

# REPORT

FINAL

REPLACEMENT  
 BEARING FOR  
 ROCKETDYNE  
 SSME HPOTPs  
 USING ALTERNATE  
 SELF-  
 LUBRICATING  
 RETAINER  
 MATERIALS

To

NASA Marshall Space Flight Center

April 1, 1992

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 (NASA-CR-184328) REPLACEMENT BEARING FOR  
 ROCKETDYNE SSME HPOTPs USING ALTERNATE  
 SELF-LUBRICATING RETAINER MATERIALS Final  
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FINAL REPORT

on

REPLACEMENT BEARING FOR ROCKETDYNE SSME HPOTPs USING  
ALTERNATE SELF-LUBRICATING  
RETAINER MATERIALS  
(Contract NAS8-36996)

to

NASA MARSHALL SPACE FLIGHT CENTER

April 1, 1992

by

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## SUMMARY

Research was conducted to develop replacement bearings for the Rocketdyne Space Shuttle main engine (SSME) high pressure oxidizer turbopumps (HPOTPs). The replacement bearings consisted of standard balls and races with a special Battelle Self-Lubricating Insert Configuration (BASIC) retainer. As pictured in Figure 1, the BASIC retainer consists of a phosphor bronze housing with inserts consisting of a polytetrafluorethylene (PTFE) and bronze compound. The PTFE contacts the balls and the land guiding surface on the outer race. A PTFE transfer film is formed on balls and races, which lubricates the critical interfaces.

The BASIC retainer is a one-to-one replacement for the current Armalon retainer, but has superior lubricating properties and is stronger over the broad temperature range anticipated for the HPOTP bearings. As a part of the project 40 sets of balls and races (two sizes) and 52 BASIC retainers were shipped to NASA/MSFC.

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BLACK AND WHITE PHOTOGRAPH

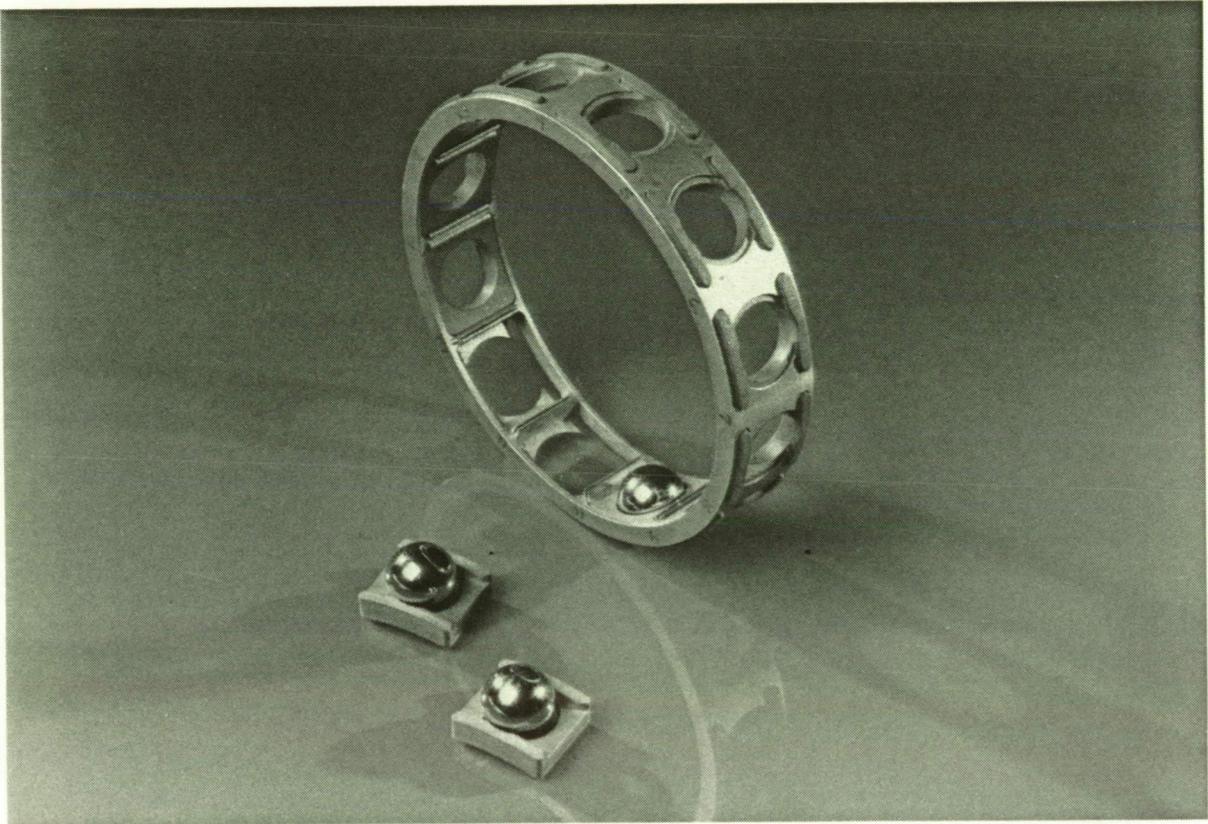


FIGURE 1. PHOTOGRAPH OF PARTIALLY ASSEMBLED BASIC RETAINER

# FINAL REPORT

on

## REPLACEMENT BEARING FOR ROCKETDYNE SSME HPOTPs USING ALTERNATE SELF-LUBRICATING RETAINER MATERIALS (Contract NAS8-36996)

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### INTRODUCTION

Rolling element bearings consist of two principal components: the load-carrying contact members (bearing races and bearing balls) and the ball retainer, also referred to as the cage or separator. The dimensions and design tolerances of the balls and races for high speed bearings are largely determined by contact stress limitations and load-carrying requirements. For the Space Shuttle main engine (SSME) high pressure oxidizer turbopump (HPOTP) bearings, the ball and race designs have been refined over several years through extensive analysis and testing at NASA and Rocketdyne. The design of the ball retainer is now receiving attention because of its possible contribution to improved lubrication and stability.

The desired multiple-launch capability of the Space Shuttle requires the main engine turbopumps to operate for 27,000 seconds and 55 starts between overhauls. Besides this extremely long service life (by rocket-engine standards), projected mission needs for the Shuttle require increases in SSME power levels to be achieved through increases in turbopump speed. Since measurements made on the MSFC bearing tester have shown that bearing power consumption increases with nearly the cube of shaft speed, an increase in power level can be expected to result in increased bearing problems.

Most of the bearing problems have occurred with the bearings in the HPOTPs. Currently the HPOTP bearings are operated at the 104 percent power level. This achievement is the result of improved load control, solid lubricant coatings, and bearing design improvements. However, the bearings experience excessive wear and currently are replaced after a single flight. The deterioration is the result of insufficient lubrication and resulting internal bearing wear. In order to achieve the performance required from the bearing, a new bearing design is needed. The new design must provide improved lubrication and less wear than the current design, but operate within the same size envelope to minimize retrofitting time and cost.

Battelle has conducted several projects to evaluate possible lubrication concepts for the HPOTP bearings. The most promising lubrication approach evaluated is a transfer film mechanism where a self-lubricating retainer material is transferred from the retainer to the balls to the races. The current retainer material, Armalon, is a glass-fiber cloth-reinforced polytetrafluoroethylene (PTFE) composite. Under some situations the PTFE acts as a transfer film. Two problems appear to restrict the usage of this composite. First, the glass fibers are abrasive, especially after the surface PTFE has been sacrificed to the balls. The abrasive action wears the balls and contributes to increases in bearing clearances. Second, there is concern that the bearings run hot because of high internal friction caused by lack of effective lubrication. At high temperatures the PTFE will not be effective, which can cause a self-escalating deterioration cycle.

The result of laboratory tests suggests that considerable improvements in the SSME-HPOTP bearing performance can be achieved with a bronze-filled-PTFE retainer material, provided the new design meets the strength requirements and provided the new retainer has no abrasive constituents such as glass or steel. The objective of this project has been to design, fabricate, and deliver bearings (for test) that incorporate bronze-PTFE solid film lubrication. In order to guide current efforts, a computer-based literature search of past work was conducted. References related to past work in bearing stability, retainer material wear resistance, lubricating transfer film generation, and cryogenic bearing development are included in Appendix A.

The fabricated test bearings are intended to be one-to-one replacements for the current HPOTP bearings (Drawings RS007955 and RS007958). It has been especially important that the retainers in the replacement bearings have the same envelope shapes and strength of the current Armalon retainers to avoid altering oxygen flow through the bearing or compromising strength. As described in the report for the Preliminary Design Review (April 21, 1989) for the project, three retainer configurations were considered:

- a laminate design,
- a ribbed design, and
- an insert configuration.

Only the insert configuration was deemed to be feasible, based on current design limitations, without considerable development efforts. The insert configuration involves the use of a bronze housing with self-lubricating inserts. The inserts are made from bronze-filled polytetrafluorethylene (PTFE) sintered materials that are available commercially. The Battelle Self-lubricating Insert Configuration (BASIC) retainers fabricated with this project have used two specific compounds (Salox: 60 percent

bronze and 40 percent PTFE, or Fluoroloy-C: 55 percent bronze, 40 percent PTFE, and 5 percent MoS<sub>2</sub>\*) although the design could incorporate other materials.

This report discusses the design of the BASIC retainer and the fabrication of the retainer, balls, and races for the bearings. Much of the efforts, including ball and race fabrication, coatings, and retainer machining, were supplied by subcontractors. Forty bearing sets (balls and races) were supplied to NASA/MSFC as part of the project. Twenty sets conformed to the current drawings for RS007955, Turbopump Bearing-57mm Bore and twenty conformed to RS007958, Turbopump Bearing-45mm Bore. The retainers fabricated for these bearings had Salox inserts. An additional 12 retainers were supplied to NASA (8-57mm and 4-45mm) that incorporated improvements in the housing geometry and had Fluoroloy-C inserts.

---

\*Salox is manufactured by Allegheny Plastics, Coraopolis, PA  
Fluoroloy-C is manufactured by Fluorocarbon, Anaheim, CA

## DESCRIPTION OF BASIC RETAINER

### Configuration

The dominating factors in the BASIC retainer design were as follows:

1. **Geometric:** The retainer was to be essentially a one-to-one replacement for the current Armalon outer-land-guided retainers used in the HPOTP bearings. Specifically, the retainer was to have the same envelope dimensions as the original designs (Reference drawings RS007955 and RS007958), as shown in Figure 1.
2. **Strength:** The replacement retainer should have equivalent tensile strength between two adjacent pockets (approximately 4400N (1000 lbs) for the 7955 bearing) with an Armalon retainer.
3. **Lubrication:** The retainer material should be Salox (or equivalent) at the ball pocket and land guiding interfaces.
4. **Temperature:** The retainer must operate over a temperature range from +120 C to -175 C.

A sketch illustrating the insert concept is given in Figure 2. Individual Salox inserts are fabricated for each ball location. Each insert contains a ball-pocket zone and two shoes which locate the retainer on the lands of the outer race of the bearing. The balls and races contact only the insert material under normal conditions. Under wear conditions sufficiently severe to wear through the insert, the housing material (phosphor bronze) should still serve as a bearing material to contact the balls.

The inserts are anchored by tabs which are integral with the housing. The housings are machined by computer numerically controlled machines to precise tolerances. Figure 2 illustrates the machined tab as well as the bent over tab. The QA plan entitled "The Procedures for Insert Design Retainer Production for NASA HPOTP Bearings" (including the methodology for tab bending) is given in Appendix B.

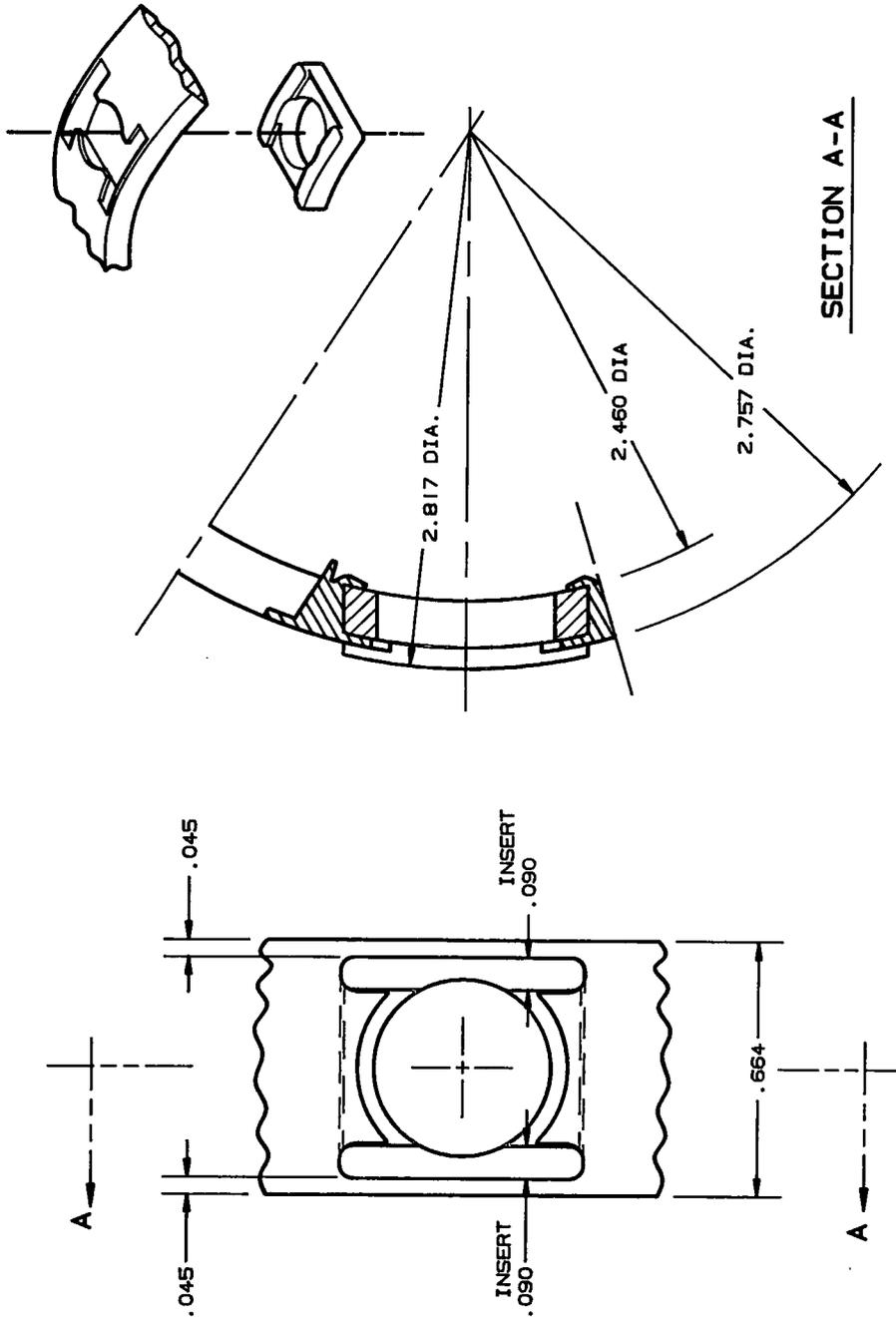


FIGURE 2. DRAWING OF INSERT RETAINER CONCEPT FOR 45 mm BEARING

The assembled BASIC retainers conform well to the geometric requirements discussed earlier. The retainers can replace existing Armalon retainers with no change in the bearing except for the elimination of one ball, which was required to provide room for the inserts and web. The elimination of one ball increases the bearing stresses by approximately 2.7 percent.

### **Insert Material**

Since the phosphor bronze housing of the BASIC retainer provides the needed structural strength and rigidity, a variety of candidate insert materials can be considered. Rub-block and rolling disk tests were previously conducted with several polymeric materials in various projects at Battelle. A 60-percent bronze, 40-percent PTFE material, commercially available as Salox, was selected based on wear rate, PTFE transferability considerations, and previous turbopump operating history. The material can be purchased (special order) as cylinders with custom inner and outer diameters. The critical factors for the acceptance of the Salox material are:

- LOX mechanical impact acceptability, and
- tensile strength.

Since each lot of Salox must be screened by LOX impact testing, maintaining controls and records on Salox purchases is very important. The role of the Salox is to provide self-lubricating material at the ball pockets and guiding surface. The inserts are not intended to provide significant strength to the retainer. The insert material needs to be sufficiently strong to maintain its own integrity during bearing operation. Tensile tests are conducted on each cylinder of insert material. Figures 3-5 are stress-strain curves for all the bronze filled PTFE composites used on this program. Each curve represents a different cylinder tested. All acceptable materials tested tended to display very similar stress strain curves. However, improperly sintered composites displayed very low ultimate tensile strengths. For example, one case in Figure 5 shows a suspect material. The QA plan includes tensile test requirements for the Salox cylinders to

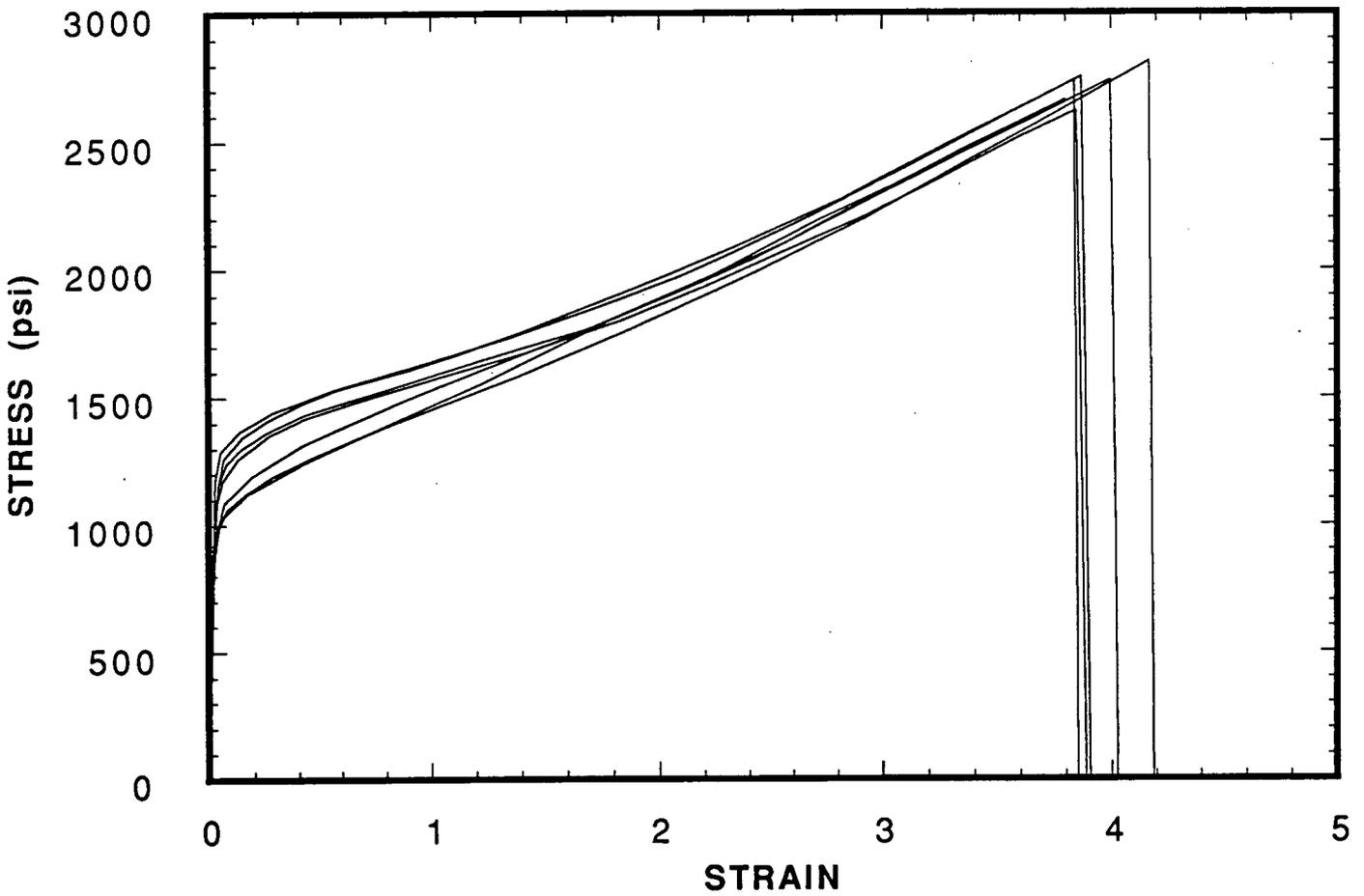


FIGURE 3. SALOX TENSILE TEST CURVES FOR LOT NO. 241307

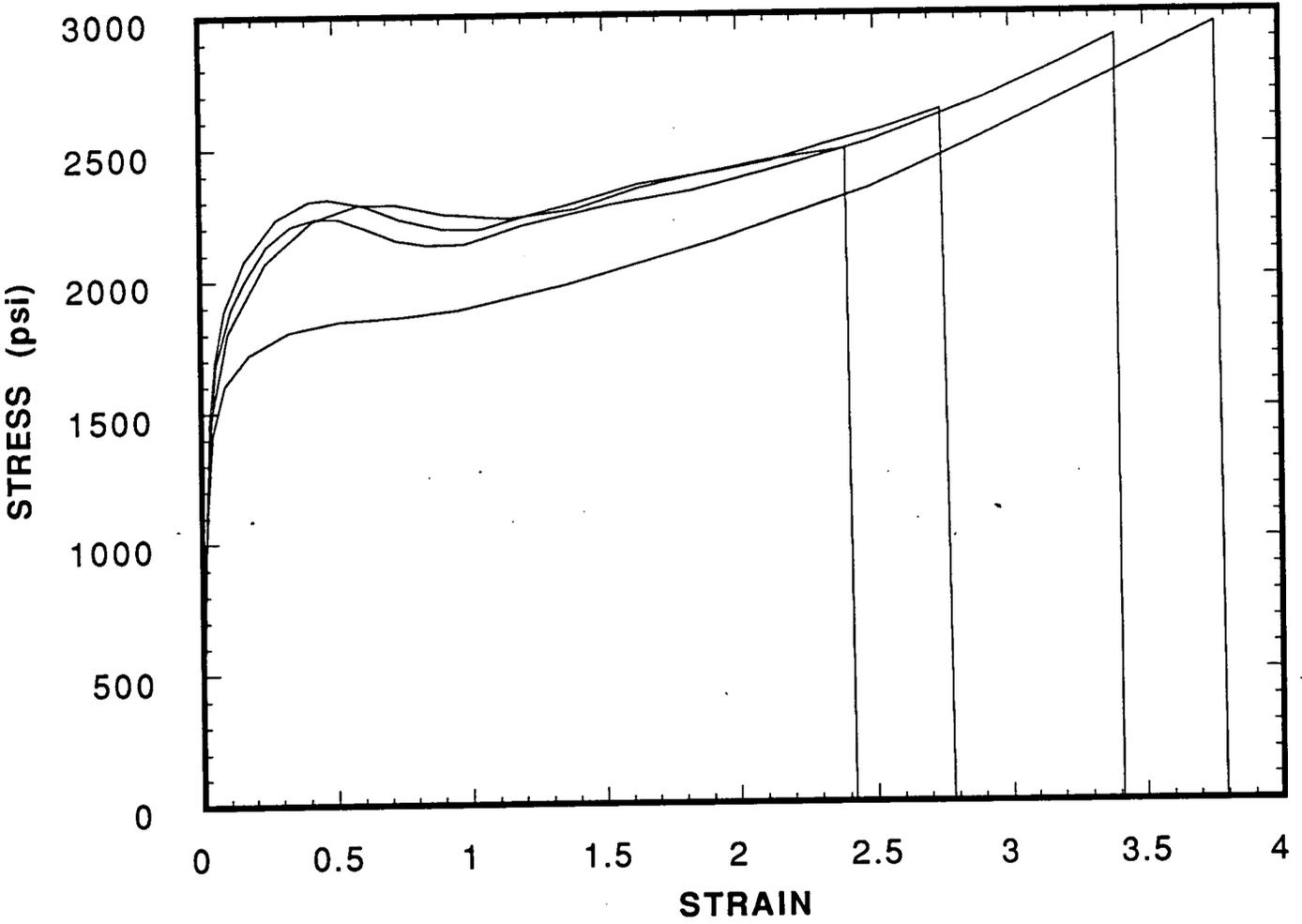


FIGURE 4. SALOX TENSILE TEST CURVES FOR LOT NO. 237746

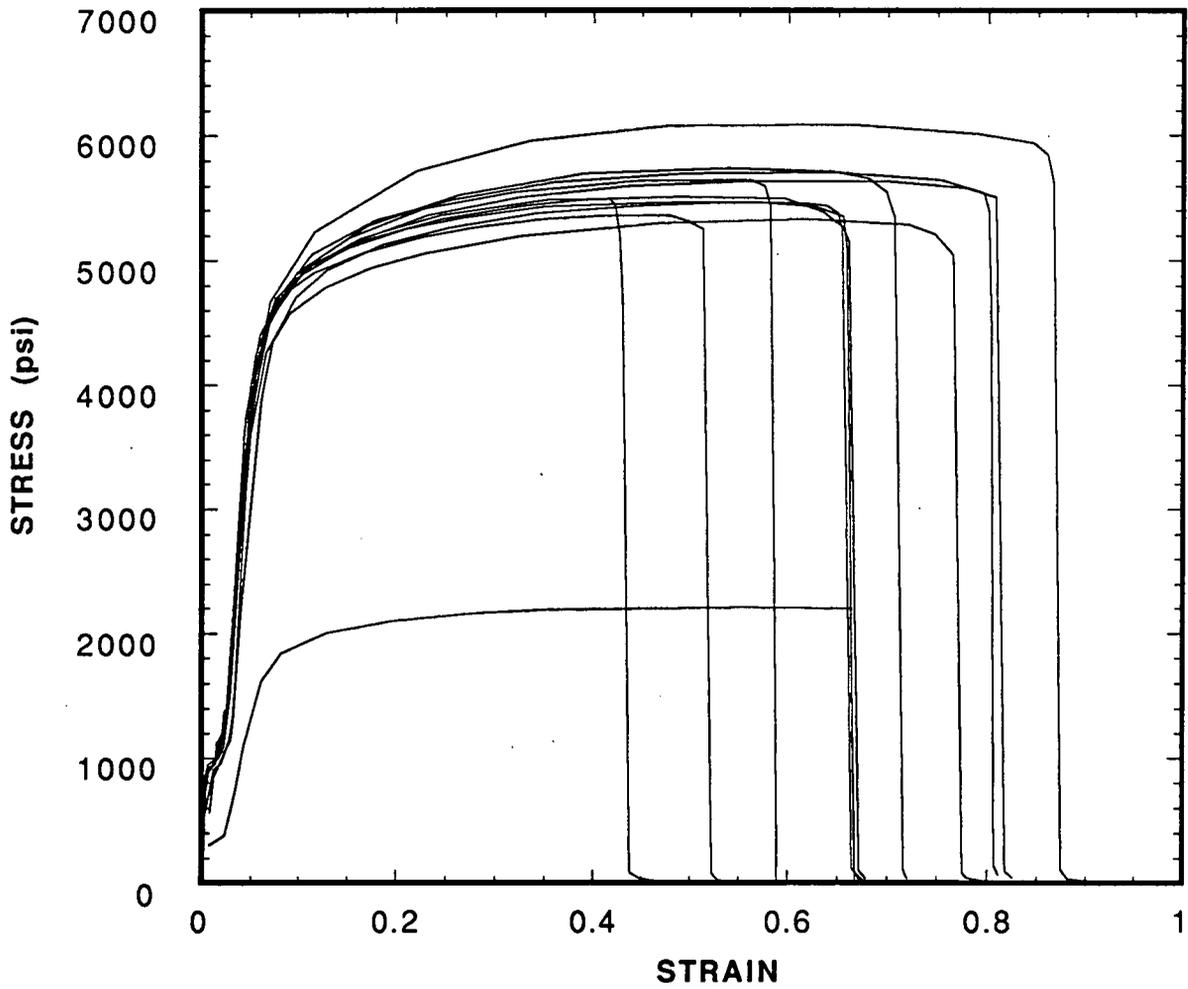


FIGURE 5. FLOUROLOY-C TENSILE TEST CURVES FOR LOT NO. 605465

ensure that the material was sintered properly and met a minimum tensile strength of 14 MPa (2,000 psi).

### **Housing Material**

Accommodating several materials property requirements guided the material selection process for the housing. The general requirements were:

1. Yield strength sufficiently high to match the housing strength provided by Armalon, but with a reduced section area because of the space required for the inserts.
2. Corrosion resistance at least equivalent to that of 440C.
3. LOX-compatible. The results of tests performed by the White Sands Test Facility on Burn/Flame Propagation Rates and Frictional Heating Ignition were used to guide the material selection. In general, nickel-based alloys and bronzes were satisfactory, while alloys containing aluminum were universally unsatisfactory.
4. Excellent machinability. Most of the envisioned housing designs required intricate machining, which would require excellent machinability to permit producing practical housings.
5. High ductility. The housing designs incorporating bent-over tabs to retain the inserts required high inherent ductility to permit the necessary bending without cracking.

The strength of the BASIC retainer is controlled by the cross sectional areas of the ribs and the yield strength of the phosphor bronze. The height of the rib is limited by envelope dimensions. The thickness of the ribs needed to be minimized to allow for the insert shoes to be as wide as possible. The target yield strength for the housing was 310 MPa (45,000 psi). Figure 6 is a stress-strain curve for one lot of phosphor bronze used on this project. In order to use the bent-over tabs the housing material needed to have a tensile elongation in excess of 20 percent.

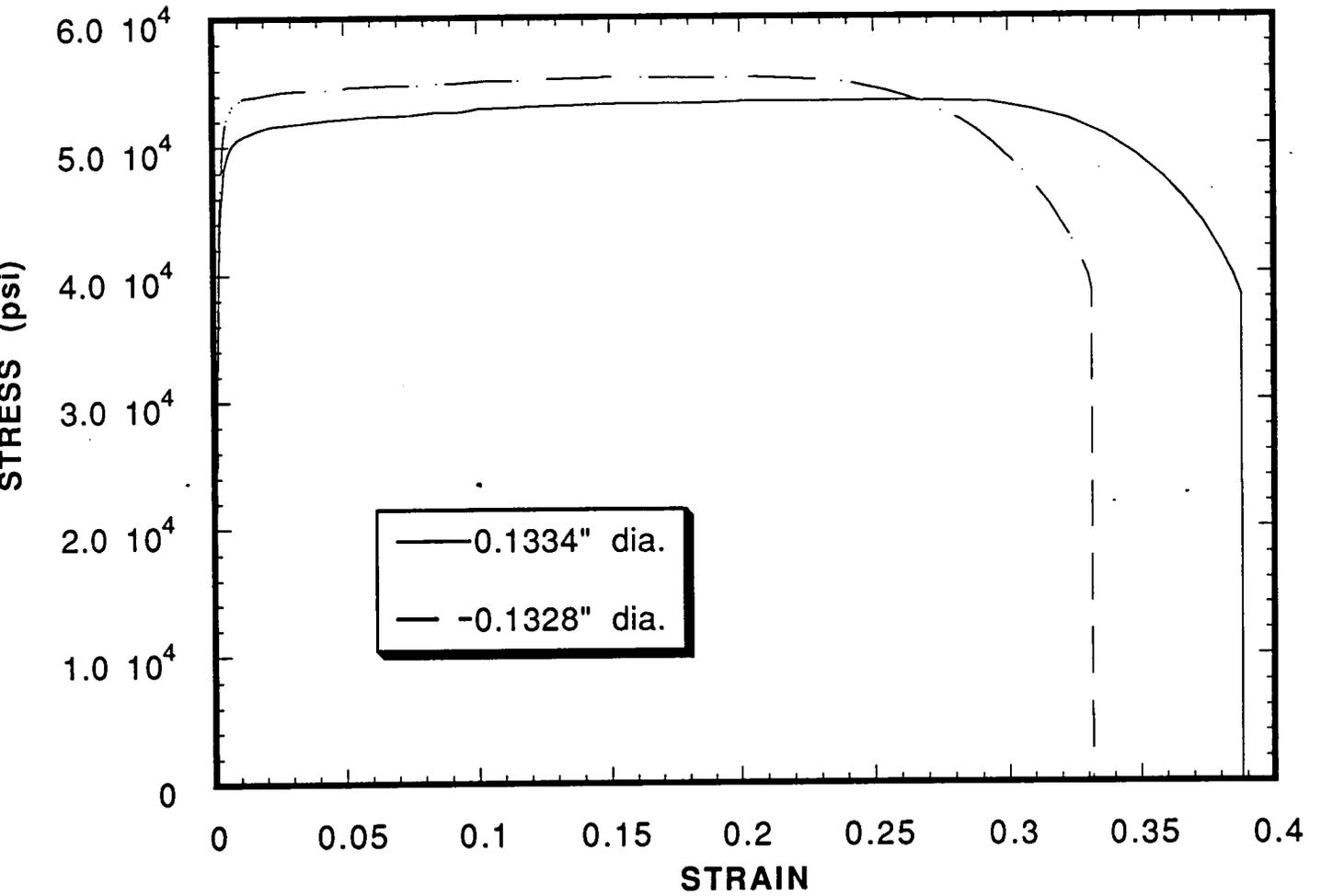
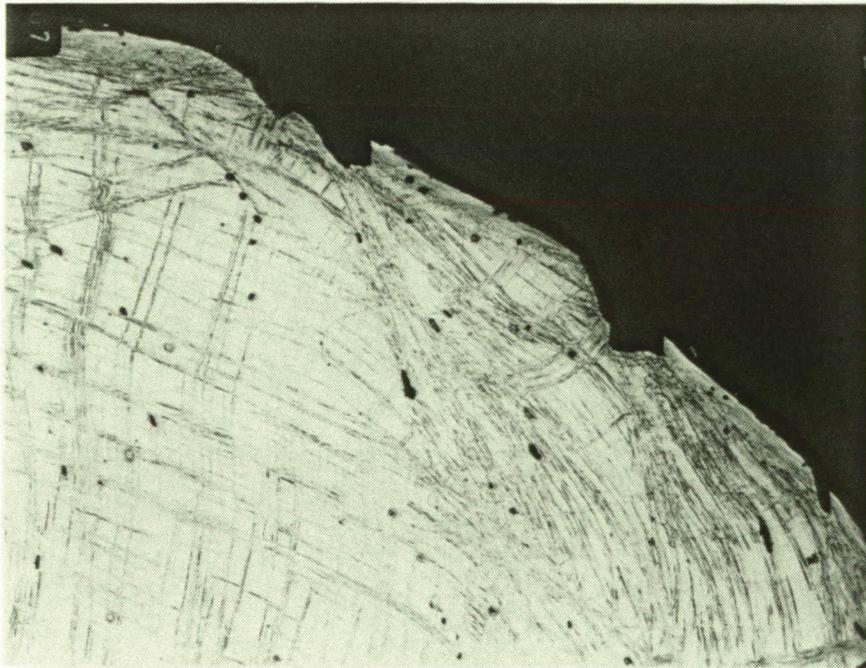


FIGURE 6. PHOSPHOR BRONZE TENSILE TEST CURVES

The material chosen for the housing was UNS C15000 Phosphor Bronze with the following specifications:

- Hard temper (HRB  $75 \pm 5$ ),
- Grain size  $\leq 0.125$  mm ( $\geq$  ASTM No. 3),
- Minimum yield strength of 310 MPa (45 ksi),
- Ultimate tensile strength  $> 345$  MPa (50 ksi),
- Elongation  $> 22$  percent.

While the hardness, yield strength, and elongation specifications can be met with work-hardened as-cast material, the finer grain size specified was found to be necessary to control the uniformity of the ductility and prevent cracking during tab bending. Early tests demonstrated that a large grain structure can have single grain boundary spanning the cross section of a tab. Figure 7 shows a typical variation in grain size; both microstructures can be found in hard condition phosphor bronze. Therefore, the cast material must be work hardened, recrystallized, and reworked to achieve the required fine grain structure. Since the grain size specifications for the bronze are not standardized, special procedures were followed to achieve the required material characteristics. Sample specimens were purchased for a given lot of material. The specimens were analyzed to determine tensile strength, grain size, and hardness. If the specimens were near specification, sufficient material for retainer fabrication was purchased. If necessary, the bronze was annealed to refine the grain size by recrystallization and work hardened to achieve proper strength. Since the procedure was time consuming, efforts were made to obtain commercially available material that fit the Battelle specification without reworking.



200X

**Hard Temper**  
**HRB 80**



200X

**Annealed at 900 F**  
**HRB 23**

FIGURE 7. PHOTOMICROGRAPHS OF BENT TABS, PHOSPHOR BRONZE UNS C51000

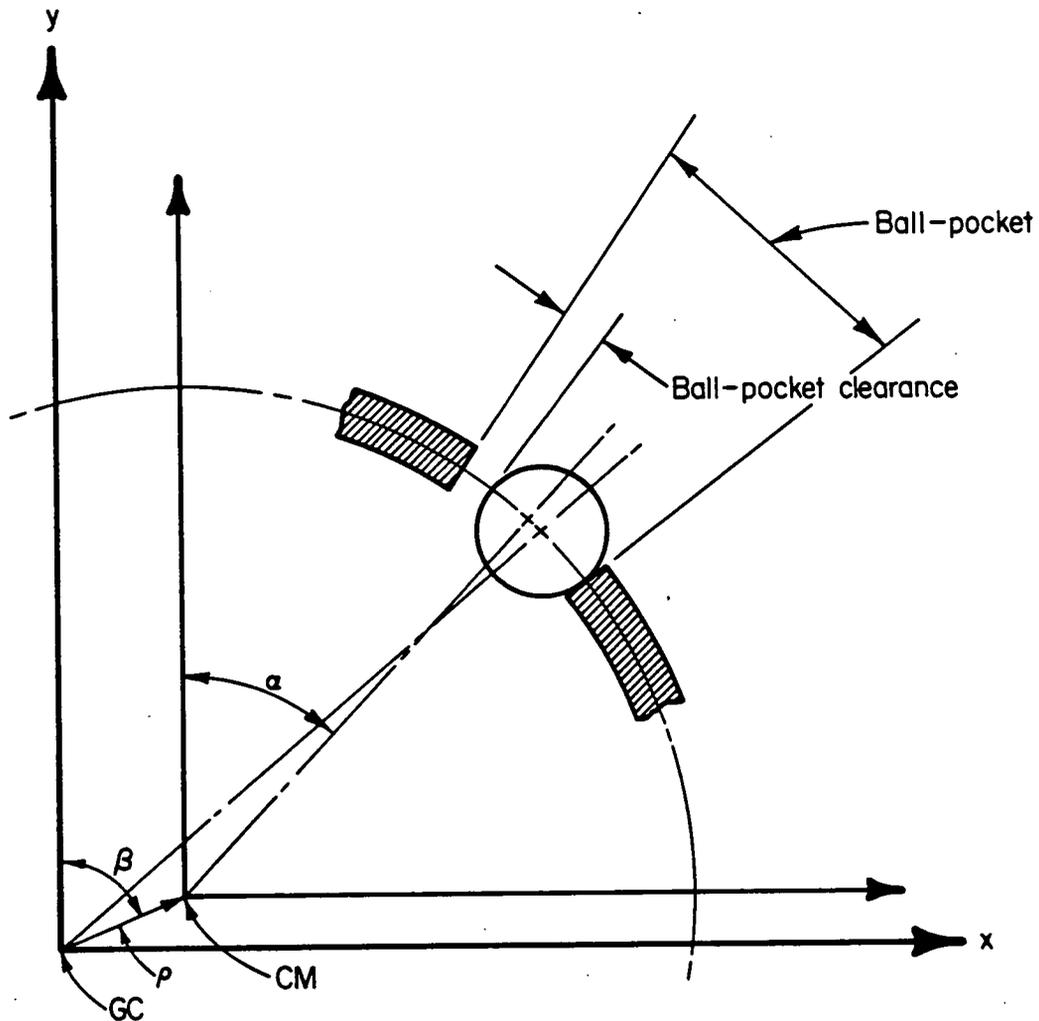
## Retainer Stability

The retainer stability was calculated using the model developed at Battelle by Kannel and Bupara<sup>(1)</sup>. The model uses a two dimensional balance of the forces acting on a ball during cage impact. Variations in retainer design predominately affect two variables: cage mass and the spring rate of the ball pocket material. These contributions are reflected in the damping parameter,  $D_p$ . The larger values of  $D_p$  imply a greater propensity for instability. Retainer stability was evaluated using the stability model discussed in the literature search (Appendix A).

A companion equation to the damping parameter equation is:

$$e_c = \exp -\pi/(Dp-1)$$

The larger the value of  $e_c$  the greater is the propensity for retainer instability. In qualitative terms  $e_c$  is a restitution factor for retainer-ball impacts. If  $e_c \approx 1$ , the retainer will bounce continuously from ball to ball without damping, which represents an instability. On a practical basis, values of  $e_c$  greater than 0.9 can represent unstable situations. Figure 8 shows the nomenclature used for the stability analysis and Figures 9 and 10 show the Cagedyn predicated stabile motion.



#### COORDINATE SYSTEM FOR CAGE-BALL LOCATIONS

- GC = Bearing Geometric Center
- CM = Cage Center of Mass
- $\alpha$  (alpha) = Rotational Angle of Cage Around Cage Center of Mass
- $\rho$  (rho) = Radial Displacement of Cage Center of Mass from Bearing Geometric Center
- $\beta$  (beta) = Rotational Angle of Cage Center of Mass Around Bearing Geometric Center

FIGURE 8. NOMENCLATURE FOR STABILITY ANALYSIS

CASE NO. 122882

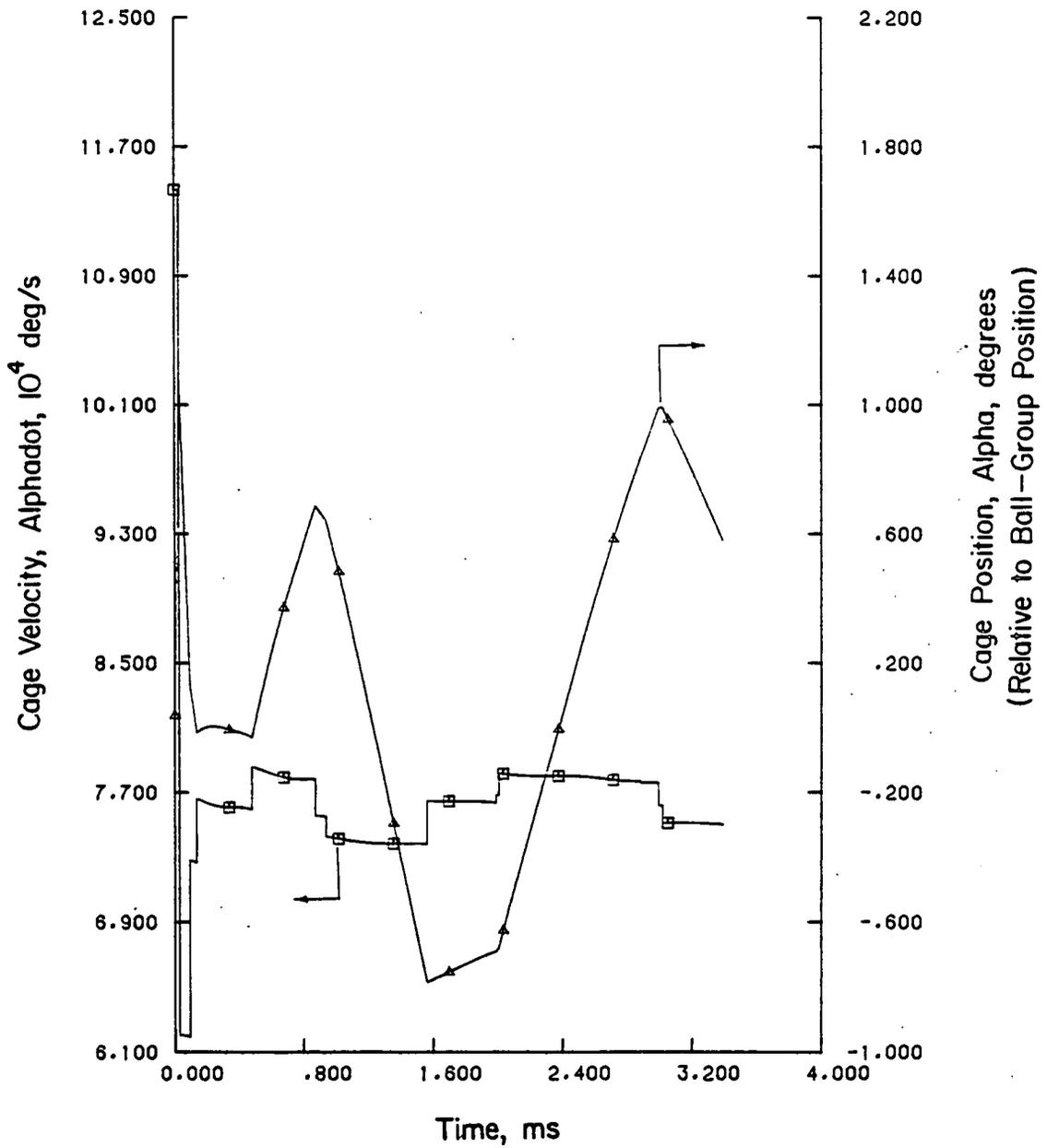


FIGURE 9. CAGEDYN PREDICTION OF CAGE MOTION FOR BEARING 7955,  
CAGE MOTION ABOUT ITS CENTER OF MASS (ALPHA)

CASE NO. 122884

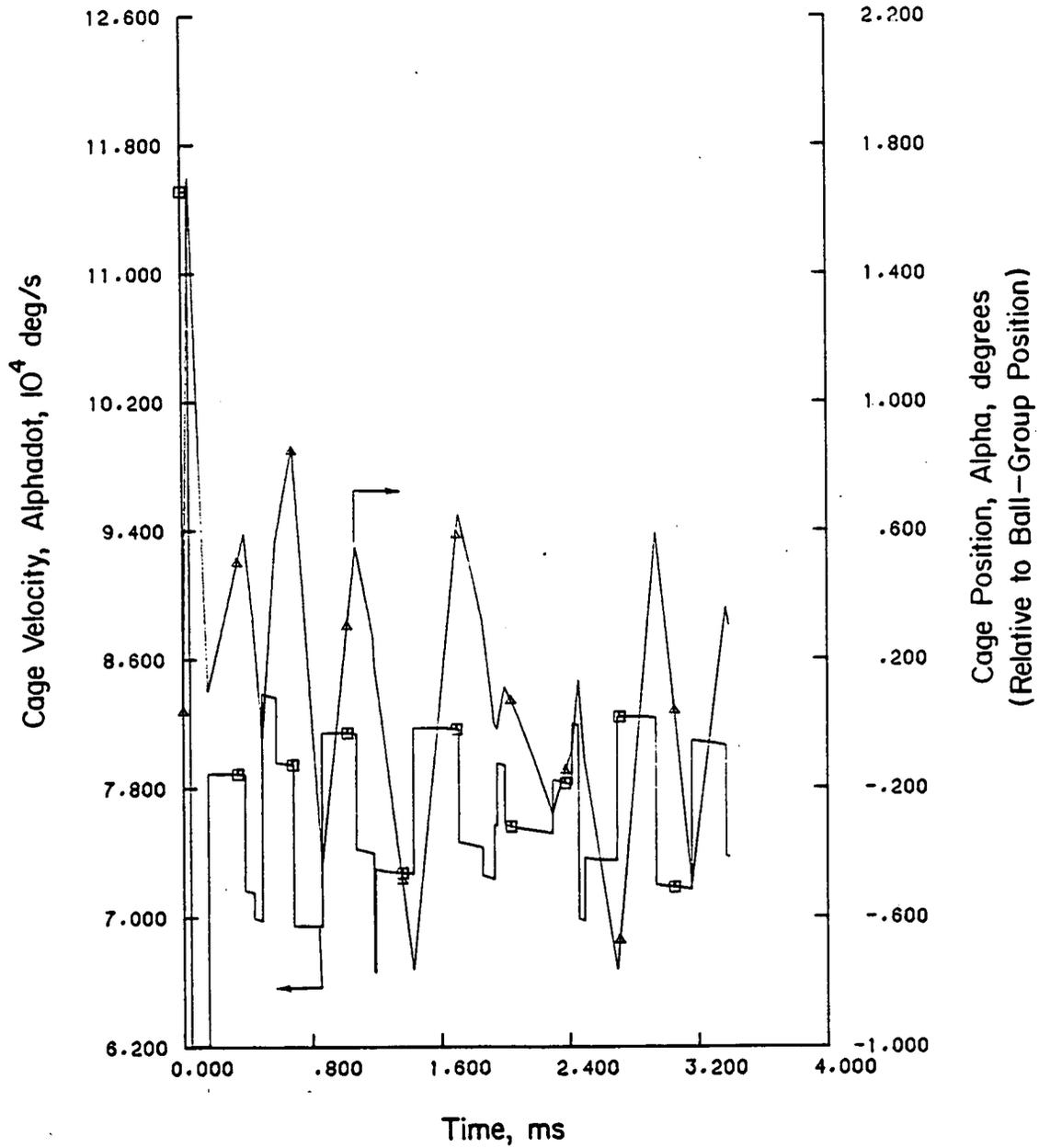


FIGURE 10. CAGEDYN PREDICTION OF CAGE MOTION FOR BEARING 7955, MOTION OF CAGE CENTER OF MASS (BETA)

## HOUSING IMPROVEMENTS

### Housing Modifications

The housing and insert drawings were revised to include a 0.8 mm (0.031 inch) radius between the housing web and shelf. Copies of the revised drawings are included with this report (Appendix C). This design modification reduces the effective cantilever length of the shelf and also significantly reduces the stress concentration factor at the attachment point. Finite element analysis was used to quantify the stress reduction in order to verify that this change will reduce any potential for cracks in this area of the housing.

The goal of the finite element analysis was to establish the stresses in the housing shelf radius and to quantify the decrease in local stresses caused by changing the radius from 0.13 mm to 0.80 mm. The analysis was applied only to the 57 mm bearing cage; because of the higher loads on this bearing this represented an evaluation of the highest stress condition. The radius of interest is indicated as: "0.031 inch R. TYP" on Battelle drawing G1230-B12 Rev. J in region B6 (Appendix C).

### FEA Evaluation

Three finite element models were used to show the change in stress in this area as a function shelf radius geometry. A 3-D quarter-symmetric, linear elastic analysis of the insert shelf area with a 0.8 mm radius was run using SDRC I-DEAS\*. A load of 138 N (31 lbs), directed radially outward, was distributed triangularly over the shelf area (near the ball pocket edge) with the maximum at the plane of symmetry. Figure 11 is a plot of this model showing the location of the applied load. The maximum principal stress in the 0.8 mm radius, on the retainer's plane of symmetry, was 363 MPa (52,000 psi). Figure 12 is a contour plot of this principal stress. The tested

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\*SDRC I-DEAS is an "Integrated Design Engineering Analysis Software" from Structural Dynamics Resource Corp.

average yield strength of the phosphor bronze alloy C51000 was 377 MPa; therefore, the predicated maximum principal stress is below the yield point of the housing's material. It should be noted that this stress is conservative, based on a conservative normal load of 138 N on the housing shelf. By comparison, the worst case estimation for the ball cage friction force (normal load on the shelf) was 67 N (15 lb) for unworn balls (Rocketdyne data) and 120 N (27 lb) for worn balls (SRS data).

To establish the decrease in local stress caused by increasing the shelf radius, 2-D finite element analyses were applied to the old and revised designs. Two, 2-D linear-elastic plane stress analyses were run using ABAQUS\*\*, one with the 0.8 mm (0.31 inch) radius and one with the original 0.12 mm (0.005 inch) radius. The cross section chosen for the 2-D models was on the retainer's plane of symmetry. Figures 13 and 14 show the models with the 0.8 mm and the 0.13 mm radii, respectively. The load applied to the 2-D model with the 0.8 mm (0.031 inch) radius was adjusted such that the maximum principal stress in the radius area matched the 363 MPa (52,700 psi) calculated in the 3-D model. The same load was applied to the 2-D model with the 0.13 mm (0.005 inch) radius. The highest maximum principal stress in the 0.13 mm (0.005 inch) radius area was 589 MPa (85,400 psi).

Figures 15 and 16 are contour models of 0.13 mm (0.005 inch) and 0.8 mm (0.031 inch) radii, respectively. Calculations using handbook\*\*\* stress concentration design factors predicted an increase from 363 MPa (52,700 psi) to 601 MPa (87,200 psi) when decreasing the radius from 0.8 mm (0.031 inch) to 0.13 mm (0.005 inch), which is consistent with the finite element prediction.

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\*\*ABAQUS is a general purpose FEA program from Hibbitt Karlson and Sorenson.

\*\*\*Stress Concentration Design Factors, R.E. Peterson, John Wiley and Sons, k 1953.

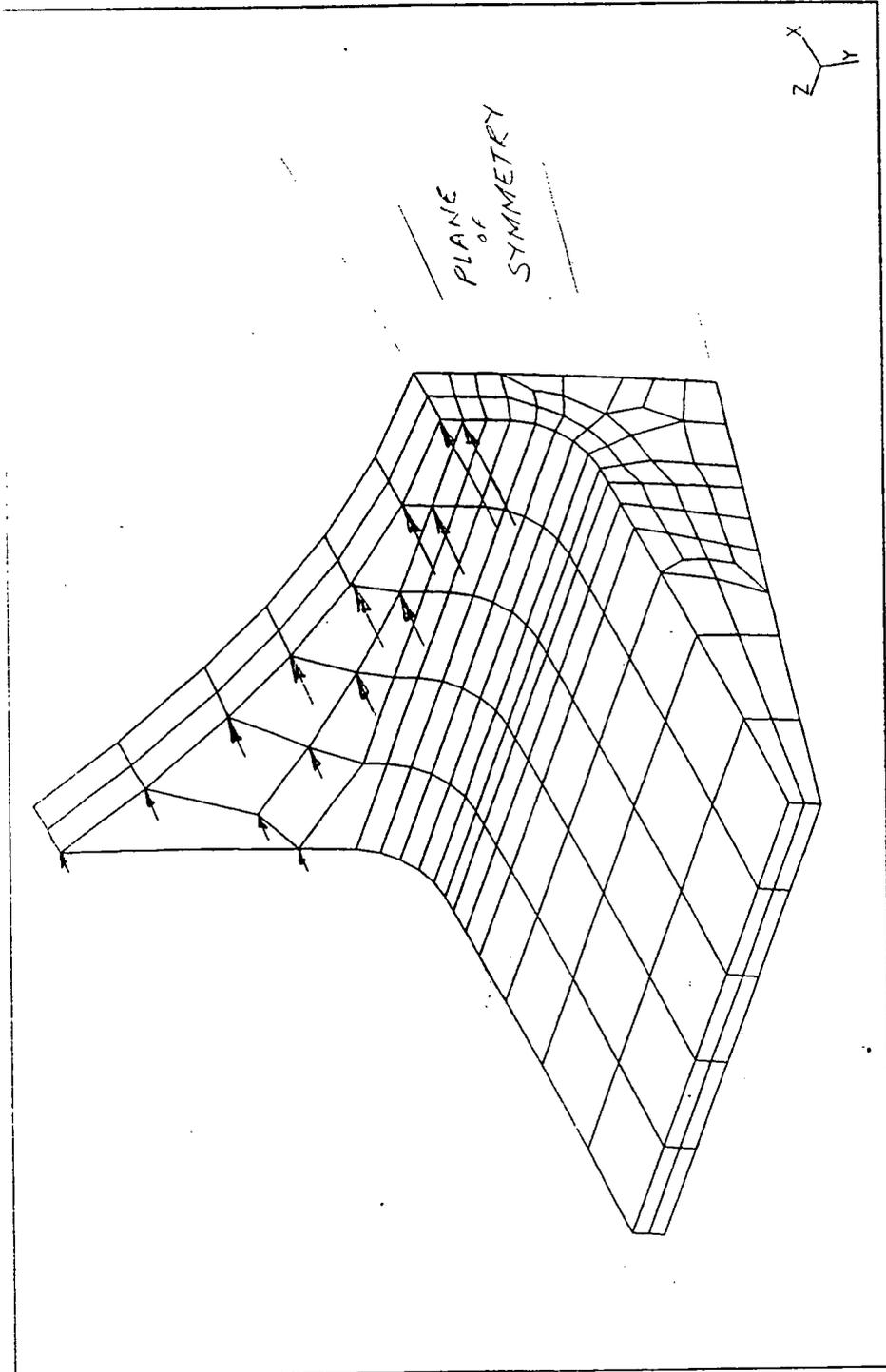


FIGURE 11. 3-D FINITE ELEMENT MODEL, 0.80 mm RADIUS

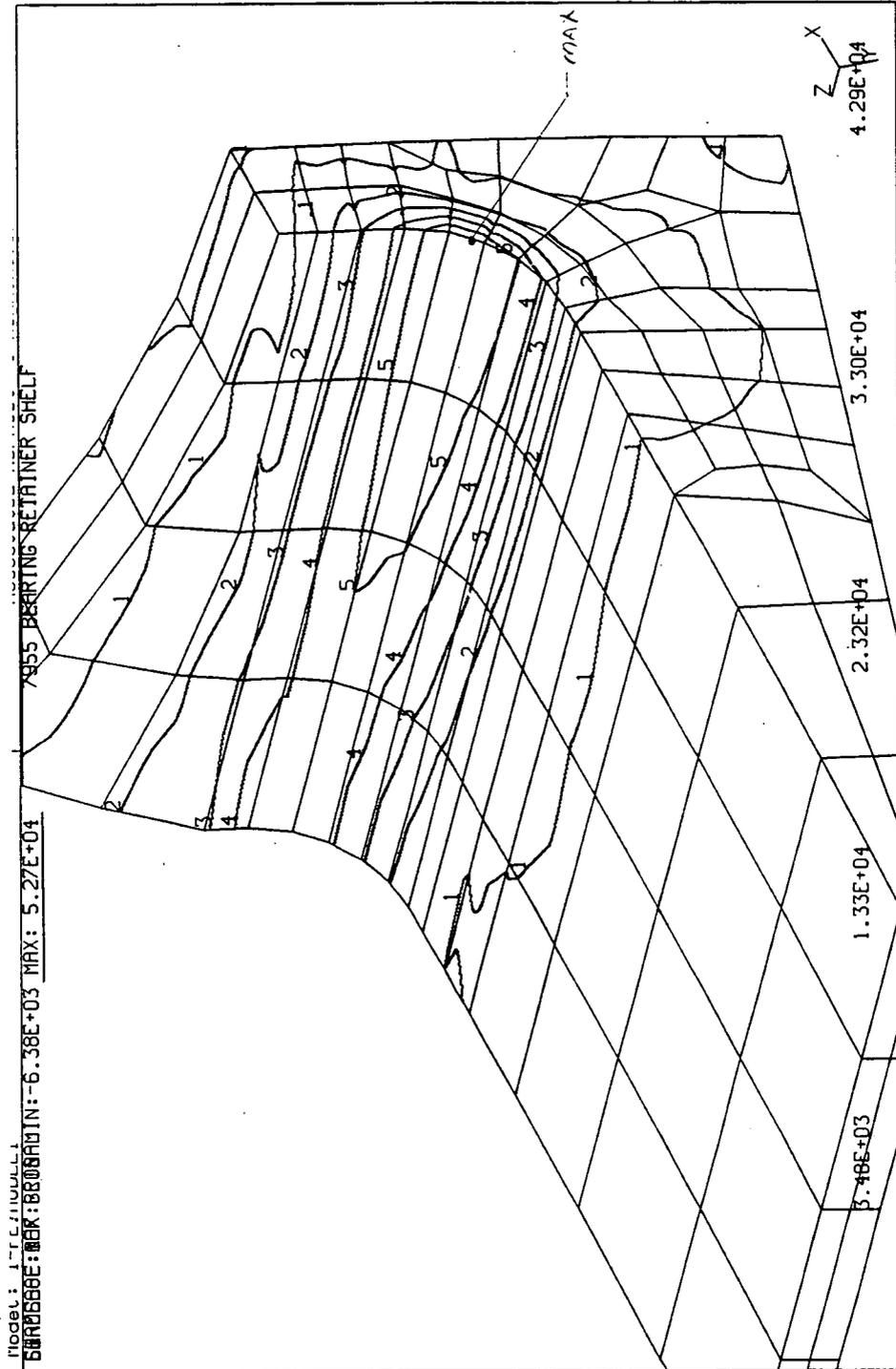


FIGURE 12. CONTOUR PLOT OF PRINCIPAL STRESSES 3-D, 0.080 mm RADIUS

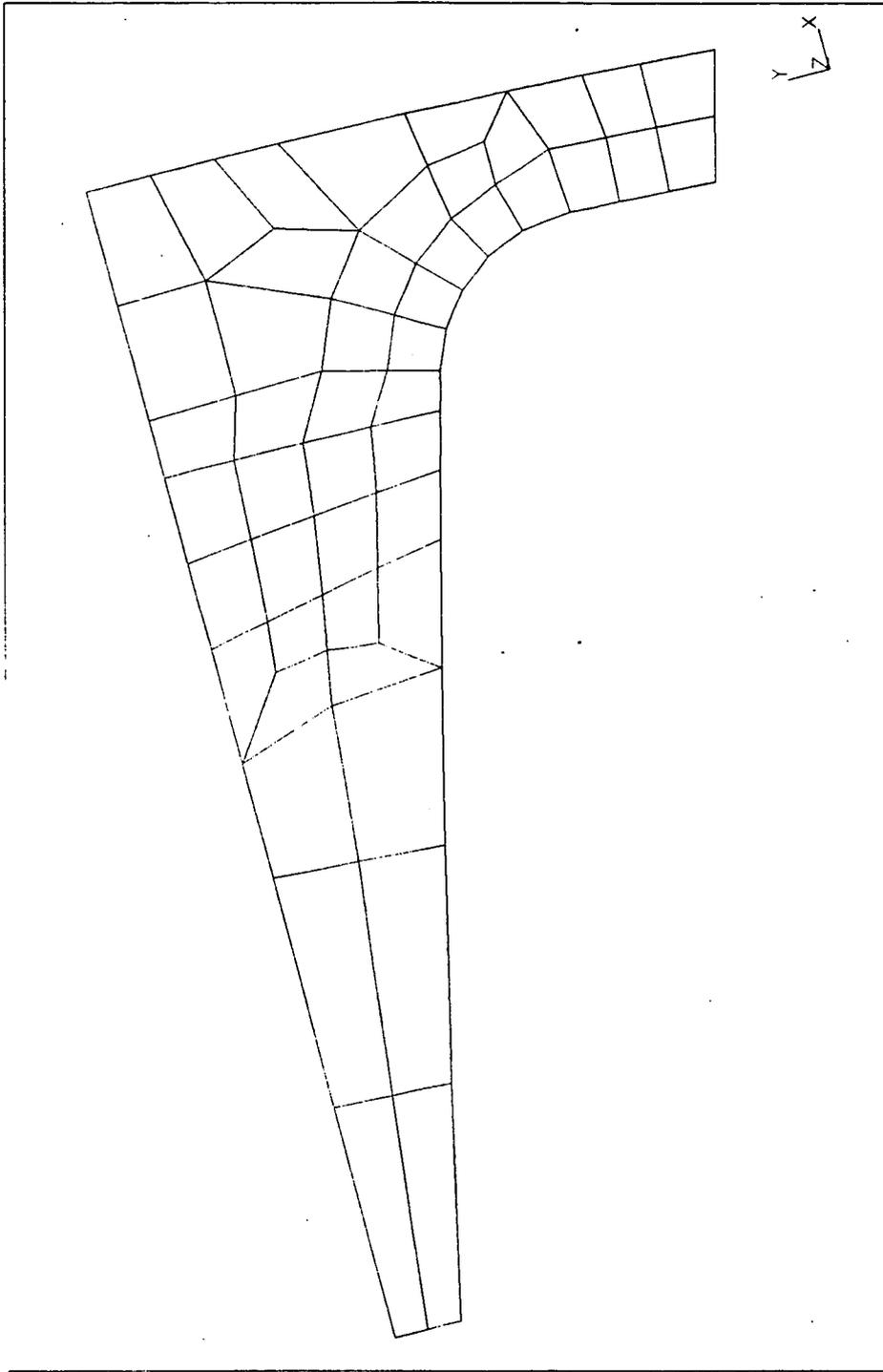


FIGURE 13. 2-D FINITE ELEMENT MODEL, 0.80 mm RADIUS

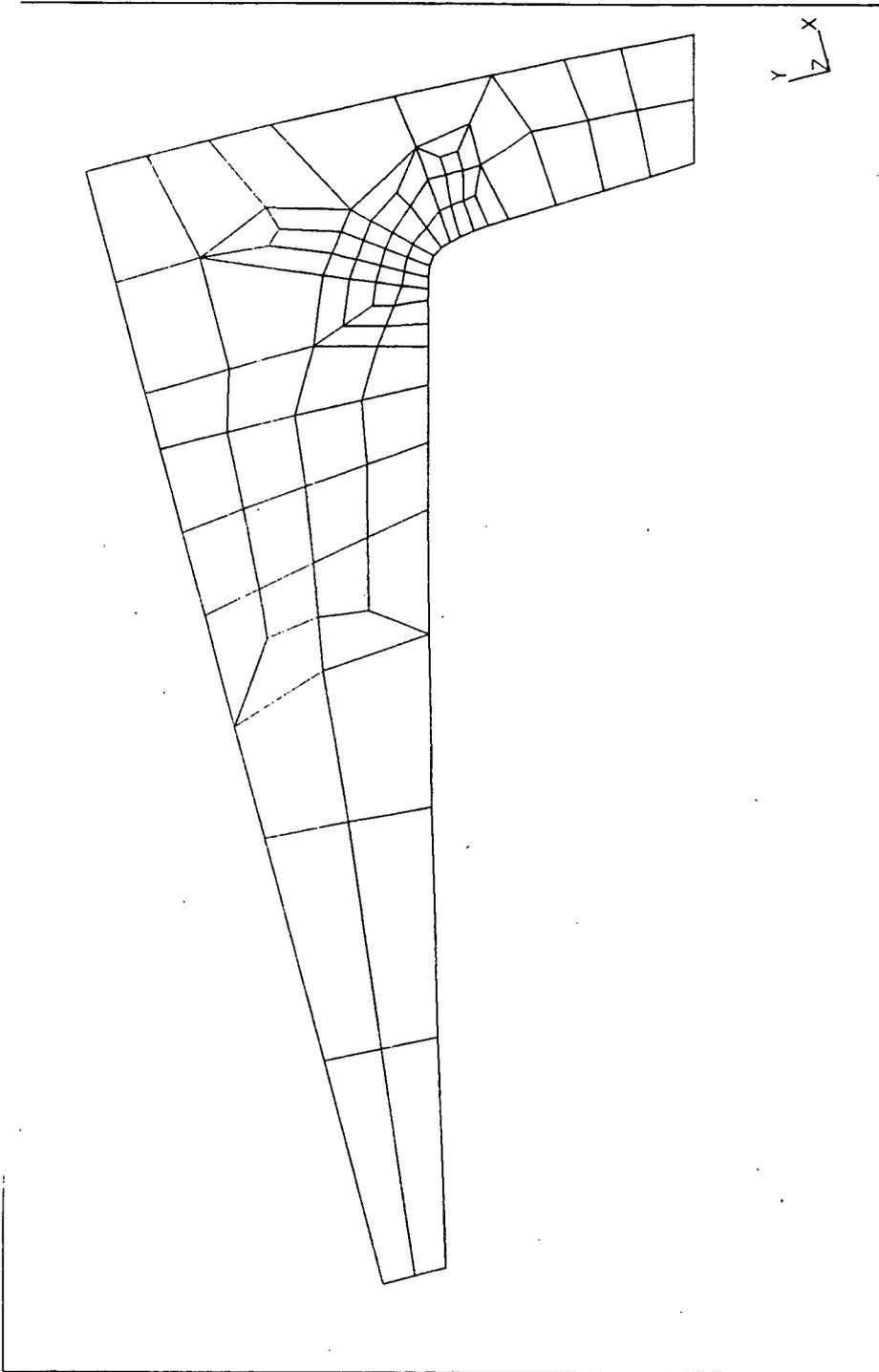


FIGURE 14. 2-D FINITE ELEMENT MODEL, 0.13 mm RADIUS

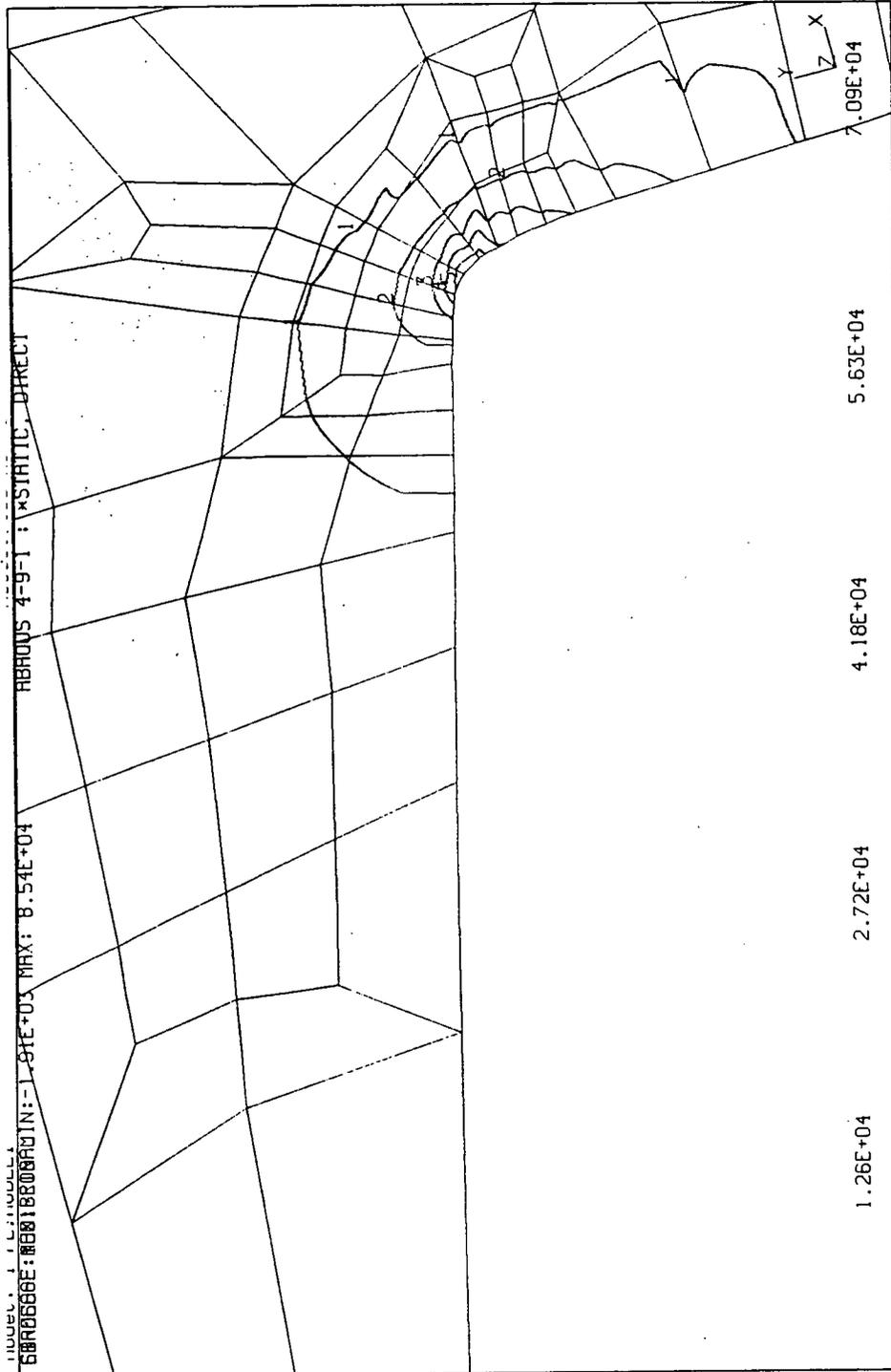


FIGURE 15. CONTOUR PLOT OF PRINCIPAL STRESSES 2-D, 0.13 mm RADIUS

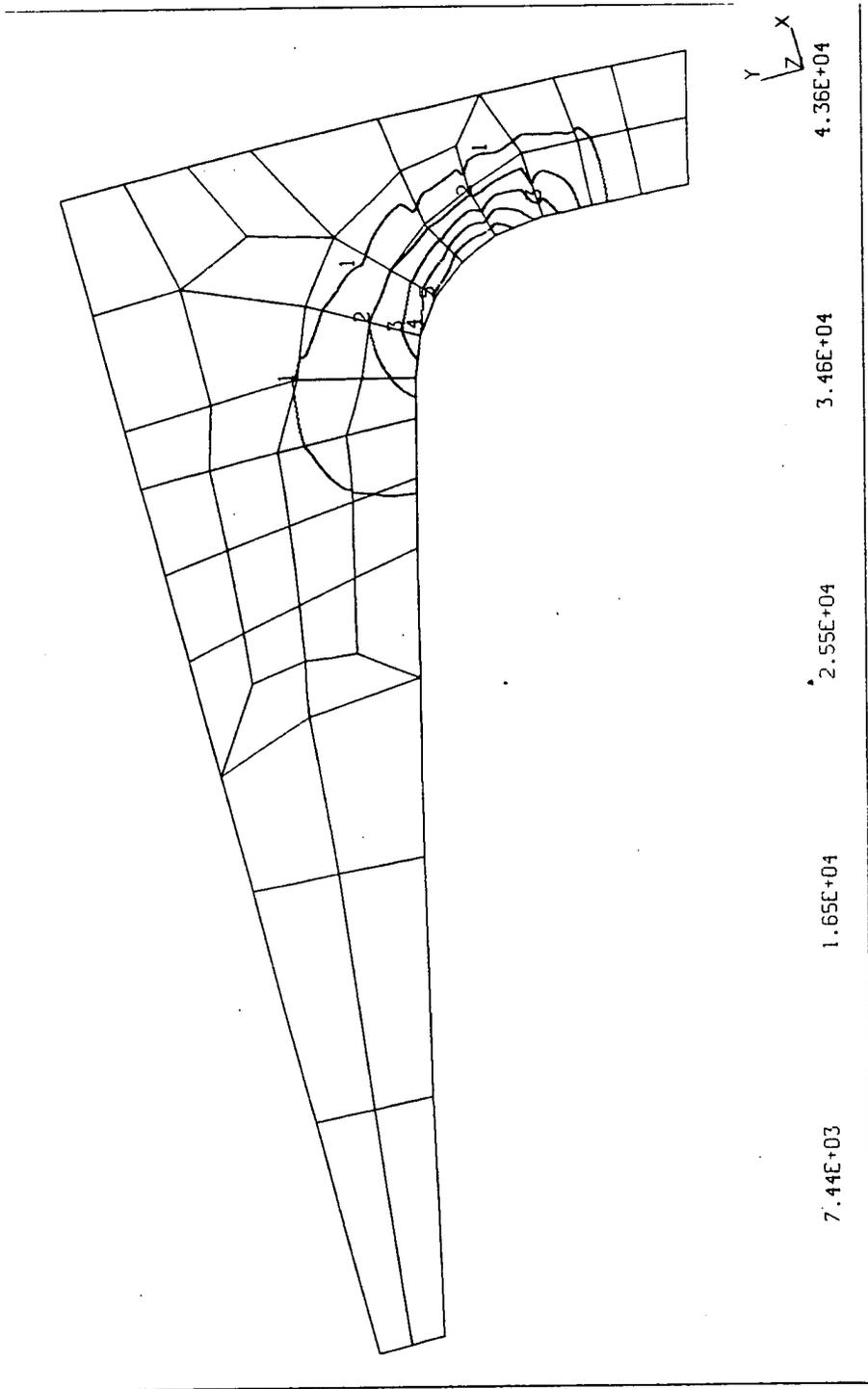


FIGURE 16. CONTOUR PLOT OF PRINCIPAL STRESSES 2-D, 0.80 mm RADIUS

## FABRICATION OF BEARINGS

### Balls and Races

The balls and races for 40 sets of bearings were purchased from Industrial Techtonics Incorporated (ITI). Twenty bearings conformed to the RS007958 drawing (45 mm bore) and twenty bearings conformed to the RS007955 drawing (57 mm bore). The balls and races were cleaned and coated as outlined in the QA specification. The coatings were as follows:

Balls -  $\text{MoS}_2$  (~ 5 micrometers thick) Hohman plating

Races -  $\text{MoS}_2$  (burnished) - Lubeco

The balls and races were shipped to NASA/MSFC for final assembly as matched sets of individual components.

### BASIC Retainers

Specimens from each lot of the insert and housing materials were shipped to NASA/MSFC for LOX impact testing. After the material had been cleared by NASA and the material properties confirmed at Battelle, the retainers were fabricated in the following steps.

- Salox and phosphor bronze were shipped to an outside machine shop (King Machine) for machining.
- Housings and inserts were inspected (including visual, metrology, and radiography analysis) at Battelle to ensure conformity to specifications.
- Housing and inserts were sent to Quality Controlled Cleaning (Q.C.C.) for precleaning.
- Housings and inserts were assembled at Battelle and reinspected.

- Post assembly machining to control the final o.d. and ball pocket dimensions was completed at an outside machine shop.
- The BASIC retainers were sent to Q.C.C. for final cleaning and packaging.

### **Evaluation of Assembled Retainers**

Tensile tests were conducted on segments of a 57 mm prototype retainer fabricated from phosphor bronze that met the material specification (C51000, hard temper,  $S_y > 340$  MPa, elongation  $> 22$  percent, HRB  $75 \pm 5$ , and a grain size  $< 0.125$  mm). Figure 17 shows the results of these tests compared with Armalon at both  $LN_2$  and room temperatures. The phosphor bronze data has been scaled to represent a retainer with a 1.02 mm (0.040 inch) housing rib. The graph established that the minimum tensile load for the phosphor bronze BASIC retainer is greater than that of Armalon over the entire bearing operating temperature range.

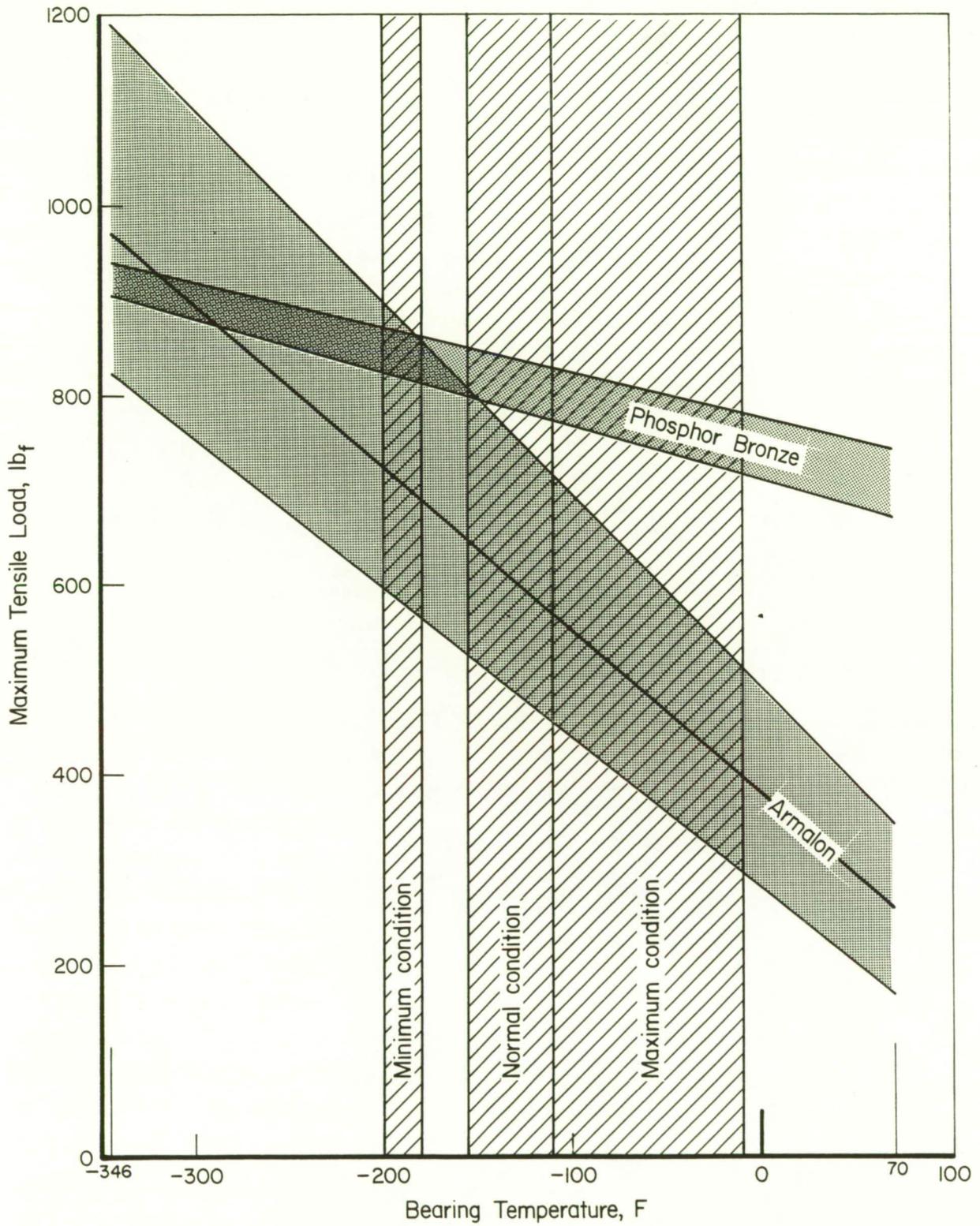


FIGURE 17. ARMALON AND PHOSPHOR BRONZE STRENGTH VERSUS TEMPERATURE

**APPENDIX A**  
**LITERATURE REVIEW**

## LITERATURE REVIEW

The primary goal of this project was to develop suitable bearing retainers using current rolling element component dimensions. While the contact element design is determined by consideration of contact stress and fatigue, the retainer design is influenced by requirements of dynamic stability, cryogenic temperature usage, retainer wear resistance, and lubricating transfer film generation. In order to guide current efforts, a computer-based literature search of past work was conducted. References related to past work in bearing stability, retainer material wear resistance and lubricating transfer film generation, and cryogenic bearing development were selected. This section discusses selected references in these three areas.

### Retainer Dynamics and Bearing Stability Theories

The retainer in an angular contact bearing is essentially an unconstrained rigid rotator with six degrees of freedom. If the retainer simply tracks the ball-group speed, the motion is stable and no unusual forces are generated. However, under some conditions, dynamic instabilities can occur with the retainers.

The various criteria affecting retainer stability were first identified by Kannel and Bupara<sup>(1)</sup>. Their investigations involved a two-dimensional analysis in which ball inertial forces, ball-race traction forces, and ball-cage friction forces were compared with the impact damping properties of the cage material and any lubricating fluid film. The damping parameter,  $D_p$ , is expressed by the following equation:

$$D_p = \frac{32C_\mu^2}{M C_{sl}}$$

where:

- $C_\mu$  = a ball-race lubrication parameter,
- $M$  = retainer mass, and
- $C_{sl}$  = spring rate of the retainer-ball interface (assumed linear).

Smaller values of  $D_p$  imply greater stability thus, qualitatively, a retainer exhibiting large mass and low ball-race traction will tend to operate in a stable manner. A computer model, CAGEDYN (cage dynamics), incorporates these stability analyses and qualitatively assesses the tendency for bearing stability under operation.

Two other computer stability models are now in use. Gupta<sup>(2,3)</sup> has generated two models, DREB and ADDRE, which can be used to assess the stability of individual bearings and bearing systems. Meeks<sup>(4)</sup> has developed a model (Sepdyne), which has been used to examine the stability of solid lubricated bearings. These computer models, though rigorous in their examination of ball and cage forces and motions, are dependent upon an accurate assessment of the ball-race traction forces in order to estimate stability correctly. Since that parameter is often difficult to quantify, especially under solid lubrication conditions, the simple CAGEDYN model is usually sufficient for judging bearing stability.

Attempts have been made to verify experimentally selected stability models. Schultze and Dill<sup>(5)</sup> used an experimental apparatus incorporating a 100 mm bore bearing that was loaded and rotated at shaft speeds of up to 15,000 rpm. A proximity probe was used to measure and track the movement of the steel cage retainer. The relationship between actual retainer movement and the retainer movement predicted by DREB was found to be qualitative; predicted values of cage movement were approximately twice the measured values. These results suggest that, with respect to the current program, the stability criteria developed by Kannel and Bupara can be used to qualitatively assess the relative performance forecast for specific candidate retainer designs.

### **Retainer Material Wear and Lubrication Studies**

Significant work has been conducted in the area of retainer materials for extreme environment applications. Cunningham and Anderson<sup>(6)</sup> experimentally evaluated various candidate retainer materials for use in a 40 mm bore liquid oxygen turbopump bearing. Five different retainer materials were investigated: glass cloth - PTFE

laminated (Armalon), glass fiber in PTFE, bronze powder in PTFE (Salox), molybdenum disulfide plus glass fiber in PTFE, and 100 percent graphite. The composite using glass fibers presumably featured randomly oriented chopped glass fibers, while the glass cloth featured woven glass fibers. Under liquid oxygen (LOX) conditions and speeds of up to 30,000 rpm, the Armalon material exhibited the best wear resistance, while the 100 percent graphite material exhibited the poorest wear resistance. Salox gave relatively poor wear resistance compared with the Armalon and glass fiber materials, although no damage to the balls and races was observed. For these experiments, thrust loads and radial loads were relatively low. Based on these initial experiments, the use of Armalon as a retainer material for cryogenic bearing applications appeared to be acceptable.

This study also examined possible reinforcement techniques for the lower strength materials, such as graphite and glass fiber-PTFE. Riveted shrouds of aluminum were used to impart tensile strength to the assembly, and riveted two-piece assemblies were also fabricated.

Possible problems stemming from Armalon's abrasivity were examined in work conducted by Scibbe, Brewe, and Coe<sup>(7)</sup>. In this experimental study, bearing surfaces were examined for evidence of any transfer lubricant or surface damage arising from contact with the retainer surface. Armalon was found to deposit transfer films of PTFE initially, but these films were eventually worn away with prolonged sliding contact, presumably due to the exposed glass fibers of the Armalon. In contrast, the Salox material appeared to provide sufficient transfer films to retard race wear from ball contact. As in the previous NASA study, riveted aluminum shrouds were used to impart strength to the cage materials. This technique was used with some success, although differences in thermal expansion between the shroud and the retainer material were shown to result in cracks in the composite material.

For the purposes of the current study, these past NASA programs reinforced the current observations regarding the abrasiveness of Armalon and supported the approach of using Salox in a reinforced retainer design.

Other investigators have also examined alternate cage materials. Stevens and Todd<sup>(8)</sup> investigated the friction and wear performance of two polymer-based materials (polyimide/MoS<sub>2</sub> and PTFE/glass fiber/MoS<sub>2</sub>) intended for use as ball retainer materials. Retainers were wholly configured from these materials and tested under relatively low speeds and loads. The lowest wear was exhibited by the PTFE/glass fiber material. These investigations showed, however, that the generation of a lubricating transfer film (presumably of PTFE) was dependent upon the applied load to the bearing. At loads above a critical value, the transfer film suffered more damage, leading to increased ball wear. In contrast, at loads below this critical value, a reduction in retainer wear rate was observed once a transfer film had formed.

Other work has been conducted on metallic-PTFE composites for aerospace retainer materials. Mortimer and Lancaster<sup>(9)</sup> produced composites by photoetching thin sheets of phosphor bronze and beryllium copper and filling the voids with sintered PTFE. In laboratory experiments, these composites successfully generated PTFE transfer films on stainless steel counterfaces. However, due to the high hardness of the beryllium copper, unsatisfactory wear of the counterface was observed with the beryllium copper-PTFE composite.

Additional studies have been made with apparatuses that simulate important features of the bearing retainer - bearing ball interface. Kissell and Snediker<sup>(10)</sup> investigated the ball-retainer friction of porous polyamide and cotton-phenolic cage materials. A 2.5 mm (0.10 inch) diameter test ball was spun at 24,000 rpm and loaded against a flat retainer material specimen. Interface friction was measured using a very sensitive cantilever transducer. This study was directed toward an examination of materials used in small gyroscope bearings rather than the high speed, high load bearings of the SSME.

Retainer wear and transfer film traction were examined in a later study by Barber and Kannel<sup>(11)</sup>. As indicated previously, the ball-race traction greatly influences retainer and bearing stability, and the accurate prediction of stable operating conditions requires a good estimate of the traction coefficient. In this study, an apparatus that simulated the contact conditions at a ball-race and ball-retainer interface was designed

and fabricated. Using a Ga-In-WSe<sub>2</sub> compact as a ball pocket, transfer films were generated between the ball and race. A load cell measured the traction force. These data were used as an input to a bearing stability model.

Meeks and Bohner<sup>(12)</sup> attempted to formulate a model to predict the life of solid lubricated bearings by combining the effects of retainer wear, ball wear, and race wear. They found that the effect of race wear on bearing life dominated any material fatigue effect for solid lubricated bearings. Their model, however, was directed toward slow-moving gimbal bearings and did not include the significant thermal effects that may accompany a heavily-loaded high speed solid lubricated bearing.

These past retainer wear studies have been concerned with either high temperature bearings or very low speed cryogenic bearings. The next section examines past development efforts on high speed cryogenic bearings.

### **Cryogenic Bearings**

As previously indicated, high speed bearings for cryogenic service have been investigated by NASA.<sup>(6)</sup> A more recent experimental study was conducted by Oike, et al<sup>(13)</sup>. This study examined the effect of ball pocket configuration on the performance of 25-mm-bore angular contact bearings operating under liquid hydrogen conditions. Armalon was used as the retainer material. In this study elongated ball pockets were found to perform better than round ball pockets. The loads and speeds for this study were substantially less than those existent in the SSME bearings.

### Summary of Literature Search

The literature search determined the following:

1. Bearing dynamics models are available for assessing, on a qualitative basis, the relative stability of different retainer designs. A stability criterion will be used in selecting preferred retainer designs.
2. Past work with alternate materials for cryogenic turbopump bearings has been conducted. These studies show that Armalon, when used as a retainer material, exhibits good wear properties. However, under long term operation, lubricating transfer films initially generated by Armalon can be abraded away by exposed glass fibers. Salox, while exhibiting higher wear, appeared to generate and maintain intact lubricating transfer films, leading to reduced level of bearing race wear and damage.
3. Alternate bearing retainer designs using reinforcing shrouds and rivets to enable the use of low strength materials have been successfully evaluated.

The past work appears to verify the current preliminary retainer design based on Salox in conjunction with a metallic load-carrying structure and reinforces the idea that an improved replacement retainer for the Armalon is feasible.

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**APPENDIX B**  
**QUALITY ASSURANCE PLAN**  
**PROCEDURES FOR INSERT DESIGN CAGE**  
**PRODUCTION FOR NASA HPOTP BEARINGS**

Title: Procedures for Insert Design Cage Production for  
NASA HP0TP Bearings

QA Document: G1230-B1

Date: 9/11/91

Revision: H

1. SCOPE

1.1 Scope - This specification documents the requirements for handling, assembly inspection, identification, maintaining cleanliness, packaging, and assuring the quality of the BASIC\* Cage as a subassembly of the SSME turbopump rolling element bearings. The BASIC Cage is a one-for-one replacement for an Armalon cage, accordingly, no changes are made to the manufacturing procedures for the balls and races.

2. APPLICABLE DOCUMENTS

2.1 Applicable Documents - Except as otherwise specified the following documents, of the latest issue in effect, form a part of this specification to the extent specified herein.

2.2 Specifications - These include but are not limited to the following:

Federal

Fed. Std. No. 209h      Federal Standard, Clean Room and Work Station  
Requirements, Controlled Environment

Military

MIL-D-3464      Desiccants, Activated, Bagged, Packaging Use and  
Static Dehumidification

MIL-B-131      Barrier Materials, Water-vapor proof, Grease proof,  
Flexible, Heat-Sealable

MIL-P-27401      Propellant Pressurizing Agent, Nitrogen

ASTM

E8-82      Standard Methods of Tension Testing of Metallic  
Materials

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\*BASIC (BAttelle Self-Lubricating Insert Configuration)

NASA

NHB 5300.4 (1D 2)	Safety, Reliability, Maintainability and Quality Provisions for the Space Shuttle Program
NHB 5300.4 (1C)	Inspection System Provisions for Aeronautical and Space System Materials, Parts, Components and Services
NHB 5300.4 (1B)	Quality Program Provisions for Aeronautical and Space System Contractors
NHB 8060.1B	Flammability, Odor, and Offgassing Requirements and Test Procedures for Materials in Environments that Support Combustion
SN-C-0005, Rev. A, March, 1982	Specification, Contamination Control Requirements for the Space Shuttle Program
MSFC-SPEC-164A	Cleanliness of Components for use in Oxygen, Fuel, and Pneumatic Systems, Specification for

Rockwell International (Rocketdyne)

RL10001	Cleanliness of Components for use in Oxygen Fuel, and pneumatic Systems, Specification for
RL00144	Applicable Documents for the Design and Construction of Components: Space Shuttle Main Engine
RL00916	Turbopump Rolling Element Bearings for Use in Hydrogen and Oxygen Systems; Handling, Storage, Assembly, Disassembly and Visual Inspection of
RA0116-094	Parts Protection: General Requirements
RB0230-001	Nitrile Elastomer, Solvent Resistant
RA0115-11B	Liquid Oxygen Compatibility Impact Testing Method
RQ0711-600	Environmental Control of Manufacturing, Test, and Inspection Work Areas

## 2.3 Drawings

### Battelle

G1230-B12	Retainer Housing; Insert Design, RS007955 Bearing, 12 Balls
G1230-B13	Insert; Insert Design, RS007955 Bearing, 12 Balls
G1230-B14	Retainer Housing; Insert Design, RS007958 Bearing, 11 Balls
G1230-B15	Insert; Insert Design, RS007958 Bearing, 11 Balls

### Rockwell International

RS007958-161SA1	Bearing, 45 mm Bore - Turbopump (matched set)
RS007955-261SA1	Bearing, 57 mm Bore - Turbopump (matched set)

## 3. REQUIREMENTS

### 3.1 General Requirements

3.1.1 All housings will be individually bagged and packaged to prevent damage during shipment to storage. Inserts shall be bagged in groups machined from a single ring of material. Assembly of cage components shall be done with utmost care to prevent contamination. Clean, lint-free gloves and clean tooling shall be used when handling cleaned surfaces, reference Rocketdyne RL00916A.

3.1.2 Specifications that are applicable to the manufacturing, processing, materials, handling, and packaging of the bearings shall be listed. Authorization for any exceptions to these specifications must be requested from Battelle. Material or components not meeting these specifications shall not be accepted and shall be returned to the supplier or contractor.

3.1.3 Personnel certification shall be required for custom processes that are unique to this specification. This applies specifically to the tab bending operation and to the housing radiographic inspection. Personnel shall be required to demonstrate acceptable workmanship and operation of the respective equipment on a nondeliverable prototype before approved by an authorized QA inspector to perform that operation or test.

### 3.2. BASIC Cage Fabrication

3.2.1 Material - Upon receipt each piece of material shall be marked or tagged with the date, supplier, and batch or lot number. Raw materials shall be segregated to prevent use of materials which do not conform to this specification.

3.2.1.1 Cage housings are to be made from phosphor bronze, UNS-C51000 (ASTM B139) in the half hard condition with traceable records as to its origin, alloying constituents, and heat lot. Material provided shall be batch tested (per heat lot) to confirm the following mechanical and physical properties:

tensile strength	> 50 ksi
yield strength	> 45 ksi (.5% extension under load)
elongation	> 22%
HRB	75 ± 5
grain size	≥ ASTM No. 3 (≤ 0.125 mm)

Records shall be kept showing that these were performed.

3.2.1.1.1 Material not meeting the grain size requirements may be annealed and then cold reduced to form acceptable properties. Phosphor bronze in the hard condition should be annealed at 900 F for 3 hours and air cooled. The phosphor bronze must then be cold worked to a hard temper. A U.S. source for rolling or drawing 3½" diameter phosphor bronze rods in small lots has not been found. Hammer forging along the axis of a phosphor bronze rod can produce the specified hardness, however, this process is not well controlled, and has resulted in unacceptable variations in hardness.

3.2.1.1.2 Each batch (heat lot) of phosphor bronze must be tested in accordance with NHB8060.1B paragraph 413, Test 13 - Ambient Liquid Oxygen and Pressurized Liquid and Gaseous Oxygen Mechanical Impact Test at 1000 psi and a 10 kg-m energy level.

3.2.1.1.3 Mechanical properties shall be determined from two tensile specimens from each bar of raw material. Specimens shall be sized according to Lockheed Drawing SK1220 and sectioned from the rod stock in a circumferential orientation. Other testing procedures should follow ASTM Standard Methods of Tension Testing of Metallic Materials (ASTM E8-82).

3.2.1.2 Cage inserts are to be made from a bronze-filled polytetrafluoroethylene (PTFE) material that has been approved by NASA. The approved materials to date are:

Salox (Allegheny Plastics, Inc.) with a weight composition of 60% bronze and 40% PTFE. Salox cylinders should be hot-press sintered, where in the final stage of hot press sintering the ingot is removed from the oven at 710 F and air cooled in a press at 2,500 psi.

Fluoroloy-C (Fluorocarbon) with a weight composition of 55% bronze, 40% PTFE, and 5% MoS<sub>2</sub>. Fluoroloy-C cylinders are free-sintered.

The supplier shall provide documentation stating that the delivered material is of the correct composition and was manufactured from a single batch of compound material.

3.2.1.2.1 Each batch (compound lot) of insert material must be tested in accordance with NHB8060.1B paragraph 413, Test 13 - Ambient Liquid Oxygen and Pressurized Liquid and Gaseous Oxygen Mechanical Impact Test at 1000 psi and a 10 kg-m energy level.

3.2.1.2.2 Each cylinder of insert material shall be tensile tested to confirm proper sintering. A dog-bone specimen oriented in a transverse direction from the cylinder shall have a tensile strength > 2,000 psi. Records shall be kept showing that these tests were performed.

3.2.3 Machining - Housings and inserts shall be machined by a qualified shop to the dimensions and specifications shown on Battelle Drawings G1230-B12 through G1230-B15. To establish qualification, manufacturers shall demonstrate their ability to machine the cage components correctly by providing prototypes that meet these dimensions and specifications. After acceptance of a prototype component (for qualification) all changes of fabrication methods or modifications to CNC software must be approved in writing by Battelle. Machine tools shall be cleaned before starting the machining to ensure parts do not contact unapproved materials. The edges of all parts shall be smooth and free of burrs.

3.2.3.1 Housing may be machined using Trim Sol or Trim EP water-miscible cutting fluid. Alternate cutting fluids must be approved in writing by Battelle.

3.2.3.2 Phosphor bronze housings are to be rough machined to 0.100 inch over dimension and heat relieved at 400-500 F for 1 hour, air cool. The oven shall be at the appropriate temperature for 15 minutes before loading parts. The oven used for heat relieving must be calibrated within 1 year of use and a record maintained of this calibration. A QA inspector shall observe a complete heat relief cycle and certify acceptable operation.

3.2.3.3 The housings shall be deburred by glass bead blasting. Bead blasting shall be performed at an oblique angle to the housing's od and shall use type BT-4 glass beads (590 - 420  $\mu$ m dia) at a maximum pressure of 60 psi. A QA inspector shall observe the deburring and certify proper blasting media and pressure were used.

3.2.3.4 Inserts shall be machined dry; use no cutting fluids. Inserts for a given cage shall be machined from a single ring of material. The insert parts fabricated from a single ring shall be bagged to maintain this sorting.

3.2.4 Component Inspection - Inspection of the cage components before assembly shall be performed in three parts as described in the following sections.

3.2.4.1 All finished housings and inserts shall be visually inspected for cracks, chips, burrs, or other flaws using no visual enhancement other than corrective lenses. Guidance for accepting or rejecting a flaw shall be provided by currently acceptable criteria such as those listed in Rocketdyne specification RL00916 REV. A, paragraph 3.3 and Table IID.

3.2.4.2 Complete verification of the following dimensions on all cage components shall be performed by the manufacturer before component delivery. The critical dimensions are the inner housing diameter; the height and the width of the housing side rails; the thickness of the housing shelves; the housing width; the length of the housing insert pocket; the length and width of the inserts; and the inner diameter of the insert ring, before separation into individual inserts. (Critical dimensions are noted and specified on Battelle Drawings G1230-B12 through G1230-B15).

3.2.4.3 All finished housings shall be radiographically inspected to reveal any internal voids. The radiographic film shall be placed in contact with and oriented perpendicular to the major axis of the part with the x-ray source aligned with the major axis. The radiographic procedure shall insure a geometric unsharpness of  $< 0.00046$ . A housing shall be rejected if any voids are found with a major dimension larger than 0.015 inches, which limits the maximum loss of tensile strength to  $< 10$  percent.

3.2.5 Cleaning - All housings and inserts shall be bright-dipped if necessary and precleaned according to Rocketdyne Specification RL10001. The housings shall be individually bagged and packaged to prevent damage during shipment. Inserts shall be bagged in groups machined from a single ring of material. The bags shall have a vacuum drawn before sealing to prevent damage during shipment. Aclar wrap is not necessary for precleaned parts.

3.2.6 Assembly - Assembly of cage components shall be done with utmost care to prevent contamination. Clean, lint-free gloves and clean tooling shall be used when handling cleaned surfaces, reference Rocketdyne RL00916A. Assembly procedures are as follows and shall be performed in at least a Class 10,000 clean room. Cleaned components shall not be unpackaged in this environment for more than 2 hours.

3.2.6.1 Using a group of inserts machined from a single ring of insert material, place each insert at an empty pocket location around the inside diameter of the housing. Press the inserts in place by applying moderate pressure with fingers of a gloved hand. If required for interference free fit, an insert may be held with forceps and sprayed with Quick Freeze (Miller-Stephenson #MS-240, compressed Dichlorofluoromethane, NSN 6850-00-405-9385) and then pressed into the housing.

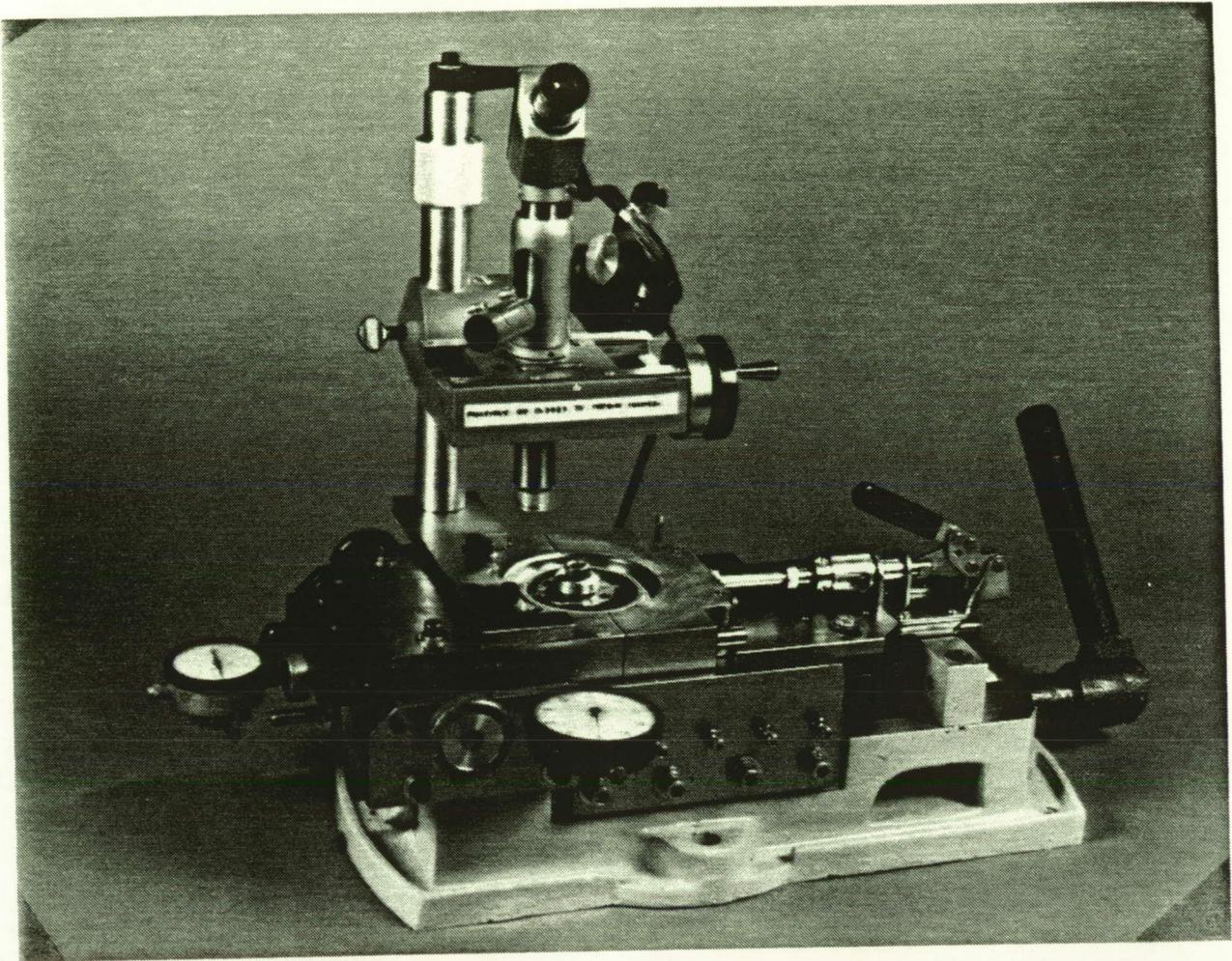


FIGURE 1. THE BATTELLE FOUR STAGE TAB BENDER

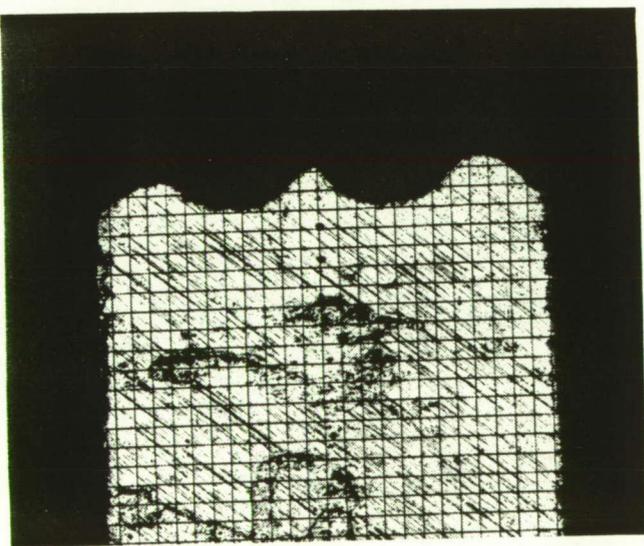


FIGURE 2. PROFILE OF THE FOURTH TAB BENDING TOOL FOR CAGES USED IN RS007955 BEARINGS (0.25 mm/div)

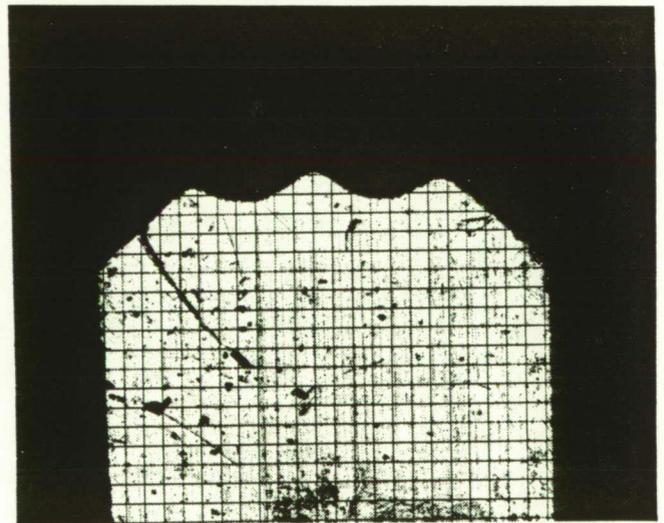


FIGURE 3. PROFILE OF THE FOURTH TAB BENDING TOOL FOR CAGES USED IN RS007958 BEARINGS (0.25 mm/div)

3.2.6.2 The inserts shall be locked in place using a Battelle four stage tab bender, which is shown in Figure 1. The tab bending procedure consists of the following steps.

- a) Install the appropriate housing clam clamp and tab forming tools for the size cage to be assembled. The fourth tab forming tool is specific for each bearing size and has the respective bearing number engraved on its top face.
- b) Align the center line of the housing clam clamp, the tool turret, and the microscope cross hair. This alignment is accomplished by temporarily installing a fine wire ( $\leq 0.003$  inch) in a groove along the center line of the housing clam clamp and then adjusting the center of the housing tool turret and the microscope along this line.
- c) Burnish a small dot on the housing on the outside of one rail at the center of a pair of tabs using a clean blunt tool.
- d) Place a housing, loaded with a full complement of inserts, into the housing clam clamp with the burnish mark up.
- e) Align the center of the first tab forming tool with the microscope cross hair and lock in place.
- f) Align the center of the pair of tabs with the burnish mark with the microscope cross hair and lock the housing clam clamp. Install clamp stop sleeve.
- g) Move the tab forming tool between the pair of tabs and using the microscope stop approximately 0.002 in. from the bottom of the tab slot.
- h) Zero the tab forming tool position indicator.
- i) Retract the tab forming tool, unlock the housing clam clamp, move housing to align the center of the next pair of tabs with the microscope cross hair and lock the housing clam clamp
- j) Move the tab forming tool between the pair of tabs to the zero position and use the microscope to assure proper forming action.
- k) Repeat steps i and j until all tabs have been formed with the first tool. The burnish mark helps track the progression of formed tabs.
- l) Align the center of the next tab forming tool with the microscope cross hair and lock in place.
- m) Repeat steps g through l and continue until all the tabs have been crimped with the fourth tab forming tool. The profile for the fourth tab forming tool for cages used in RS007955 and RS007958 bearings are shown in Figures 2 and 3 respectively.
- n) Remove the clamp stop sleeve, unlock the housing clam clamp, remove the housing and turn it over. Replace the housing into the housing clam clamp with the burnish mark down.
- o) Repeat steps i and j for the second time with the fourth tab forming tool.

3.2.7 Post Assembly Machining - After the inserts are assembled in the housing, final machining is done on the cage o.d. and on each ball pocket diameter. Specifications for the final dimensions are included on the insert drawings G1230-B13 and G1230-B15. Clean, lint-free gloves and clean tooling shall be used when handling precleaned

cages. The cages shall not be unpackaged for more than 2 hours in the shop environment.

3.2.8 Assembly Inspection - Inspection after final cage assembly addresses four areas of concern as described in the following sections.

3.2.8.1 Tab Integrity - Each tab shall be visually inspected for cracks under 10X magnification, using a stereo microscope.

3.2.8.2 Insert Looseness - Each insert shall be held tightly in place by the bent-over tabs. Reject any cage with an insert that can be moved within the insert pocket by moderate hand pressure.

3.2.8.3 Insert Integrity - Each insert shall be inspected for burrs or chipping resulting from the assembly procedure. Use the same rejection criteria as in Section 3.2.1.4.1.

3.2.8.4 Cage Form - To ensure compliance, all assembled cages shall be examined for proper envelope dimensions. These inspections include the cage inner diameter, outer diameter, and width. Diametral dimensions measured on a CMM will use an average circle method with a minimum of 6 points. Other metrology methods will measure diameters along 2 perpendicular major axes. These measurements shall be recorded on the inspection sheet for each cage.

3.2.9 Cleaning - All assembled cages shall be final cleaned according to Rocketdyne Specification RL10001. The bags shall have a vacuum drawn before sealing to prevent damage to the cages during shipment.

#### 4. QUALITY ASSURANCE PROVISIONS

##### 4.1 Inspections

4.1.1 Visual Inspection - Each part shall be visually inspected without use of magnification other than corrective lens, except for inspecting tab integrity at 10X (per paragraph 3.2.7). Criteria for accepting or rejecting a flaw is given in Rockwell International Specification RL00916 Rev. A.

4.1.2 Radiography - All housings shall be radiographically inspected prior to assembly. A test housing section shall have a series of machined voids from 0.010 to 0.025 inch and used to calibrate the radiographic procedure (per paragraph 3.2.4.3). The test housing section shall be included in each series of radiographs is taken.

4.1.3 Metrology - Measurement standards and equipment shall be selected and controlled to the degree necessary to meet the fabrication requirements. Random and systematic errors in any article or material measurement process shall not exceed 10% of the dimensional tolerance being measured (per NHB5300.4 (2C) Section 1C310). Contractors shall maintain individual records of measurement standards and equipment

calibration. All measurement data sheets shall record the type of instrument used and its calibration date. All measurement standards shall be traceable to standards maintained by the National Institute of Standards and Technology. Environmental characteristics (e.g., temperature, humidity, vibration, cleanliness) shall be compatible with the accuracy requirements of the article or material and the measurement process.

4.2 Records - Records shall be compiled to verify compliance with the detailed requirements (Section 3.2). A Quality Assurance (QA) Checklist shall be maintained for each bearing and/or cage fabricated. Each housing shall be engraved (per specifications on housing drawing) or tagged with a distinct identification number, which shall be incorporated on the QA Checklist and sealed between the outer bags of each completed cage. Upon completion, persons responsible for a specific task shall sign and date the QA checklist. Their signature certifies that the task was completed according to the instructions and detailed requirements of this specification. When prescribed, copies of inspection and test results shall be attached to the QA Checklist. The completed QA Checklist shall be delivered along with each cage. Battelle shall maintain its records of the inspection and test results for 2 years after shipment of the cages.

4.2.1 Inspection Status Controls - An inspection stamp shall be used for indicating the status of individual cage inspections. All persons authorized to use this stamp shall be listed in the QA Checklist (Section 4.3.2). Upon completion of an inspection requirement, the stamp shall be applied to the QA Checklist and the inspector shall initial and date next to the stamped mark. Only one stamp shall be maintained and its security shall be assigned to one of the authorized inspectors.

4.2.2 Nonconforming Article or Material Controls - When an article or material does not conform to applicable drawings, specifications or other requirements it shall be identified as nonconforming by permanently marking "REJECT" on the item. No provision for remedial action is authorized. Disposition of the nonconforming article or material is limited to the following actions, in conformance to NHB 5300.4(1D-2), paragraph 1D506-2G.

4.2.2.1 Return to Supplier - When an article or material is found to be nonconforming on receipt, it shall be returned to the supplier. The supplier shall be provided with nonconformance information and assisted, as necessary, to permit preventive action.

4.2.2.2 Scrap - If the article or material is unfit for use, it shall be dispositioned in accordance with Government approved contractor procedures for identifying, controlling, and disposing of scrap. Considerations shall be given to alternate use of the scrapped article for personnel certification of tab bending operations and housing radiographic inspection, or engineering laboratory work, in order to minimize the financial loss resulting from scrap dispositions. Scrap shall be accounted for as to its end use, i.e., it is not to be used for flight hardware.

4.3 Personnel Certification - Personnel certification shall be required for custom processes that are unique to this specification. This applies specifically to the tab bending operation (Section 3.2.6) and the housing radiographic inspection (Paragraph 3.2.4.3). Personnel shall be required to demonstrate acceptable workmanship and operation of the respective equipment on a nondeliverable prototype before approved by an authorized QA inspector to perform that operation or test. Personnel shall be recertified if changes in techniques, parameters, or required skills are incorporated, per NHB5300.4(1D-2), paragraph 1D500-7.

4.4 Procurement Requirements - The procurement source shall have a previous and continuing record of supplying quality articles, materials, or services of the type being procured. Each procurement source and its subtier sources shall be required to comply with the applicable portions of the general requirements of this specification. Additionally all procurement sources must comply with the following requirements:

- (a) Changes. The procurement source shall be required to notify the contractor of any proposed changes in design, fabrication methods, or processes approved by the contractor, including changes which may affect the quality or intended end-use of the item, and obtain written approval of the change from the contractor before making the change. Changed articles shall be identified differently from previous articles. When a proprietary item is procured by the contractor, the procurement source shall be required to notify the contractor of changes in its design, fabrication methods or processes.
- (b) Nonconforming Article or Material. When an article or material is found to be nonconforming on receipt, it shall be returned to the supplier. The supplier shall be provided with nonconformance information and assisted, as necessary, to permit preventive action.

4.5 Fabrication Requirements - Whenever possible all machining and assembly operations shall be initially qualified by fabrication or assembly of a nondeliverable prototype. After inspection of the prototype any changes or modifications in process or procedure must be approved in writing by the contractor. All bearing components are contaminate sensitive and must be cleaned according to Rocketdyne specification RL10001. All cleaned components are to be handled, and packaged according to the applicable sections of Rocketdyne specification RL00916. After precleaning of cage components they shall only be unpackaged for assembly (Section 3.2.6) or post assembly machining (Section 3.2.7). Any component or assembly shall be recleaned if it becomes or is suspected of being contaminated.

4.6 Quality Assurance Checklist - The QA Checklist is a catalog of the tests and inspections that are required by this specification and shall be used to verify the appropriate records and data are generated and compiled. Persons with responsibility for each step shall sign and date (or stamp) in the appropriate spaces. Their signature certifies that the item was addressed in accordance with the existing quality assurance program for the BASIC cage. Signatures also certify that the Detail Requirements

contained in this specification were followed and recorded at the completion of the specific task involved. A copy of all requisite records and data shall be attached to the QA Checklist (data package) for each cage. Whenever applicable, each cage shall be identified by its identification number.

## 5. PACKAGING, STORAGE AND SHIPMENT

5.1 Packaging - Unless otherwise specified, all bearing components shall be packaged individually in at least two protective bags. The first bag is made of a LOX compatible material at least 0.003 inch thick. The second is made of polyethylene at least 0.004 inch thick. The components are heat sealed into the first bag while purging it with purified nitrogen gas (reference MIL-P-27401). This bag is then sealed inside the second bag, which is again purged with purified nitrogen during the sealing procedure. Components shall be packaged as described above after being cleaned, per Rocketdyne RL10001. The packages should not be opened until the components are required for assembly, coating, or post assembly machining and then in a class 10,000 clean room if possible. Furthermore, the components should be repackaged immediately following the assembly, coating, or post assembly machining procedure. All components shall be packaged individually. Each cage shall be packaged in a third clear plastic bag which shall contain the Cage QA Checklist.

5.2 Storage - Cleaned components shall be stored in areas where they shall be protected from contamination and damage.

5.3 Shipment - Bearings shall not be sent to NASA as an assembled unit. Each component inner ring, outer ring, balls, and cage shall be packaged individually for shipment. Each bearing assembly shall be a matched set and shall require the appropriate identification to insure bearing parts are not interchanged.

5.3.1 The contractor shall include a complete documentation package with every shipment. The location of the data package shall be indicated on the exterior of the shipping container.

## 6. NOTES

6.1 See Battelle drawings for manufacturing comments.

APPENDIX A. QUALITY ASSURANCE CHECKLIST FOR INSERT DESIGN  
CAGE PRODUCTION (QA Number G1230-B1, Rev H)

A.1 Quality Assurance Checklist for:

Customer	<u>NASA MSFC</u>
Contract Number	<u>NAS8-36996</u>
Cage ID Number	_____
Bearing Size	_____
Insert Material	_____
Cage Drawings & Rev	_____

A.2 Signature Authorization - The following persons have authorization for approval of QA inspections in their areas of responsibility. Each contractor shall specify at least one person with signature authority.

\_\_\_\_\_, assigned control of inspection stamp

\_\_\_\_\_

A.3 General Instructions - The QA Checklist is a catalog of the tests and inspections that are required by the specification for procedures for Insert Design Cage Production for NASA HPOTP Bearings. Persons with responsibility for each step shall sign (or stamp) and date in the appropriate space below. Their signature certifies that the item was addressed in accordance with the existing quality assurance program for the BASIC\* cage. Signatures also certify that the Detail Requirements contained in this specification were followed and recorded at the completion of the specific task involved. A copy of all requisite records and data shall be attached to the QA Checklist (data package) for each cage. Whenever applicable, each cage shall be identified by its identification number.

A.4 CAGE FABRICATION

A.4.1 Material

A.4.1.1 \_\_\_\_\_ Phosphor bronze has traceable records per patch (heat lot) showing that it is UNS-C51000. Attach copies of records of origin, heat lot, and chemical composition.

\_\_\_\_\_  
\*BASIC (BAttelle Salox Insert Configuration)

Cage ID Number	Bearing Size	Insert Material
A.4.1.2	_____	Each batch of phosphor bronze material was tested and meets the requirements for physical and mechanical properties (Section 3.2.1.1.1). Attach copies of test results.
A.4.1.3	_____	Insert material is approved by NASA (Section 3.2.1.2). Attach copies of records identifying the material and tracing the material to its origin.
A.4.1.4	_____	Each cylinder of insert material was tested and meets the requirements for physical and mechanical properties (Section 3.2.1.1.). Attach copies of test results.
A.4.1.5	_____	Certification of LOX impact tests for each batch or lot of material used per NASA 8060.1B. Attach copy of test results.
A.4.2	<u>Machining</u>	
A.4.2.1	_____	Manufacturer has produced an acceptable prototype that meets the required dimensions and specifications.
A.4.2.2	_____	The heat relieving operation was observed and was found in compliance with this specification.
A.4.2.3	_____	The glass bead deburring operation was observed and was found in compliance with this specification.
A.4.3	<u>Component Inspections</u>	
A.4.3.1	_____	Visual - The Housing and inserts have been visually inspected for flaws (per Rocketdyne RL00916A). The inspector shall stamp and initial indicating the parts are acceptable.
A.4.3.2	_____	Dimensional - The critical dimensions for each part have been verified to be within specifications by the manufacturer (refer to 3.2.4.2). Attach a copy of dimensional certification from machine shop or attach signed inspection measurement sheet.

Cage ID Number	Bearing Size	Insert Material
----------------	--------------	-----------------

A.4.3.3 _____		<p>Radiographic - The housing has been radiographically examined for internal voids. The housing is acceptable if no voids are found with a major dimension larger than 0.015 inches (specification 3.2.1.4.3). The inspector shall stamp and initial indicating the housing passed this inspection. Attach x-ray film envelope to data package. Also indicate the certified personnel for this inspection.</p>
---------------	--	---

\_\_\_\_\_ Certified Inspection Personnel

A.4.4 Cleaning

_____	<p>The housing and inserts in the cage have been cleaned according to Rocketdyne Specification RL10001.</p>
-------	---

A.4.5 Assembly Inspection

_____	<p>The assembled cage has been inspected for tab integrity, insert looseness, and insert integrity in accordance with the assembly inspection specification, Section 3.2.1.7. The inspector shall stamp and initial to indicate acceptance. Also indicate the certified personnel for this assembly.</p>
-------	--

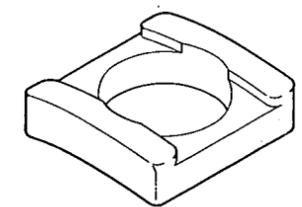
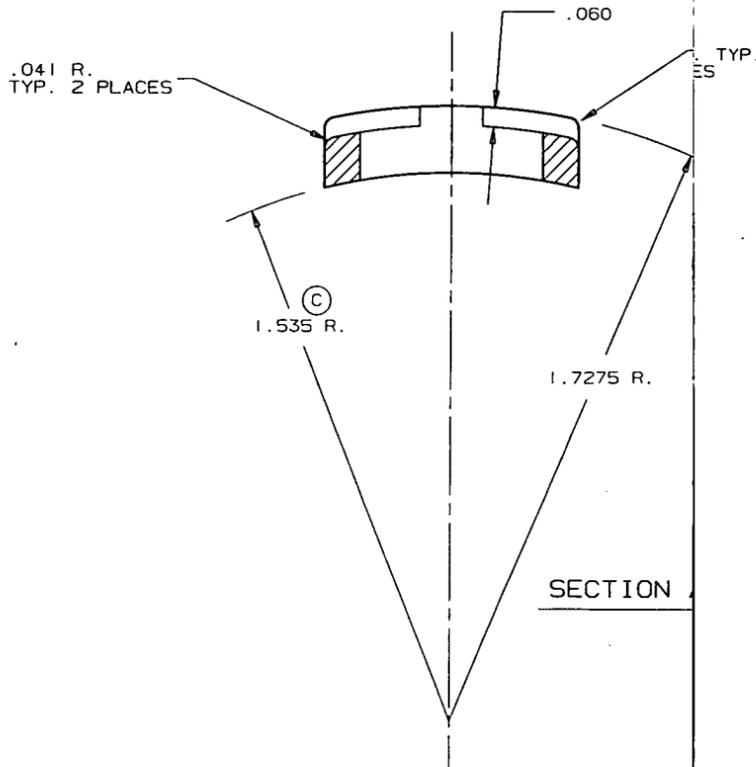
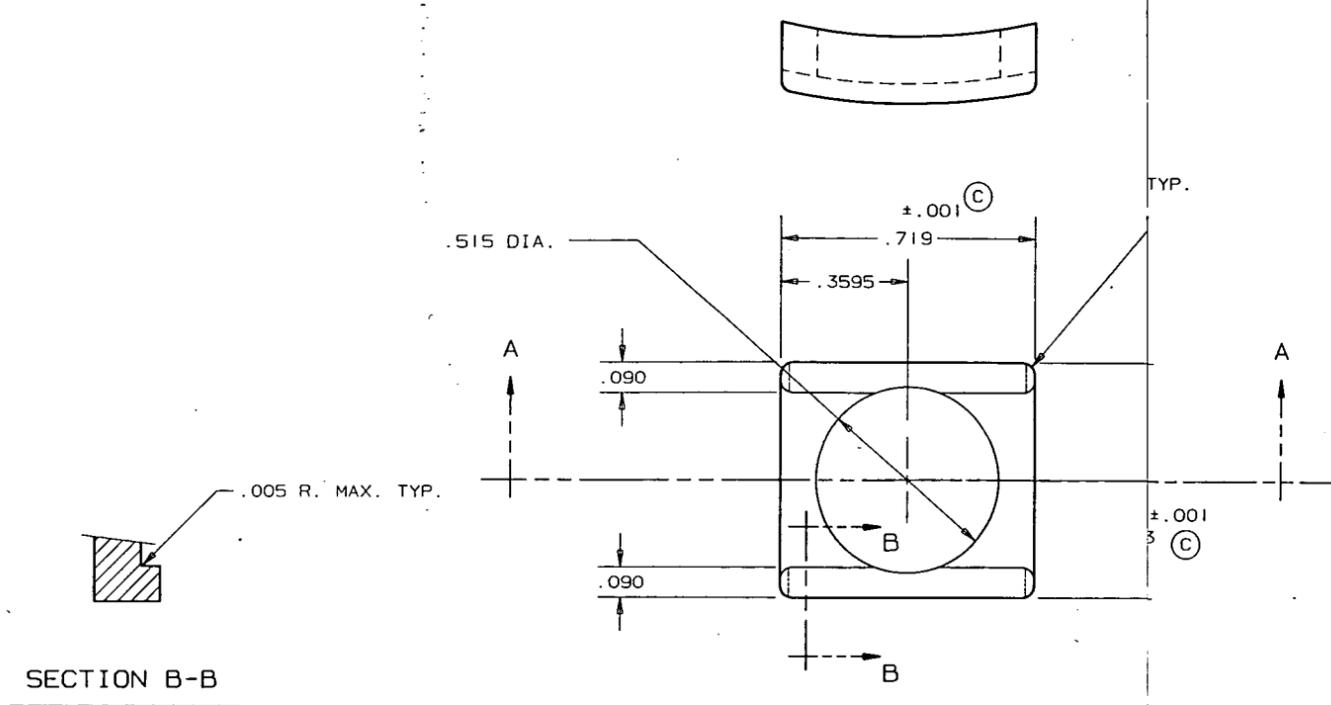
\_\_\_\_\_ Certified Assembly Personnel

A.4.6 Dimensional - The assembled Cage has been inspected for proper envelope dimensions. These measurements are recorded below. The inspector shall stamp and initial if the recorded dimensions are within specification (3.2.4.2).

	Runout	90° Orientation (if necessary)
_____ Cage id _____	_____	_____
_____ Cage od _____	_____	_____
_____ Cage width _____		

**APPENDIX C**  
**DRAWINGS FOR BASIC RETAINER HOUSINGS AND INSERTS**

REV. NO.		SH		REV.		J			
ZONE		REV		DESCRIPTION		DATE		APPROVED	
5C	H			.719 DIM WAS .721 AND .3595 DIM WAS .3605		11-7-89		JG	
6D	I			.515 DIA. WAS .525 DIA.		6-15-90		JG	
5B	I			.060 WAS .055 +.000/-.002 ©		6-15-90		JG	
4B	I			1.7275 WAS 1.7225 +.000/-.002 ©		6-15-90		JG	
3B	I			NOTE #6 WAS ADDED		6-15-90		JG	
5B	I			.031 R. TYP. 4 PLACES WAS ADDED		6-15-90		JG	
3B	I			NOTE #2 MAT'L SPEC. REMOVED		6-15-90		JG	
5B	J			.041 R. WAS .010 x 45°		3-4-91		JG	
3B				NOTE #6; .533 DIA. WAS .525 DIA.					



NOTES:

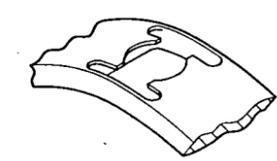
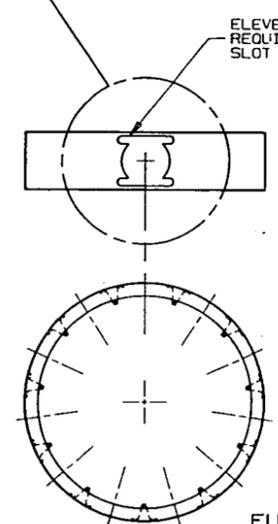
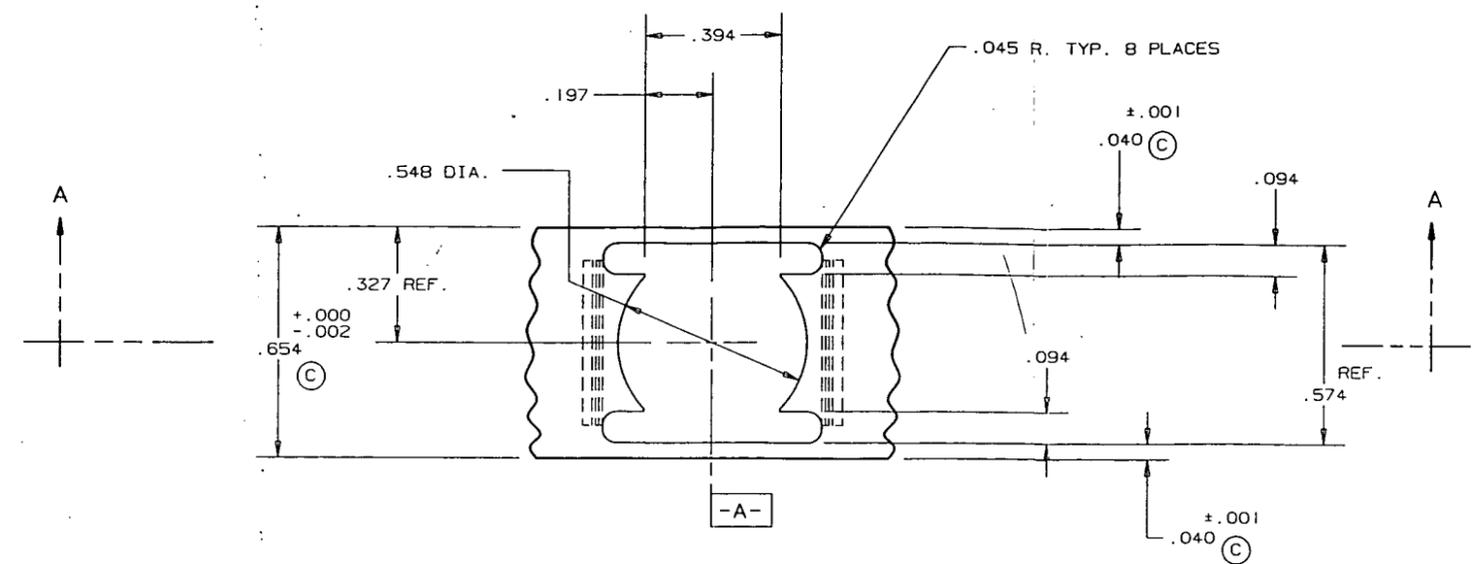
1. TOLERANCE ALL DIMENSIONS ±.002, UNLESS OTHERWISE SPECIFIED.
2. USE ONLY THE SPECIFIC BATCH OF MATERIAL SUPPLIED BY BATTELLE.
3. PARTS MUST BE MACHINED DRY! MACHINE TOOLS WILL REQUIRE CLEANING BEFORE STARTING MACHINING OF HOUSINGS TO ENSURE PART DOES NOT COME IN CONTACT WITH RESIDUAL CUTTING FLUID FROM PREVIOUS OPERATIONS.
4. ALL EDGES SHALL BE SMOOTH AND FREE OF BURRS.
5. CRITICAL DIMENSIONS ARE FOLLOWED BY A © AND REQUIRE A COMPLETE VERIFICATION ON ALL PARTS BY THE MANUFACTURER.
6. FINAL MACHINING WILL BE DONE AFTER ASSEMBLY TO CONTROL THE FOLLOWING DIMENSIONS:  
 0.515 DIA. (BALL POCKET HOLE) TO BE MACHINED TO 0.533 ±.001 DIA.  
 1.7275 R. (OUTER SURFACE) TO BE MACHINED TO 1.7225 R. +.000/-.002.

REV. NO.	REV. STATUS	STATUS
5		
4		
3		
2		
1		

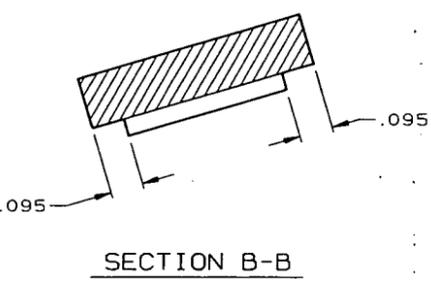
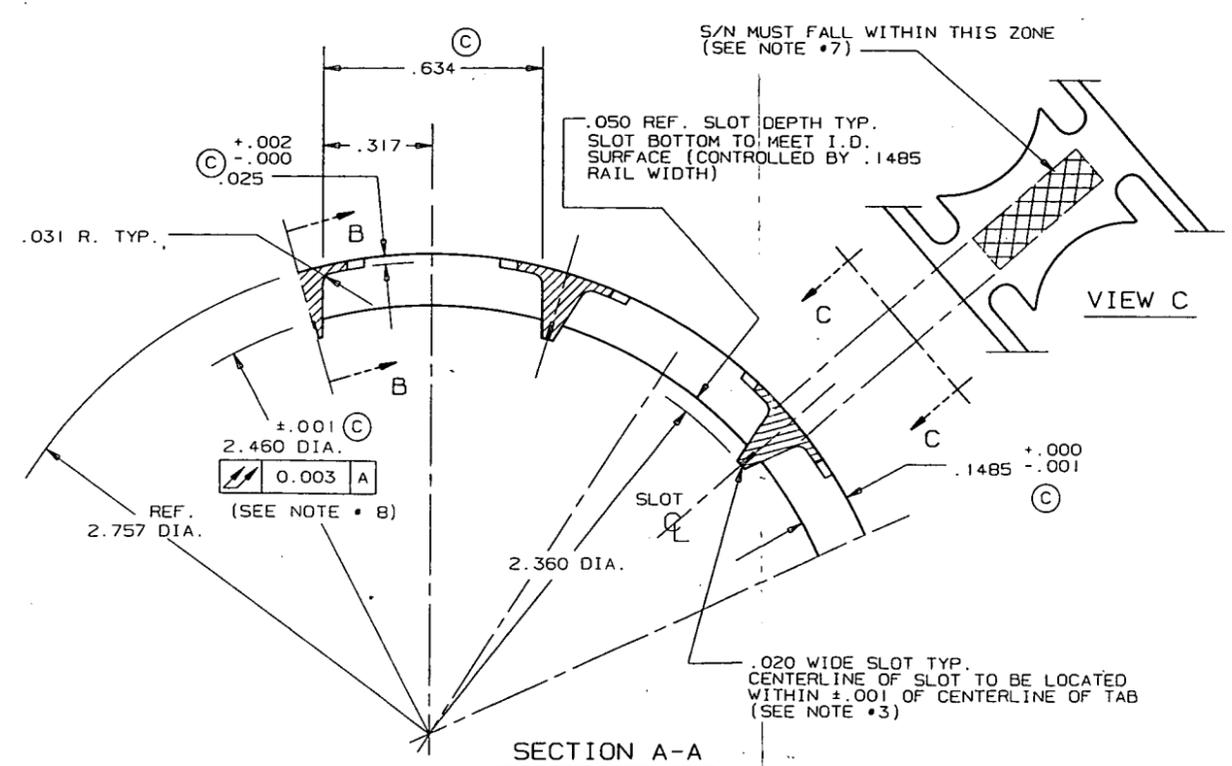
QTY.	REQ'D.	FSCH NO.	PART OR IDENTIFYING NO.	ABBREVIATURE OR DESCRIPTION	MATERIAL SPECIFICATION	ZONE NO.	ITEM NO.
PARTS LIST							
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES. TOLERANCES ARE:			CONTRACT NO.		505 King Avenue Columbus, Ohio 43201-2693 Telephone (614) 424-6424 Telex 24-5454		
FRACTIONS    DECIMALS    ANGLES xxx ± .01            ± 1/2			APPROVALS				
DO NOT SCALE DRAWING			DATE		TITLE		
TREATMENT			DRAWN S. GRIMES		INSERT: INSERT DESIGN 7955 BEARING, 12 BALLS		
FINISH			CHECKED		ISSUED		
SIMILAR TO			ACT. VT		SCALE 4X		
DATE			PART DASH NO.		SIZE FSCH NO.    DWO. NO.		
NEXT FINAL			NEXT ASS'Y.		D 79986    G1230-B13		
QTY REQ'D FOR ASSY			USED ON		G1230-1		
APPLICATION			CALC. VT		SHEET 1 OF 1		



REV. NO.		SH	REV.	REVISIONS	
ZONE	REV	DESCRIPTION		DATE	APPROVED
6C	H	TOLERANCE ON DIM'S .654 & .025 WERE CHANGED		11-7-89	JG
6C	I	.031 R. WAS .005 R. .050 REF. DIM WAS .050 NOTE WITH .050 REF. WAS ADDED		3-4-91	JG
6B	J	2.757 DIA. REF. WAS 2.757 DIA. .002 (C) 2.460 DIA. WAS 2.460 DIA. REF. (RUNOUT TOLERANCE WAS ADDED TO THIS DIM.) VIEW C WAS ADDED		9-4-91	JG
4J	2A	NOTES 7 & 8 WERE ADDED			



FULL SCALE



- NOTES:
- TOLERANCE ALL DIMENSIONS ±.002, UNLESS OTHERWISE SPECIFIED
  - MATERIAL: PHOSPHOR BRONZE; UNS C51000, HARD TEMPER (HR<sub>B</sub> 75 ±5) YIELD STRENGTH > 50 KSI, ELONGATION > 22% GRAIN SIZE > ASTM NO. 3 (< 0.125 MM) USE ONLY THE SPECIFIC BATCH OF MATERIAL SUPPLIED BY BATTELLE. HOUSINGS ARE TO BE ROUGH MACHINED TO 0.100 OVER DIMENSION AND HEAT RELIEVED AT 400-500 °F FOR ONE HOUR, AIR COOL.
  - SLOT SHALL BE BROACHED WITH A CARBIDE TOOL.
  - IF CUTTING FLUID IS REQUIRED, PRIOR APPROVAL FOR THE SPECIFIC FLUID MUST BE REQUESTED. MACHINE TOOLS WILL REQUIRE CLEANING BEFORE STARTING MACHINING OF HOUSINGS TO ENSURE PART DOES NOT COME INTO CONTACT WITH RESIDUAL CUTTING FLUID FROM PREVIOUS OPERATIONS.
  - ALL EDGES SHALL BE SMOOTH AND FREE OF BURRS. GLASS BEAD BLASTING SHALL BE USED FOR DEBURRING.
  - CRITICAL DIMENSIONS ARE FOLLOWED BY A (C) AND REQUIRE A COMPLETE VERIFICATION ON ALL PARTS BY THE MANUFACTURER.
  - EACH HOUSING MUST HAVE A SPECIFIC ASSIGNED SERIAL NUMBER.
  - RUNOUT MEASURED USING AVERAGE CIRCLE METHOD, WITH A MINIMUM OF 6 POINTS.

COMPUTER FILE NO.		WEIGHTS		STRESS		MATERIALS & PROCESSES		MANUFACTURING CHGR		QUALITY ASSURANCE		ADDITIONAL APPROVALS		DATE	

REV	STATUS	REV STATUS	REV STATUS	REV STATUS	REV STATUS
5	4	3	2	1	

QTY REQD PER ASSY	NEXT FINAL	NEXT ASSY.	USED ON	APPLICATION

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES. TOLERANCES ARE:	CONTRACT NO.	
FRACTIONS: XXX ± .01 DECIMALS: XXX ± .005 ANGLES: 1/2° DO NOT SCALE DRAWING		

PARTS LIST		APPROVALS		DATE	

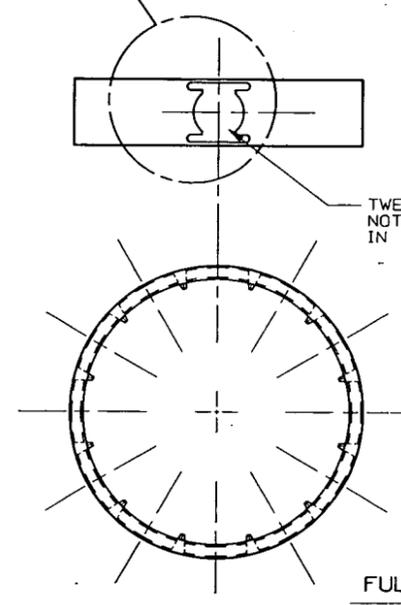
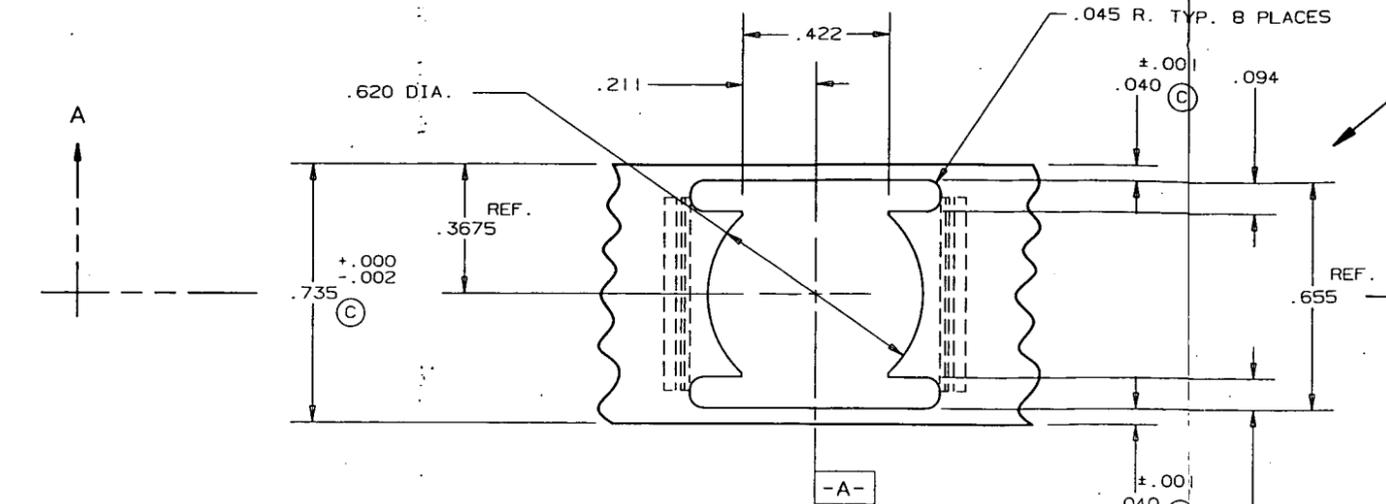
  

SIZE	FSCH NO.	DWG. NO.	REV.
D	79986	G1230-B14	J

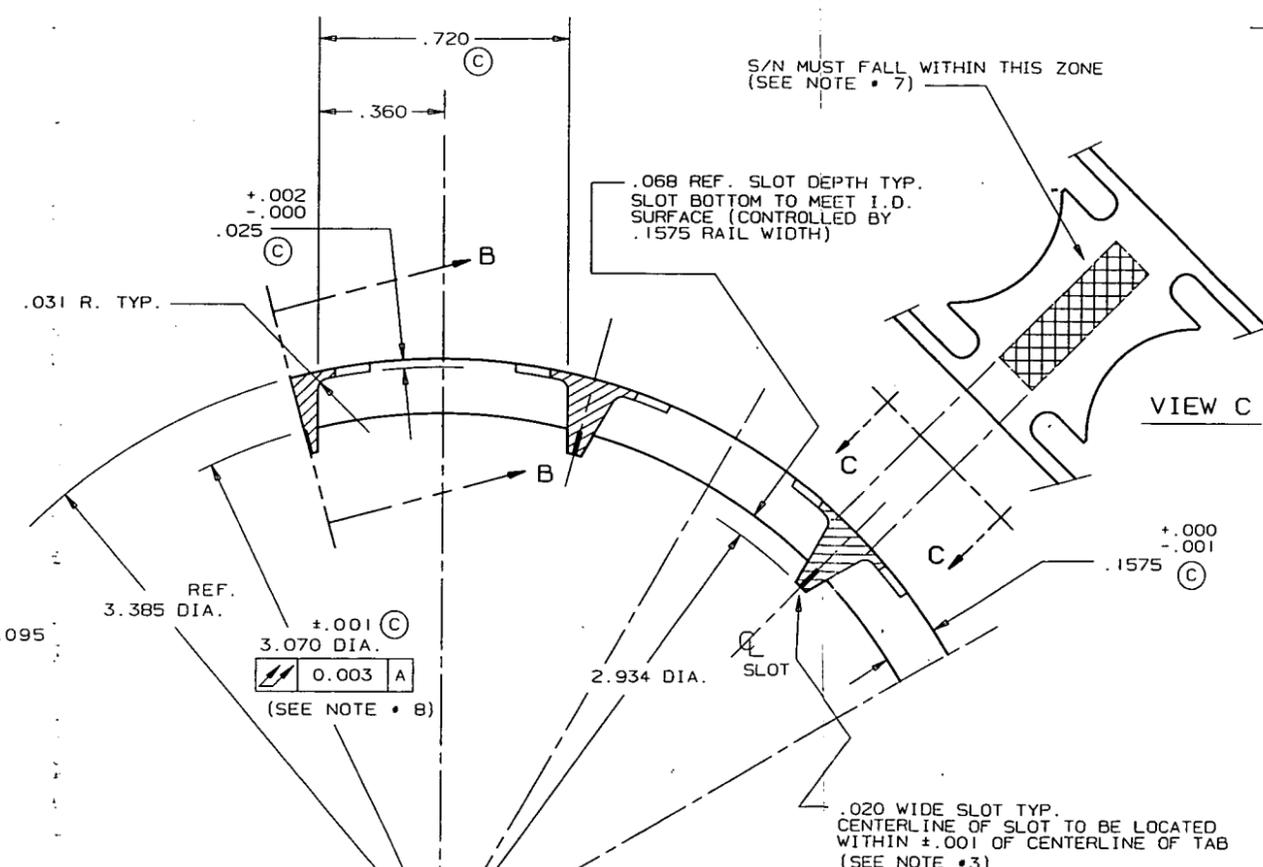
  

Battelle		505 King Avenue Columbus, Ohio 43201-2693 Telephone (614) 424-6424 Telex 24-5484	
TITLE: RETAINER HOUSING, INSERT DESIGN 7958 BEARING, 11 BALLS			
SCALE: 4X	G-1230-1	SHEET 1 OF 1	

Dwg. No.		G1230-B12		REV. 1	J
REVISIONS					
ZONE	REV	DESCRIPTION	DATE	APPROVED	
6C	H	TOLERANCE ON DIM'S .735 & .025 WERE CHANGED	11-7-89	JG	
6C	I	.031 R. WAS .005 R. .068 REF. DIM WAS .068 NOTE WITH .068 REF. WAS ADDED	3-4-91	JG	
6B	J	3.385 DIA. REF. WAS 3.385 DIA. .002 (C)	9-4-91	JG	
6B		3.070 DIA. WAS 3.070 DIA. REF. (RUNOUT TOLERANCE WAS ADDED TO THIS DIM.)			
4B	2A	VIEW C WAS ADDED NOTES 7 & 8 WERE ADDED			



FULL SCALE



S/N MUST FALL WITHIN THIS ZONE (SEE NOTE \* 7)

- NOTES:
- TOLERANCE ALL DIMENSIONS ±.002, UNLESS OTHERWISE SPECIFIED
  - MATERIAL: PHOSPHOR BRONZE; UNS C51000, HARD TEMPER (HR<sub>B</sub>75\*5) YIELD STRENGTH > 50 KSI, ELONGATION > 22% GRAIN SIZE > ASTM NO. 3 (< 0.125 MM) USE ONLY THE SPECIFIC BATCH OF MATERIAL SUPPLIED BY BATTELLE. HOUSINGS ARE TO BE ROUGH MACHINED TO 0.100 OVER DIMENSION AND HEAT RELIEVED AT 400-500 °F FOR ONE HOUR, AIR COOL.
  - SLOT SHALL BE BROACHED WITH A CARBIDE TOOL.
  - IF CUTTING FLUID IS REQUIRED, PRIOR APPROVAL FOR THE SPECIFIC FLUID MUST BE REQUESTED. MACHINE TOOLS WILL REQUIRE CLEANING BEFORE STARTING MACHINING OF HOUSINGS TO ENSURE PART DOES NOT COME INTO CONTACT WITH RESIDUAL CUTTING FLUID FROM PREVIOUS OPERATIONS.
  - ALL EDGES SHALL BE SMOOTH AND FREE OF BURRS. GLASS BEAD BLASTING SHALL BE USED FOR DEBURRING.
  - CRITICAL DIMENSIONS ARE FOLLOWED BY A (C) AND REQUIRE A COMPLETE VERIFICATION ON ALL PARTS BY THE MANUFACTURER.
  - EACH HOUSING MUST HAVE A SPECIFIC ASSIGNED SERIAL NUMBER.
  - RUNOUT MEASURED USING AVERAGE CIRCLE METHOD, WITH A MINIMUM OF 6 POINTS.

QTY. REQ'D.	FSOH NO.	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL SPECIFICATION	ZONE NO.
PARTS LIST					
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES. TOLERANCES ARE:			CONTRACT NO.		
FRACTIONS	DECIMALS	ANGLES	APPROVALS	DATE	
	XXX ± .01	1/2°	DRAWN	S. GRIMS 11-9-89	
	XXX ± .005		CHECKED		
DO NOT SCALE DRAWING			ISSUED		
TREATMENT			TITLE		
FINISH			RETAINER HOUSING; INSERT DESIGN		
SIMILAR TO			7955 BEARING, 12 BALLS		
ACT. WT			SIZE FSOH NO. D 79986		
CALC. WT			Dwg. No. G1230-B12		
			REV. J		
			SCALE 4X 6-1230-1		
			SHEET 1 OF 1		

COMPUTER FILE NO.	WEIGHTS	STRESS	MATERIALS & PROCESSES	MANUFACTURING ENGRS	QUALITY ASSURANCE	ADDITIONAL APPROVALS	DATE

REVISION	REV STATUS	REV. SHEETS
5		
4		
3		
2		
1		
	STATUS	

