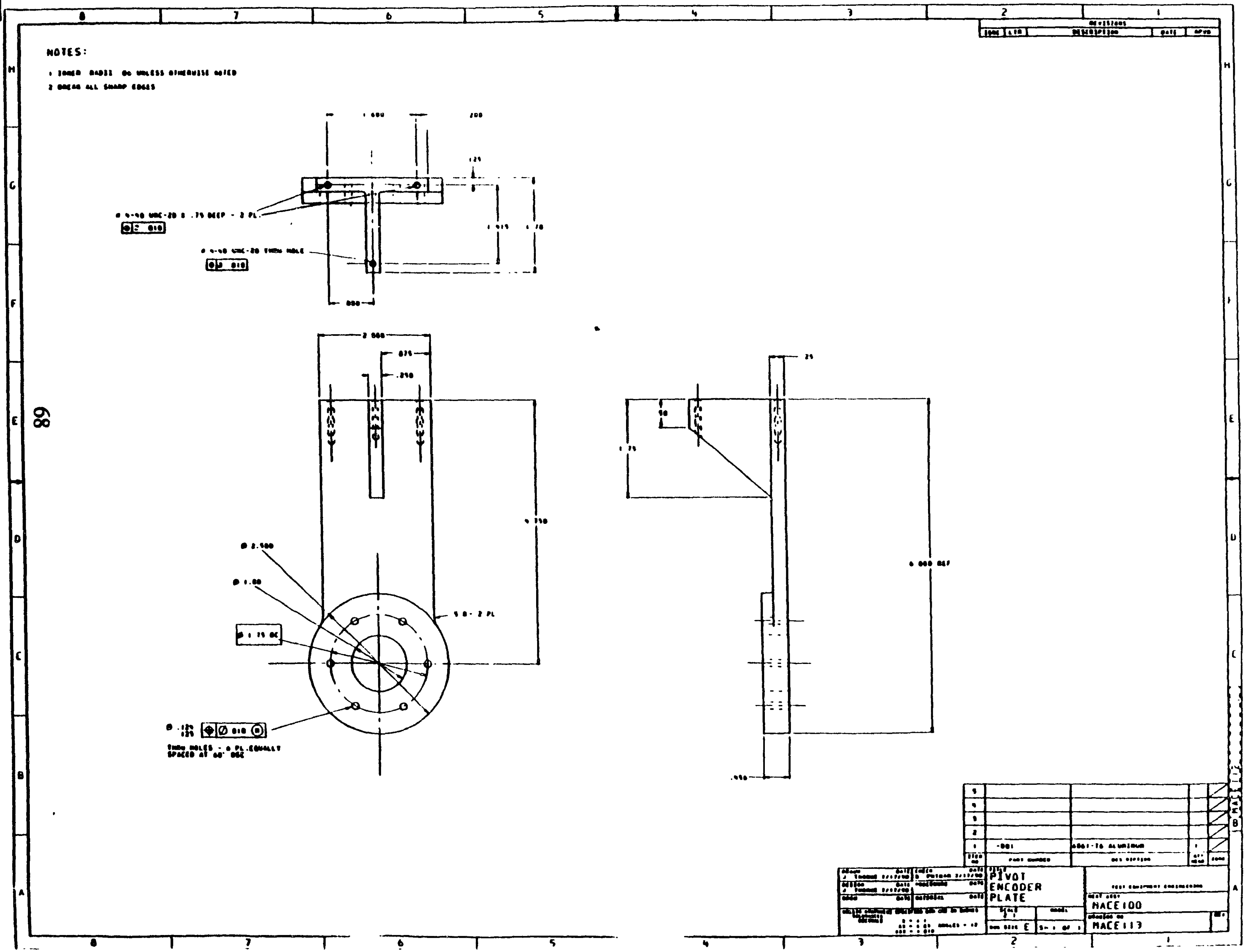
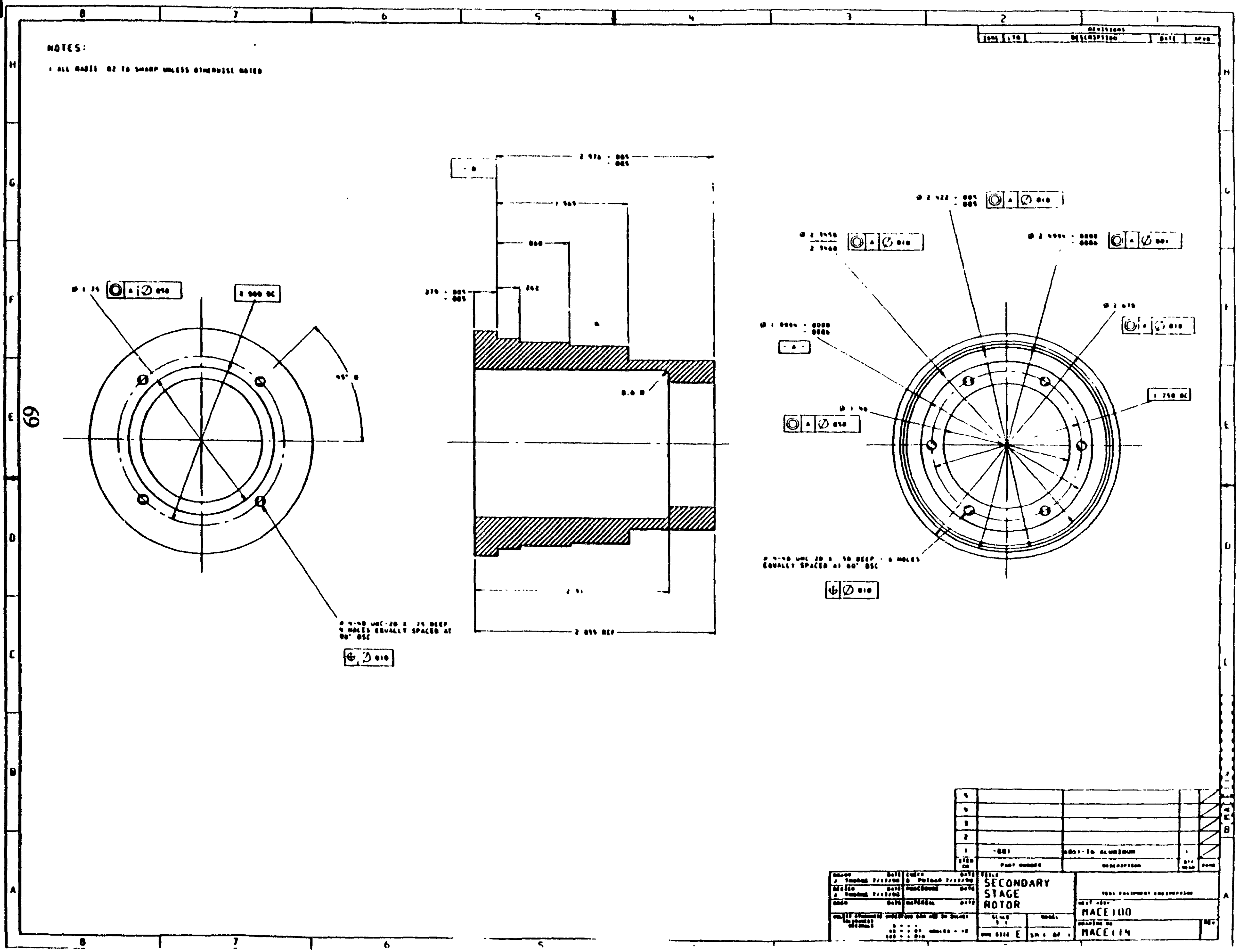
SSTX PROGA
08/22/90

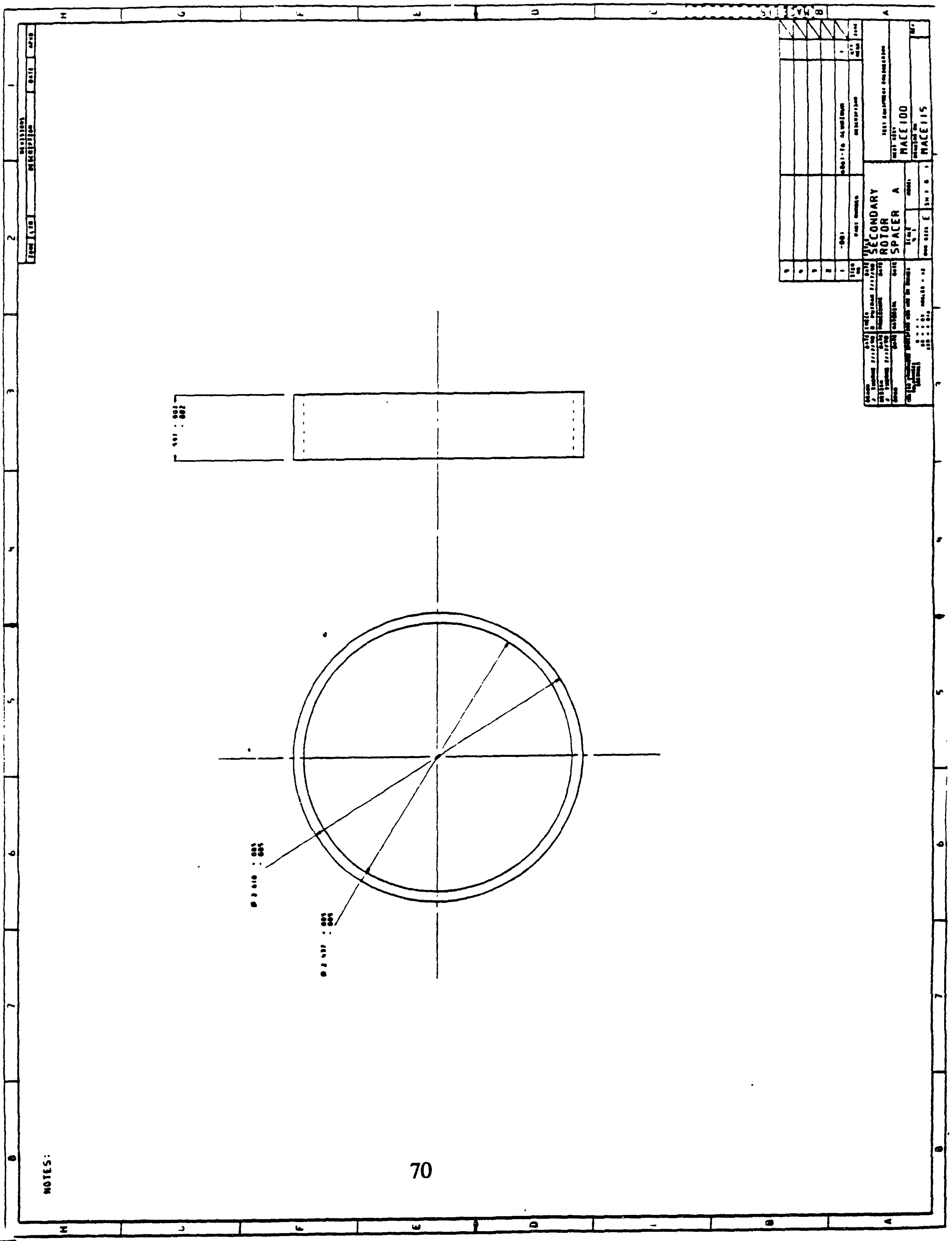


STDLIB

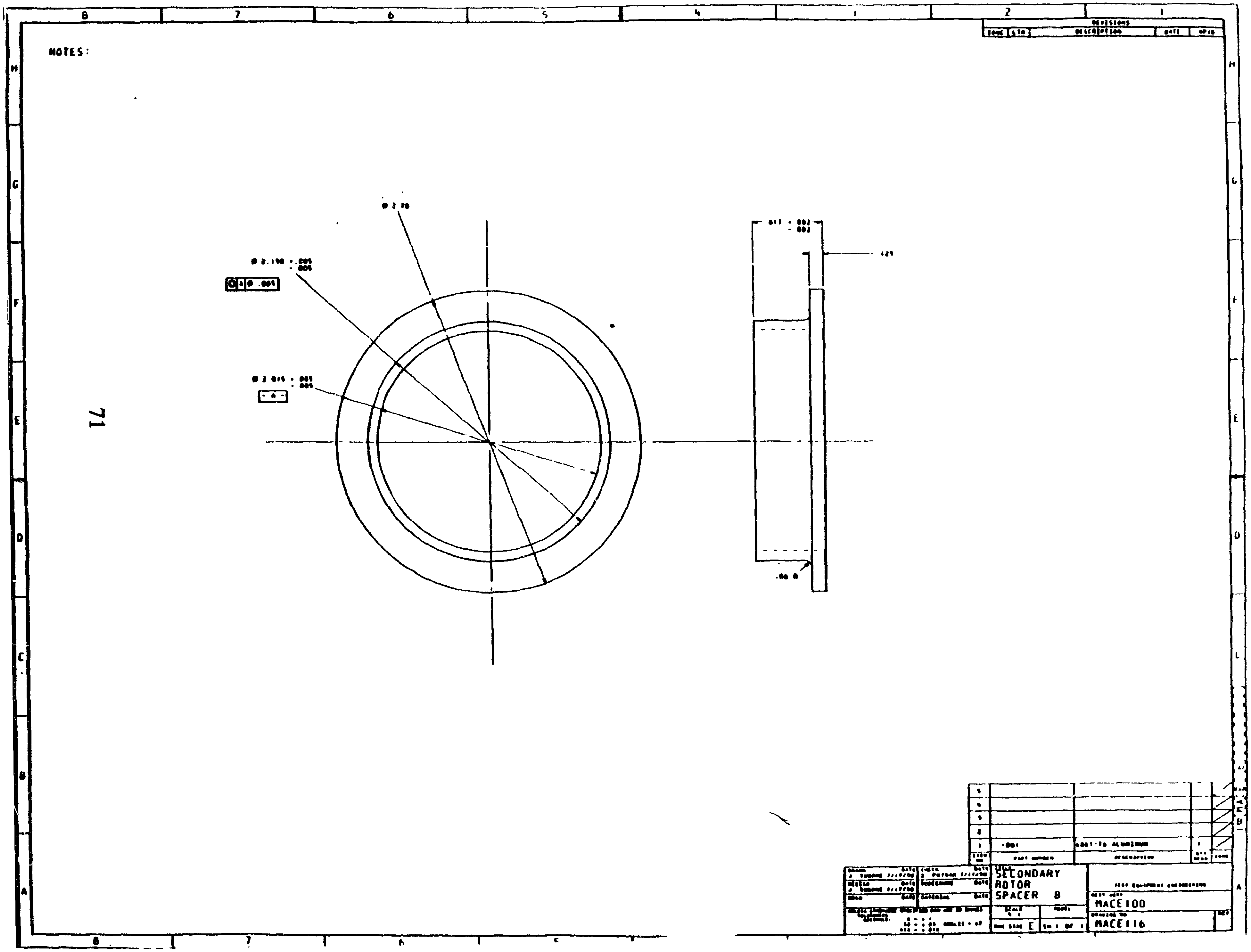
SSTX.PROGA
08/22/90

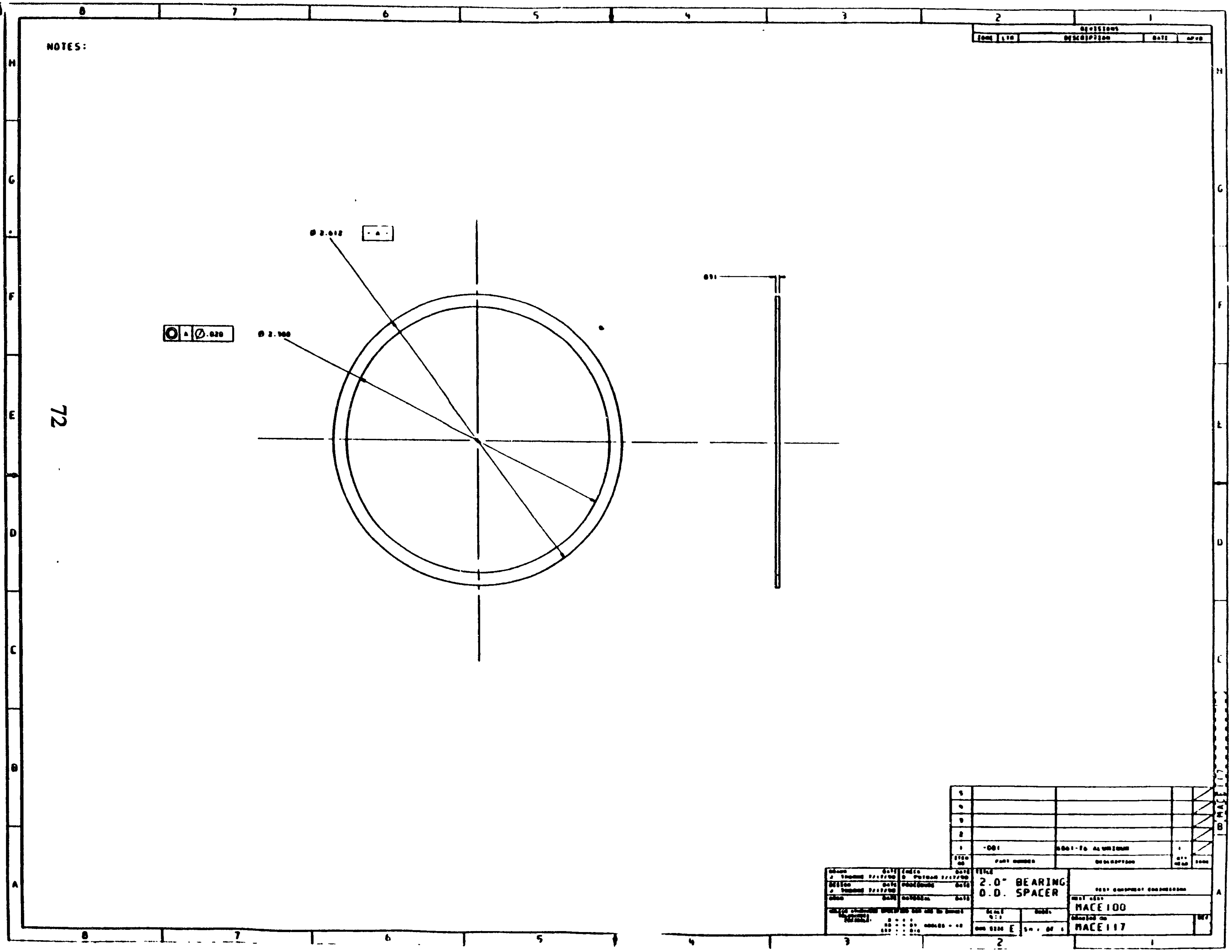


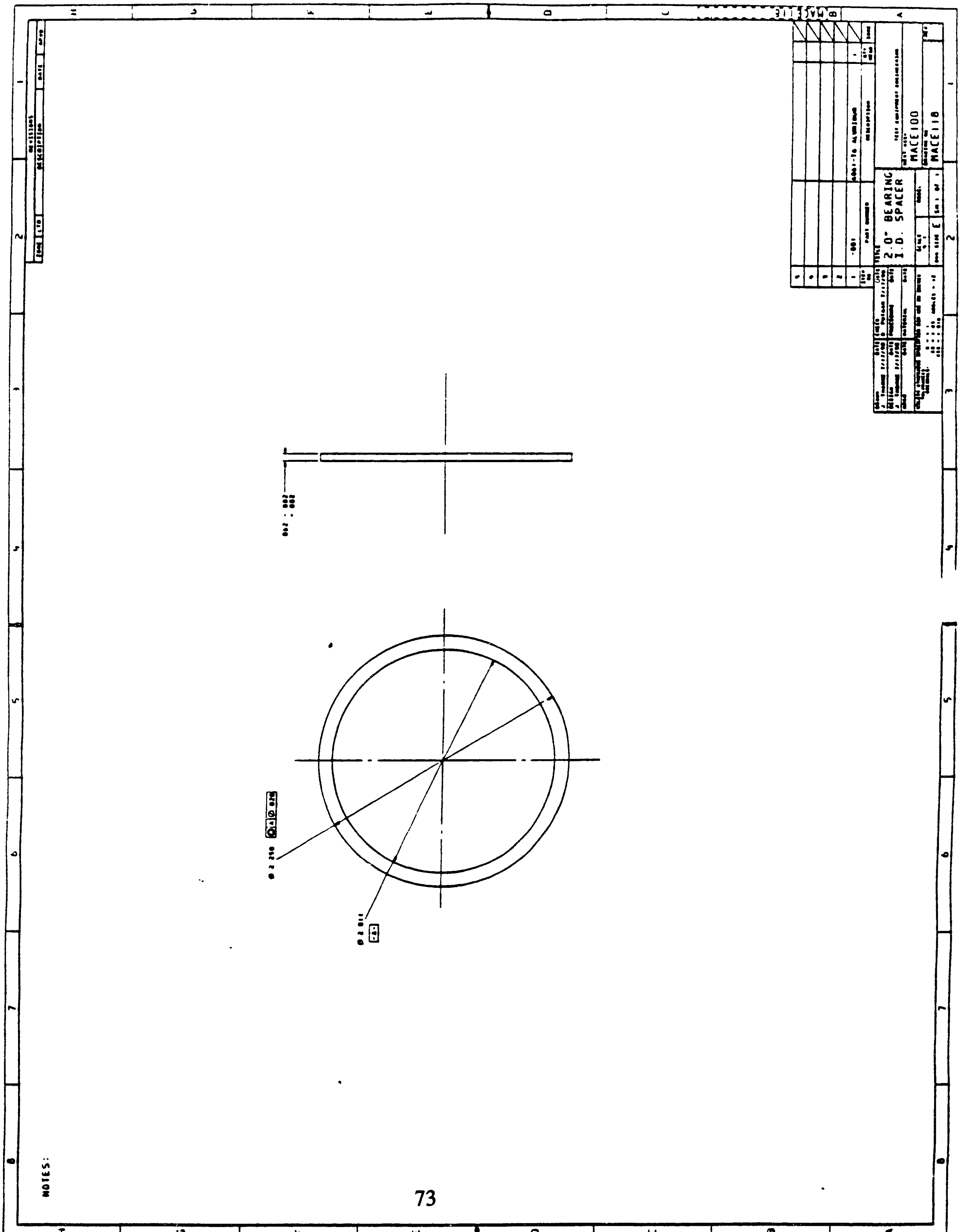

NOTES:
1 ALL RADII .02 TO SHARP UNLESS OTHERWISE NOTED
SECONDARY
STAGE
ROTOR
MACE100
MACE114


SECONDARY
ROTOR
SPACER A
MACE100
MACE115
NOTES:

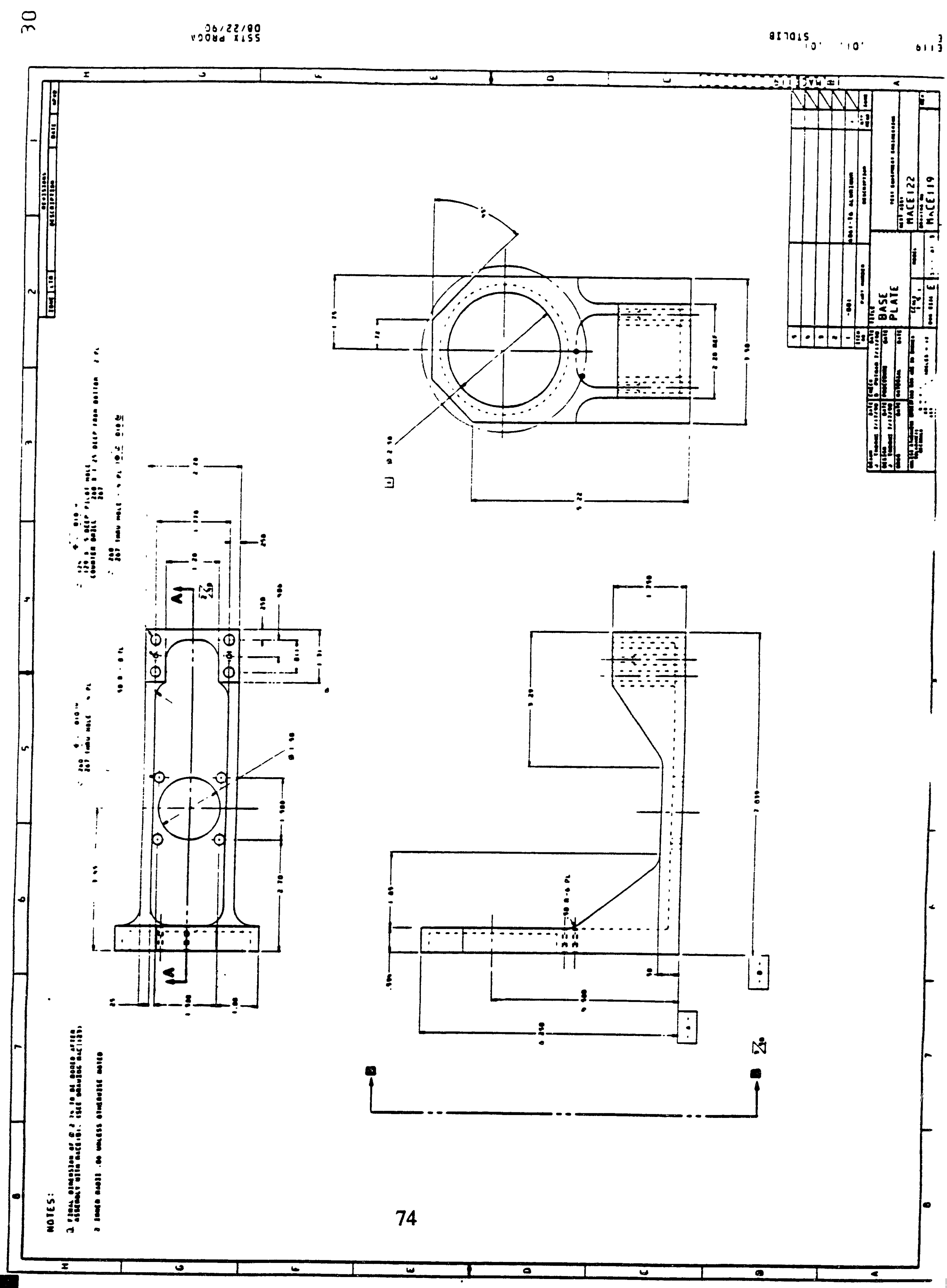
27


NOTES:
REVISIONS
SECONDARY
ROTOR
SPACER B
-001
6061-T6 ALUMINUM
MACE100
MACE116

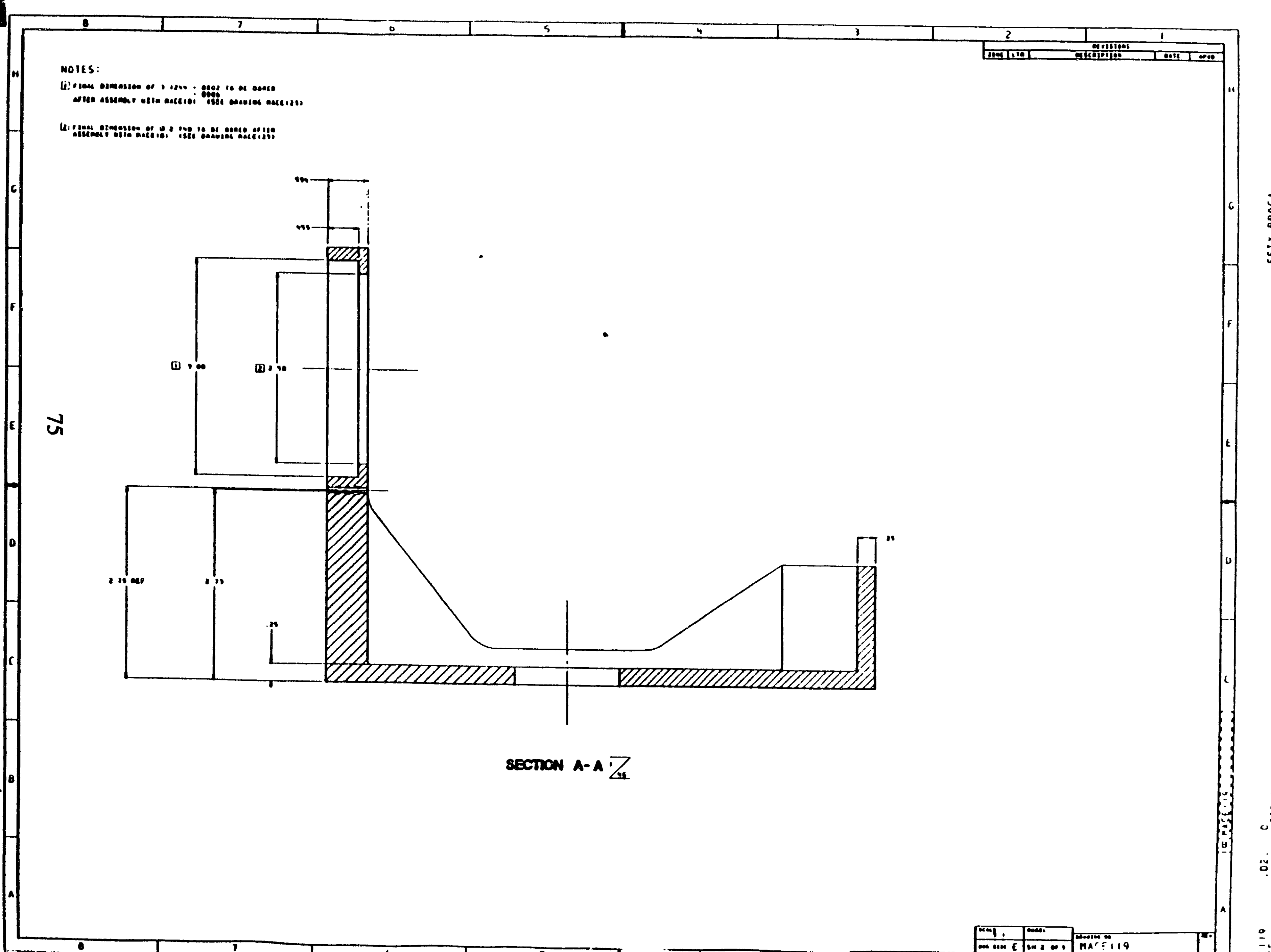

NOTES:
2.0" BEARING
O.D. SPACER
MACE100
MACE117
-001
6061-T6 ALUMINUM



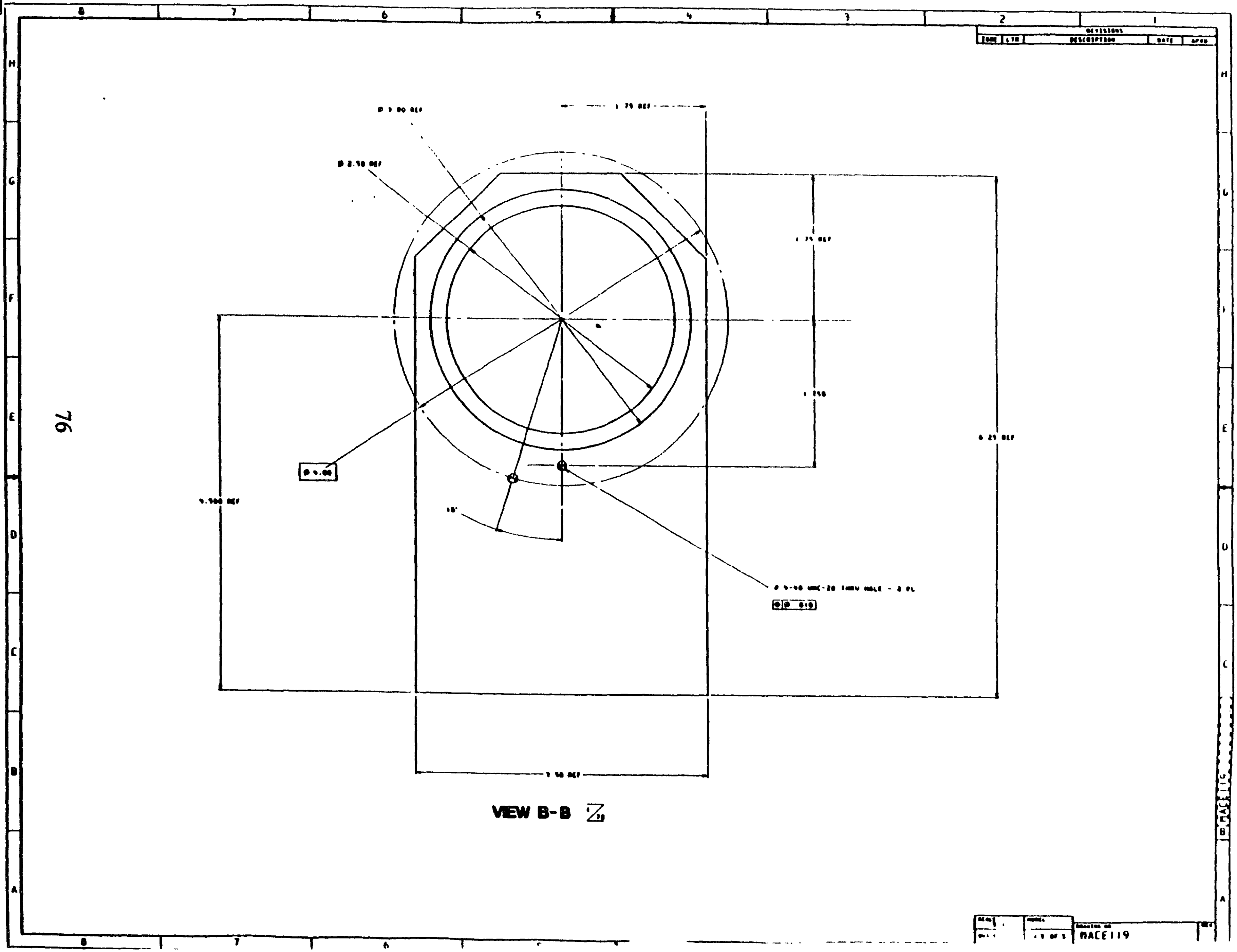
2.0" BEARING
I.D. SPACER
MACE100
MACE118
6061-T6 ALUMINUM
NOTES:

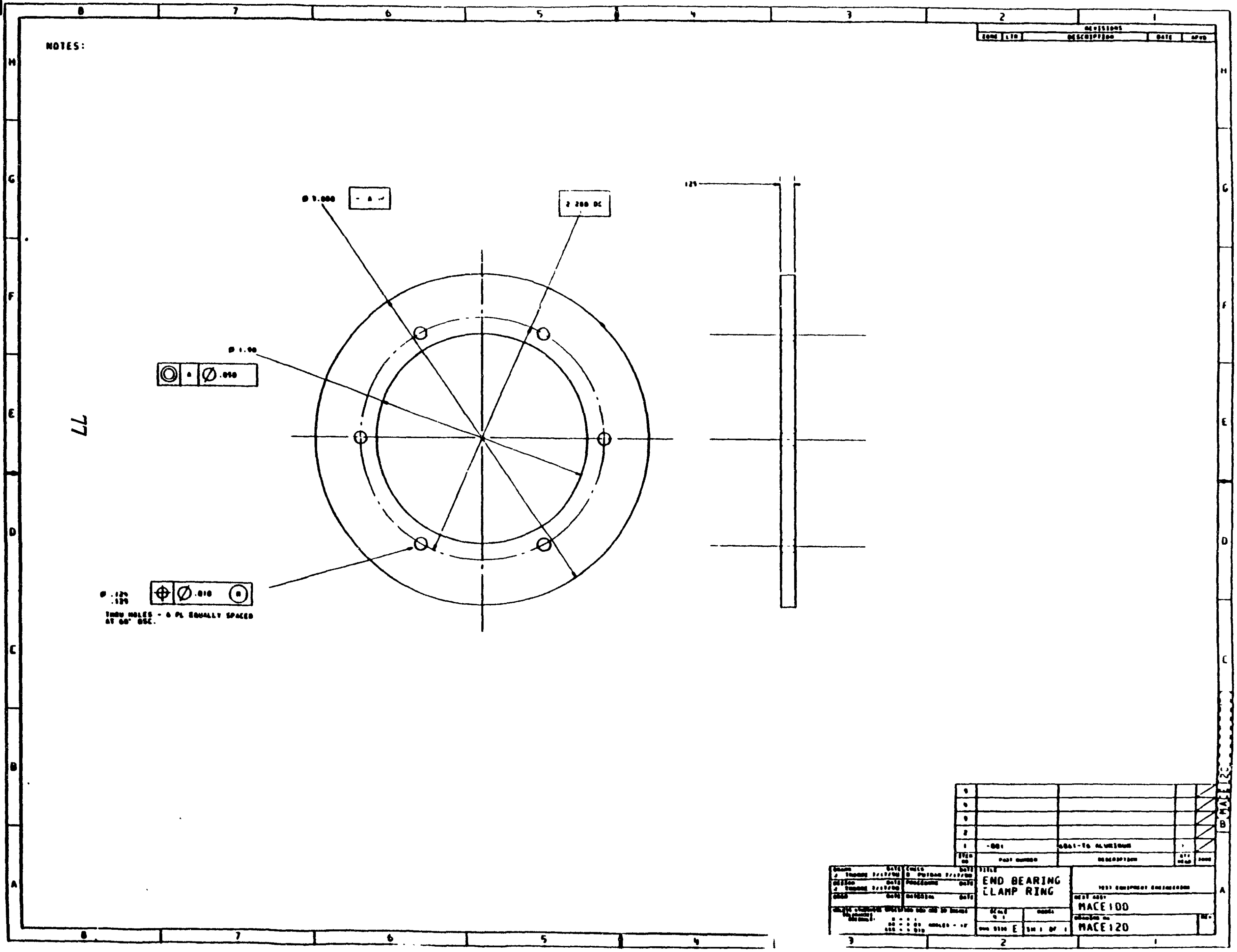

NOTES:
BASE PLATE
MACE122
MACE119

NOTES:



SECTION A-A

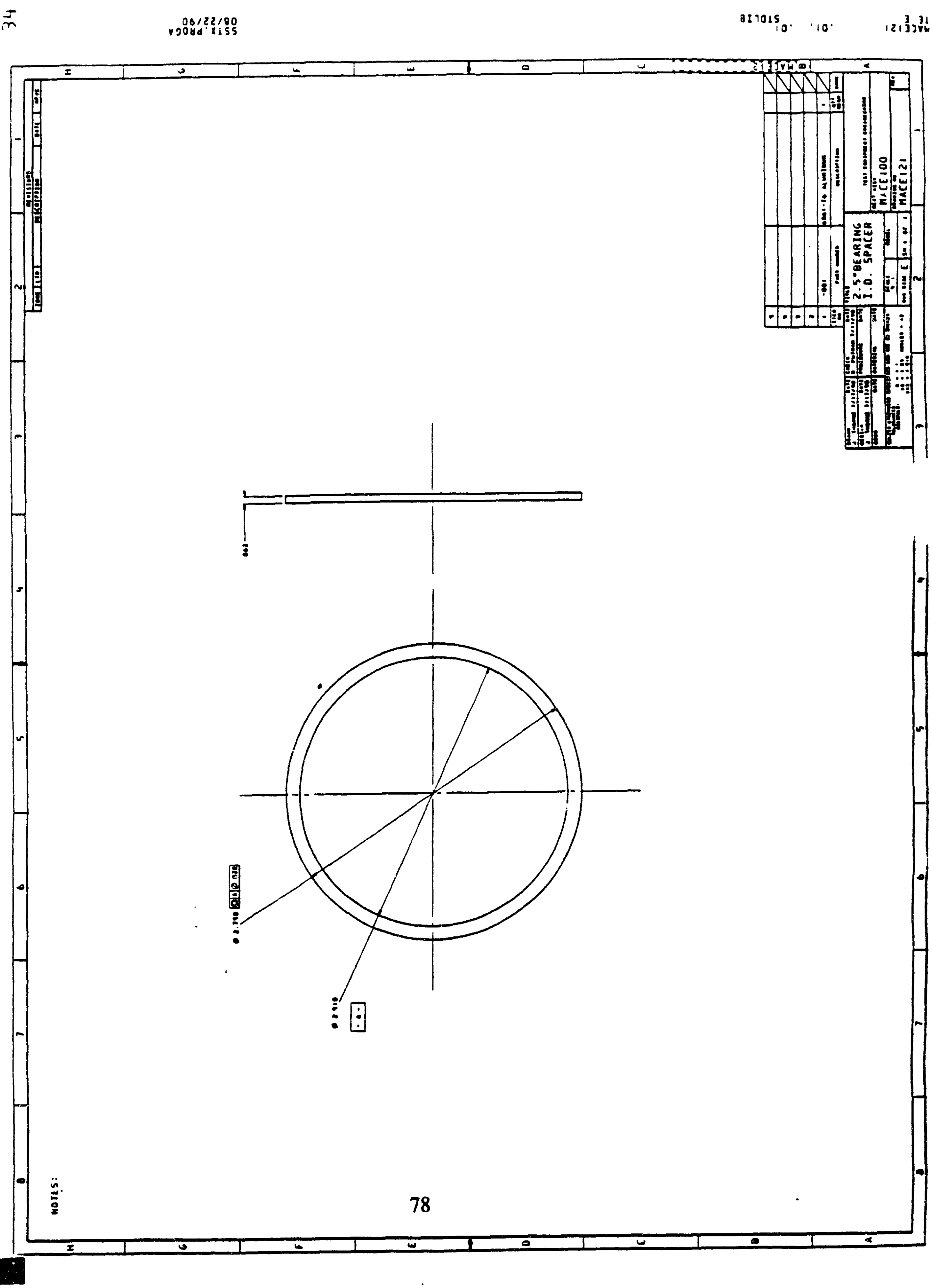

VIEW B-B
MACE119

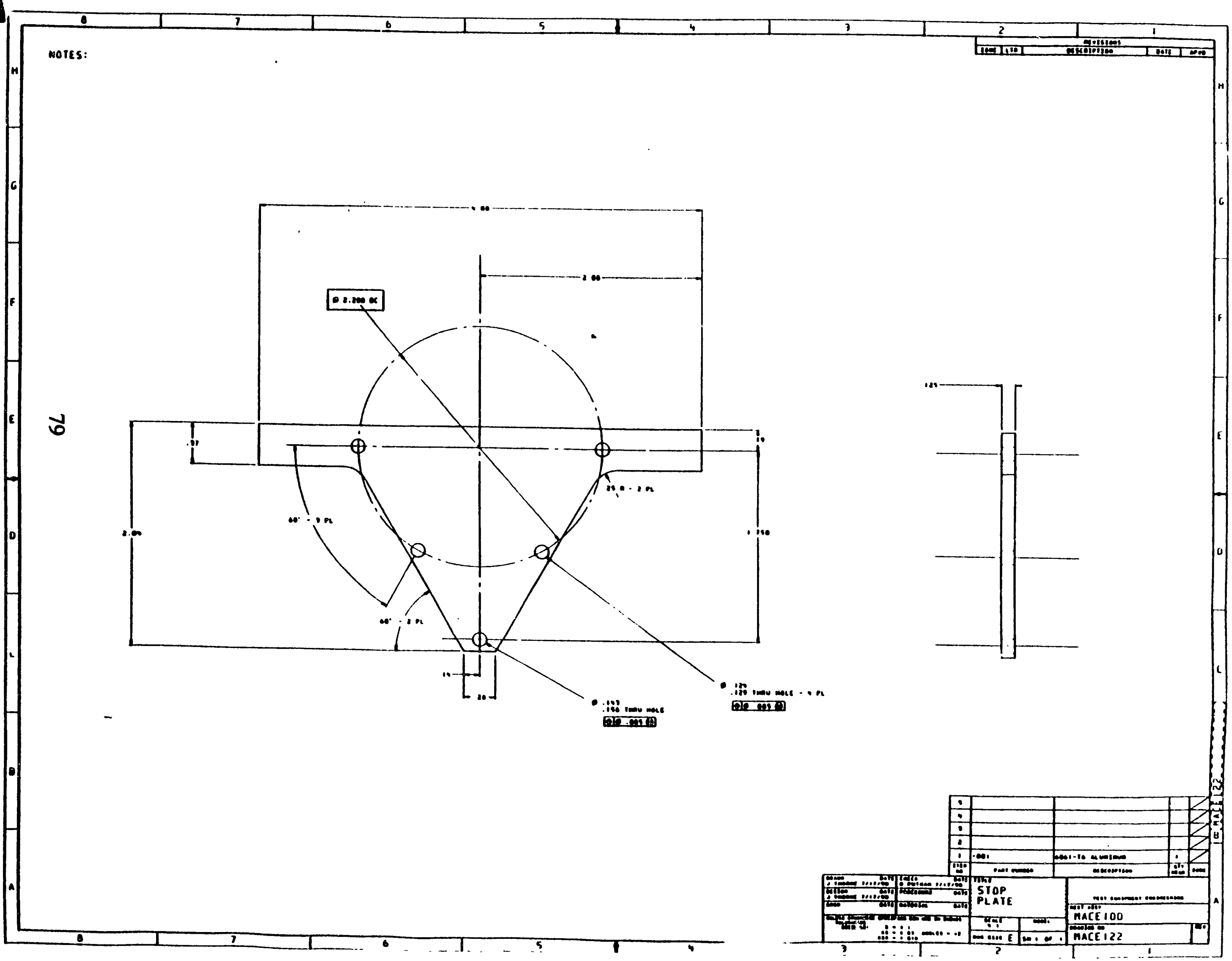


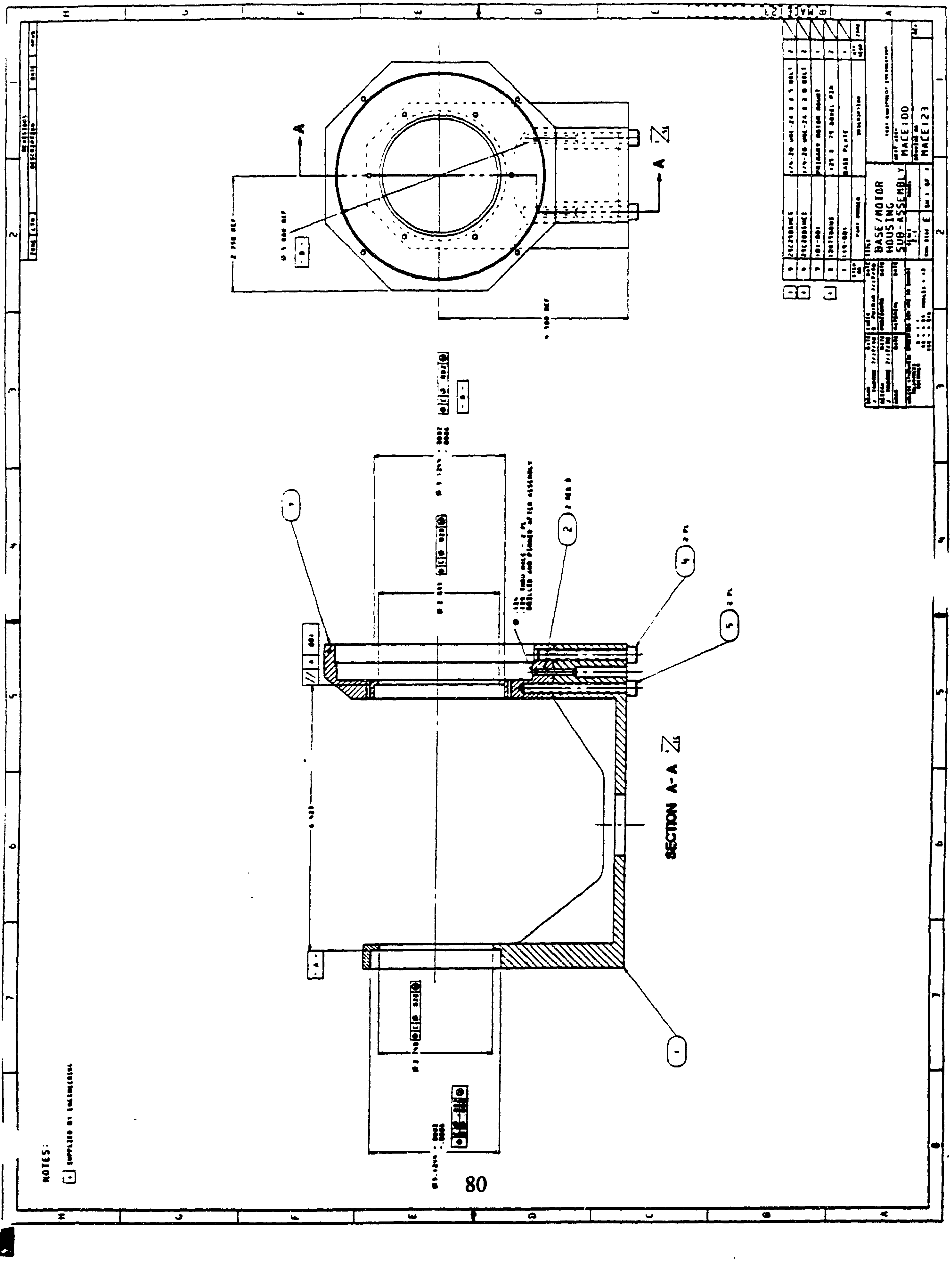
33

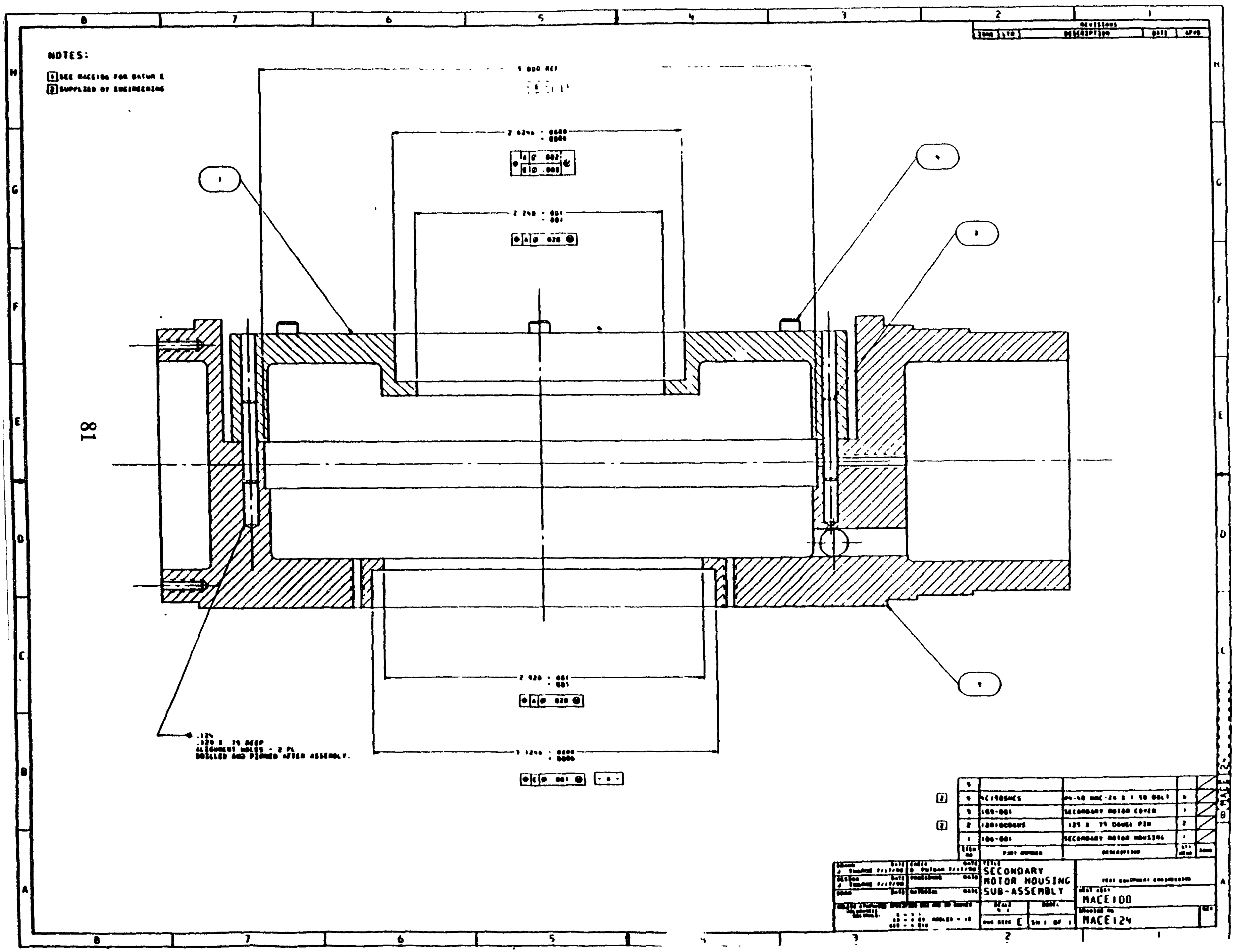
SSTX.PROGA
08/22/90

STDLIB


2.5" BEARING
I.D. SPACER
MACE100
MACE121
NOTES:


NOTES:
STOP
PLATE
MACE100
MACE122
Ø 2.200 BC
SSTX PROGA
08/22/90
STDLIB
35


SECTION A-A
BASE/MOTOR HOUSING SUB-ASSEMBLY
MACE100
MACE123
NOTES:



SSTX.PROGA
08/22/90

STDLIB

ACE SCNDRY MTR HSING SUBASS J THORNE.0/62-14

APPENDIX B

Component Specifications

An engineering material/component list for the gimbal assembly is presented showing time of purchase and acquisition in addition to cost of each component. Specifications for the gimbal components are presented where possible with the actual manufacturer specification literature.

MIT MACE GIMBAL EM	ENGINEERING MATERIAL / COMPONENT LIST

INDENTURE																	TITLE	ORDERED		PRICE		SUPPLIER / REMARKS
*	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16		ON	REC'D	UNIT	TOTAL	
	R	B	E	0	3	0	0	0	B	5	0						BRUSHLESS DC MOTOR	4/16/90	6/4/90	1050.00	2100.00	INLAND MOTOR CORP.
	B	C	L	0	2	8	1	0	A	0	0						MOTOR DRIVE AMPLIFIER	4/16/90	6/4/90	1300.00	2600.00	INLAND MOTOR CORP
	K	B	0	2	5	C	P	O									2.5" THIN WALL BEARING	6/13/90	7/10/90	86.25	345.00	KAYDON CORP.
	K	B	0	2	0	C	P	O									2.0" THIN WALL BEARING	6/13/90	7/10/90	76.25	152.50	KAYDON CORP.
	S	S	R	0	3	1	2	S	1	7							2.5" WAVE SPRING	7/5/90	7/13/90	7.68	92.16	SMALLEY STEEL RING
	S	S	R	S	0	3	1	2	S	1	7						2.5" SHIM STOCK	7/5/90	7/13/90	2.64	31.68	SMALLEY STEEL RING
	S	S	R	0	2	6	2	S	1	7							2.0" BEARING WAVE SPRING	7/13/90	7/22/90	7.98	15.96	SMALLEY STEEL RING
	S	S	R	S	0	2	6	2	S	1	7						2.0" SHIM STOCK	7/13/90	7/22/90	2.63	10.52	SMALLEY STEEL RING
	R	1	O														LASER ROTARY ENCODER	4/27/90	6/4/90	1950.00	3900.00	CANON U.S.A. INC.
	A	C	R	0	6	2	5	4									FLEXIBLE ENCODER COUPLING	7/2/90	7/10/90	11.18	134.16	HELICAL PRODUCTS
																						COMPONENT SUBTOTL
																						$9,292.98
	6	0	6	1	T	6	5	1	1								ALUMINUM STOCK	6/28/90	7/13/90		414.41	RYERSON & SONS, INC
																	MACHINING	8/6/90	10/9/90		12000.00	CHAMP MACHINING
																						MACHINING SUBTOTAL
																						$21,706.39
																	1/8" Al ROD STOCK		8/6/90			OLANDER CO.
																	1/8" DOWEL PINS		8/6/90			OLANDER CO.
																	ADJUSTABLE HOSE CLAMP		8/6/90			OLANDER CO.
																	RUBBER CUSHION STRIP		8/6/90			OLANDER CO.
																	4-40 BOLTS		8/6/90			OLANDER CO.
																	1/4-20 BOLTS		8/6/90			OLANDER CO.
																	M2 ENCODER SCREWS 5mm		8/6/90			OLANDER CO.
																	1/16" ROLL PIN		8/6/90			OLANDER CO.
																	LOCTITE		8/6/90			OLANDER CO.
																	KEENSERTS		8/6/90			OLANDER CO.
																	ROLL PIN		6/6/90			OLANDER CO.
																	TIE WRAPS		8/6/90			OLANDER CO.
																	#4 SPACERS		8/6/90			OLANDER CO.
																	.125 ADEL CLAMPS		8/6/90			OLANDER CO.
																	#4 SHOULDER BOLTS		8/6/90			OLANDER CO.
																						FASTENER SUBTOTAL
																						$49.06
																					TOTAL	$21,755.45

SIZE CONSTANTS

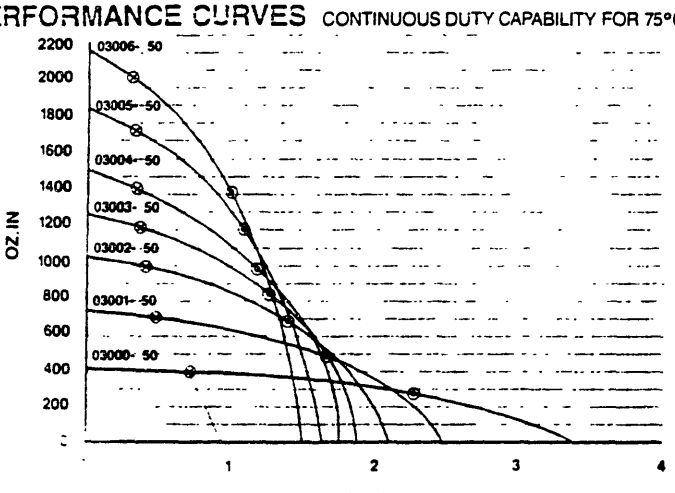
PARAMETERS / MODEL NO.		UNITS	RBE-03000-A50	RBE-03001-A50	RBE-03002-A50	RBE-03003-A50	RBE-03004-A50	RBE-03005-A50	RBE-03006-A50
Peak Rated Torque, ±25%		oz-in Nm	2074 14.6	3988 28.2	5971 42.2	7822 55.2	9452 66.7	11620 82.0	13799 97.4
Power at Peak Rated Torque		Watts	1532	2020	2495	3077	3441	3799	4085
Max. Continuous Stall Torque, T_C		oz-in Nm	413 2.9	723 5.1	1020 7.2	1254 8.9	1485 10.5	1630 12.9	2150 15.2
Max. Continuous Output Power		Watts	457.0	581.1	687.1	759.1	833.5	953.1	1026
Motor Constant, ± 15%, Km		oz-in/$\sqrt{W}$ Nm/$\sqrt{W}$	53.7 0.38	89.7 0.63	119.6 0.84	141.1 1.00	160.5 1.13	190.5 1.34	216.7 1.53
TPR, ± 15% +		(°C/W)	1.2	1.1	1.0	0.91	0.85	0.78	0.73
Viscous Damping, F_i		oz-in/RPM Nm/RPM	6.3x10^{-3} 4.4x10^{-5}	11.6x10^{-3} 8.2x10^{-5}	16.8x10^{-3} 11.9x10^{-5}	21.7x10^{-3} 15.3x10^{-5}	26.1x10^{-3} 18.4x10^{-5}	31.7x10^{-3} 22.4x10^{-5}	38.8x10^{-3} 27.4x10^{-5}
Hysteresis Drag Torque, T_F		oz-in Nm	8.61 0.06	16.03 0.11	23.39 0.16	30.28 0.21	36.46 0.26	44.47 0.31	54.06 0.38
Max. Cogging Torque		oz-in Nm	12.0 0.08	22.0 0.15	30.0 0.21	39.0 0.27	48.0 0.34	57.0 0.40	65.0 0.46
Frameless Motor	Inertia	oz-in-sec^2 Kg-m^2	3.9x10^{-2} 2.8x10^{-4}	6.8x10^{-2} 4.8x10^{-4}	9.9x10^{-2} 7.0x10^{-4}	12.8x10^{-2} 9.0x10^{-4}	15.4x10^{-2} 10.8x10^{-4}	18.9x10^{-2} 13.3x10^{-4}	21.6x10^{-2} 15.3x10^{-4}
	Weight	oz gm	39.6 1123	66.4 1882	96.6 2739	123 3487	147 4167	181 5131	208 5897
Housed Motor	Inertia	oz-in-sec^2 Kg-m^2	6.4x10^{-2} 4.5x10^{-4}	11.1x10^{-2} 7.8x10^{-4}	16.2x10^{-2} 11.4x10^{-4}	21.0x10^{-2} 14.8x10^{-4}	25.2x10^{-2} 17.8x10^{-4}	30.9x10^{-2} 21.8x10^{-4}	35.4x10^{-2} 25.0x10^{-4}
	Weight	oz gm	75 2126	113 3189	155 4376	192 5431	225 6366	272 7698	308 8741
No. of Poles			12	12	12	12	12	12	12

100 VOLT WINDING CONSTANTS   Alternate Windings Available

PARAMETERS		UNITS	RBE-03000-A50	RBE-03001-A50	RBE-03002-A50	RBE-03003-A50	RBE-03004-A50	RBE-03005-A50	RBE-03006-A50
Peak Torque, ± 25%, T_p		oz-in Nm	2016 14.2	3715 26.2	5450 38.5	6719 47.4	8115 57.3	10989 77.6	13172 93.0
Peak Current, ± 15%, I_p		Amps	14.1	17.2	20.8	22.7	25.6	33.3	37.0
Torque Sensitivity, ± 10%, K_T		oz-in/Amp Nm/Amp	143 1.00	216 1.52	262 1.85	296 2.09	317 2.24	330 2.33	356 2.51
No Load Speed, ± 10%		RPM	940	620	515	455	425	410	375
Voltage Constant, ± 10%, K_B		V/Rad/sec V/KRPM	1.00 105.70	1.52 159.66	1.85 193.67	2.09 218.80	2.24 234.32	2.33 243.93	2.51 263.15
Terminal Resistance, ± 12%, R_M		ohms @ 25°C	7.1	5.8	4.8	4.4	3.9	3.0	2.7
Terminal Inductance, ± 30%, L_M		mH	18.0	19.0	17.0	17.0	17.0	16.0	14.0
Max. Continuous Output Power	Power	Watts	210.0	248.7	293.3	319.9	355.5	426.3	466.3
	Torque	oz-in Nm	389.4 2.75	682.0 4.82	959.0 6.77	1178.1 8.32	1393.5 9.84	1706.8 12.05	2004.0 14.15
	Speed	RPM	729	493	413	367	345	337	314

+ TPR assumes housed motor mounted to 12.0 x 12.0 x .50" aluminum heat sink or equivalent.

PERFORMANCE CURVES   CONTINUOUS DUTY CAPABILITY FOR 75°C RISE

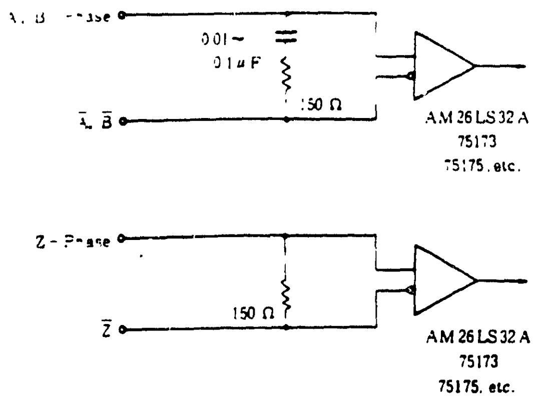


Design Features of RBE(H) Brushless Motors

- High torque to weight and inertia ratios
- Samarium cobalt rare earth magnets
- 3 phase delta or wye connection
- Housed or frameless designs
- Stationary outer stator winding rotating inner permanent magnet rotor
- Stainless steel shafts (housed versions)
- All motors built to MIL-Q-9858A
- Encapsulated windings available for harsh environments
- Built-in Hall effects for electronic commutation

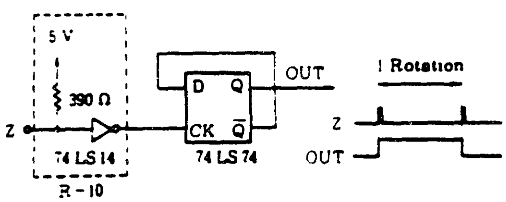
4020 E. Inland Road, Sierra Vista, Az. 85635   TEL 602-459-1150   TWX 910-973-9869   FAX 602-458-2161

R-1L



ADDITIONAL INFORMATION ABOUT THE Z-PHASE

1. The Z-phase outputs one pulse per rotation. But, because the pulse width is so narrow, viewing the waveform using a standard oscilloscope may be difficult. To view the waveform, use a storage oscilloscope, etc.
2. Another method for confirmation of the Z-phase output is to use a "D-flip-flop." By using the D flip-flop, two pulses are combined to make the pulse width wider and therefore easier to recognize.

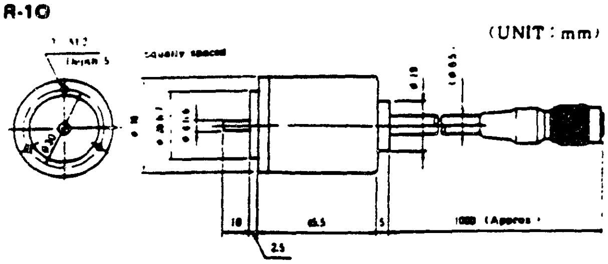


3. The pulse width of the Z-phase is 100 – 250 nsec. In case the receiving IC needs a wider pulse width increase the width using a one-shot multi-vibrator.

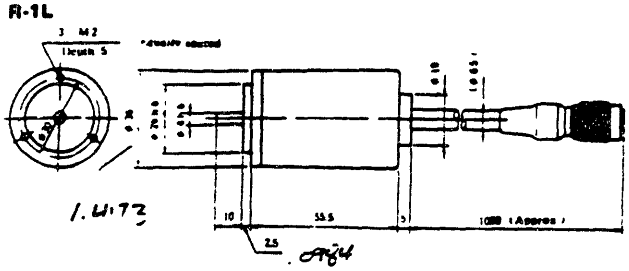
OUTLINE DIMENSIONS

R-1O

(UNIT : mm)



R-1L



SPECIFICATIONS

1. Unit pulse no./rotation:
   81,000 (without electric division)
2. Angle/pulse:
   16arc-sec. (Without electric division)
3. Max response. 500 kHz (6rps)
4. Output signal.
   81,000 pulses per rotation; 2-phase square wave incremental signals, plus a Z phase square wave signal
   a. A-phase and B-phase:
      R-1O Open collector output
         I_{OL} = 8mA Max (V_{OL} ≦ 0.4V)
         Recommended load resistance: 680Ω (5V)
         Pull-up voltage: 15V Max
      R-1L. Line driver output (Balanced)
         Load current: ±20mA Max
      Difference between A-phase and B-phase: 90° ±10° (Both R-1O and R-1L)
   b. Z-phase: 1 pulse/rotation:
      R-1O: Open collector output
         I_{OL} = 16mA Max. (V_{OL} ≦ 0.4V)
         Recommended load resistance: 390Ω (5V)
         Pull-up voltage: 5.25V Max
         Pulse width: 100 ~ 250 nsec.
      R-1L: Line driver output (Balanced)
         Load current: ±20mA Max
         Pulse width: 100 ~ 250 nsec.
5. Outer diameter: 36 mm
6. Overall length: R-1O: 48 mm; R-1L: 58 mm
7. Weight: R-1O: 80 g; R-1L: 95 g
8. Max. permissible rotating speed: 5,000 rpm
9. Starting torque: 3g-cm Max.
10. Rotor's intertial moment (GD^2): 8g-cm^2
11. Power supply (voltage): ±5V DC, ±5%
12. Power supply (current):
    R-1O: +5V ... 200mA Max. (Recommended load)
    -5V .. 100mA Max.;
    R-1L: +5V ... 250mA Max. (No load)
    -5V ... 100mA Max.
13. Light source:
    Semiconductor laser
    Wave length: 780nm,
    Max. output: 5mW
    Life cycle: 200,000 hours (MTTF, 30°C, 5mW)
14. Working environment:
    Operating temperature: 0°C – 50°C
    Storage temperature: –30°C – 80°C
    Humidity: 90% RH Max. (No condensation)
    Vibration: 10G 500 Hz or less
    Impact: 30G 11msec. or less
15. Max. permissible shaft load:
    Radial 0.4 kg
    Thrust 1.0 kg

For further details concerning the R-1, please direct inquiries to the following in writing or by telephone.

Canon

CANON U.S.A., INC.
Components Division One Canon Plaza
Lake Success, N.Y. 11042-9979 U. S. A.
Telephone 516/488-6700

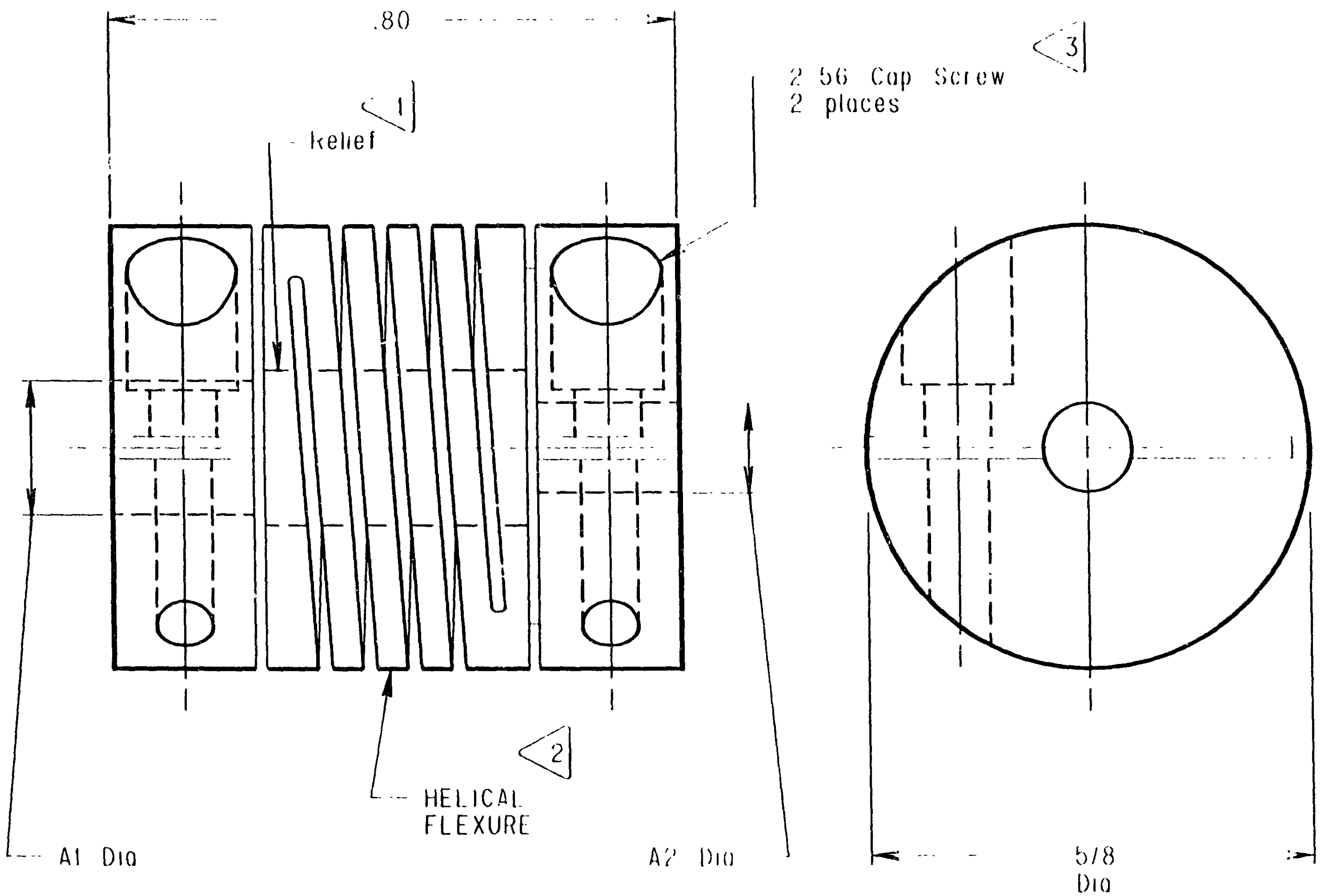
CANON EUROPA N. V.
Industrial Products Division
Unit 3, Brent Trading Centre, North Circular Road, Neasden
London NW 10 OJF, United Kingdom
Telephone (01)451-4511 Facsimile (01)459-0331
Telex 295776

CANON INC.
7-1, Nishi-Shinjuku 2-Chome, Shinjuku-ku, Tokyo 163, Japan.
Mailing address: P O. Box 5060. Dai-ichi Seimei Building, Tokyo 163, Japan.

Y5094 DWG NO **ACR 062** SH 1 of 2

Notes: See Tabulated Sheet

1. Relief permits component shafts to near butt.
2. Hubs and HELI-CAL FLEXURE are made from a single piece of material.
3. Integral Clamp attachment, hex. socket, cap screw furnished: both hubs.
4. Backlash: None. No lubrication required.
5. Permitted axial motion from free length: ± .010in
6. RPM: Up to 10,000, depending upon application.
7. Working torque ratings are based upon continuous duty with noted misalignments applied separately and may be increased with improved alignment: See Tabulated Sheet
8. Permissable shaft misalignment: Angular, up to 5 degrees; Offset, up to .010in. (TIR .020in.)



ACR 062-6-4 SHOWN

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DO NOT SCALE DRAWING

8-16 89	Clerical format update/ no revision BJM

Unless otherwise noted dimensions in inches

Tolerances are
Fractions ± 1/64
Decimals: XX ± .010
XXX ± .005
XXXX ± .0010
Angles ± 1/2 degree
Break sharp corners .010 max

APPROVALS		DATE
DRAWN	MC	1 2 80
CHECKED	MC	1 2 80
PRODN	APA	1 2 80
ISSUED		
WEIGHT		10g (ea)

HELICAL PRODUCTS CO., INC.
P.O. BOX 1069 SANTA MARIA, CA 93456 U.S.A.
PHONE (805) 928-3851 FSC13201

TITLE	HELICAL FLEXIBLE SHAFT COUPLING
MATERIAL	7075 T6 Aluminum Alloy
FINISH	Chromic Acid Anodize, Type 1

Wave Springs

Serial number:SSR0312S17,SSR0262S17
Manufacturer: Smalley Steel Ring Co.
Size: 2.5" diameter, 2" diameter
Stiffness: 515 lb/in
Material: stainless steel

Motor Amplifier

Serial number: BCL02810A00
Manufacturer: Inland Motor, Kollmorgan Corp.
Power: 2000 W
Type: current controlled, with hall effect sensor commutation

Bearings

Serial number: KB025CPO, KB020CPO
Manufacturer: Kaydon Bearing Corp.
Size: 2.5", 2.0"
Type: thin profile, deep groove

APPENDIX C

Bearing Analysis

The results from the A.B. Jones bearing analysis program are presented. The bearing analysis takes the dynamic loading values for axial and radial load, applied moment and preload stiffness and calculates bearing characteristics by modeling each rcller ball in the bearing as an element in a finite element model.

HIGH-SPEED BALL AND RADIAL ROLLER BEARING ANALYSIS PROGRAM
A PROPRIETARY ITEM OF A. B. JONES, CONSULTING ENGINEER, NEWINGTON, CONNECTICUT 06111
08/01/83

MACE KAYDON KB025CPO CONRAD (515#/in spring,25 LB Preload, 5#thrust10# radial)
BY S.H. LOEWENTHAL 3-2491 7/13/90

* INPUT DATA FOR SYSTEM NO. 1

BEARING NUMBER	BEARING TYPE	NUMBER OF ELEMENTS	ELEMENT DIAMETER	PITCH DIAMETER	RACE CURVATURES OUTER	INNER	CONTACT ANGLE INITIAL	MOUNTED	INTERNAL CLEARANCE INCREMENT	MOUNTED
1	BALL	2.8000E+01	1.5620E-01	2.8125E+00	5.5040E-01	5.5040E-01	-1.0000E-03	-1.4478E+01	1.0000E-03	1.0000E-03
2	BALL	2.8000E+01	1.5620E-01	2.8125E+00	5.5040E-01	5.5040E-01	1.0000E-03	1.4478E+01	1.0000E-03	1.0000E-03

BEARING NUMBER	TOTAL ROLL LENGTH	ROLL FLAT LENGTH	ROLL CROWN RADIUS	ROLL CROWN DROP	CROWN DROP GAGE POINT	ROLL END RADIUS	RACE RADIUS OUTER	INNER	RACE CONE SLOPE OUTER	INNER
1	0.0000E-01	0.0000E-01	0.0000E-01	0.0000E-01	0.0000E-01	0.0000E-01	0.0000E-01	0.0000E-01	0.0000E-01	0.0000E-01
2	0.0000E-01	0.0000E-01	0.0000E-01	0.0000E-01	0.0000E-01	0.0000E-01	0.0000E-01	0.0000E-01	0.0000E-01	0.0000E-01

BEARING NUMBER	MODULUS OF ELASTICITY OUTER	INNER	ELEMENT	POISSON'S RATIO OUTER	INNER	ELEMENT	AXIAL PRELOAD	PRELOAD DEFLECTION	CONSTRAINT-SPRING RATES AXIAL	RADIAL
1	2.9000E+07	2.9000E+07	2.9000E+07	2.8000E-01	2.8000E-01	2.8000E-01	-2.5000E+01	-3.2827E-04	5.1500E+02	0.0000E-01
2	2.9000E+07	2.9000E+07	2.9000E+07	2.8000E-01	2.8000E-01	2.8000E-01	2.5000E+01	3.2827E-04	0.0000E-01	0.0000E-01

BEARING NUMBER	SHIM THICKNESS OUTER	INNER	INITIAL DISPLACEMENTS AT BEARING CENTER ALONG X	ALONG Y	ALONG Z	ABOUT Y	ABOUT Z	1.= OUTER RING FLOATS AXIALLY	RADIALLY	PHASE FACTOR
1	0.0000E-01	0.0000E-01	0.0000E-01	0.0000E-01	0.0000E-01	0.0000E-01	0.0000E-01	1.0000E+00	0.0000E-01	0.0000E-01
2	0.0000E-01	0.0000E-01	0.0000E-01	0.0000E-01	0.0000E-01	0.0000E-01	0.0000E-01	0.0000E-01	0.0000E-01	0.0000E-01

BEARING NUMBER	ELEMENT DENSITY	COEF. OF FRICTION	I.D. OF BALL	FLEXURE CONSTANT	BALL DIA. EXPONENT	BEARING LOCATION	LIFE MULTIPLIER OUTER	INNER	SINGLE BEARING ENDPLAY MOUNTED	UNMOUNTED
1	2.8000E-01	2.0000E-01	0.0000E-01	0.0000E-01	1.8000E+00	-3.5000E+00	1.0000E+00	1.0000E+00	7.8727E-03	5.4960E-07
2	2.8000E-01	2.0000E-01	0.0000E-01	0.0000E-01	1.8000E+00	3.5000E+00	1.0000E+00	1.0000E+00	7.8727E-03	5.4960E-07

BEARING NUMBER	RMS SURFACE ROUGHNESS OUTER	INNER	ELEMENT
1	8.0000E-06	8.0000E-06	2.0000E-06
2	8.0000E-06	8.0000E-06	2.0000E-06

* INPUT DATA FOR LOAD NO. 1, SYSTEM NO. 1

LOAD NUMBER	EXTERNAL LOADS APPLIED TO SHAFT ALONG X	ALONG Y	ALONG Z	ABOUT Y	ABOUT Z	DISTANCE FROM ORIGIN	RPM OF OUTER	RPM OF INNER	DURATION PERCENT
1	5.0000E+00	0.0000E-01	1.0000E+01	1.0000E+00	0.0000E-01	0.0000E-01	0.0000E-01	1.0000E+00	100.0000

INITIAL ESTIMATES OF DISPLACEMENTS AT ORIGIN

ALONG X	ALONG Y	ALONG Z	ABOUT Y	ABOUT Z
-1.0000E-05	-1.0000E-05	-1.0000E-05	0.0000E-01	0.0000E-01

THE OUTER RACES ARE STATIONARY WITH RESPECT TO LOAD

THE INNER RACES ROTATE WITH RESPECT TO LOAD

* OUTPUT DATA FOR BEARING NO. 1

ELEMENT NUMBER	ELEMENT AZIMUTH	CONTACT LOAD OUTER	CONTACT LOAD INNER	CONTACT ANGLE OUTER	CONTACT ANGLE INNER	CONTACT DEFLECTION OUTER	CONTACT DEFLECTION INNER	MEAN HERTZ STRESS OUTER	MEAN HERTZ STRESS INNER	TYPE OF CONTROL
1	0.0000E-01	2.9595E+00	2.9595E+00	-1.5635E+01	-1.5635E+01	3.9302E-05	3.9762E-05	9.6320E+04	1.0093E+05	INNER
2	1.2857E+01	2.9682E+00	2.9682E+00	-1.5635E+01	-1.5635E+01	3.9379E-05	3.9840E-05	9.6414E+04	1.0103E+05	INNER
3	2.5714E+01	2.9939E+00	2.9940E+00	-1.5635E+01	-1.5635E+01	3.9607E-05	4.0070E-05	9.6692E+04	1.0132E+05	INNER
4	3.8571E+01	3.0356E+00	3.0356E+00	-1.5634E+01	-1.5634E+01	3.9974E-05	4.0441E-05	9.7139E+04	1.0179E+05	INNER
5	5.1429E+01	3.0914E+00	3.0914E+00	-1.5633E+01	-1.5633E+01	4.0461E-05	4.0934E-05	9.7730E+04	1.0240E+05	INNER
6	6.4286E+01	3.1585E+00	3.1585E+00	-1.5631E+01	-1.5631E+01	4.1045E-05	4.1525E-05	9.8432E+04	1.0314E+05	INNER
7	7.7143E+01	3.2339E+00	3.2340E+00	-1.5630E+01	-1.5630E+01	4.1696E-05	4.2184E-05	9.9210E+04	1.0396E+05	INNER
8	9.0000E+01	3.3139E+00	3.3139E+00	-1.5628E+01	-1.5628E+01	4.2381E-05	4.2876E-05	1.0002E+05	1.0481E+05	INNER
9	1.0286E+02	3.3947E+00	3.3946E+00	-1.5627E+01	-1.5627E+01	4.3066E-05	4.3569E-05	1.0083E+05	1.0565E+05	INNER
10	1.1571E+02	3.4719E+00	3.4719E+00	-1.5625E+01	-1.5625E+01	4.3717E-05	4.4228E-05	1.0159E+05	1.0644E+05	INNER
11	1.2857E+02	3.5417E+00	3.5417E+00	-1.5624E+01	-1.5624E+01	4.4301E-05	4.4819E-05	1.0226E+05	1.0715E+05	INNER
12	1.4143E+02	3.6003E+00	3.6002E+00	-1.5623E+01	-1.5623E+01	4.4788E-05	4.5312E-05	1.0282E+05	1.0774E+05	INNER
13	1.5429E+02	3.6446E+00	3.6446E+00	-1.5622E+01	-1.5622E+01	4.5155E-05	4.5683E-05	1.0324E+05	1.0818E+05	INNER
14	1.6714E+02	3.6722E+00	3.6722E+00	-1.5622E+01	-1.5622E+01	4.5383E-05	4.5913E-05	1.0350E+05	1.0845E+05	INNER
15	1.8000E+02	3.6816E+00	3.6816E+00	-1.5622E+01	-1.5622E+01	4.5460E-05	4.5991E-05	1.0359E+05	1.0855E+05	INNER
16	1.9286E+02	3.6722E+00	3.6722E+00	-1.5622E+01	-1.5622E+01	4.5383E-05	4.5913E-05	1.0350E+05	1.0845E+05	INNER
17	2.0571E+02	3.6446E+00	3.6446E+00	-1.5622E+01	-1.5622E+01	4.5155E-05	4.5683E-05	1.0324E+05	1.0818E+05	INNER
18	2.1857E+02	3.6003E+00	3.6002E+00	-1.5623E+01	-1.5623E+01	4.4788E-05	4.5312E-05	1.0282E+05	1.0774E+05	INNER
19	2.3143E+02	3.5417E+00	3.5417E+00	-1.5624E+01	-1.5624E+01	4.4301E-05	4.4819E-05	1.0226E+05	1.0715E+05	INNER
20	2.4429E+02	3.4719E+00	3.4719E+00	-1.5625E+01	-1.5625E+01	4.3717E-05	4.4228E-05	1.0159E+05	1.0644E+05	INNER
21	2.5714E+02	3.3947E+00	3.3946E+00	-1.5627E+01	-1.5627E+01	4.3066E-05	4.3569E-05	1.0083E+05	1.0565E+05	INNER
22	2.7000E+02	3.3139E+00	3.3139E+00	-1.5628E+01	-1.5628E+01	4.2381E-05	4.2876E-05	1.0002E+05	1.0481E+05	INNER
23	2.8286E+02	3.2339E+00	3.2340E+00	-1.5630E+01	-1.5630E+01	4.1696E-05	4.2184E-05	9.9210E+04	1.0396E+05	INNER
24	2.9571E+02	3.1585E+00	3.1585E+00	-1.5631E+01	-1.5631E+01	4.1045E-05	4.1525E-05	9.8432E+04	1.0314E+05	INNER
25	3.0857E+02	3.0914E+00	3.0914E+00	-1.5633E+01	-1.5633E+01	4.0461E-05	4.0934E-05	9.7730E+04	1.0240E+05	INNER
26	3.2143E+02	3.0356E+00	3.0356E+00	-1.5634E+01	-1.5634E+01	3.9974E-05	4.0441E-05	9.7139E+04	1.0179E+05	INNER
27	3.3429E+02	2.9939E+00	2.9940E+00	-1.5635E+01	-1.5635E+01	3.9607E-05	4.0070E-05	9.6692E+04	1.0132E+05	INNER
28	3.4714E+02	2.9682E+00	2.9682E+00	-1.5635E+01	-1.5635E+01	3.9379E-05	3.9840E-05	9.6414E+04	1.0103E+05	INNER

ELEMENT NUMBER	CONTACT AREA LENGTH OUTER	CONTACT AREA LENGTH INNER	CONTACT AREA WIDTH OUTER	CONTACT AREA WIDTH INNER	GYROSCOPIC MOMENT	CENTRIFUGAL FORCE	SPINNING VELOCITY OUTER	SPINNING VELOCITY INNER	ROLLING VELOCITY OUTER	ROLLING VELOCITY INNER
1	1.3419E-02	1.3557E-02	2.9154E-03	2.7539E-03	4.6802E-11	4.9943E-09	-2.6951E-01	0.0000E-01	-8.5214E+00	9.4844E+00
2	1.3432E-02	1.3571E-02	2.9183E-03	2.7566E-03	4.6802E-11	4.9943E-09	-2.6951E-01	0.0000E-01	-8.5214E+00	9.4844E+00
3	1.3470E-02	1.3610E-02	2.9267E-03	2.7645E-03	4.6800E-11	4.9943E-09	-2.6950E-01	0.0000E-01	-8.5214E+00	9.4844E+00
4	1.3533E-02	1.3673E-02	2.9402E-03	2.7773E-03	4.6798E-11	4.9943E-09	-2.6949E-01	0.0000E-01	-8.5214E+00	9.4844E+00
5	1.3615E-02	1.3756E-02	2.9581E-03	2.7942E-03	4.6795E-11	4.9943E-09	-2.6947E-01	0.0000E-01	-8.5214E+00	9.4844E+00
6	1.3713E-02	1.3855E-02	2.9794E-03	2.8143E-03	4.6791E-11	4.994[illegible]	2.6945E-01	0.0000E-01	-8.5214E+00	9.4844E+00

7	[illegible]	1.3964E-02	3.0029E-03	2.8365E-03	4.6787E-[illegible]	4.9943E-09	-2.6942[illegible]	0.0000E-01	-8[illegible]	9.4844E+00
8	[illegible]	1.4078E-02	3.0275E-03	2.8597E-03	4.6782E-[illegible]	4.9943E-09	-2.6940E-01	0.0000E-01	-8.[illegible]	9.4844[illegible]
9	1.4046E-02	1.4192E-02	3.0519E-03	2.8827E-03	4.6778E-[illegible]	4.9943E-09	-2.6937E-01	0.0000E-01	-8.52[illegible]E+00	9.4844[illegible]
10	1.4152E-02	1.4299E-02	3.0748E-03	2.9044E-03	4.6774E-11	4.9943E-09	-2.6935E-01	0.0000E-01	-8.5214E+00	9.4844E+00
11	1.4246E-02	1.4394E-02	3.0953E-03	2.9237E-03	4.6770E-11	4.9943E-09	-2.6933E-01	0.0000E-01	-8.5214E+00	9.4844E+00
12	1.4325E-02	1.4473E-02	3.1123E-03	2.9398E-03	4.6767E-11	4.9943E-09	-2.6931E-01	0.0000E-01	-8.5214E+00	9.4844E+00
13	1.4383E-02	1.4532E-02	3.1250E-03	2.9518E-03	4.6765E-11	4.9943E-09	-2.6929E-01	0.0000E-01	-8.5214E+00	9.4844E+00
14	1.4419E-02	1.4568E-02	3.1329E-03	2.9592E-03	4.6763E-11	4.9943E-09	-2.6929E-01	0.0000E-01	-8.5214E+00	9.4844E+00
15	1.4432E-02	1.4581E-02	3.1355E-03	2.9617E-03	4.6763E-11	4.9943E-09	-2.6928E-01	0.0000E-01	-8.5214E+00	9.4844E+00
16	1.4419E-02	1.4568E-02	3.1329E-03	2.9592E-03	4.6763E-11	4.9943E-09	-2.6929E-01	0.0000E-01	-8.5214E+00	9.4844E+00
17	1.4383E-02	1.4532E-02	3.1250E-03	2.9518E-03	4.6765E-11	4.9943E-09	-2.6929E-01	0.0000E-01	-8.5214E+00	9.4844E+00
18	1.4325E-02	1.4473E-02	3.1123E-03	2.9398E-03	4.6767E-11	4.9943E-09	-2.6931E-01	0.0000E-01	-8.5214E+00	9.4844E+00
19	1.4246E-02	1.4394E-02	3.0953E-03	2.9237E-03	4.6770E-11	4.9943E-09	-2.6933E-01	0.0000E-01	-8.5214E+00	9.4844E+00
20	1.4152E-02	1.4299E-02	3.0748E-03	2.9044E-03	4.6774E-11	4.9943E-09	-2.6935E-01	0.0000E-01	-8.5214E+00	9.4844E+00
21	1.4046E-02	1.4192E-02	3.0519E-03	2.8827E-03	4.6778E-11	4.9943E-09	-2.6937E-01	0.0000E-01	-8.5214E+00	9.4844E+00
22	1.3934E-02	1.4078E-02	3.0275E-03	2.8597E-03	4.6782E-11	4.9943E-09	-2.6940E-01	0.0000E-01	-8.5214E+00	9.4844E+00
23	1.3821E-02	1.3964E-02	3.0029E-03	2.8365E-03	4.6787E-11	4.9943E-09	-2.6942E-01	0.0000E-01	-8.5214E+00	9.4844E+00
24	1.3713E-02	1.3855E-02	2.9794E-03	2.8143E-03	4.6791E-11	4.9943E-09	-2.6945E-01	0.0000E-01	-8.5214E+00	9.4844E+00
25	1.3615E-02	1.3756E-02	2.9581E-03	2.7942E-03	4.6795E-11	4.9943E-09	-2.6947E-01	0.0000E-01	-8.5214E+00	9.4844E+00
26	1.3533E-02	1.3673E-02	2.9402E-03	2.7773E-03	4.6798E-11	4.9943E-09	-2.6949E-01	0.0000E-01	-8.5214E+00	9.4844E+00
27	1.3470E-02	1.3610E-02	2.9267E-03	2.7645E-03	4.6800E-11	4.9943E-09	-2.6950E-01	0.0000E-01	-8.5214E+00	9.4844E+00
28	1.3432E-02	1.3571E-02	2.9183E-03	2.7566E-03	4.6802E-11	4.9943E-09	-2.6951E-01	0.0000E-01	-8.5214E+00	9.4844E+00

ELEMENT NUMBER	SPINNING TORQUE OUTER	SPINNING TORQUE INNER	ROLLING TORQUE OUTER	ROLLING TORQUE INNER	ORBITAL VELOCITY	ROTATIONAL VELOCITY	OUTER PATH EXTREMITIES UPPER EDGE	OUTER PATH EXTREMITIES LOWER EDGE	INNER PATH EXTREMITIES UPPER EDGE	INNER PATH EXTREMITIES LOWER EDGE
1	1.5752E-03	1.5825E-03	2.6836E-05	2.7390E-05	4.7326E-01	-8.9782E+00	-2.0111E+01	-1.1159E+01	-2.0158E+01	-1.1113E+01
2	1.5814E-03	1.5887E-03	2.6967E-05	2.7524E-05	4.7326E-01	-8.9782E+00	-2.0115E+01	-1.1155E+01	-2.0162E+01	-1.1108E+01
3	1.5997E-03	1.6072E-03	2.7357E-05	2.7923E-05	4.7326E-01	-8.9782E+00	-2.0128E+01	-1.1141E+01	-2.0174E+01	-1.1095E+01
4	1.6295E-03	1.6371E-03	2.7993E-05	2.8572E-05	4.7326E-01	-8.9782E+00	-2.0148E+01	-1.1120E+01	-2.0195E+01	-1.1073E+01
5	1.6695E-03	1.6773E-03	2.8853E-05	2.9449E-05	4.7326E-01	-8.9782E+00	-2.0174E+01	-1.1091E+01	-2.0221E+01	-1.1044E+01
6	1.7180E-03	1.7260E-03	2.9902E-05	3.0519E-05	4.7326E-01	-8.9782E+00	-2.0206E+01	-1.1057E+01	-2.0253E+01	-1.1010E+01
7	1.7729E-03	1.7812E-03	3.1098E-05	3.1741E-05	4.7326E-01	-8.9782E+00	-2.0240E+01	-1.1019E+01	-2.0288E+01	-1.0972E+01
8	1.8316E-03	1.8402E-03	3.2387E-05	3.3056E-05	4.7326E-01	-8.9782E+00	-2.0277E+01	-1.0980E+01	-2.0325E+01	-1.0932E+01
9	1.8913E-03	1.9001E-03	3.3708E-05	3.4404E-05	4.7326E-01	-8.9782E+00	-2.0313E+01	-1.0941E+01	-2.0361E+01	-1.0893E+01
10	1.9490E-03	1.9580E-03	3.4993E-05	3.5715E-05	4.7326E-01	-8.9783E+00	-2.0347E+01	-1.0904E+01	-2.0396E+01	-1.0855E+01
11	2.0014E-03	2.0107E-03	3.6170E-05	3.6916E-05	4.7326E-01	-8.9783E+00	-2.0377E+01	-1.0871E+01	-2.0426E+01	-1.0822E+01
12	2.0456E-03	2.0551E-03	3.7169E-05	3.7937E-05	4.7326E-01	-8.9783E+00	-2.0402E+01	-1.0844E+01	-2.0451E+01	-1.0795E+01
13	2.0792E-03	2.0890E-03	3.7932E-05	3.8716E-05	4.7326E-01	-8.9783E+00	-2.0421E+01	-1.0824E+01	-2.0470E+01	-1.0774E+01
14	2.1003E-03	2.1101E-03	3.8412E-05	3.9205E-05	4.7326E-01	-8.9783E+00	-2.0432E+01	-1.0811E+01	-2.0482E+01	-1.0761E+01
15	2.1075E-03	2.1173E-03	3.8575E-05	3.9371E-05	4.7326E-01	-8.9783E+00	-2.0436E+01	-1.0807E+01	-2.0486E+01	-1.0757E+01
16	2.1003E-03	2.1101E-03	3.8412E-05	3.9205E-05	4.7326E-01	-8.9783E+00	-2.0432E+01	-1.0811E+01	-2.0482E+01	-1.0761E+01
17	2.0792E-03	2.0890E-03	3.7932E-05	3.8716E-05	4.7326E-01	-8.9783E+00	-2.0421E+01	-1.0824E+01	-2.0470E+01	-1.0774E+01
18	2.0456E-03	2.0551E-03	3.7169E-05	3.7937E-05	4.7326E-01	-8.9783E+00	-2.0402E+01	-1.0844E+01	-2.0451E+01	-1.0795E+01
19	2.0014E-03	2.0107E-03	3.6170E-05	3.6916E-05	4.7326E-01	-8.9783E+00	-2.0377E+01	-1.0871E+01	-2.0426E+01	-1.0822E+01
20	1.9490E-03	1.9580E-03	3.4993E-05	3.5715E-05	4.7326E-01	-8.9783E+00	-2.0347E+01	-1.0904E+01	-2.0396E+01	-1.0855E+01
21	1.8913E-03	1.9001E-03	3.3708E-05	3.4404E-05	4.7326E-01	-8.9783E+00	-2.0313E+01	-1.0941E+01	-2.0361E+01	-1.0893E+01
22	1.8316E-03	1.8402E-03	3.2387E-05	3.3056E-05	4.7326E-01	-8.9782E+00	-2.0277E+01	-1.0980E+01	-2.0325E+01	-1.0932E+01
23	1.7729E-03	1.7812E-03	3.1098E-05	3.1741E-05	4.7326E-01	-8.9782E+00	-2.0240E+01	-1.1019E+01	-2.0288E+01	-1.0972E+01
24	1.7180E-03	1.7260E-03	2.9902E-05	3.0519E-05	4.7326E-01	-8.9782E+00	-2.0206E+01	-1.1057E+01	-2.0253E+01	-1.1010E+01
25	1.6695E-03	1.6773E-03	2.8853E-05	2.9449E-05	4.7326E-01	-8.9782E+00	-2.0174E+01	-1.1091E+01	-2.0221E+01	-1.1044E+01
26	1.6295E-03	1.6371E-03	2.7993E-05	2.8572E-05	4.7326E-01	-8.9782E+00	-2.0148E+01	-1.1120E+01	-2.0195E+01	-1.1073E+01
27	1.5997E-03	1.6072E-03	2.7357E-05	2.7923E-05	4.7326E-01	-8.9782E+00	-2.0128E+01	-1.1141E+01	-2.0174E+01	-1.1095E+01
28	1.5814E-03	1.5887E-03	2.6967E-05	2.7524E-05	4.7326E-01	-8.9782E+00	-2.0115E+01	-1.1155E+01	-2.0162E+01	-1.1108E+01

ELEMENT NUMBER	PATH HEIGHT/BALL DIA. OUTER	PATH HEIGHT/BALL DIA. INNER	BALL CENTER COORDINATES AXIAL	BALL CENTER COORDINATES RADIAL	OPERATING PITCH DIA.	GYRO SLIP COEFFICIENT	MAXIMUM SV VALUE	SPIN/ROLL RATIO	BALL/RACE CLEARANCE OUTER	BALL/RACE CLEARANCE INNER

1	3.3559E-02	3.3713E-02	-1.6414E-04	-3.4584E-06	2.8125E+00	2.0249E-10	1.1399E+00	3.1628E-02	0.0000E-01	0.0000E-01
2	3.3573E-02	3.3727E-02	-1.6414E-04	-3.3776E-06	2.8125E+00	2.0189E-10	1.1422E+00	3.1628E-02	0.0000E-01	0.0000E-01
3	3.3614E-02	3.3769E-02	-1.6413E-04	-3.1396E-06	2.8125E+00	2.0015E-10	1.1487E+00	3.1626E-02	0.0000E-01	0.0000E-01
4	3.3681E-02	3.3836E-02	-1.6412E-04	-2.7562E-06	2.8125E+00	1.9739E-10	1.1593E+00	3.1625E-02	0.0000E-01	0.0000E-01
5	3.3768E-02	3.3924E-02	-1.6411E-04	-2.2460E-06	2.8125E+00	1.9382E-10	1.1734E+00	3.1623E-02	0.0000E-01	0.0000E-01
6	3.3872E-02	3.4030E-02	-1.6410E-04	-1.6357E-06	2.8125E+00	1.8968E-10	1.1902E+00	3.1620E-02	0.0000E-01	0.0000E-01
7	3.3988E-02	3.4147E-02	-1.6408E-04	-9.5497E-07	2.8125E+00	1.8524E-10	1.2090E+00	3.1617E-02	0.0000E-01	0.0000E-01
8	3.4108E-02	3.4269E-02	-1.6406E-04	-2.3840E-07	2.8125E+00	1.8075E-10	1.2287E+00	3.1614E-02	0.0000E-01	0.0000E-01
9	3.4228E-02	3.4390E-02	-1.6404E-04	4.7821E-07	2.8125E+00	1.7644E-10	1.2485E+00	3.1611E-02	0.0000E-01	0.0000E-01
10	3.4341E-02	3.4505E-02	-1.6403E-04	1.1590E-06	2.8125E+00	1.7250E-10	1.2672E+00	3.1608E-02	0.0000E-01	0.0000E-01
11	3.4442E-02	3.4607E-02	-1.6401E-04	1.7693E-06	2.8125E+00	1.6909E-10	1.2840E+00	3.1606E-02	0.0000E-01	0.0000E-01
12	3.4526E-02	3.4692E-02	-1.6400E-04	2.2785E-06	2.8125E+00	1.6632E-10	1.2981E+00	3.1604E-02	0.0000E-01	0.0000E-01
13	3.4589E-02	3.4756E-02	-1.6399E-04	2.6622E-06	2.8125E+00	1.6429E-10	1.3086E+00	3.1602E-02	0.0000E-01	0.0000E-01
14	3.4628E-02	3.4795E-02	-1.6398E-04	2.9011E-06	2.8125E+00	1.6305E-10	1.3152E+00	3.1601E-02	0.0000E-01	0.0000E-01
15	3.4641E-02	3.4809E-02	-1.6398E-04	2.9814E-06	2.8125E+00	1.6264E-10	1.3174E+00	3.1601E-02	0.0000E-01	0.0000E-01
16	3.4628E-02	3.4795E-02	-1.6398E-04	2.9011E-06	2.8125E+00	1.6305E-10	1.3152E+00	3.1601E-02	0.0000E-01	0.0000E-01
17	3.4589E-02	3.4756E-02	-1.6399E-04	2.6622E-06	2.8125E+00	1.6429E-10	1.3086E+00	3.1602E-02	0.0000E-01	0.0000E-01
18	3.4526E-02	3.4692E-02	-1.6400E-04	2.2785E-06	2.8125E+00	1.6632E-10	1.2981E+00	3.1604E-02	0.0000E-01	0.0000E-01
19	3.4442E-02	3.4607E-02	-1.6401E-04	1.7693E-06	2.8125E+00	1.6909E-10	1.2840E+00	3.1606E-02	0.0000E-01	0.0000E-01
20	3.4341E-02	3.4505E-02	-1.6403E-04	1.1590E-06	2.8125E+00	1.7250E-10	1.2672E+00	3.1608E-02	0.0000E-01	0.0000E-01
21	3.4228E-02	3.4390E-02	-1.6404E-04	4.7821E-07	2.8125E+00	1.7644E-10	1.2485E+00	3.1611E-02	0.0000E-01	0.0000E-01
22	3.4108E-02	3.4269E-02	-1.6406E-04	-2.3840E-07	2.8125E+00	1.8075E-10	1.2287E+00	3.1614E-02	0.0000E-01	0.0000E-01
23	3.3988E-02	3.4147E-02	-1.6408E-04	-9.5497E-07	2.8125E+00	1.8524E-10	1.2090E+00	3.1617E-02	0.0000E-01	0.0000E-01
24	3.3872E-02	3.4030E-02	-1.6410E-04	-1.6357E-06	2.8125E+00	1.8968E-10	1.1902E+00	3.1620E-02	0.0000E-01	0.0000E-01
25	3.3768E-02	3.3924E-02	-1.6411E-04	-2.2460E-06	2.8125E+00	1.9382E-10	1.1734E+00	3.1623E-02	0.0000E-01	0.0000E-01
26	3.3681E-02	3.3836E-02	-1.6412E-04	-2.7562E-06	2.8125E+00	1.9739E-10	1.1593E+00	3.1625E-02	0.0000E-01	0.0000E-01
27	3.3614E-02	3.3769E-02	-1.6413E-04	-3.1396E-06	2.8125E+00	2.0015E-10	1.1487E+00	3.1626E-02	0.0000E-01	0.0000E-01
28	3.3573E-02	3.3727E-02	-1.6414E-04	-3.3776E-06	2.8125E+00	2.0189E-10	1.1422E+00	3.1628E-02	0.0000E-01	0.0000E-01

ELEMENT NUMBER	PATH/SPLIT OUTER	CLEARANCE INNER	BALL AXIS INCLINATION
1	0.0000E-01	0.0000E-01	-1.6541E+01
2	0.0000E-01	0.0000E-01	-1.6541E+01
3	0.0000E-01	0.0000E-01	-1.6541E+01
4	0.0000E-01	0.0000E-01	-1.6540E+01
5	0.0000E-01	0.0000E-01	-1.6539E+01
6	0.0000E-01	0.0000E-01	-1.6537E+01
7	0.0000E-01	0.0000E-01	-1.6536E+01
8	0.0000E-01	0.0000E-01	-1.6534E+01
9	0.0000E-01	0.0000E-01	-1.6532E+01
10	0.0000E-01	0.0000E-01	-1.6531E+01
11	0.0000E-01	0.0000E-01	-1.6530E+01
12	0.0000E-01	0.0000E-01	-1.6528E+01
13	0.0000E-01	0.0000E-01	-1.6528E+01
14	0.0000E-01	0.0000E-01	-1.6527E+01
15	0.0000E-01	0.0000E-01	-1.6527E+01
16	0.0000E-01	0.0000E-01	-1.6527E+01
17	0.0000E-01	0.0000E-01	-1.6528E+01
18	0.0000E-01	0.0000E-01	-1.6528E+01
19	0.0000E-01	0.0000E-01	-1.6530E+01
20	0.0000E-01	0.0000E-01	-1.6531E+01
21	0.0000E-01	0.0000E-01	-1.6532E+01
22	0.0000E-01	0.0000E-01	-1.6534E+01
23	0.0000E-01	0.0000E-01	-1.6536E+01
24	0.0000E-01	0.0000E-01	-1.6537E+01
25	0.0000E-01	0.0000E-01	-1.6539E+01

26	0.0000E-01	0.0000E-01	-1.6540E+01
27	0.0000E-01	0.0000E-01	-1.6541E+01
28	0.0000E-01	0.0000E-01	-1.6541E+01

* OUTPUT DATA FOR BEARING NO. 2

ELEMENT NUMBER	ELEMENT AZIMUTH	CONTACT LOAD OUTER	CONTACT LOAD INNER	CONTACT ANGLE OUTER	CONTACT ANGLE INNER	CONTACT DEFLECTION OUTER	CONTACT DEFLECTION INNER	MEAN HERTZ STRESS OUTER	MEAN HERTZ STRESS INNER	TYPE OF CONTROL
1	0.0000E-01	2.3034E+00	2.3034E+00	1.5487E+01	1.5487E+01	3.3255E-05	3.3644E-05	8.8599E+04	9.2840E+04	INNER
2	1.2857E+01	2.3125E+00	2.3125E+00	1.5487E+01	1.5487E+01	3.3343E-05	3.3732E-05	8.8716E+04	9.2962E+04	INNER
3	2.5714E+01	2.3394E+00	2.3393E+00	1.5487E+01	1.5487E+01	3.3600E-05	3.3993E-05	8.9057E+04	9.3320E+04	INNER
4	3.8571E+01	2.3828E+00	2.3828E+00	1.5486E+01	1.5486E+01	3.4015E-05	3.4412E-05	8.9606E+04	9.3894E+04	INNER
5	5.1429E+01	2.4410E+00	2.4410E+00	1.5485E+01	1.5485E+01	3.4566E-05	3.4971E-05	9.0329E+04	9.4653E+04	INNER
6	6.4286E+01	2.5113E+00	2.5113E+00	1.5484E+01	1.5484E+01	3.5227E-05	3.5638E-05	9.1187E+04	9.5552E+04	INNER
7	7.7143E+01	2.5904E+00	2.5904E+00	1.5482E+01	1.5482E+01	3.5963E-05	3.6383E-05	9.2136E+04	9.6546E+04	INNER
8	9.0000E+01	2.6746E+00	2.6745E+00	1.5481E+01	1.5481E+01	3.6738E-05	3.7167E-05	9.3123E+04	9.7580E+04	INNER
9	1.0286E+02	2.7596E+00	2.7597E+00	1.5479E+01	1.5479E+01	3.7512E-05	3.7951E-05	9.4100E+04	9.8604E+04	INNER
10	1.1571E+02	2.8412E+00	2.8413E+00	1.5478E+01	1.5478E+01	3.8248E-05	3.8696E-05	9.5018E+04	9.9567E+04	INNER
11	1.2857E+02	2.9152E+00	2.9152E+00	1.5477E+01	1.5477E+01	3.8909E-05	3.9364E-05	9.5835E+04	1.0042E+05	INNER
12	1.4143E+02	2.9774E+00	2.9774E+00	1.5476E+01	1.5476E+01	3.9461E-05	3.9922E-05	9.6512E+04	1.0113E+05	INNER
13	1.5429E+02	3.0244E+00	3.0245E+00	1.5475E+01	1.5475E+01	3.9875E-05	4.0342E-05	9.7017E+04	1.0166E+05	INNER
14	1.6714E+02	3.0538E+00	3.0538E+00	1.5474E+01	1.5474E+01	4.0133E-05	4.0602E-05	9.7330E+04	1.0199E+05	INNER
15	1.8000E+02	3.0638E+00	3.0638E+00	1.5474E+01	1.5474E+01	4.0220E-05	4.0691E-05	9.7436E+04	1.0210E+05	INNER
16	1.9286E+02	3.0538E+00	3.0538E+00	1.5474E+01	1.5474E+01	4.0133E-05	4.0602E-05	9.7330E+04	1.0199E+05	INNER
17	2.0571E+02	3.0244E+00	3.0245E+00	1.5475E+01	1.5475E+01	3.9875E-05	4.0342E-05	9.7017E+04	1.0166E+05	INNER
18	2.1857E+02	2.9774E+00	2.9774E+00	1.5476E+01	1.5476E+01	3.9461E-05	3.9922E-05	9.6512E+04	1.0113E+05	INNER
19	2.3143E+02	2.9152E+00	2.9152E+00	1.5477E+01	1.5477E+01	3.8909E-05	3.9364E-05	9.5835E+04	1.0042E+05	INNER
20	2.4429E+02	2.8412E+00	2.8413E+00	1.5478E+01	1.5478E+01	3.8248E-05	3.8696E-05	9.5018E+04	9.9567E+04	INNER
21	2.5714E+02	2.7596E+00	2.7597E+00	1.5479E+01	1.5479E+01	3.7512E-05	3.7951E-05	9.4100E+04	9.8604E+04	INNER
22	2.7000E+02	2.6746E+00	2.6745E+00	1.5481E+01	1.5481E+01	3.6738E-05	3.7167E-05	9.3123E+04	9.7580E+04	INNER
23	2.8286E+02	2.5904E+00	2.5904E+00	1.5482E+01	1.5482E+01	3.5963E-05	3.6383E-05	9.2136E+04	9.6546E+04	INNER
24	2.9571E+02	2.5113E+00	2.5113E+00	1.5484E+01	1.5484E+01	3.5227E-05	3.5638E-05	9.1187E+04	9.5552E+04	INNER
25	3.0857E+02	2.4410E+00	2.4410E+00	1.5485E+01	1.5485E+01	3.4566E-05	3.4971E-05	9.0329E+04	9.4653E+04	INNER
26	3.2143E+02	2.3828E+00	2.3828E+00	1.5486E+01	1.5486E+01	3.4015E-05	3.4412E-05	8.9606E+04	9.3894E+04	INNER
27	3.3429E+02	2.3394E+00	2.3393E+00	1.5487E+01	1.5487E+01	3.3600E-05	3.3993E-05	8.9057E+04	9.3320E+04	INNER
28	3.4714E+02	2.3125E+00	2.3125E+00	1.5487E+01	1.5487E+01	3.3343E-05	3.3732E-05	8.8716E+04	9.2962E+04	INNER

ELEMENT NUMBER	CONTACT AREA LENGTH OUTER	CONTACT AREA LENGTH INNER	CONTACT AREA WIDTH OUTER	CONTACT AREA WIDTH INNER	GYROSCOPIC MOMENT	CENTRIFUGAL FORCE	SPINNING VELOCITY OUTER	SPINNING VELOCITY INNER	ROLLING VELOCITY OUTER	ROLLING VELOCITY INNER
1	1.2343E-02	1.2471E-02	2.6818E-03	2.5331E-03	-4.6370E-11	4.9939E-09	2.6702E-01	0.0000E-01	-8.5210E+00	9.4847E+00
2	1.2359E-02	1.2487E-02	2.6854E-03	2.5364E-03	-4.6369E-11	4.9939E-09	2.6702E-01	0.0000E-01	-8.5210E+00	9.4847E+00
3	1.2407E-02	1.2535E-02	2.6957E-03	2.5462E-03	-4.6368E-11	4.9939E-09	2.6701E-01	0.0000E-01	-8.5210E+00	9.4847E+00
4	1.2483E-02	1.2613E-02	2.7123E-03	2.5619E-03	-4.6366E-11	4.9939E-09	2.6700E-01	0.0000E-01	-8.5210E+00	9.4847E+00
5	1.2584E-02	1.2714E-02	2.7342E-03	2.5826E-03	-4.6363E-11	4.9939E-09	2.6698E-01	0.0000E-01	-8.5210E+00	9.4847E+00
6	1.2704E-02	1.2835E-02	2.7602E-03	2.6071E-03	-4.6359E-11	4.9939E-09	2.6696E-01	0.0000E-01	-8.5210E+00	9.4847E+00
7	1.2836E-02	1.2969E-02	2.7889E-03	2.6342E-03	-4.6355E-11	4.9939E-09	2.6694E-01	0.0000E-01	-8.5210E+00	9.4847E+00
8	1.2973E-02	1.3108E-02	2.8188E-03	2.6624E-03	-4.6351E-11	4.9939E-09	2.6691E-01	0.0000E-01	-8.5210E+00	9.4847E+00
9	1.3109E-02	1.3245E-02	2.8483E-03	2.6904E-03	-4.6347E-11	4.9939E-09	2.6689E-01	0.0000E-01	-8.5210E+00	9.4847E+00
10	1.3237E-02	1.3374E-02	2.8761E-03	2.7166E-03	-4.6343E-11	4.9939E-09	2.6687E-01	0.0000E-01	-8.5210E+00	9.4848E+00
11	1.3351E-02	1.3489E-02	2.9009E-03	2.7400E-03	-4.6339E-11	4.9939E-09	2.6685E-01	0.0000E-01	-8.5210E+00	9.4848E+00
12	1.3446E-02	1.3585E-02	2.9214E-03	2.7593E-03	-4.6336E-11	4.9939E-09	2.6683E-01	0.0000E-01	-8.5210E+00	9.4848E+00
13	1.3516E-02	1.3656E-02	2.9367E-03	2.7738E-03	-4.6334E-11	4.9939E-09	2.6682E-01	0.0000E-01	-8.5210E+00	9.4848E+00
14	1.3560E-02	1.3700E-02	2.9461E-03	2.7827E-03	-4.6333E-11	4.9939E-09	2.6681E-01	0.0000E-01	-8.5210E+00	9.4848E+00
15	1.3574E-02	1.3715E-02	2.9493E-03	2.7858E-03	-4.6332E-11	4.9939E-09	2.6681E-01	0.0000E-01	-8.5210E+00	9.4848E+00
16	1.3560E-02	1.3700E-02	2.9461E-03	2.7827E-03	-4.6333E-11	4.9939E-09	2.6681E-01	0.0000E-01	-8.5210E+00	9.4848E+00
17	1.3516E-02	1.3656E-02	2.9367E-03	2.7738E-03	-4.6334E-11	4.9939E-09	2.6682E-01	0.0000E-01	-8.5210E+00	9.4848E+00

18	1.3446E-02	1.3585E-02	2.9214E-03	2.7593E-03	-4.6336E-[illegible]	4.9939E-09	2.6683E-01	0.0000E-01	-8.5210E+00	9.484[illegible]+00
19	1.3351E-02	1.3489E-02	2.9009E-03	2.7400E-03	-4.6339E-11	4.9939E-09	2.6685E-01	0.0000E-01	-8.5210E+00	9.4848E+00
20	1.3237E-02	1.3374E-02	2.8761E-03	2.7166E-03	-4.6343E-11	4.9939E-09	2.6687E-01	0.0000E-01	-8.5210E+00	9.4848E+00
21	1.3109E-02	1.3245E-02	2.8483E-03	2.6904E-03	-4.6347E-11	4.9939E-09	2.6689E-01	0.0000E-01	-8.5210E+00	9.4847E+00
22	1.2973E-02	1.3108E-02	2.8188E-03	2.6624E-03	-4.6351E-11	4.9939E-09	2.6691E-01	0.0000E-01	-8.5210E+00	9.4847E+00
23	1.2836E-02	1.2969E-02	2.7889E-03	2.6342E-03	-4.6355E-11	4.9939E-09	2.6694E-01	0.0000E-01	-8.5210E+00	9.4847E+00
24	1.2704E-02	1.2835E-02	2.7602E-03	2.6071E-03	-4.6359E-11	4.9939E-09	2.6696E-01	0.0000E-01	-8.5210E+00	9.4847E+00
25	1.2584E-02	1.2714E-02	2.7342E-03	2.5826E-03	-4.6363E-11	4.9939E-09	2.6698E-01	0.0000E-01	-8.5210E+00	9.4847E+00
26	1.2483E-02	1.2613E-02	2.7123E-03	2.5619E-03	-4.6366E-11	4.9939E-09	2.6700E-01	0.0000E-01	-8.5210E+00	9.4847E+00
27	1.2407E-02	1.2535E-02	2.6957E-03	2.5462E-03	-4.6368E-11	4.9939E-09	2.6701E-01	0.0000E-01	-8.5210E+00	9.4847E+00
28	1.2359E-02	1.2487E-02	2.6854E-03	2.5364E-03	-4.6369E-11	4.9939E-09	2.6702E-01	0.0000E-01	-8.5210E+00	9.4847E+00

ELEMENT	SPINNING TORQUE		ROLLING TORQUE		ORBITAL	ROTATIONAL	OUTER PATH EXTREMITIES		INNER PATH EXTREMITIES	
NUMBER	OUTER	INNER	OUTER	INNER	VELOCITY	VELOCITY	UPPER EDGE	LOWER EDGE	UPPER EDGE	LOWER EDGE
1	1.1278E-03	1.1330E-03	1.7694E-05	1.8060E-05	4.7324E-01	-8.9782E+00	1.9604E+01	1.1371E+01	1.9646E+01	1.1328E+01
2	1.1337E-03	1.1390E-03	1.7810E-05	1.8178E-05	4.7324E-01	-8.9782E+00	1.9609E+01	1.1365E+01	1.9652E+01	1.1322E+01
3	1.1513E-03	1.1566E-03	1.8155E-05	1.8530E-05	4.7324E-01	-8.9782E+00	1.9624E+01	1.1349E+01	1.9667E+01	1.1306E+01
4	1.1799E-03	1.1854E-03	1.8719E-05	1.9106E-05	4.7324E-01	-8.9782E+00	1.9649E+01	1.1322E+01	1.9692E+01	1.1279E+01
5	1.2184E-03	1.2241E-03	1.9485E-05	1.9887E-05	4.7324E-01	-8.9782E+00	1.9682E+01	1.1288E+01	1.9725E+01	1.1244E+01
6	1.2654E-03	1.2713E-03	2.0426E-05	2.0848E-05	4.7324E-01	-8.9782E+00	1.9721E+01	1.1247E+01	1.9765E+01	1.1203E+01
7	1.3189E-03	1.3250E-03	2.1507E-05	2.1951E-05	4.7324E-01	-8.9782E+00	1.9763E+01	1.1201E+01	1.9808E+01	1.1157E+01
8	1.3763E-03	1.3827E-03	2.2681E-05	2.3149E-05	4.7324E-01	-8.9782E+00	1.9808E+01	1.1154E+01	1.9853E+01	1.1109E+01
9	1.4350E-03	1.4417E-03	2.3892E-05	2.4386E-05	4.7324E-01	-8.9782E+00	1.9852E+01	1.1107E+01	1.9897E+01	1.1061E+01
10	1.4918E-03	1.4988E-03	2.5078E-05	2.5596E-05	4.7324E-01	-8.9782E+00	1.9893E+01	1.1063E+01	1.9939E+01	1.1017E+01
11	1.5438E-03	1.5510E-03	2.6171E-05	2.6712E-05	4.7324E-01	-8.9782E+00	1.9930E+01	1.1023E+01	1.9976E+01	1.0977E+01
12	1.5879E-03	1.5953E-03	2.7106E-05	2.7666E-05	4.7324E-01	-8.9782E+00	1.9961E+01	1.0991E+01	2.0007E+01	1.0944E+01
13	1.6214E-03	1.6290E-03	2.7821E-05	2.8397E-05	4.7324E-01	-8.9782E+00	1.9983E+01	1.0966E+01	2.0030E+01	1.0920E+01
14	1.6425E-03	1.6501E-03	2.8272E-05	2.8857E-05	4.7324E-01	-8.9782E+00	1.9997E+01	1.0951E+01	2.0044E+01	1.0904E+01
15	1.6496E-03	1.6573E-03	2.8426E-05	2.9014E-05	4.7324E-01	-8.9782E+00	2.0002E+01	1.0946E+01	2.0049E+01	1.0899E+01
16	1.6425E-03	1.6501E-03	2.8272E-05	2.8857E-05	4.7324E-01	-8.9782E+00	1.9997E+01	1.0951E+01	2.0044E+01	1.0904E+01
17	1.6214E-03	1.6290E-03	2.7821E-05	2.8397E-05	4.7324E-01	-8.9782E+00	1.9983E+01	1.0966E+01	2.0030E+01	1.0920E+01
18	1.5879E-03	1.5953E-03	2.7106E-05	2.7666E-05	4.7324E-01	-8.9782E+00	1.9961E+01	1.0991E+01	2.0007E+01	1.0944E+01
19	1.5438E-03	1.5510E-03	2.6171E-05	2.6712E-05	4.7324E-01	-8.9782E+00	1.9930E+01	1.1023E+01	1.9976E+01	1.0977E+01
20	1.4918E-03	1.4988E-03	2.5078E-05	2.5596E-05	4.7324E-01	-8.9782E+00	1.9893E+01	1.1063E+01	1.9939E+01	1.1017E+01
21	1.4350E-03	1.4417E-03	2.3892E-05	2.4386E-05	4.7324E-01	-8.9782E+00	1.9852E+01	1.1107E+01	1.9897E+01	1.1061E+01
22	1.3763E-03	1.3827E-03	2.2681E-05	2.3149E-05	4.7324E-01	-8.9782E+00	1.9808E+01	1.1154E+01	1.9853E+01	1.1109E+01
23	1.3189E-03	1.3250E-03	2.1507E-05	2.1951E-05	4.7324E-01	-8.9782E+00	1.9763E+01	1.1201E+01	1.9808E+01	1.1157E+01
24	1.2654E-03	1.2713E-03	2.0426E-05	2.0848E-05	4.7324E-01	-8.9782E+00	1.9721E+01	1.1247E+01	1.9765E+01	1.1203E+01
25	1.2184E-03	1.2241E-03	1.9485E-05	1.9887E-05	4.7324E-01	-8.9782E+00	1.9682E+01	1.1288E+01	1.9725E+01	1.1244E+01
26	1.1799E-03	1.1854E-03	1.8719E-05	1.9106E-05	4.7324E-01	-8.9782E+00	1.9649E+01	1.1322E+01	1.9692E+01	1.1279E+01
27	1.1513E-03	1.1566E-03	1.8155E-05	1.8530E-05	4.7324E-01	-8.9782E+00	1.9624E+01	1.1349E+01	1.9667E+01	1.1306E+01
28	1.1337E-03	1.1390E-03	1.7810E-05	1.8178E-05	4.7324E-01	-8.9782E+00	1.9609E+01	1.1365E+01	1.9652E+01	1.1322E+01

ELEMENT	PATH HEIGHT/BALL DIA.		BALL CENTER COORDINATES		OPERATING	GYRO SLIP	MAXIMUM	SPIN/ROLL	BALL/RACE CLEARANCE	
NUMBER	OUTER	INNER	AXIAL	RADIAL	PITCH DIA.	COEFFICIENT	SV VALUE	RATIO	OUTER	INNER
1	3.1904E-02	3.2041E-02	1.4283E-04	-3.8007E-06	2.8125E+00	2.5775E-10	9.5562E-01	3.1337E-02	0.0000E-01	0.0000E-01
2	3.1921E-02	3.2059E-02	1.4283E-04	-3.7106E-06	2.8125E+00	2.5674E-10	9.5813E-01	3.1337E-02	0.0000E-01	0.0000E-01
3	3.1970E-02	3.2109E-02	1.4284E-04	-3.4449E-06	2.8125E+00	2.5379E-10	9.6549E-01	3.1336E-02	0.0000E-01	0.0000E-01
4	3.2050E-02	3.2190E-02	1.4285E-04	-3.0166E-06	2.8125E+00	2.4915E-10	9.7737E-01	3.1334E-02	0.0000E-01	0.0000E-01
5	3.2156E-02	3.2297E-02	1.4286E-04	-2.4479E-06	2.8125E+00	2.4319E-10	9.9315E-01	3.1332E-02	0.0000E-01	0.0000E-01
6	3.2281E-02	3.2424E-02	1.4287E-04	-1.7665E-06	2.8125E+00	2.3637E-10	1.0120E+00	3.1330E-02	0.0000E-01	0.0000E-01
7	3.2420E-02	3.2564E-02	1.4289E-04	-1.0064E-06	2.8125E+00	2.2913E-10	1.0331E+00	3.1327E-02	0.0000E-01	0.0000E-01
8	3.2565E-02	3.2711E-02	1.4290E-04	-2.0697E-07	2.8125E+00	2.2190E-10	1.0553E+00	3.1324E-02	0.0000E-01	0.0000E-01
9	3.2708E-02	3.2856E-02	1.4292E-04	5.9249E-07	2.8125E+00	2.1504E-10	1.0774E+00	3.1321E-02	0.0000E-01	0.0000E-01
10	3.2844E-02	3.2993E-02	1.4293E-04	1.3522E-06	2.8125E+00	2.0884E-10	1.0985E+00	3.1319E-02	0.0000E-01	0.0000E-01
11	3.2964E-02	3.3115E-02	1.4295E-04	2.0336E-06	2.8125E+00	2.035[illegible] 10	1.1173E+00	3.1316E-02	0.0000E-01	0.0000E-01

12	3.3064E-02	3.3217E-02	1.4296E-04	2.6031E-06	2.8125E+00	1.9927E-10	1.1331E+00	3.1314E-02	0.0000E-01	0.0000E-01
13	3.3139E-02	3.3292E-02	1.4297E-04	3.0307E-06	2.8125E+00	1.9616E-10	1.1450E+00	3.1313E-02	0.0000E-01	0.0000E-01
14	3.3185E-02	3.3339E-02	1.4297E-04	3.2969E-06	2.8125E+00	1.9427E-10	1.1523E+00	3.1312E-02	0.0000E-01	0.0000E-01
15	3.3201E-02	3.3355E-02	1.4297E-04	3.3869E-06	2.8125E+00	1.9363E-10	1.1548E+00	3.1311E-02	0.0000E-01	0.0000E-01
16	3.3185E-02	3.3339E-02	1.4297E-04	3.2969E-06	2.8125E+00	1.9427E-10	1.1523E+00	3.1312E-02	0.0000E-01	0.0000E-01
17	3.3139E-02	3.3292E-02	1.4297E-04	3.0307E-06	2.8125E+00	1.9616E-10	1.1450E+00	3.1313E-02	0.0000E-01	0.0000E-01
18	3.3064E-02	3.3217E-02	1.4296E-04	2.6031E-06	2.8125E+00	1.9927E-10	1.1331E+00	3.1314E-02	0.0000E-01	0.0000E-01
19	3.2964E-02	3.3115E-02	1.4295E-04	2.0336E-06	2.8125E+00	2.0353E-10	1.1173E+00	3.1316E-02	0.0000E-01	0.0000E-01
20	3.2844E-02	3.2993E-02	1.4293E-04	1.3522E-06	2.8125E+00	2.0884E-10	1.0985E+00	3.1319E-02	0.0000E-01	0.0000E-01
21	3.2708E-02	3.2856E-02	1.4292E-04	5.9249E-07	2.8125E+00	2.1504E-10	1.0774E+00	3.1321E-02	0.0000E-01	0.0000E-01
22	3.2565E-02	3.2711E-02	1.4290E-04	-2.0697E-07	2.8125E+00	2.2190E-10	1.0553E+00	3.1324E-02	0.0000E-01	0.0000E-01
23	3.2420E-02	3.2564E-02	1.4289E-04	-1.0064E-06	2.8125E+00	2.2913E-10	1.0331E+00	3.1327E-02	0.0000E-01	0.0000E-01
24	3.2281E-02	3.2424E-02	1.4287E-04	-1.7665E-06	2.8125E+00	2.3637E-10	1.0120E+00	3.1330E-02	0.0000E-01	0.0000E-01
25	3.2156E-02	3.2297E-02	1.4286E-04	-2.4479E-06	2.8125E+00	2.4319E-10	9.9315E-01	3.1332E-02	0.0000E-01	0.0000E-01
26	3.2050E-02	3.2190E-02	1.4285E-04	-3.0166E-06	2.8125E+00	2.4915E-10	9.7737E-01	3.1334E-02	0.0000E-01	0.0000E-01
27	3.1970E-02	3.2109E-02	1.4284E-04	-3.4449E-06	2.8125E+00	2.5379E-10	9.6549E-01	3.1336E-02	0.0000E-01	0.0000E-01
28	3.1921E-02	3.2059E-02	1.4283E-04	-3.7106E-06	2.8125E+00	2.5674E-10	9.5813E-01	3.1337E-02	0.0000E-01	0.0000E-01

ELEMENT NUMBER	PATH/SPLIT CLEARANCE OUTER	INNER	BALL AXIS INCLINATION
1	0.0000E-01	0.0000E-01	1.6385E+01
2	0.0000E-01	0.0000E-01	1.6385E+01
3	0.0000E-01	0.0000E-01	1.6384E+01
4	0.0000E-01	0.0000E-01	1.6383E+01
5	0.0000E-01	0.0000E-01	1.6382E+01
6	0.0000E-01	0.0000E-01	1.6381E+01
7	0.0000E-01	0.0000E-01	1.6380E+01
8	0.0000E-01	0.0000E-01	1.6378E+01
9	0.0000E-01	0.0000E-01	1.6377E+01
10	0.0000E-01	0.0000E-01	1.6375E+01
11	0.0000E-01	0.0000E-01	1.6374E+01
12	0.0000E-01	0.0000E-01	1.6373E+01
13	0.0000E-01	0.0000E-01	1.6372E+01
14	0.0000E-01	0.0000E-01	1.6371E+01
15	0.0000E-01	0.0000E-01	1.6371E+01
16	0.0000E-01	0.0000E-01	1.6371E+01
17	0.0000E-01	0.0000E-01	1.6372E+01
18	0.0000E-01	0.0000E-01	1.6373E+01
19	0.0000E-01	0.0000E-01	1.6374E+01
20	0.0000E-01	0.0000E-01	1.6375E+01
21	0.0000E-01	0.0000E-01	1.6377E+01
22	0.0000E-01	0.0000E-01	1.6378E+01
23	0.0000E-01	0.0000E-01	1.6380E+01
24	0.0000E-01	0.0000E-01	1.6381E+01
25	0.0000E-01	0.0000E-01	1.6382E+01
26	0.0000E-01	0.0000E-01	1.6383E+01
27	0.0000E-01	0.0000E-01	1.6384E+01
28	0.0000E-01	0.0000E-01	1.6385E+01

* OUTPUT DATA FOR LOAD NO. 1 SYSTEM NO. 1

BEARING NUMBER	FATIGUE LIFE IN HOURS OUTER	INNER	BEARING	EHD LAMBDA VALUE	ADJUSTED BRG LIFE	REACTIONS OF BEARING ON SHAFT ALONG X	ALONG Y	ALONG Z	ABOUT Y	ABOUT Z
1	3.5748E+08	2.7332E+08	1.6585E+08	4.0734E-39	1. [illegible] +08	-2.5022E+01	-2.1612E-06	-4.8695E+00	1.9178E+00	6.6703E-07
2	6.7105E+08	5.1247E+08	3.1111E+08	4.0734E-39	3. [illegible] 08	2.0022E+01	-1.5295E-07	-5.1309E+00	-2.0030E+00	1.5595E-07

BEARING NUMBER	RELATIVE RING DISPLACEMENTS ALONG X	ALONG Y	ALONG Z	ABOUT Y	ABOUT Z	DISPLACEMENTS OF ORIGIN ALONG X	ALONG Y	ALONG Z	ABOUT Y	ABOUT Z
1	-3.2826E-04	0.0000E-01	-6.4741E-06	-1.0762E-07	0.0000E-01	-4.2357E-05	0.0000E-01	-6.8505E-06	-1.0761E-07	0.0000E-01
2	2.8592E-04	0.0000E-01	-7.2275E-06	-1.0762E-07	0.0000E-01					

PARTIAL DERIVATIVES OF BEARING REACTIONS WITH RESPECT TO DISPLACEMENTS AT BEARING CENTER

BEARING NUMBER	DFX/DX	DFX/DY	DFX/DZ	DFX/DALY	DFX/DALZ	DFY/DY	DFY/DZ	DFY/DALY	DFY/DALZ	DFZ/DZ
1	1.2388E+05	5.1270E-03	7.5307E+03	-3.3900E+03	1.5869E-03	7.5712E+05	-1.5456E-02	9.1974E-03	-2.9829E+05	7.5687E+05
2	1.1263E+05	-2.2949E-02	-9.1142E+03	-4.0099E+03	-4.8828E-03	7.0581E+05	-6.3229E-03	-8.4459E-03	2.7546E+05	7.0541E+05

PARTIAL DERIVATIVES (CONTINUED)

BEARING NUMBER	DFZ/DALY	DFZ/DALZ	DMY/DALY	DMY/DALZ	DMZ/DALZ
1	-2.9819E+05	9.3294E-03	1.2380E+05	-5.6827E-03	1.2384E+05
2	2.7530E+05	-4.3724E-03	1.1255E+05	-2.7447E-03	1.1260E+05

LOCATION	NON-LINEAR SPRING RATES FOR RIGID SYSTEM ALONG X	ALONG Y	ALONG Z	ABOUT Y	ABOUT Z	DEFLECTIONS OF FLEXIBLE SHAFT ALONG Y	ALONG Z	ABOUT Y	ABOUT Z	FRICTION TORQUE
BRG. 1	2.3631E+05	8.3763E+05	8.3711E+05	2.2117E+07	2.2146E+07	0.0000E-01	0.0000E-01	0.0000E-01	0.0000E-01	3.0439E-02
BRG. 2	2.3631E+05	7.8044E+05	7.7964E+05	2.2117E+07	2.2146E+07	0.0000E-01	0.0000E-01	0.0000E-01	0.0000E-01	2.1988E-02
LOAD 1	2.3631E+05	1.4611E+06	1.4604E+06	2.2117E+07	2.2146E+07	0.0000E-01	0.0000E-01	0.0000E-01	0.0000E-01	
ORIGIN	2.3631E+05	1.4611E+06	1.4604E+06	2.2117E+07	2.2146E+07					

LIFE CALCULATIONS BASED ON 90.00 PERCENT SURVIVAL

LIFE OF SYSTEM FOR CONTINOUS OPERATION AT THIS LOAD =1.1534E+08 HRS.

PRORATED LIFE OF BEARING NO. 1FOR LOADS 1 THRU 1 =1.6585E+08 HRS.

PRORATED LIFE OF BEARING NO. 2FOR LOADS 1 THRU 1 =3.1111E+08 HRS.

PRORATED LIFE OF SYSTEM FOR LOADS 1 THRU 1 =1.1534E+08 HRS.

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