SRS/STD-TR86-011
549

INTERCHANGEABLE END EFFECTOR TOOLS UTILIZED ON THE PROTOFLIGHT MANIPULATOR ARM

FINAL REPORT

MAY, 1987

Prepared For:

Information and Electronics Systems Laboratory
George C. Marshall Space Flight Center
National Aeronautics and Space Administration

Contract No. NAS8-36307

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FOREWORD

This report was prepared by SRS Technologies under contract NAS8-36307 for the George C. Marshall Space Flight Center of the National Aeronautics and Space Administration. This work was administered under the technical direction of the Electronics System Laboratory, Guidance Control and Optical Systems Division with Mr. Donald R. Scott as Project Manager.

This report summarizes the work performed by SRS Technologies, Aerospace and Commercial Systems Department and its subcontractors, New Technology, Inc. and Battelle Columbus Laboratories during the February 1985 - March 1986 period. Mr. Joseph C. Cody was the SRS Technologies Project Manager. The project technical staff included:

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ITEM NO.	DESCRIPTION
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SERIES 15/5&16/5	MICROMOTOR GEARHEADS
SERIES 1624	D.C. MICROMOTORS
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SERIES 16/3&16/3K	MICROMOTOR GEARHEADS
SERIES 1212	D.C. MICROMOTORS
SERIES 12/3&12/3K	MICROMOTOR GEARHEADS
1SX1-T&3SX1-T	MICROSWITCH
000-396	AEG MODEL EZ506 SPEED CONTROL DRILL PARTS DWG.

1.0 INTRODUCTION

This report describes the work accomplished for Tasks One through Five during the contract period February 15, 1985 to March 1, 1986 to provide and demonstrate end effector tools for the MSFC Protoflight Manipulator Arm (PFMA). The overall objective of the program is to design, fabricate, and demonstrate PFMA end effector tools for demonstrating the functional capability of on-orbit satellite repair/servicing by teleoperation. The specific objectives of the five tasks were to:

- Task 1: Synthesize and evaluate satellite maintenance requirements; prioritize these requirements; develop end effector tools requirements/specifications meeting the highest priority maintenance requirements; and conceptually design a set of end effector tools capable of satisfying satellite on-orbit maintenance requirements.

- Task 2: Select a tool subset based upon the total tool suit defined in Task One; and to conceptually design the tools and storage mechanisms of this tool concept.

- Task 3: Provide tools design and fabrication for the subset defined in Task Two; design and fabricate each tool and its required storage system to be compatible with a ground test program using the PFMA; design and construct each tool to be readily adapted to flight qualified hardware; and conduct fit checks on all interfacing hardware to assure smooth operation of all components.

- Task 4: Demonstrate and verify requirements for the task function simulator based on a full range of tool subset capabilities; design the simulator to fully satisfy all requirements and demonstrate interchangeable tools/PFMA/ RMTB system capability; fabricate the simulator according to the drawings and specifications developed in the previous design task; and functionally check the simulator prior to delivery to MSFC.

- Task 5: Demonstrate the broad range of functional capabilities of the tool subset utilizing the function simulator based on the established evaluation test program objectives, requirements, and procedures; and define each functional test, descriptions, and step by step test procedures in response to the objectives and requirements.

2.0 SUMMARY

A subset of teleoperator end effector tools has been designed, fabricated, delivered, and successfully demonstrated on the MSFC protoflight manipulator arm (PFMA). The tools delivered include a rotary power tool with interchangeable collets and two fluid coupling mate/demate tools; one for a Fairchild coupling and the other for a Purolator coupling. An electrical interface connector was also provided for the rotary power tool.

A tool set, from which the subset was selected, for performing on-orbit satellite maintenance was identified and conceptually designed. Maintenance requirements were synthesized, evaluated, and prioritized to develop design requirements for a set of end effector tools representative of those needed to provide on-orbit maintenance of satellites to be flown in the 1986-2000 timeframe. A current STS mission payload model was interrogated for identification and prioritizing maintenance categories. A priority listing of these includes unplanned maintenance and repair, fluid transfer, construction and assembly, and deployment and retraction of appendages. Based on past, and planned near term on-orbit maintenance requirements, specific tool operations and requirements were determined to support these maintenance categories. From this information, a representative tool set was defined and includes the following: rotary power tools with attachments, fluid connector mate/demate tool, shearing tool, electrical connector mate/demate tool, general purpose grappling device, power spreader, hinge/handle installation tools, nonpowered pry bar, hold punch and rivet tool, and special grips/jaws. Conceptual designs and specifications were developed for the first six in this tool set and a description is provided for the hinge handle installation tool.

The subset of tools was selected from the above set. This subset was selected to represent tools needed for the highest priority tasks, and to demonstrate as many functions as possible of the tools in the tool set. The tool subset consisted of: a rotary power tool with interchangeable collets, two fluid connect/disconnect tools, a special tool for installation of hinges and handles, and an electrical connector connect/disconnect tool. Preliminary designs were generated for the rotary power tool and fluid coupling tools. Preliminary designs were also provided for the PFMA/tool standard electrical and mechanical interfaces; and storage mechanisms for the rotary power tool, interchangeable collets, and fluid coupling tools. In addition, conceptual designs were provided for a power spreader and a general purpose grappling device.

Final designs were developed for the rotary power tool and two fluid connect/disconnect tools. The final design of the rotary power tool was similar to the preliminary design developed in Task 2. The designs of the fluid connect/disconnect tools were modified to simplify operation, improve reliability, and eliminate the need for electrical power to the tools. An electrical interfacing fixture to supply electrical power to the rotary power tool was designed, fabricated, and installed.

In addition to the end effector tools, a tool storage receptacle and a task board were designed, fabricated, and delivered. The capabilities of the delivered hardware was demonstrated utilizing the MSFC PFMA. Although the tools performed as designed, there are areas for refinement and improvement. The ability of the rotary tool to interface with the collets could be improved. The PFMA control in one "g" is less precise, due to counter weights, than would be expected in a low gravity environment. A more forgiving tool/collet interface would reduce the time and effort needed to pick up the collets with the power tool attached to the PFMA. Precise tool alignment with sensors and feedback control would also reduce operator time and effort in starting the screw fasteners, and also aid in preventing cross threading. Additional tools identified in the tool set should be designed, fabricated, and demonstrated to broaden the capability of on-orbit spacecraft maintenance/servicing with teleoperated robotics. These developments should lead to a flight demonstration of critical servicing requirements such as on-orbit propellant transfer.

3.0 TOOLS DEFINITION TASK SUMMARY

3.1 Space Teleoperations Requirements

Current NASA mission payload model data were synthesized to develop on-orbit servicing requirements across a broad range of payloads planned from mid 1986 to the end of the year 2000.

3.1.1 Identification of Payload Servicing Requirements

In order to identify the payloads that would require or benefit from on-orbit servicing, the "STS Mission Model with Space Station Philosophy" (Revision 7, January, 1984) was chosen as the baseline reference for future payload information (Reference 1). The following generic set of identifiers for the different types of on-orbit servicing was established and updated as a result of an orientation meeting.

- Fluid Transfer
- Deploy/Retract Appendages
- Construction/Assembly
- Module Exchange
- Maintain/Repair
- Stabilize Craft
- Inspection
- Contingency Cases

With these defined categories, the payloads for the years 1986-2000 were scrutinized for servicing requirements to establish a set of ground rules to aid in determining the on-orbit servicing requirements for payloads which are still in conceptual design (true of most payloads after 1995). An on-orbit servicing payload model data base which represents NASA's planned spaceflight activity from mid 1986 to the end of the year 2000 was constructed with this information. There are 1245 payload flights identified in the model which include those sponsored by U.S. government agencies, commercial enterprises, and foreign governments and organizations. Exhibit 1 shows the percentage of payloads that have requirements related to each of the servicing categories. Note that the most frequently required services are inspection, maintain/ repair, and contingencies. Consequently, the more specific categories like module exchange depict a lower level of involvement (around 250 payloads). Exhibit 2 shows the year by year total of the number of payloads with service requirements in each category on the same plot. Since payload/mission analysis and modeling is by definition a planning task and is subject to change, a trend line was calculated for each category and used as the basis for Exhibit 2. The inspection and contingency lines are plotted on top of

EXHIBIT 1 PERCENT OF P/L'S REQUIRING CATEGORIES OF SERVICING

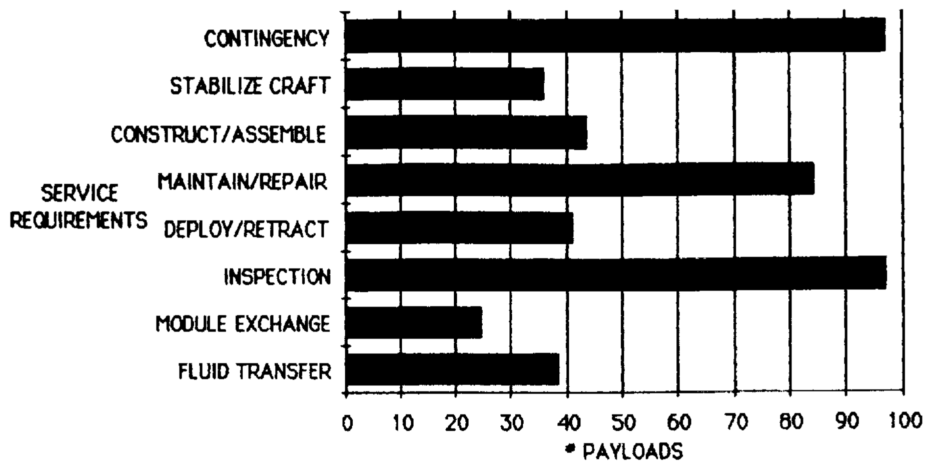
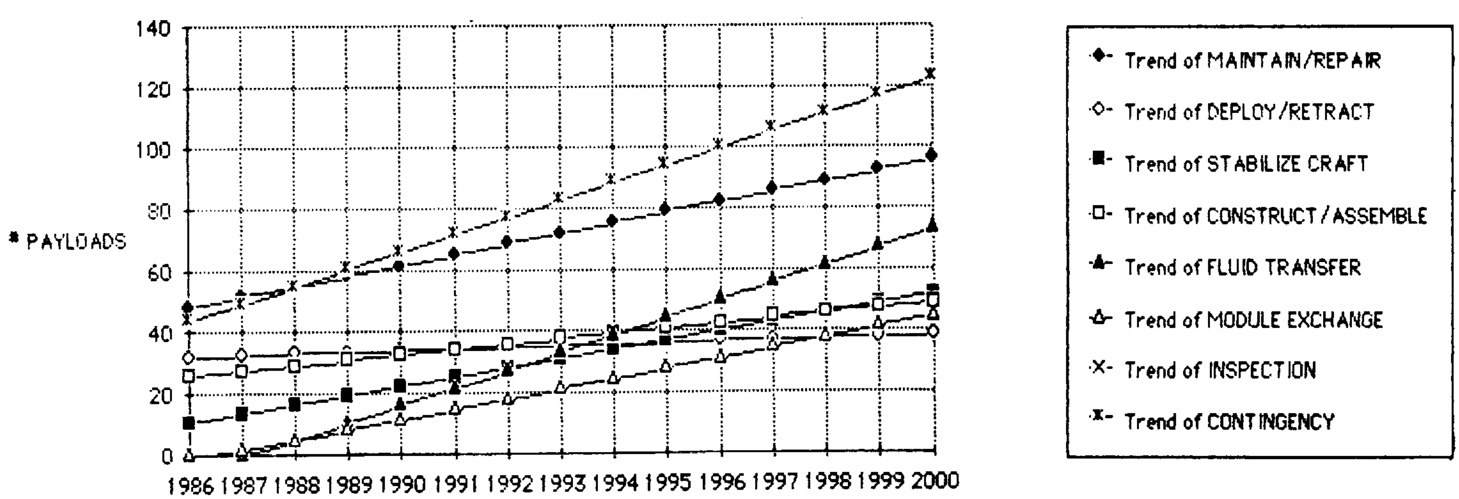


EXHIBIT 2. TRENDS IN NUMBER OF PAYLOADS PER YEAR REQUIRING TYPES OF ON-ORBIT SERVICING



each other since they are essentially identical. The next step was to count the number of servicing tasks rather than the payloads (since more than one task/tool is required by each payload) to determine the implications on the number and types of tools needed. Exhibit 3 is an area plot of the trend data where the tasks are added to show the year by year total of the categories. An alternate form of the same data is shown in Exhibit 4. The percentage of total service tasks associated with each service category is plotted. Based on this information the following conclusions were given: inspection, contingency, and maintain/repair remained constant; module exchange and fluid transfer tasks increased steadily, thus increasing the potential use of tools past the year 2000; deployment/retraction servicing tasks decreased; and payloads requiring deployment/retraction increased but not at the rate that other requirements increased. Exhibit 5 provides a comparison to the number of payloads to be flown each year.

Prioritization of servicing requirements is determined by the criticality of the service to the mission and the frequency of the servicing function to payloads to be flown, as indicated in Exhibit 5. The criticality to mission success must be evaluated more subjectively since preliminary planning of the payloads surveyed required specific requirements and design details which were not available to adequately evaluate criticality of on-orbit maintenance. This is true for unplanned or contingency maintenance, while planned servicing such as fluid transfer is more defined. To prevent severely degraded or mission loss, a planned service must be provided.

The servicing requirements were used to develop the information shown in Exhibit 6. Contingency and inspection functions have been combined, since maintenance functions will be preceded by inspections, so as to evaluate the required maintenance tasks.

Scheduled maintenance/repair, module exchange, and spacecraft stabilization were excluded because these planned operations have special tools available or in the development phase. Fluid transfer operations must be considered for robotic tool development because of its hazardous nature and planned operation frequency. End effector tools for stabilizing uncontrolled satellites were excluded because of low requirements and a lack of specific design information. Construct/assemble and design/retract were selected as

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EXHIBIT 3. YEARLY SUM OF SERVICES TO PAYLOADS

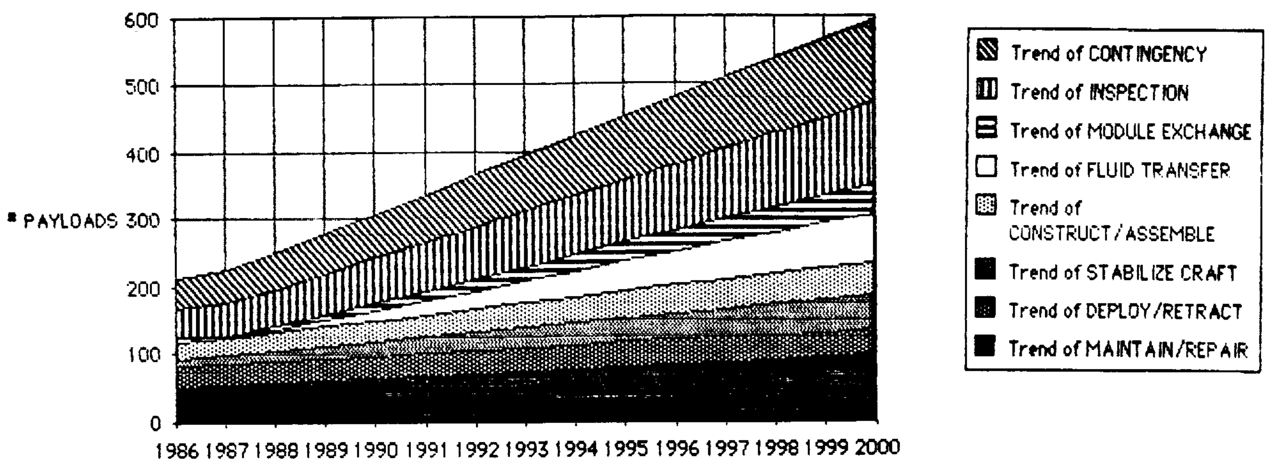


EXHIBIT 4. YEARLY PERCENT OF TOTAL SERVICE REQUIRED IN EACH SERVICE CATEGORY

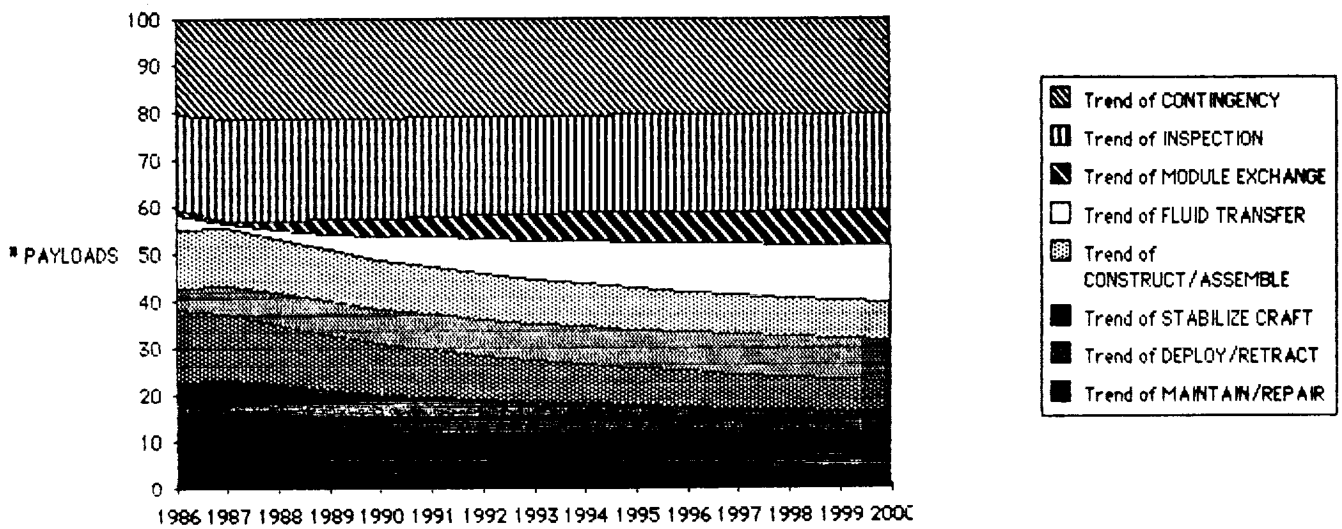
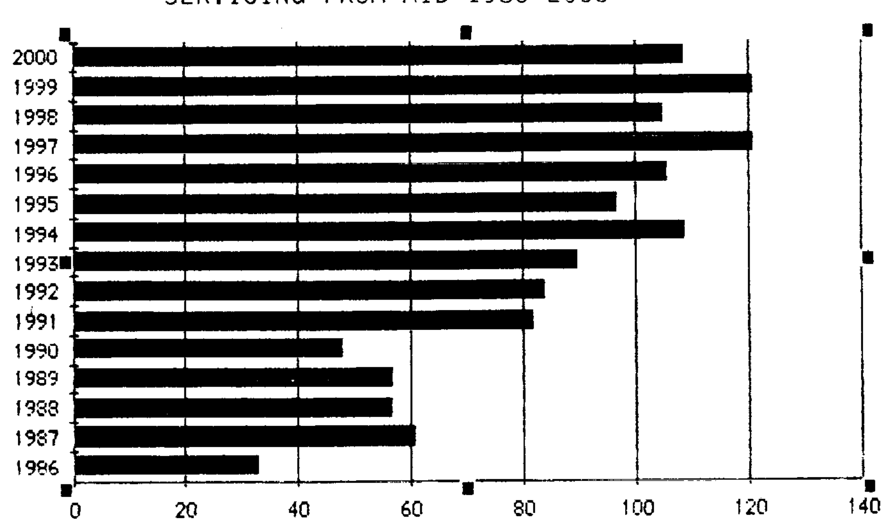


EXHIBIT 5. TOTAL NUMBER OF PAYLOADS WITH POTENTIAL FOR ON-ORBIT SERVICING FROM MID 1986-2000



the last two categories because the servicing requirements are not as high as the tool needed for high priority maintenance tasks.

EXHIBIT 6. PRIORITIZATION OF FUNCTIONS AND SUPPORTING RATIONALE

	INCLUDE/ EXCLUDE	JUSTIFICATION	PRIORITY	JUSTIFICATION
CONTINGENCY	INCLUDE	HIGH REQUIREMENTS	1	HIGH REQUIREMENTS
INSPECTION	INCLUDE	HIGH REQUIREMENTS		CONTINGENCY INCLUDES LARGE PORTION OF INSPECTION REQUIREMENTS
MAINTAIN/REPAIR	EXCLUDE	DEVELOPED UNDER SPECIFIC PROGRAMS & INCLUDED IN PART IN CONTINGENCY		
FLUID TRANSFER	INCLUDE	MEDIUM REQUIREMENTS	2	HIGH CRITICALITY
STABILIZE CRAFT	EXCLUDE	LOW REQUIREMENTS HIGHLY SPECIALIZED TOOLS REQUIRED		
CONSTRUCT/ASSEMBLE		MEDIUM REQUIREMENTS	3	LOWER IN CRITICALITY AND REQUIREMENTS. TOOLS REQUIRED SIMILAR TO THOSE NEEDED FOR HIGHER PRIORITY MAINTENANCE TASKS
MODULE EXCHANGE	EXCLUDE	DEVELOPED UNDER SPECIFIC PROGRAMS. INCLUDED IN PART IN CONTINGENCY		
DEPLOY/RETRACT	INCLUDE	LOW REQUIREMENTS	4	LOWER IN CRITICALITY AND REQUIREMENTS. TOOLS REQUIRED SIMILAR TO THOSE NEEDED FOR HIGH PRIORITY MAINTENANCE TASKS

3.1.2 PFMA Capabilities and Constraints

The following Capabilities/Constraints of the PFMA that can affect end effector tool design are summarized in References 2-4.

Exhibit 7 provides the deployed configuration of the PFMA and linear dimensions. Exhibit 8 provides the maximum travel and torques of each joint.

EXHIBIT 7. PFMA DIMENSIONS

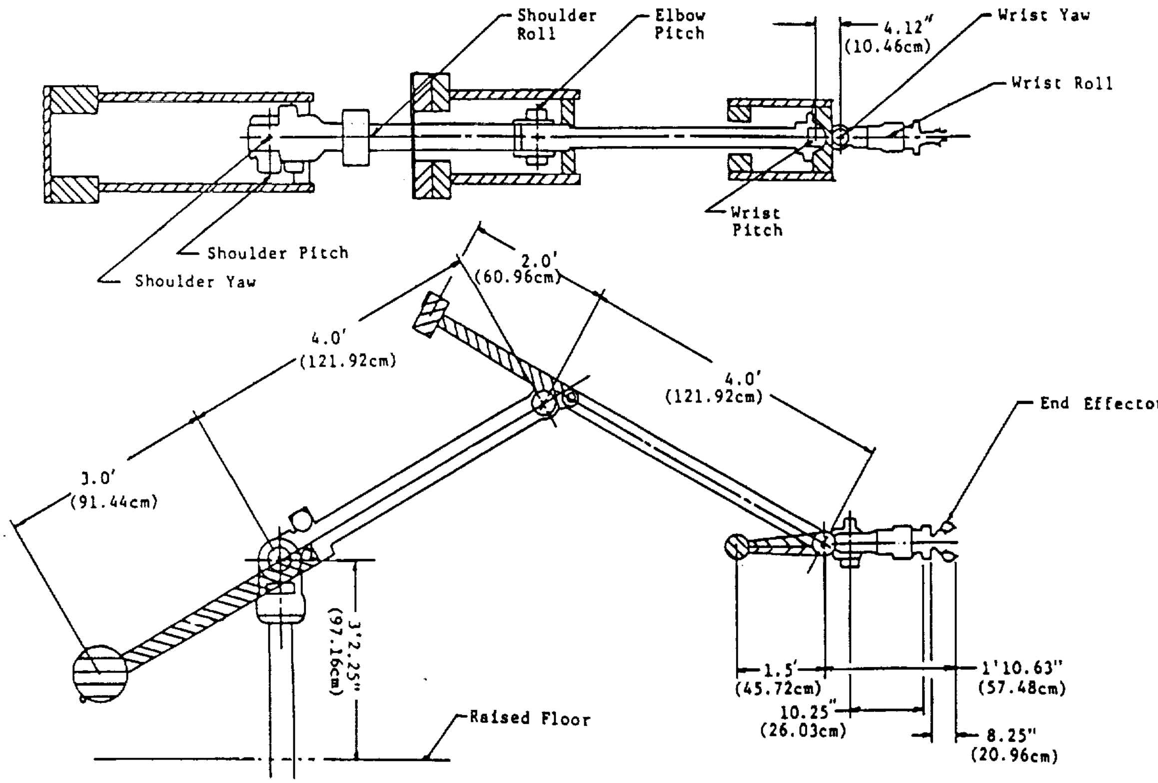
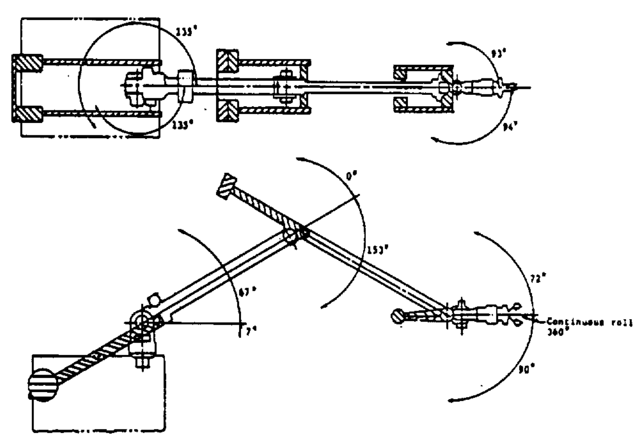


EXHIBIT 8. PFMA MAXIMUM TRAVEL OF EACH JOINT

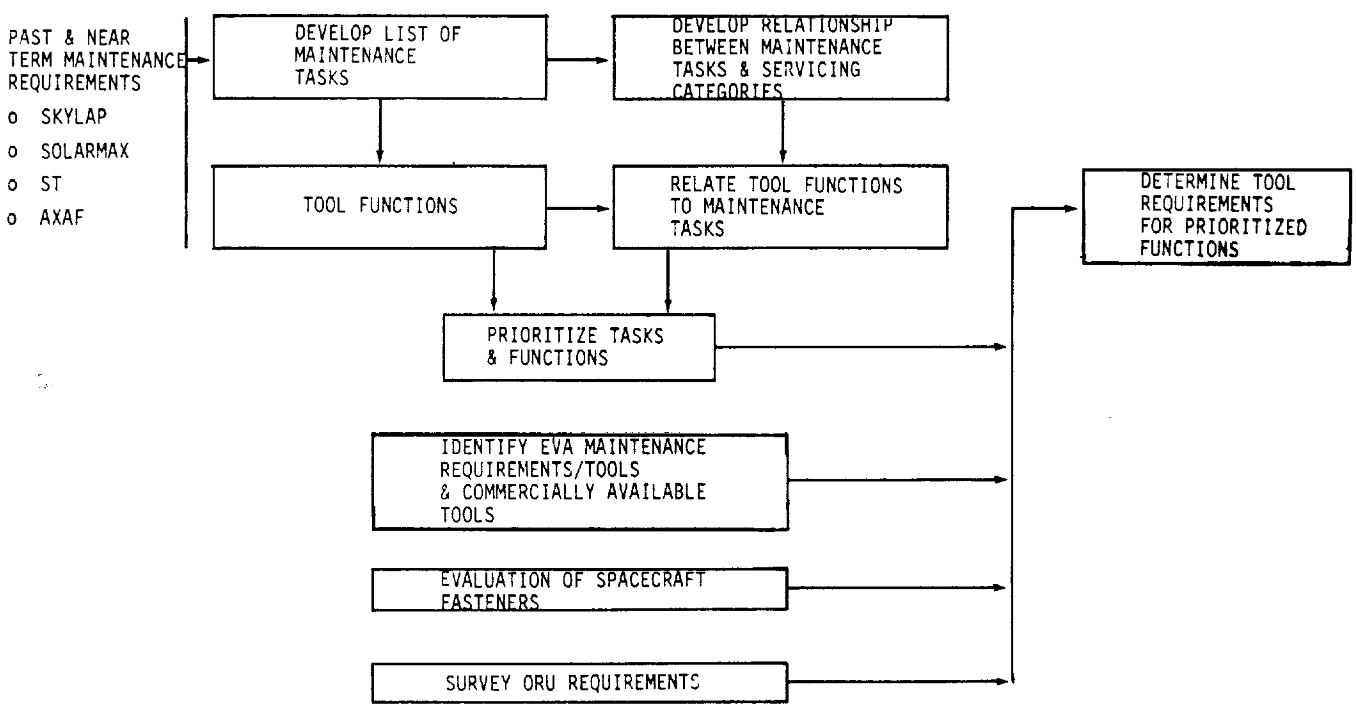


The End Effector Closure Force is 35.4 pounds with a standard deviation of 3.27 lbs. Maximum jaw opening is approximately 3.5 inches. The allowable PFMA payload weight is 10 lbs in one g.

3.1.3 PFMA End Effector Tool Requirements

The approach for developing specific tool requirements to support the previously defined maintenance categories is shown in Exhibit 9. Past and near term spacecraft maintenance requirements were used to develop a list of maintenance tasks. In parallel, tool functions were defined for the list of tasks. The results provided a prioritized set of tasks and functions. EVA tool requirements were surveyed as well as the potential for using modified commercially available tools. To establish specific tools to work interfaces, typical spacecraft fasteners were characterized and ORU requirements reviewed. In addition, two typical fluid connectors were selected and tests conducted to measure connect/disconnect force requirements. The data was synthesized and evaluated to provide a representative set of tool requirements for conceptual design of the end effector tool set.

EXHIBIT 9. DEFINITION OF TOOL REQUIREMENTS



Identification of Maintenance Tasks: The following on-orbit maintenance tasks were identified.

A. Remove and Stow Inspection/Access Panels/Protective Covers
B. Remove/Replace Thermal Panels/Insulation
C. Inspect/Replace Modular Equipment/Insulation
D. Connect/Disconnect and Stow Fluid Connectors
E. Connect/Disconnect and Stow Electrical Connectors
F. Extension, Retraction, Jettison of Equipment Booms, Jammed Payload Systems and/or Mechanisms
G. Space Construction and Assembly of Large Structures

Developing the Relationships: These tasks can be related to the servicing categories as shown in Exhibit 10.

EXHIBIT 10. MAINTENANCE TASKS RELATED TO SERVICE CATEGORIES

SERVICE	TASKS A	B	C	D	E	F	G
1) CONTINGENCY	X	X	X		X	X	
INSPECTION	X	X	X			X	
2) FLUID TRANSFER	X			X	X		
3) CONSTRUCT/ASSEMBLE		X					X
4) DEPLOY/RETRACT						X	

Tool Functions Related to Maintenance Tasks: Before the information shown in Exhibit 6 can be used to identify the highest priority tool requirements, a second matrix of tool functions and on-orbit maintenance tasks must be identified and developed as shown in Exhibit 11.

EXHIBIT 11. TOOL FUNCTIONS RELATED TO SERVICE/MAINTENANCE

TASKS \ TOOL FUNCTION	ROTATION	TRANSLATION	ALIGNMENT	SHEARING	GRIPPING	PRYING
(A) Removal and stow inspection/ access panels/ protective covers	1 2	1 2	1 2		1 2	1 2
(B) Remove/replace thermal panels/insulation	1 3	1 3	1 3	3	1 3	1 3
(C) Inspect/replace modular equipment/ instrumentation	1	1	1		1	
(D) Connect/disconnect and stow fluid connectors	2	2	2			
(E) Connect/disconnect and stow electrical connectors	1 2	1 2	1 2			
(F) Extension, retraction, jettison of equipment booms, jammed payload systems and/or mechanisms	4	4	4	4	4	4
(G) Space construction and assembly of large structures	3	3	3	3	3	3

The numbers shown in the Exhibit 11 matrix represent the priority of the servicing category as defined in Exhibit 10 and indicates that the first three tool functions are of equal importance. Rotation in the majority of the task requirements involves removal/installation and stowage of fasteners which require unique end effector tools. Translation and alignment can be a shared function between the end effector tool and the manipulator arm. These considerations strongly support a powered rotary tool with interchangeable bits to accommodate different fastener characteristics. Fluid transfer was determined to be a priority two servicing category, and Task E, electrical connectors, is part of contingency maintenance and possibly fluid transfer, depending on the design of the fluid/electrical umbilicals. Based on this rating system, Task E is more important than mating/demating of fluid connectors. However, when the mission criticality criteria is applied, the ability to perform on-orbit fluid transfer becomes a higher priority than the ability to perform unplanned maintenance on electrical components not designed for on-orbit service. The last two tasks, F and G, require a broad base of tool functions, with many functions overlapping with the preceding tasks. Task G is rated at a higher priority than F because the development of large space structures requires build-up in orbit and is therefore mission critical.

Based on the above evaluation and rationale, a candidate set of tool functions can be established as shown in Exhibit 12.

EXHIBIT 12. CANDIDATE TOOL DESIGN REQUIREMENTS

FUNCTIONAL REQUIREMENTS	OPERATIONS	TOOL
Unplanned Maintenance and Repair	o Removal/replace/install protective covers, insulation o Loosen captive fasteners o Loosen/capture non-captive fasteners o Install restraints (hinges for covers/panels) o Remove/store loose objects	o Rotary power tool, sockets and extensions
	o Inspection	o Grips (special purpose or PFMA intermeshing jaws)
	o Override of damaged or jammed payload systems or mechanisms	o Powered spreader/pry bar
	o Jettison of solar arrays, antenna booms	o Tube/cable/bolt cutter

EXHIBIT 12. (CONTINUED)

FUNCTIONAL REQUIREMENTS	OPERATIONS	TOOL
Unplanned Maintenance and Repair (Continued)	o Loosen or remove/ capture jammed or cross threaded bolts o Cut and remove cables tubing, wiring causing module jamming	o Impact wrench extensions, sockets o Tube/cable/bolt cutter
Fluid Connectors	o Remove/install protective covers o Connect/disconnect and stow connectors	o Rotary tool o Special fixture designed for specific connector
Electrical Connectors	o Disconnect/connect and stow connectors	o Special fixture designed for specific connectors
Inspection	o Remove/replace protective covers o Translate/rotate inspection system	o Rotary tool extensions, sockets o Hinge installation o Grips

*Force values are minimum; design values should be at least 20% greater.

<u>Identify EVA Maintenance Requirements and Tools, and Survey Commercially Available Tools</u>: The development of specific tool design specifications requires both detailed information on the task to be performed and the interface definition between the tool and the work piece.

Several NASA documents (MSFC, JSC, GSFC, JPL, etc.) pertaining to spacecraft servicing (repair and maintenance) in low earth orbit were reviewed concerning servicing requirements, procedures, and tool sets to perform those tasks (References 5, 6, 7). There was little information available on end effector tools for robotic manipulators. Documents primarily described manually-operated tools for astronaut EVA operations. Tools stored in a shuttle tool crib for astronaut use on EVA operations are shown in Exhibit 13.

EXHIBIT 13. TOOLS USED ON EVA OPERATIONS

- Disconnect and Jam Removal Tools:
  - Diagonal cutters, 1 inch blades with maximum opening of 7/8 inch
  - Needle nose pliers with nose bent 60° from plane of handle, with maximum of 2 inches
  - Hammer, 11 inches long, 1 1/4 inch diameter brass head, weight 3 pounds
  - Probe (like heavy duty long screwdrivers), approximately 14 inches long
  - Vice grip pliers, maximum 1 5/8 inches
  - Bolt puller crowbar, 1/2 inch diameter, ends with "V" notch
  - Forceps, 2 3/4 inch wide opening
  - Lever wrench, self adjusting, to grab bolts and nuts during removal
  - Tube cutter, resembles plumber's tube cutter
  - Winch
  - Pry bar
- Assembly/Disassembly Tools for Removal of Bolts and Nuts:
  - 3/8 inch drive ratchet, including extensions, with 1/4 inch allen hex
  - 3/8 inch drive ratchet with 7/16 inch socket (NOTE: It was stated that fastener heads on orbital replacement units (ORU's) should be standardized to 7/16 inch hex when practical.)
  - 1/2 inch box end socket ratchet wrench
  - 1/2 inch open end wrench
  - Adjustable end wrench (like crescent wrench) with maximum opening of 1 1/8 inches
  - Scissors
  - Loop pin extractor

On all of the above manually-operated tools, each tool has a tether loop and increased handle size for astronaut feel. All the tools appear to be modified standard shop tools.

- Manually-Operated power tools:
  - Power ratchet tools, hand held, with power cord to electronic control box. The electronic controller controls pre-set torque an number of turns and has operator manual override, forward and reverse. Tool only, weight 2 pounds, .75 ounces. Capabilities: 75 foot-pound maximum and 25 foot-pound normal mode.
  - Battery operated portable screwdriver, forward-reverse, variable torque preset or manual operation. Uses standard 1/4 inch hex adapter for interchangeable tool bits. Weight described as 1.3 pounds, operates on 2.4 volts DC. No load speed = 190 RPM. Rated up to 22 inch-pound.
  - Battery operated power tool, cordless, variable forward-reverse speed. Has a socket adapter for screwdrivers or wrenches. Two speeds, four torque settings up to 53 inch-pounds max. No load speed = 300 to 600 RPM. Tool weight 2.6 pounds.

Fluid Connectors: Since the specific designs for on-orbit fluid system servicing hardware is not currently available, representative fluid connectors were selected to establish design requirements for the fluid connector mate/demate tools. These connectors are a Purolator (Part No. 7541588) and a Fairchild fluid coupling. SRS has conducted connect/disconnect tests on these connectors and has also weighed them. The results are shown in Exhibit 14.

EXHIBIT 14. CONNECT/DISCONNECT CONNECTOR RESULTS

CONNECTOR	FORCE TO CLOSE (LBS)	FORCE TO OPEN (LBS)	WEIGHT (LBS) MALE HALF	WEIGHT (LBS) FEMALE HALF
Purolator	24.2	11.3	0.35	0.17
Fairchild	42	None	1.1	2.38*

*Includes a mounting flange.

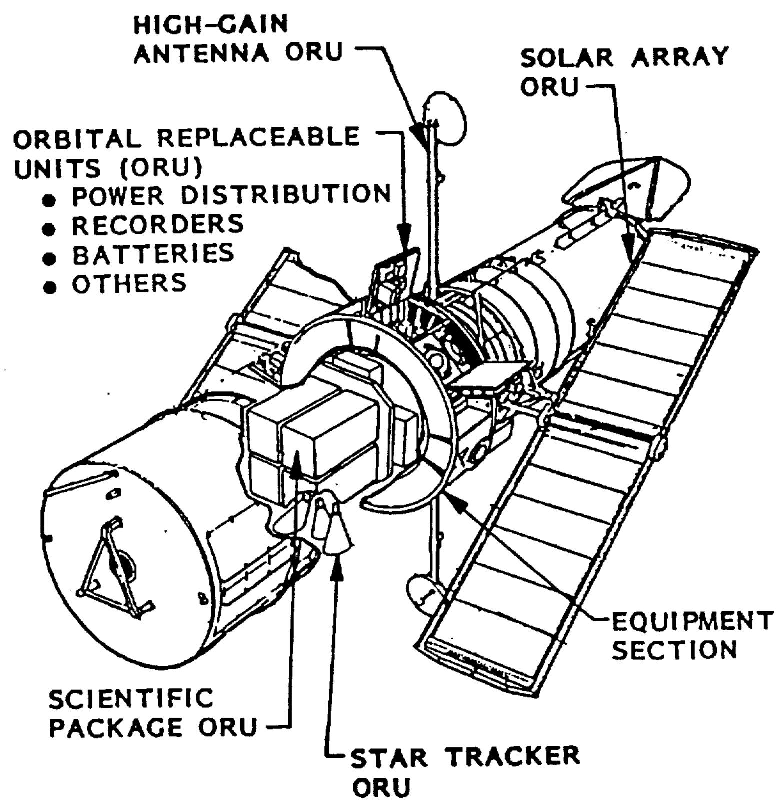
This data was used as design loads for the fluid connector tool designs.

Evaluation of Spacecraft Fasteners: There is a wide spectrum of materials types and configurations, both American Standard and Metric, used for fastener types that apply to both U.S. and European spacecraft and/or shuttle payloads. While the smaller fastener sizes (up to 1/4-inch diameter) have greater application in scientific apparatus assemblies, electronic boxes, control apparatus, subassembly enclosures and the like, screw sizes (or bolts) 1/4-inch diameter and larger may be expected in larger structural systems where primary structural loads may require the high strength fastener (200 ksi), A286 steel. Large fasteners and/or higher strength fasteners naturally impose higher torque requirements.

Twelve point high strength (200 ksi, A286 steel) bolts will require higher torque values. For the PFMA tool set, the power tools should accommodate both hex head bolts and socket head cap screws. The PFMA power wrenching tool must be designed so as to grasp the fastener during either the loosening and removal mode or during the tightening mode.

Survey of Orbital Replacement Unit (ORU) Requirements: Although the tasks surveyed are planned on-orbit services and will be performed by an astronaut, design constraints and characteristics will be similar to maintenance and repair using remote manipulation operations. The capability to provide on-orbit repair of satellites has recently been demonstrated by the repair of the Solar Maximum Mission (Solar Max). Consequently, future spacecrafts such as the Space Telescope, Landsat satellites, and the Gamma Ray Observatory are being designed using ORUs in critical components or scientific instruments to allow on-orbit maintenance by either EVA or remote teleoperations/telepresence operations. Typical ORUs for the Space Telescope are shown in Exhibit 15.

EXHIBIT 15. TYPICAL ORU'S FOR THE SPACE TELESCOPE



General design guidelines for orbital replacement units (ORUs) and planned/contingent procedures for on-orbit maintenance and repair (M&R) for serviceable spacecrafts were reviewed. Design constraints and characteristics for these systems were identified to support the PFMA tool definition and design.

NASA has demonstrated the feasibility of using astronaut EVA operations to perform payload work and maintenance operations. The capability to perform M&R operations for all spacecrafts, independent of orbital positions and/or size, must be developed as the payload requirements for NASA increase. Performing M&R operations via remote teleoperations/telepresence provides a viable alternative to EVA and creates the necessity to have available end effectors for ORUs.

Developing the appropriate end effector tools to interface with ORUs requires a definition of the general design guidelines established for ORUs. Currently, NASA is establishing interface guidelines to provide equipment commonality for on-orbit satellite servicing. JSC has developed a satellite servicing handbook intended to be used by spacecraft designers to establish design guidelines for ORUs and to provide some specific interface requirements with respect to volume/size constraints, acceptable fasteners and sizes, and allowable torques/loads for certain components [5]. This handbook was extensively reviewed to identify design constraints and characteristics to support end effector tool concept definition and design.

Information relating to scheduled maintenance of ORUs obtained from space telescope documentation provides the necessary candidate guidelines for standardizing future system designs for fasteners. Table 1 lists these fasteners.

TABLE 1. GUIDELINES FROM SPACECRAFT MODULE ORU'S DESIGN SPECIFICATIONS

TOOLS FOR END EFFECTOR RMS - SCHEDULED MAINTENANCE

TYPICAL CANDIDATE FASTENERS (LISTED IN DOCUMENTS)	APPLICATION	TOOL
KEYHOLE BOLTS	MODULE DOORS, GROUNDING STRAPS. (FASTENERS ARE CAPTIVE)	POWER RATCHET, SOCKETS, EXTENSIONS
J HOOK LATCHES	CAPTIVE FASTENERS-INSTALLATION OF ORU'S INTO STRUCTURE	SAME AS ABOVE
WING TAB CONNECTORS	MATE/DEMATE-DESIGNED FOR MMU EVA OP'NS (COULD OP RMS). DESIGNED FOR ST ORU'S	SPECIAL TOOL REQUIRED FOR RMS

TABLE 1. (CONTINUED)

GRIP LATCHES	PRIMARILY IVA OP'NS	HAND OP'NS
HANDRAILS/HANDHOLDS	EVA-MMU-STRUCTURAL HARDPOINTS FOR MMU OR RMS OP'NS. APPLICABLE TO ORU'S OR SPACECRAFT.	GRIPPERS TO MANEUVER MODULES
12 POINT SOCKET HEAD BOLTS	ORU CAPTIVE FASTENERS-AN ATTEMPT TO STANDARDIZE 7/16" SIZE, 12-POINT BOLT HEADS. NOTE: A 7/16", 12-POINT BOLT HEAD IS NORMALLY SIZE 3/8" DIA. THE SAME 12 POINT SOCKET HEAD WILL FIT A STANDARD 1/4" DIA. HEX HEAD BOLT. (MIN HD HT=5/16").	POWER RATCHET, SOCKET, (7/16") EXTENSIONS. (SOCKET TYPE 12 POINT) TORQUE SETTINGS 90-110 IN-LB SPECIFIED (1/4")
GRAPPLE FIXTURE RECEPTACLE (SOCKETS)	A DEVICE MOUNTED TO THE APPARATUS STRUCTURAL HARD POINTS TO PERMIT REMOVING, MANEUVERING, CAPTURING, STABILIZING, REPOSITIONING LARGE MASS.	PFMA GRAPPLE TOOL 35-40 LB.

ORU Volume/Size Constraints:

The minimum clearance defined between staggered rows and single rows of bare connectors should be 2.5 inches and 1.6 inches, respectively. The minimum clearance defined between staggered and single rows of winged connectors should be 1.5 inches [6].

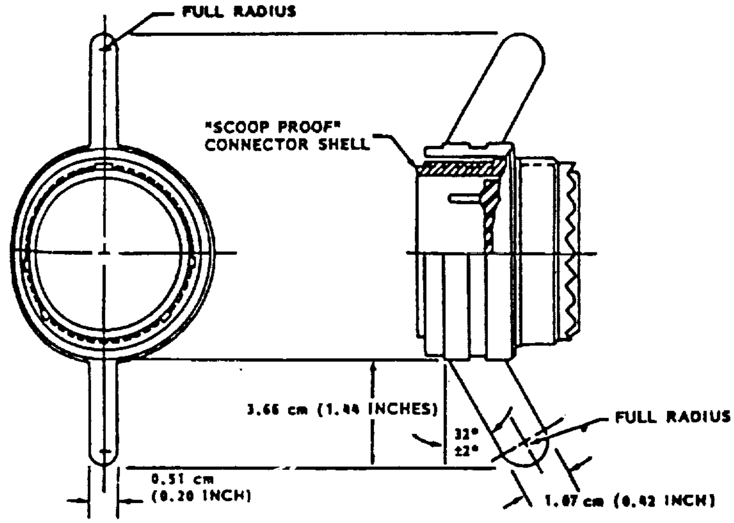
The ORU sizes will vary depending upon the type. However, the maximum size of any ORU, excluding scientific instruments, should be 40 x 30 x 20 inches. For permanent handholds, which may be used by an end effector tool to transfer an ORU, the minimum clearance between the lower surface of the handhold and the mounting surface should be 3 inches, and the minimum inside handhold grip length should be 6 inches [6].

Equipment Attachment Fasteners:

The type of fasteners recommended for ORUs is captive; however the keyhole slot, U-slot, hook and lock, and off-center locks are acceptable. Equipment, as well as ORU, fastener heads should be 7/16 inch 12 point "hex" where practical and should allow for a greatly enhanced grip area for a ratchet wrench. Other types of fasteners can be used depending upon the design requirements. For example, allen head fasteners should be used where positive and critical tool alignment engagement is required; countersunk fasteners should be used where high shear loads (>150 lbs) will be produced or a smooth surface is required; and quick release fasteners should be used where very simplified engagement is required or low loads (<40 lbs) exist. Where thermal materials are used to cover a removable cover or plate, a velcro hook and pile, snap buttoning, or hinged panel mounting technique should be used.

Electrical connectors should use winged tabs similar to the one shown in Exhibit 16. The toggle switch handle length should be a minimum of 1.0 inch and a maximum of 2.0 inches.

EXHIBIT 16. EVA STANDARD CONNECTOR



Torques/Loads:

Electrical connectors having an effective grasping diameter (shell plus wing tabs) greater than 3.0 inches but less than 5.0 inches may be hand-torqued but should not exceed the EVA gloved hand torque values shown in Table 2. Although these values are for hand torques, it is assumed that the same values are necessary for using end effector tools.

If an electrical connector does not employ wing tabs, but instead employs knurled connector shells having a diameter greater than 1.0 inch but less than 3.0 inches, torque values cannot exceed those values in Table 3 (if the connector may be actuated during ground maintenance). Tools should not exceed a breakaway force of 20-lbs or a torque of more than 15 ft-lbs.

Summary of Tool Design Requirements: The preceeding information was synthesized and evaluated to determine the tool requirements which were matched with the prioritized servicing requirements as shown in Exhibit 17. In the following sections, these requirements will be matched with the prioritized functional requirements to provide criteria for selection of the tool set.

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TABLE 2. MAXIMUM WORK FORCE APPLICATIONS, EVA CREWMEMBER

Restrained Crewmember Actuations	Limit Load
o Gloved hand, steady-state force application	25 lb
o Gloved hand, instantaneous or breakaway force	36 lb
o Gloved hand torque, wing tab connector	50 in.-lb
o Gloved hand, single cycle hand squeeze	30 lb
o Gloved finger, toggle switch actuation	0.63 to 6.25 lb
o Booted foot, toe-button detent (one foot restrained)	4.0 to 20.0 lb

TABLE 3. CONNECTOR ACTUATION RESISTANCE FINGER/THUMB TORQUE

Connector Diameter	Torque
1.0 in.	4.0 in.-lb
1.5 in.	5.6 in.-lb
2.0 in.	8.6 in.-lb
2.5 in.	12.4 in.-lb
3.0 in.	16.0 in.-lb (finger curl)
4.0 in.	24.8 in.-lb (finger curl)
5.0 in.	33.6 in.-lb (finger curl)

EXHIBIT 17. SUMMARY OF TOOL DESIGN REQUIREMENTS

FUNCTIONAL REQUIREMENTS	OPERATIONS	TOOL	TOOL SPEC'S
Unplanned Maintenance and Repair	o Removal/replace/install protective covers, insulation o Loosen captive fasteners o Loosen/capture non-captive fasteners o Install restraints (hinges for covers/panels) o Remove/store loose objects	o Rotary power tool, sockets and extensions	o Rotary power tool: preset torque values 40 to 100 in-lbs ± 10%. Typical socket to fit 7/16-in 12-point hex head; #10 Allen Cap screw Speed of 100 RPM; motor. Reversible and Rev counter
	o Inspection	o Grips (special purpose or PFMA intermeshing jaws)	o Jaw squeeze of 34-40 lbs
	o Override of damaged or jammed payload systems or mechanisms	o Powered spreader/pry bar	o Tool ends similar to flats on two heavy duty parallel screw drivers. 20 ft-lbs
	o Jettison of solar arrays, antenna booms	o Tube/cable/bolt cutter	o Accommodate tubing to 1 1/2" O.D.
	o Loosen or remove/capture jammed or cross threaded bolts	o Impact wrench extensions, sockets	o 100 ft-lbs torque
	o Cut and remove cables tubing, wiring causing module jamming	o Tube/cable/bolt cutter	o Accommodate tubing to 1 1/2" diameter
Fluid Connectors	o Remove/install protective covers o Connect/disconnect and stow connectors	o Rotary tool o Special fixture designed for specific connector	o Gripping, alignment translation, depending on specific connector design. * Purolator connector - force to open 11.3 lbs, force to close 24.2 lbs. Fairchild connector 42 lbs applied continuously to maintain closure

EXHIBIT 17. (CONTINUED)

Electrical Connectors	o Disconnect/connect and stow connectors	o Special fixture designed for specific connectors	o Gripping, alignment translation, and rotary motion depending on specific connector design
Inspection	o Remove/replace protective covers o Translate/rotate inspection system	o Rotary tool extensions, sockets o Hinge installation o Grips	o Similar to unplanned maintenance/repair
Construction Assembly	o Payload transfer o Module connections o Structural fastening o Deploy deployable structures	o Grapple(s) o Power head sockets, extensions o Blind rivet gun	o Similar to unplanned maintenance and repair o Special grapple(s) for large fragile structures, padded jaws, force sensing feedback control
Deployment and Retraction	o Release and capture payload o Lever/latch release and lock o Reposition antennas and solar arrays o Extend, retract, jettison equipment booms o Inspection o Remove/replace protective covers, thermal insulation seals, pumps valves o Install, remove, and transfer film cassettes, material samples, batteries o Remove loose objects	o Grapple or capture fixture o Power head extensions, sockets o Impact wrench o Special tools (seal remover, snap locks, etc.)	o Similar to unplanned maintenance/repair

3.2 Definition of Representative Tool Set

Criteria for tool set selection were developed, and the tools needed in a representative tool set identified.

3.2.1 Criteria for Tool Set Selection

The criteria for identifying a representative set of end effector tools capable of supporting on-orbit satellite repair and/or servicing was to identify the tools needed to meet the maintenance requirements and group these as they apply to the specific area of maintenance/service. The results of this evaluation are shown in Exhibit 18. As shown, the majority of the tools needed for unplanned maintenance will support the other categories of maintenance. In summary, these criteria have been developed through synthesis and evaluation of satellite maintenance requirements, prioritization of the requirements, and identification of tools needed to meet these requirements.

EXHIBIT 18. CRITERIA FOR SELECTING TOOL SET

FUNCTIONAL REQUIREMENTS	PRIORITY	TOOLS REQUIRED
UNPLANNED MAINTENANCE & REPAIR (CONTINGENCY & INSPECTION)	1	o Power rotary tool(s) with extensions, socket, screw driver bits, and impact capability for high torgue applications o Electrical connector mate/demate o Hinge installation tool o General purpose grappling device o Shearing tool(s) o Spreader (powered) o Special grips/jaws o Nonpowered pry bar o Hole punch & rivet tools
FLUID TRANSFER	2	o Fluid connector mate/demate tool
CONSTRUCT & ASSEMBLE	3	o General purpose grappling device o Specialized grappling devices depending on structures being assembled o Powered fasteners (blind rivet gun) o Tools as described for unplanned maintenance and repair
DEPLOY/RETRACT	4	o Power rotary tools with special sockets, extensions o Impact wrench o Other tools as described for unplanned maintenance and repair

3.2.2 Selection of Tool Set

The tools identified to support the highest priority requirements (unplanned maintenance and repair) are also needed to support the requirements of the other categories of maintenance/service which require specialized tools such as fluid connector mate/demate tools. The following list of tools best represent the overall satellite/servicing requirements as they are currently defined: Rotary Power Tool(s) with Interchangeable Bits, Sockets, Extensions, and Impact Attachments; Electrical and Fluid Connector Mate/Demate Tool; Shearing Tool(s) (Tubing Wire, Tape); Hinge/Handle Installation Tools; General Purpose Grappling Device; Spreader (Power); Nonpowered Pry Bar; Hole Punch and Rivet Tools; and Special Grips/Jaws. The tools judged to be most useful for the highest priority tasks were selected for conceptual design. This allows the limited resources to be used for the development of more detailed design information for the tools selected.

Based on this rationale, conceptual design drawings for the following tools are provided:

1. Rotary power tools (quick release, impact, with extensions and sockets)
2. Fluid connector mate/demate
3. Electrical connector mate/demate
4. Jettison shearing tool
5. Power spreader
6. General purpose grapple tool

In addition, written descriptions of other tools are provided. A tool subset was selected from the tool set for further detailed design in Task 2.

3.3 Interchangeable Tool Concepts

Tool concepts were developed for the representative set of tools defined in Section 3.2. Operational and design requirements that were developed in Section 3.1 were factored into this tool development effort, as were the PFMA/RMTB capabilities and constraints defined in Section 3.1.3. Tool concepts were developed for: rotary power tool with interchangeable collets, fluid connector, electrical connector, jettison tool, powered spreader, and general purpose grapple tool.

Tools that were also selected as part of the representative tool set, but for which specific concepts were not developed were: hinge installation tool, unpowered pry bar, latch open, close, and hole punch and riveter. These tools were judged to have a lower priority than those for which concepts were developed.

The tools for which concepts were developed are described in conceptual layout drawings and brief descriptions. The layout drawings are provided as attachments to this report, and the descriptions are provided in the following sections. Also, descriptions of the more pertinent tools for which concepts were not generated are provided.

3.3.1 Standard Electrical Interface

Functional Description: The PFMA and associated intermeshing end effector are to be used in conjunction with a suit of tools for the purpose of on-orbit satellite repair. Each of the tools in the defined tool suit will be interfaced to the intermeshing end effector through the use of a standardized tool base. For the unpowered tools, this standard base is a simple mechanical connection which can be easily grasped by the manipulator in a single operation. The power tools, however, require an additional electrical interface which must also be capable of remote manipulator mating. Therefore, alignment techniques must be incorporated into the design to compensate for manipulator positioning error.

Design: The conceptual drawing (Ref. Dwg. 200) shows the proposed method of providing a mechanical and electrical interface between the intermeshing end effector and the standard tool base. With this concept, the mechanical and electrical interfaces are mated in two discrete operations. The electrical interface would not be made until after the manipulator had securely grasped the tool base, and possibly removed the tool from the tool storage area. Separating the mating process eliminates the need for performing two alignment operations simultaneously.

The mechanical portion of the interface is similar to that currently being used with the PFMA. A length of square cross section tubing with a geometry matching that of the intermeshing fingers is fixed between two parallel plates which are spaced with approximately 1/8 inch clearance for the intermeshing end effector to grasp the tubing.

This 1/8 inch clearance defines the translation alignment requirements for the electrical interface along the axis of the manipulator finger closure. The rotation alignment and the translation alignment in the plane of the manipulator finger closure are provided by the previously mated mechanical interface. Thus, compliance will have to be built into the electrical interface only in this one plane of translation.

The electrical interface is achieved through the use of a small, linear electromechanical actuator which moves the male portion of the connector into contact with the female. The concept drawing shows the use of the NASA developed cup-cone electrical connection. However, this concept could be used to advantage with other types of connectors also. It is anticipated that a standard rectangular connector will be utilized in the detail design stage since this type of connector is more readily available.

3.3.2 Fluid Connector Mate/Demate Tool

Functional Description: The remote control of fluid transfer operations is especially desirable due to the hazardous nature of the task. Many of the specific tasks for this operation can be done with relatively generic tools such as: a rotary tool for panel access, a general manipulator grip for umbilical placement, or a grip for valve operation. Mating/demating the fluid connector must be achieved with a special purpose tool designed for the specific connector being operated. Two entirely different conceptual designs were pursued for accomplishing fluid connector mate/demate operations. The designs were made by both Battelle Laboratories and New Technology, Inc. The Battelle design requires electrical power to drive the mechanical worm-screw mechanism that accomplishes fluid connector mating, whereas the New Technology mechanism depends only upon the operation of the PFMA to grip and turn the tool to accomplish the fluid connector mating. The latter tool works on the included plane principle to change turning (rotary) action to translation. Both types will be discussed. For the purpose of this program design, Battelle chose a Purolator connector (part no. 7541588) while New Technology chose a Fairchild connector (Drawing 76300001) for the inclined plane tool design.

Battelle Tool Design: A slight modification to the female half of the connector will be required to allow remote operation with the manipulator. The existing 1.33 inch diameter outer body of the connector will have to be increased by approximately .38 inch on the diameter, and a 0.5 inch wide radial alignment groove machined into the additional material. This addition will not affect the operation or internal configuration of the connector.

The female half of the connector will be mounted to the bulkhead of the satellite. The male portion will be handled by the special fixture. An approximately 2.25 inch locking ring is located on the male half of the connector and is used to both lock and release the two halves. No retaining force is required to maintain closure once latched. The connector requires approximately 24.2 lbs. of force to latch and approximately 11.3 lbs. to release.

The associated drawing (Ref. Dwg. 300) shows the concept design of the fluid connector mate/demate fixture. It is assumed that the connector halves are latched prior to the manipulator grasping the male half, as it would be virtually impossible to grasp a connector which is floating in space. A dummy connector could be located in the tool storage area to temporarily store the connector between use.

The tool consists of: a back mounting flange which connects to the standard tool base, a front alignment flange which supplies the necessary reaction force for mate/demate operations, and a set of connector interface jaws which grip the male portion of the connector. The interface jaws translate between the two end flanges along a pair of ball screws to provide the mate and demate force. Two small motors are required to operate the fixture. The motors are used to lock and translate the interface jaws.

To demate the connector, the manipulator would position the tool over the connector and lower down over the alignment groove located in the female half of the connector. The connector interface jaws would then be moved over the connector locking ring and lock down with the jaw motor. The interface jaws can then be retracted away from the male connector, with sufficient force to release the connector lock ring. The female half of the connector is firmly held in place with the interface jaws. The mating operation would simply be the reverse of demating.

Another design option would have the male portion of the connector integral to the mate/demate fixture. With this type of system, a separate fixture would be required for each male connector, while with the design described above a single fixture would operate any connector of this type. The advantage of having an integral system would be the elimination of an alignment process and also the elimination of the jaw motor from the system. Trade-offs will have to be made to determine which system would be the most versatile and least expensive in the long term.

New Technology Tool Design: Fluid connector tool design was simplified, in that there were no drive motor, worm-screws, or close-tolerance alignment requirements to perform connector mate/demate operations. A one-piece tool performed connector mating by rotary action of the PFMA. Once the male and female halves of the Fairchild Connector were aligned, the rotary action pulled the two halves of the connector together by axial force produced by a circular inclined plane. The inclined plane became a part of the fixed half of the connector, while the inclined plane roller-follower was a part of the connector half to be mated.

3.3.3 Rotary Power Tool(s)

Functional Description: A tool capable of performing various rotary operations was judged to have the highest functional priority based upon past experience with unplanned maintenance and the tool design requirements generated in this program. In addition, overall size, cost, and time savings could be realized by limiting the number of power heads and utilizing interchangeable bits, sockets, and/or extensions.

The torque and speed requirements for the various rotary operations will determine the number and size of tools required. These parameters differ so widely over the entire range of rotary tool operations that a number of rotary power tools will be required in the overall tool suit. However, rotary operation is a nearly generic function. Thus, a single rotary tool with a variety of quick-change bits could be used in a wide range of operations. Impact attachments may also decrease the number and size of tools required. The bits (rotary or impact) may include a standard socket, specialty sockets (such as one that would interface with quarter-turn fasteners), or some other specialty fastener. Various extensions would be desirable to allow the tool to reach into tight locations.

Bolt Running: A specific bit and/or socket will probably have to be designed for each particular type of fastener and possibly for each fastener within a type in some instances. Bits for each of these fasteners will not be addressed presently; however, they could be addressed as required. The fastener judged to be most prevalent, and therefore discussed at this time, is the 7/16-inch, 12-point hex head with either a 1/4 or 3/8 inch thread.

Torque requirements for the various bolt running operations shall fall between 40 and 100 in-lbs and have a torque accuracy of 10 percent depending upon the specific fastener and application. Limiting tool torque capability can be accomplished by a slip clutch mechanism or by limiting the voltage to the motor. A maximum speed of approximately 100 rpm would be desirable for bolt running operations.

Alignment will be a driving consideration in the design of a bolt running tool. It is imperative that the fastener not be cross-threaded during the fastener insertion operation. This alignment can be incorporated through the use of remote center compliance mechanisms, standoffs to hold the tool in a known position against the bulkhead or component containing the thread hole, or through the use of sensors. The sensor package would be the most versatile; however, it could become quite complex.

The use of a very slow, very low torque rotary power tool during fastener insertion would greatly minimize the alignment problem. In operation, this tool would utilize some trial and error methods for inserting and starting the fastener. The manipulator would place the fastener into the thread hole and provide alignment as best as possible. The tool would attempt to start the fastener following the initial manipulator alignment. If the fastener cross-threads, the tool would not have enough speed or torque to cause any damage, the torque sensor would indicate a motor stall condition, and the fastener would be removed and re-aligned for another attempt.

Some testing would be required to determine the torque and speed parameters which would allow initial insertion of the fastener without having the potential of damaging the threads. It is estimated that these parameters would be in the area of 10 in-lbs and 20 rpm.

Additional work in both calculation and design will be required to determine whether an additional rotary tool is required to perform this low speed, low torque operation. The potential exists for utilizing the same tool for both the standard bolt running (40-100 in-lbs) and for low-speed, low-torque operations. However, the torque and speed ratios between the two operations are greater than can generally be achieved with standard speed and torque reduction techniques. In addition, a design of a quick-disconnect, positive-gripping mechanism would have to be developed. While this task is definitely feasible, the time and cost constraints of this program may not make it possible.

Positive gripping of the fastener will be another driving parameter of the tool design. The fastener must not be allowed to inadvertently drop or be knocked from the tool during any operation that is performed upon it. The critical times will occur during insertion, removal, and transport of the fastener. A worst case situation would occur if the fastener had a side-ways force exerted upon the free, threaded end while gripped by the tool.

The proposed technique for providing positive gripping is through the use of a locking collet, which utilizes the entire outside surface of the fastener head. In operation, the fastener head would be positioned in the collet, and the collet locked down onto the external surface of the fastener.

This type of device would work on either the socket head or hex head screws, with the use of slightly different collets. No method of positively holding standard screws, without modifying the fastener, is currently available.

A variable speed tool would greatly improve the operational characteristics of the tool. The speed could be varied by adjusting the voltage to the tool which would also vary the available motor torque. Another method would be to use Pulse Width Modulated (PWM) speed control in which a full voltage would be pulsed to the tool, with the speed varying according to the duty cycle of the pulse. PWM speed control has the advantage of providing relatively constant torque at any motor speed.

Some types of fasteners only require that a bolt be loosened to release a component. For this type of fastener, a revolution counter would be required. Revolution counting could be implemented in many ways; however, the use of a Hall Effect Transistor would be the simplest. This type of transistor senses the rate of change of flux through an electrical field. A simple, digital on/off counter could be implemented to count the number of times that the field is broken or completed by the socket as it rotates. The counter could be easily configured to break power to the tool after the required number of revolutions is made. The number of revolutions could be switch selectable.

In an actual bolt running operation, it is anticipated that the standard bolt-running tool would be used to loosen the desired fastener, using the revolution counter to ensure that the bolt is not threaded completely out. The positive gripping, insert/remove tool or attachment would then be used to lock onto the already loosened fastener and remove it from the thread hole. The fastener would remain locked into the tool and transported to its desired location. It is anticipated that a fastener storage area will be required in the tool storage area. This could consist of a pattern of various sized threaded holes in which the fasteners could be temporarily stored. Spare fasteners could also be kept in this area to replace any that may have been damaged.

Override or Cross-threading: The torque requirements for removing a cross-threaded fastener are much greater than that of an undamaged fastener. The torque requirements for this operation vary greatly, but it is estimated to be less than 100 ft-lbs. It is assumed that the torque requirement for overriding a mechanism with a damaged primary actuator is roughly similar.

An impact mechanism can be used to amplify the torque output of a tool through the use of impact loading. A torque amplification of up to 20 times that of a non-impact tool can be realized utilizing an efficient mechanism. To achieve this amplification, however, the input speed to the impact mechanism must be high. Thus, a standard 100 RPM, 100 in-lb tool could not produce an application of this magnitude without modifying the tool output speed considerably. Because of the speed requirements into the impact mechanism, it is anticipated that a separate rotary tool will be required. However, separate tools with the same size motors could be used for both bolt running and performing the higher torque operations.

The use of extensions will be required in some operations, however they will lessen the torque produced by the impact mechanism. Trade-offs will have to be made between the use of 3/8 or 1/2 inch drives as to weight versus stiffness.

Other Operations: A rotary tool could be used to perform many other operations as required. Among these would be drilling, cleaning, and the actuation of specialty fixtures. These functions will not be defined in detail in this report due to the number of functions which could be performed and the specialty of these types of operations.

One of the more obvious of these "other operations" would be that of drilling. This function is commonly done on earth using rotary tools. However, in space the additional requirements for contamination containment must be addressed. While this containment problem will require some creative design, the actual tool used could easily be the same as that used for bolt running operations. It is anticipated that one of the three potential rotary tools described above -- standard bolt running, low-speed, low-torque, and impact -- could be used for many of these "other operations".

Tool Design: For the Task I tool definition, Battelle conceptually designed the set of rotary power tools around the worst case scenario, in which three separate tools are required. These tools include: the standard bolt running tool with quick-disconnect chuck for switching between various sockets, bits, and specialty attachments; an impact tool using the same motor as used in the standard bolt-running tool, but with different gearing; and the positive gripping, fastener insert/removal tool.

<u>Standard Rotary Power Tool</u>: The standard rotary power tool (see attached drawing) will utilize an approximately 1/4 hp permanent-magnetic, dc-motor geared to produce an output shaft speed of 100 rpm. The quick-disconnect chuck and associated manipulator operated quick-disconnect holder are designed to be operated with a single manipulator arm.

To perform a standard rotary operation, the PFMA must first acquire the rotary power tool from its storage rack. The electrical connection to the tool will be made as part of the acquisition procedure. The proper tool bit must then be selected. All of the tool bits will be equipped with a hex end compatible with the quick-disconnect mechanism of the rotary power tool. The tools bits, which for the Battelle developed Works Systems Package include socket heads, drills, wire brushes, grinding wheels and cutoff wheels, will be stored in individual holders in the storage rack. To acquire a tool bit, the tool is slid directly onto the bit and rotated slightly to align the hex end to the bit with the mating surfaces in the quick-disconnect mechanism. The tool must be pushed forward with less than five pounds of force to complete the mating operation. The tool is then moved "upward", with a radial motion of the arm to release the tool bit from its holder.

After completion of the operation, the tool bit is replaced in its holder by reversing the previous sequence of motions. The arm moves radially "downward" to reinsert the tool bit into its holder. This action also requires less than five pounds of force. At the bottom of the stroke, the quick-disconnect mechanism is contacted by a base plate which is part of the storage rack that causes it to release the tool bit along the axis of the bit. A different bit can then be selected or the rotary power tool can then be replaced in its storage rack.

<u>Rotary Impact Power Tool</u>: The rotary impact power tool (see attached drawings) would probably utilize the same 1/4 hp motor used on the standard rotary tool. The shaft output speed for the impact tool would, however, have to be on the order of 900 rpm. The actual speed would have to be played with somewhat to obtain an optimal configuration.

The impact tool would utilize a quick-disconnect chuck identical to that of the standard tool, although this is not shown in the drawings. The same sockets and bits could be utilized on both tools.

There are numerous impact mechanisms, such as the spring loaded ball/cam type, swinging weight, and hydraulic impulse drivers. However, based upon past experience, the mechanism that produces the highest, most efficient torque while being fairly simple in construction is the twin-hammer mechanism.

In operation, the twin-hammer mechanism is direct rotor and simultaneously strikes one impact with each hammer for each complete revolution of the hammer frame. Because of the direct drive design, the mechanism and rotor come to a complete stop at each impact and actually rebound or back up to some degree, depending upon the tightness or solidity of the joint. This characteristic results in at least 360° - and usually more - of motor acceleration for each impact. This contributes to more energy per blow, however it necessitates a special design of the tool gear reduction. This design must, due to the complex nature of the mechanism, be somewhat a trial and error effort.

Fastener Insert/Removal Tool: The fastener insert/removal tool provides the positive gripping and thread damage prevention features for the insert, removal, and transport of fasteners. The motor requirements of this tool will be very small due to its low-speed and low-torque characteristics. Various design trade-offs will have to be made to determine whether the standard bolt running tool could be utilized, or whether another tool would be required.

If the standard bolt-running tool were utilized, a means of positively limiting the speed and torque would be required. In addition, a means of utilizing the fixture with a quick-disconnect would have to be developed. These trade-offs will be further investigated in Task II. The tool, as shown in the attached drawing, utilizes a fixed attachment; however, the same basic principles would apply for a quick-disconnect system.

To remove a fastener, the manipulator would align the tool over the fastener and lock around the outer surface of the fastener head. This would be accomplished by activating the chucking solenoid to prevent the locking ring from rotating. With the locking ring fixed, motor rotation causes the locking collet to either be drawn in to lock around the fastener or pushed out to release the fastener. The locking collet would be configured to tightly hold a specific fastener to prevent inadvertent loss of the fastener.

After the fastener is locked in the collet, the chucking solenoid would be released, allowing the locking ring to rotate, which would cause the fastener to also rotate for removal or insertion. Self locking threads would be used at the collet/lock ring interface to ensure that the collet does not loosen during fastener removal.

To insert a fastener, the manipulator would obtain a fastener from the storage area and align the fastener over the threaded hole. The tool would then rotate (with the chucking solenoid released) to start the fastener. If misalignment occurs, the tool would not have enough force to cause damage to the threads. The tool would reverse itself to back the fastener out, and a new alignment would be tried. After the fastener has been started, the chucking solenoid would be actuated to prevent the lock ring, and hence the fastener, from rotating, and the motor would be reversed to release the fastener. The standard bolt running tool would then be utilized to tighten the fastener in place.

3.3.4 Electrical Connector Mate/Demate Tool

Functional Description: The electrical connector is approximately 1.5 inches in diameter. The torque required to mate or part the connector is 24 in-lbs. More than 360° of rotation is required to mate the connector, but only 60° of rotation is required to demate the connector.

To mate the connector, three distinct operations must be performed. First, the two portions of the connector must be axially aligned. Accurate alignment is extremely important to prevent binding, and possible failure, of subsequent operations. Second, the keyed portion of the connector (attached to the electrical cable) must be placed in contact with the stationary portion of the connector, then rotated until the keys engage the keyways. This could be as much as 360° of rotation, however the rotation can be in either direction. If the cable were rotated in only one direction in order to engage the keys, it would be possible to put a 360° twist in the cable. In addition to requiring more torque, this is undesirable because it would stress the wires in the cable and possibly break them. Hence a reciprocating rotational search is necessary. This means that the effector would be programmed to search for the key-keyway engagement by rotating +180° to -180° until the keys engage the keyways. During this operation a small force must be applied along the connector axis to keep the two parts of the connector in contact. Once the key engages the keyway, the locking ring must be rotated until it locks. The locking ring will only engage if it is rotated in the proper direction.

The ring locking operation requires more torque than the key engaging operation. Hence engaging the locking ring is the limiting operation with respect to torque and direction of rotation, while engaging the keys is the limiting operation with respect to the amount of rotation.

<u>Design</u>: The associated drawing (Dwg. 200) shows the end effector grasping the connector (A). In the left most view, the end effector is beginning to contact the connector. The rollers (C_1 and C_2) come into contact with the connector first. They guide the effector so that the alignment slot (B) seats properly against the connector. The alignment slot keeps the two parts of the connector axially aligned. Driven friction rollers (C_1, C_2, and C_3) are used to mate and demate the connector. The rollers are driven by a motor through a chain and socket power transmission system. The rollers are sectioned such that they can contact both the keyed end of the connector and the locking ring simultaneously. The rollers are composed of two sections. The section that contacts the locking ring is rigidly mounted on the drive shaft. The other section is mounted on the drive shaft by a slip clutch. When the rollers are powered, they rotate both the keyed end of the connector and the locking ring, until the keys and the keyways engage. The locking ring will rotate freely at this stage. The process of getting the keys and keyways to engage should follow the reciprocating rotational search scenario outlined above. Once the keys and keyways are engaged, the sections of the rollers which rotate the keyed end of the connector begin to slip, via the slip clutch. However, the section of the roller against the locking ring continues to rotate at full torque, until the ring locks into place.

One of the nominal 1 inch friction rollers must be driven with a torque of 32 inch-lbs to mate or part the connector. It must be pressed against the connector with a force of 32 lbs.

<u>Operation</u>: To part a connector, the end-effector is positioned at one side of the cable and connector, then slipped over the connector. The alignment slot orients the end-effector with respect to the connector. Next,

the friction rollers are driven to part the connector. Still grasping the cable half of the connector, the end effector can now move away from the other half of the connector. Now the cable half of the connector must be mated with a dummy connector half for storage. Then the end effector can release the cable half of the connector and proceed to another task. A dummy connector for storage is necessary, because it is virtually impossible to grasp a connector which is floating freely in space.

The primary sensor requirements discussed for these on-orbit maintenance tools are torque sensors and revolution counters for the rotary tools. However, in the development of these tools, some additional sensor requirements may be imposed by operational constraints. For example, if visibility is restricted for some of the tools, some type of feedback signal may be required to indicate completion of an operation. These signals could include storage of a tool or tool bit in the storage rack or positive acquisition of a tool bit or a fastener by the tool. In addition, due to the severe alignment requirements imposed by the mate/demate operations for the fluid and electrical connectors, some additional sensors may be required to indicate proper alignment. (In these concepts, it has been assumed for the present that the connectors can be modified to provide an alignment groove to ensure proper alignment.) As these concepts are developed further, these sensors will be incorporated into the design if the need arises.

3.3.5. Jettison Tool (Explosive Shearing Tool)

Functional Description: The explosive jettison tool was included in the overall tool suit to provide the capability for removing damaged satellite appendages, such as antenna booms or solar array supports. It is anticipated that this tool would only be used as a last resort if more conventional means of removal, such as unbolting, prove to be unsuccessful. Contamination avoidance was a major factor in the choice of an explosive jettison-type tool. The shearing operation of the proposed tool would prevent such contamination.

Design: The jettison tool is a single operation tool which uses a totally contained explosive charge to supply force to a shear blade. A shear pin is used to retain the blade until actuation is desired. Upon actuation, the gasses from the explosion fracture the shear pin, and provide the force to drive the blade through the material located in the entry slot. Alignment is assisted through the use of the lip protruding beyond the shear tool.

3.3.6 Power Spreader

Functional Description: The powered spreader is a device that converts rotary motion into translation motion to separate uncooperative objects or mechanisms. This tool can be used to separate jammed mechanisms, and free jammed satellite appendages, such as antennas or solar array booms. The tool can be applied to any jammed object, such as inspection panels, for which clearance can be found for inserting the blades of the tool.

Tool Design: The conceptual pry tool drawing illustrates an axial pry bar rather than a scissor type. One advantage of the axial type is that it allows the PFMA teleoperator arm to extend directly toward the work pieces, using the force of the PFMA arm to react against.

The axial pry bar has a pry arm plus a reaction foot. For example, a jammed door or bolt on a space module may require prying action for loosening, or pulling out part way. The operation would be as follows:

1. Position the pry tool (which is normally in the home position) to the desired position on the work piece, extending the teleoperator arm until the reaction foot is firm against the module. A built-in sensing switch will indicate that the foot is firmly against the module when a green light comes on at the operator station.

2. Position the point of the pry arm between the work piece and the module and initiate prying action with the "pry" control button. The pry arm can move a full two (2) inches if needed, or can be stopped at any point.

3. An AFT Limit Switch (A.L.S.) will stop the pry arm automatically at the end of travel.

4. Repositioning the pry arm to the home position is accomplished by pushing the "home" button at the operator's station. This overrides the A.L.S. for homing the pry arm. The arm will stop automatically in the normal or home position.

5. A small relay box (control box) is located on the PFMA end effector pry tool structure. This box contains relays K1 and K2 (small, light

weight) which performs the necessary switching of the pry arm, and which also prevents operator error during operations. An emergency off button at the operator's control station is a latching/unlatching type push button which will kill all power to the pry tool.

Options to the tool would be a stain gauge force sensor which could be incorporated into the circuitry to automatically initiate power off.

The tool is designed with a gear motor driving a 2 work screw mechanism with a speed reduction ratio of 147.70 to 1.00. The time required for the pry arm to travel the full two (2) inches is calculated to be 30 seconds.

The tool is designed for a maximum pry force of 100 pounds, therefore consideration should be given to the space module structure that the reaction foot rests against, to prevent possible damage to this structure. Because of this consideration, it would be advantageous, if not required, to provide a force sensor in the control circuitry that could be remotely set to any value, say, between 20 to 100 pounds.

3.3.7 General Purpose Grapple Tool

Functional Description: The concept provides an expandable device that provides flexibility for grappling large fragile space structures without over-stressing the structure in the contact areas. The tool will capture any structure that provides an opening large enough to accommodate the unexpanded tool.

Design: The design features a spring loaded concept mounted on the standard end effector tool base and powered by an electrical drive unit with a two way rotating shaft. The drive is connected to an enclosed internal threaded shaft which extends into a fixed threaded sleeve inside a telescoping tube. No exposed threads, mechanism, or lubricants are present in this design. Extending or retracting the tube causes the six equally spaced leaf springs to either bow for gripping or flutter for release. The outer skin is a durable plastic material lined with a soft cushion material. This concept allows contact forces to be distributed over a large surface area, thus minimizing contact stresses. The device is self compensating in that high point load will deflect the spring and redistribute the force along the spring and to other areas of the structure in a manner similar to a pneumatically inflated bladder.

3.3.8 Hinge and Attachment Concept (No Conceptual Drawing Provided)

Functional Description: Many remote operations, such as the removal of an electrical panel, would be difficult to achieve with a single manipulator arm, since the arm would have to both remove the last retaining fastener and hold the panel in place at the same time. A possible alternative to this problem would be in the use of an additional manipulator arm. If this is not feasible, some means of permanently or temporarily holding the panel while removing its fasteners will be required. In addition, it may be desirable to have the capability of connecting an attachment point to some component to allow easy control with the PFMA intermeshing end effector.

Design: A potential solution to the problem stated above would be to attach a hinge and/or a standard tool base as required onto the components requiring attention. For instance, access into an electrical enclosure would be required for the replacement of a component. To achieve this with a single manipulator, a hinge could be attached between the enclosure and the panel cover, and an attachment point could be attached to the cover. The panel cover fasteners could then be removed with the hinge holding the cover to the enclosure, thus preventing inadvertent displacement. The manipulator would replace the fastener removal tool and use the intermeshing end effector to grasp the attachment point and open the panel cover, allowing easy access into the enclosure.

The proposed method for attaching the hinge and attachment point is with the use of hot melt and two-part tape adhesives. Each of the adhesives would be placed on the attachment components prior to launch, or at the Space Station. No conceptual drawings were made for this system since the attachment components themselves would be fairly straight forward. The major design area for this concept would be in developing an adhesive.

A major advantage to the hot melt type adhesive would be that the hinge and attachment components would be held against the substrate and heated to melt the adhesive. The adhesive would then be allowed to cool, causing the attachment components to adhere to the substrate. A major disadvantage to this type of adhesion is that no materials of this type are presently commercially available for use in space. In addition, the extreme temperature differences in space could cause some design difficulties.

The two-part adhesives would have tiny crushable capsules of two part polyurethane components glued to the attachment components. When the attachment components are pressed into place the capsules break, allowing the two parts to mix and adhere. This type of system would not be removable.

The tape adhesive is the only one found that has had some exposure to testing in a vacuum. Also, some outgassing tests have been performed. Testing showed that the tape would remain sticky in a vacuum for several days after the liner was removed. After two weeks, the tape was no longer sticky. In use, the sticky backed attachment components would simply be pressed against the substrate. Care would have to be taken to prevent inadvertent attachment to the wrong substrate. In addition, the tape would have to be protected from dust and contaminants.

3.4 Tool Storage Concepts

Functional Description: A multiple tool system requires a storage system to hold the tools which are not being used. This storage system must be designed so that the tools are accessible to the manipulator while under teleoperated or computer control while in the remote working position. The tool storage system must both firmly hold the tools, or prohibit the loss of tools during the manipulator operation and system transfer, and also allow relatively easy insertion and extraction of the tools from the holder. The storage system must be designed to contain the tools during all mission phases including launch and ascent.

Design: The proposed tool storage system (see attached drawings) utilizes a simple friction concept for holding the tools. Each tool is stored in an individual bin that is attached to a bolt-on framework. An advantage to this type of bolt-on, individual bin storage system is that only the specific tools required for a given mission would be carried, thus greatly saving space and weight. In addition, those tools most frequently used for the specific mission would be advantageously placed for easy manipulator access. As additional tools are developed for the manipulator system, individual bins would be designed and fabricated rather than redesigning the entire storage system.

The tool storage bins utilize a stiff brush material to hold the tools in place and also to center the tools within the bin for easy access.

Trade-offs will have to be investigated between the tightness of hold and the ease of access. Each bin would be designed for the particular tool that it held and would feature guides and retaining devices to assist in replacing and accessing the tools.

Positive locks may be required to hold the tools in place during launch and other high load time periods. These systems could be positive latches which are actuated either by individual motors located on each storage bin or by the manipulator end effector. This type of system would hold the tool tightly against forces in any direction. A potential simplification to this type of positive hold mechanism would be to use a passive system in which the tool storage bin would be positioned so that the major loads on the tools would force the tool down into the bottom of the bin rather than side-to-side. With this type of system, the tool would be positively held in only one direction, and held by the brushes in the other directions.

The tool concepts described in Task 1 primarily address maintenance and servicing requirements, effector tool requirements and specifications, and conceptual design of effector tools for on-orbit satellites to be flown in the years 1986 to 2000. Based on the documentation provided from Task 1 analysis, detailed layout designs and operation descriptions for each of the representative tool sets and storage mechanism will be developed in Task 2.

4.0 TOOL SUBSET DEFINITION TASK SUMMARY

4.1 Criteria/Rationale for Selection of Tool Sub-Set

From the representative tool set of Table 4, the tool subset selected for final detailed design, construction, and demonstration of the PFMA was based on the criteria that tools should functionally represent the tools needed for the highest priority tasks, and should demonstrate as many functions as possible of the tools in the tool set.

TABLE 4. REPRESENTATIVE TOOL SET

- 0 ROTARY POWER TOOL(S) WITH INTERCHANGEABLE BITS/SOCKETS, EXTENSIONS, AND IMPACT ATTACHMENTS
- 0 FLUID CONNECTOR MATE/DEMATE TOOL
- 0 ELECTRICAL CONNECTOR MATE/DEMATE TOOL
- 0 SHEARING TOOL(S) (TUBING, WIRE, TAPE)
- 0 HINGE/HANDLE INSTALLATION TOOLS
- 0 GENERAL PURPOSE GRAPPLING DEVICE
- 0 SPREADER (POWER)
- 0 NONPOWERED PRY BAR
- 0 HOLE PUNCH AND RIVET TOOLS
- 0 SPECIAL GRIPS/JAWS

To provide visibility of the relationship of tasks and tool functions, a matrix of prioritized tasks, operations, tools, and functions was developed, as shown in Exhibit 19. Based on past experience with unplanned maintenance, such operations will require removal and replacement. The basic tool for such an operation is judged to be a power head with interchangeable extensions, bits, and/or sockets. Due to the numerous types of fasteners used in the aerospace industry, a specific bit and/or socket which has not been defined in detail will have to be used in an actual repair. This, however, is not judged to be a serious problem since the design and demonstration of a tool capable of working on typical fasteners will demonstrate the operational capabilities of the PFMA and the end effector tools. As shown in Exhibit 19 other maintenance tasks will require a power tool with various chucks, bits, and sockets.

EXHIBIT 19. TOOL FUNCTIONS

PRIORITIZED TASKS	OPERATIONS	TOOL	FUNCTIONS
Unplanned Maintenance and Repair	o Remove/replace/install protective covers, insulation	o Rotary power tool o Shears	o Rotation, gripping, control of loose items, alignment, translation
	o Electrical connector disconnect/connect	o Special fixture designed for specific connector	o Alignment, translation, rotation, gripping
	o Install restraints (hinges & handles for covers/panels)	o Special fixture to install restraints	o Alignment, translation, rotation
	o Override of damaged or jammed payload systems or mechanisms. Cut and remove cables tubing, wiring causing module jamming	o Tube/cable/bolt cutter o Powered spreader/ pry bar	o Sheering, alignment, translation o Alignment, translation
	o Loosen or remove jammed or cross threaded bolts	o Impact wrench	o Rotation, gripping, alignment, translation
Fluid Transfer	o Remove/install protective covers. Connect/ disconnect stow connectors	o Special fixture designed for specific connector	o Rotation, gripping, alignment, translation
Inspection	o Remove/replace protective covers	o Rotary power tool	o Rotation, gripping, control of loose items, alignment, translation
	o Translate, rotate inspection system o Photographs	o Hinge/handle installation	o Alignment, translation, rotation, gripping
Construct/Assemble	o Payload transfer o Structural fastening/ assembly o Deployment of structure	o Grapple(s) o Power tools - blind rivet gun o Special grapples/ power tools	o Rotation, gripping, control of loose items, alignment, translation
Deployment/Retraction	o Reposition Solar arrays/antennas	o Grapple(s) power tools	o Gripping, alignment, rotation, translation
	o Remove/replace protective covers, thermal insulation	o Power tools	o Rotation, gripping, control of loose items, alignment, translation
	o Extend retract, jettison equipment booms	o Cable/tube cutters power tools/ spreaders pry bar	o Shearing, gripping, rotation, alignment, translation
	o Capture, removal, store loose objectives	o Grips	o Gripping, alignment, rotation, translation

Special fixtures will be required to remotely connect and disconnect typical fluid connectors for on orbit fluid replenishment, and to demate/mate electrical connectors for electronic box change out. The design of these specialized tools requires specific detailed design information on the specific connector to be serviced. Since this information is unavailable, typical connectors were selected and tools will be designed to service these connectors, demonstrating the PFMA servicing capabilities. Unplanned removal of electronic packages and other maintenance tasks will require capability of handling and stowing of inspection plates, access panels, etc. This will require tools for installation of hinges and handles for opening and controlling these items. Tools recommended for final design, construction, and demonstration are the powered rotary tools with extensions and interchangeable bits, fluid connect/disconnect tool, special tool for installation of hinges and handles, and electric connector connect/disconnect tool. Only the first two tools will be designed and constructed since resources are limited.

4.2 Tool Subset

The tool subset, defined jointly by SRS, Battelle, and NASA, consists of the Fluid Coupling Tool (FCT) and the Rotary Power Tool (RPT). The mechanisms and hardware associated with these tools are the Standard Electrical Interface (SEI), Standard Mechanical Interface (SMI), Rotary Power Head, Fastener Gripping Mechanism and Interchangeable Collets, Storage Mechanism for Rotary Power Tool, Storage Mechanism for Interchangeable Collets, Fluid Coupling Tool for the Fairchild Fluid Coupling, Fluid Coupling Tool for the Purolator Fluid Coupling, and Storage Mechanism for Fluid Coupling Tool.

The SEI and SMI are used to interface the tools to the PFMA. Identical mechanisms are incorporated on both the FCT and RPT, and could be utilized with any additional tools which might be designed for future applications.

The RPT is comprised of a Rotary Power Head, Fastener Gripping Mechanism, and Interchangeable Collets. The Fastener Gripping Mechanism provides positive gripping to prevent inadvertent fastener loss during any bolt-running operation, while specific Interchangeable Collets are used for each type of fastener. Collets for a 7/16 inch, 12-point hex head and Number 10 socket head cap screw are provided with the tool subset. The Rotary Power Head, while dedicated to the Fastener Gripping Mechanism as presently designed, could be slightly modified for use with other rotary functions such as drilling.

The FCT is designed specifically for the remote mating and demating of the Purolator connector (part no. 7541588). However, it could be modified to operate many other brands of fluid connectors.

Individual storage mechanisms are provided for both of the tools and for the interchangeable collets. These storage devices can be separately bolted to a storage board in locations best suited for a given mission. As more tools are added to the set, additional storage devices can be mounted to the board. Only those tools required for a given mission need be added to the storage board.

4.3 PFMA Design Capabilities

The Tool Subset developed in this task was designed to operate with the PFMA. The PFMA is a single arm, nonanthropomorhic robotic manipulator with 7 degrees of freedom. Its design was optimized for radial and axial servicing tasks and can be commanded to relative or absolute coordinates. The constraints around which the tool subset were designed are as follows:

- o Maximum lift weight - 10 pounds (in 1-g environment)
- o Accuracy of ±0.125 inch
- o Maximum torque resistance of wrist roll assembly - 25 to 30 ft-lbs
- o Wrist roll torque - 8.7 ft-lbs
- o Maximum jaw opening - 3.25 inches
- o Maximum squeeze force of jaws - 35 to 40 pounds
- o Available voltage - 0 to 31 Vdc
- o Allowable current (via slip rings) - 6 amp (intermittent), 3 amp (continuous)

Both tools and associated mechanisms have been designed to operate within these system capabilities.

4.4 Tool Subset Design

4.4.1 Standard Mechanical and Electrical Interface

Background: Mechanical and electrical interfaces are required to mate individual tools to the PFMA intermeshing end effector. For this reason, the SMI and SEI will be used to provide the common interface between the PFMA and the tools developed during this task.

Drawing 200 shows the "hand side" of the SMI and SEI, with the mechanical portion being the existing intermeshing end effector. The "tool side" of both mechanisms is shown in drawings 300 and 400 (FCT and RPT respectively). In operation, the mechanical and electrical interfaces are mated in two discrete operations. The electrical interface will not be made until the manipulator has first securely grasped the tool, and possibly removed it from the tool storage area. Separat g these interface processes eliminates the need for performing two alignment operations simultaneously, and also minimizes the manipulator force required for grasping the tools.

SMI Design: The "tool side" of the SMI is a simple mechanical arrangement similar to that presently utilized for PFMA interface. A length of "square" cross section tubing with a geometry matching that of the PFMA intermeshing end effector (slightly skewed from square) is fixed between two parallel plates. The plates are spaced to provide 1/16 inch "hand" clearance for the PFMA end effector, and are tapered to assist in hand alignment.

Mechanical interface between the tool and the PFMA is achieved by simply grasping the tool with the intermeshing end effector. The tapered finger design of the end effector causes the hand and SMI to be "pulled" tightly together into a known mated position, thus minimizing the alignment requirements for the SEI.

SEI Design: The 1/16-inch SMI hand clearance defines the translational alignment requirements for the SEI -- along the axis of the manipulator finger closure. The rotational alignment and the translational alignment in the plane of the manipulator finger closure are provided by the previously mated mechanical interface. Thus, compliance has to be built into the electrical interface only in this one plane of translation, although some additional compliance has been built into the design.

Electrical interface is achieved by translating the male connector and connector probe into contact with the female connector and associated alignment mechanism. The electrical connector utilized is the Amphenol 26-4100-8P and 26-4200-8S plug and receptacle, as specified by the customer.

The "hand" side of the SEI consists of the male connector, connector probe, and drive mechanism (shown in drawing 200). The system is driven by a 0.062-inch-lead, ball screw powered by a small dc motor and integral gearhead (262:1 reduction ratio). The drive mechanism provides approximately 50 lbs. closure force, and transverses the full two inch travel in 22 seconds. Limit switches (further discussed in Section 4.4.5) are provided to control the overall travel.

The connector probe and guide housing are fabricated from aluminum with hard coat and anodizing (Nimet Industries Nituff process) applied to the mating surfaces. The "hand" side of the SEI is hard mounted to the PFMA wrist, and is anticipated to weigh approximately 3/4 lbs.

The "tool" side of the SEI consists of the female connector, connector socket, and alignment mechanism (shown in drawings 300 and 400, as part of the FCT and RPT respectively). The connector socket is the first point of contact with the male connector probe. The probe and socket are both tapered to accommodate the maximum misalignment, and are in full contact for approximately 5/8 inch prior to plug/receptacle contact. This initial contact ensures plug and receptacle alignment prior to mating.

The 1/16 inch maximum PFMA/tool misalignment is overcome by allowing the connector socket to translate (along the axis of manipulator finger closure) ±1/32 inch from center in a slotted bracket. Therefore, the tolerancing of the connector socket must be tightly maintained with respect to the possible misalignment. The misalignment would be corrected during the initial contact with the connector probe. The connector socket is held against the face of the slotted bracket by spring plungers. These plungers will accommodate any rotational misalignment if present.

4.4.2 Rotary Power Tool (RPT)

Background: A rotary power tool was judged to have the highest functional priority during the task one overall tool suit development. In addition, it was determined that significant size, cost, and time savings could be realized by utilizing a minimal number of power heads, with interchangeable attachments.

Based upon an analysis of the torque and speed requirements for the various rotary operations, it is anticipated that three rotary power heads will eventually be required. These heads include: a "standard" rotary tool which would be used in most applications; a high speed rotary tool using the same motor as used in the standard rotary tool, but with different gearing; and a low-torque, low-speed head.

Each of the rotary tools would have some type of quick release chuck to allow for remote interchange of specialty attachments. The "standard" head would be used for most bolt running operations using a socket, and extension if required. In addition, other attachments would be used to operate quarterturn fasteners, perform drilling operations, or other specialty functions.

The high speed rotary head would be used with an impact attachment if higher torques were required, or it could be used for various cleaning or circular cutting operations. Higher torques would be required for such operations as removing fasteners which may have been cross-threaded or otherwise jammed, or in performing override operations, as with appendages with failed primary actuators.

The low-torque, low-speed head would be used for bolt running operations on small fasteners and for all fastener insertion, with the low torque and speed used to minimize the potential for cross-threading. In operation, this tool would utilize a trial and error method for inserting and starting the fastener. The manipulator would place the fastener into the thread hole and provide as much alignment as possible. The tool would then attempt to start the fastener. If the fastener is not correctly aligned and cross-threads, the tool would not have sufficient torque or speed to cause damage. A torque sensor would, in this case, indicate motor stall condition, and the fastener would be removed and re-aligned for another attempt.

Another required feature of the fastener insert and removal tool will be a means of positively gripping the fastener to prevent its inadvertent loss during any of the operations performed upon it. The Rotary Power Tool (RPT) developed in task two incorporates this low-torque, low-speed capability along with an integral positive gripping mechanism.

Tool Design: The RPT has been designed to provide a means of positively holding a threaded fastener, such as a hex head bolt or socket head cap screw, while performing bolt running (insert, removal, or transport) operations. This mechanism is essential for remote bolt running operations since the inadvertent loss of a fastener could jeopardize the successful completion of an operation. The use of standard sockets and extensions is not acceptable, since no positive gripping mechanism is incorporated.

The RPT consists of the Rotary Power Head (drawing 300), the Fastener Gripping Mechanism (drawing 100), and the Interchangeable Collets (drawing 105).

The Rotary Power Head design is based upon the internal components of the commercially available AEG EZ506 hand power tool. The EZ506 is an adaptation of the EZ505, which has been used on three NASA Space Shuttle

Missions. The EZ506 introduces a tachometer generator on the motor and torque sensitive electronics that were not present on the previous model. Both models are designed for battery operation. The basic capabilities of the EZ506 are as follows:

- o Forward/Reverse Option
- o Six-stage Torque Control (4 to 57 in-lb)
- o Variable Speed (100 to 600 rpm)
- o 7.2 Vdc Motor

The internal components which will be incorporated into the RPT include the gear block, the motor block, the switch block, and some electronic circuitry.

An EZ506 battery system will not be included as used on the RPT. The system power will be supplied directly from the PFMA power bus. All of the tool control functions, with the exception of the torque, will be operated remotely from the PFMA control console. The torque setting will be chosen by inserting the tool head into a special fixture (see drawing 503) and using the manipulator wrist motion for selection.

The Rotary Power Head as presently designed does not incorporate a turn counter. However, a counter could be incorporated without much difficulty. The counter would be used to prevent a fastener from being removed entirely if not required. This type of device would be required if a "standard" rotary power tool was used to loosen a fastener, and then a smaller tool with a gripper mechanism was used to remove and transport the fastener to another location.

Revolution counting could be implemented in many ways; however, the use of a Hall Effect Transistor would be the simplest. This type of transistor senses the rate of change of flux through an electrical field. A simple, digital on/off counter could be implemented to count the number of times that the field was broken or completed by the socket as it rotates.

In addition to the AEG tool components, the Rotary Power Head consists of the SMI and SEI interface mechanisms discussed earlier, and a drive mechanism utilized with the Fastener Gripping Mechanism. The Fastener Gripping Mechanism is pinned directly to the Rotary Power Head, and is used to provide the positive gripping mechanism.

The Fastener Gripping Mechanism utilizes interchangeable collets to provide positive gripping to the fasteners. Each collet has a socket type head designed to match a specific fastener head. The collet head is slotted so that a radial force applied around the collet head causes it to squeeze down tightly over the fastener, thus securing it. The Fastener Gripping Mechanism and collets interface so that this "squeezing" radial force is supplied when the collet is threaded into the fixture.

In operation, the appropriate collet would be selected and interfaced with the Gripping Mechanism. The collet storage mechanism is shown in drawing 106. The entire RPT would then be placed over the desired fastener, with the collet socket head interfacing with the fastener. The collet could then be squeezed down onto the head of the fastener, positively holding the fastener in preparation for removal, transport, or insertion as desired.

The Gripping Mechanism is designed to operate remotely through all required bolt running operations. The operations include: the selection of the appropriate collet; the locking of the collet onto the desired fastener; the individual tasks of fastener removal, transport, and re-insertion; and the subsequent release of the fastener. The collet, lock shaft, and gripping mechanism must be rotated simultaneously to perform the fastener removal, transport, and re-insertion tasks. During these operations, the lock shaft is fixed to the gripper via the notched plate (part of the lock shaft) and the gripper lock mechanism, thus positively locking the collet with respect to the gripper.

In contrast, during the fastener release and grasp (chucking) tasks, the lock shaft must be rotated with the gripper held rigidly. The collet is pinned to the gripper mechanism with slotted grooves to prevent the collet from rotating independently of the gripper while allowing the collet to be threaded in and out to, respectively, grasp and release the fastener. The lock shaft's notched plate, and associated lock mechanism, are again used to properly control the rotation of the collet fixture and lock shaft.

The drive mechanism located on the Rotary Power Head is used to operate the lock control of the Fastener Gripping Mechanism. An integral motor/gear-head is used to power a ball screw that drives the lock pin into the Fastener Gripping Mechanism. The lock pin is spring loaded to prevent damage to the gripping mechanism if the lock mechanisms are not aligned. Limit switches are used to control the overall stroke of the lock pin.

At present, the design utilizes a gearhead with a 104:1 reduction. This configuration provides approximately 9 pounds of force to the lock pin, and requires 3.5 seconds to travel the full half-inch stroke. If this force is not sufficient, a 235:1 gearhead could be utilized. This configuration would provide approximately 20 pounds of pin force, and require 8 seconds for full travel. A smaller ratio, 46.4:1, would provide 4 pounds of force for a 1-second travel time. The change of gearheads could be accomplished without modification to the overall design, as the physical dimensions of the gear-head would remain unchanged.

In operation, the Rotary Power Head's lock pin would be driven out against the gripping mechanism. If the mechanisms are not aligned, the spring compresses and provides a constant force on the gripping mechanism, which would be slowly rotated. As the lock mechanisms of the power head and the gripper align, the spring would snap the lock pin into position in the gripping mechanism. The system springs must be chosen so that the lock pin spring has a greater spring rate than that of the lock mechanism spring (first approximation would be 8 pounds and 6 pounds respectively). It must, however, be light enough to prevent potential damage to the Fastener Gripping Mechanism.

The Rotary Power Head drive mechanism is utilized only during fastener grasp and release operations. When actuated, the lock pin enters the collet fixture lock mechanism, and thus both locks the collet fixture and releases the lock shaft's notched plate to allow the lock shaft to rotate. The notched latch is released by pushing the lock pin beyond the plate's notched area. This allows the collet to be threaded in or out of the collet fixture.

Collet interchange is accomplished in much the same manner as fastener grasp and release. To replace a collet into the collet storage mechanism, the collet fixture is aligned with the storage mechanism via the fixture alignment notch. This notch is used to orient the collet anti-rotation pins and grooves. After alignment, the chucking solenoid is actuated and the collet threaded out of the fixture into the storage mechanism. The collet is captured and held by the fixture springs. The fastener head located in the mechanism is used to assist in aligning the collet and to prevent the collet from rotating after moving beyond the collet anti-rotation components. A collet is retrieved by reversing the steps described above.

Additional collets for different fastener types can be provided. In addition, specialty attachments could be developed where the Fastener Gripping Mechanism would be used to simply "hold" the attachment. An example of this could be a drill bit with a hex head attachment point to interface with a matching collet.

4.4.3 Fluid Coupling Tool (FCT)

4.4.3.1 Applicable to Purolator Fluid Connector

Background: The FCT was designed to demonstrate remote mating and demating of the Purolator (part no. 754187 and 7541588) fluid connector. While this tool was designed to operate with this connector specifically, other connectors could be operated with similar type tools. The FCT layout design is shown in drawing 300.

The design requires no modification to the male portion of the connector. However, an alignment groove must be added to the female half of the connector. The alignment groove is incorporated by increasing the existing 1.33 inch outer body diameter by approximately 0.38 inch and machining a 0.5 inch wide radial groove into the additional material. This addition will not affect the operation or internal configuration of the connector.

The female half of the connector is bulkhead mounted to the satellite, and weighs 0.17 pounds. The male half of the connector weighs 0.35 pounds. An approximately 2.25 inch locking ring is located on the male connector and is used to both lock and release the two halves. No retaining force is required to maintain closure once it is latched.

The Purolator connector is mated by simply pushing the two halves together. An approximate 24 pound force is required for mating. The connector design requires close translational alignment; however, it can handle some rotational misalignment. Demating is accomplished by pulling the lock ring (located on the male connector) away from the bulkhead connector with approximately 11 pounds of force.

Design: The major functional components of the FCT consist of: the front plate, the drive mounting plate, the connector housing, and the drive components. The connector housing translates between the front and drive mounting plate along a pair of ball screws to provide the mate and demate forces.

The front plate is notched to match the female collector alignment groove (discussed above), and dimensioned to a close tolerance of their final position. The notch is tapered to assist in interfacing the tool and the connector, and has an integral sensor at the top of the notch to indicate proper positioning. The front plate notch and connector alignment groove also provide the necessary reaction force for connector mating and demating.

The drive mounting plate is tied to the front plate by the ball screws and also by a pair of guide rods. The drive mounting plate provides the interface to the manipulator and houses the tool drive components.

The ball screws are coupled with a chain and sprocket arrangement to ensure coordinated operation, and are powered by a small dc motor and integral gearhead (485:1 reduction ratio). The drive components are designed to supply a linear force of approximately 75 pounds to mate and demate the connectors. The total time to traverse the approximately 1 inch travel will be 21 seconds. Limit switches are provided to control the overall travel (further discussed in Section 4.4.5). An additional sensor is provided to ensure proper alignment to the female bulkhead connector.

The present design has the male half of the connector permanently mounted to the connector housing. An alternative design (as shown in the Task Two Fluid Connector Concept Drawing) would be to have the FCT capable of releasing and grasping the male half of the connector. The alternative design would be more versatile, as a separate FCT tool would not be required for each umbilical. However, the alternative design would require an additional alignment mechanism and would thus be more complex and expensive. The present design was chosen as being the more reliable system.

In operation, the manipulator would position the front plate of the FCT into the bulkhead connector alignment groove. The alignment sensor would indicate correct positioning. The tool drive motor could then be activated to mate the connector, with limit switches or other sensors used to stop the motor at the end of travel. The manipulator would have to release the entire

FTC if required for other operations prior to demating. The demating process would be the reverse of that described above.

4.4.3.2 Applicable to Fairchild Fluid Connector

Background: The FCT was designed to demonstrate remote mating and demating of the Fairchild (part no. 76300000) fluid connector. The Fairchild connector requires a mating closing force (measured) of 42 pounds which must be maintained by the FCT during fluid operations. Unlike the Purolator coupling, there is no force required to demate the coupling halves. The male half of the fluid coupling which is attached to the FCT is 1.1 pounds. The female mating half of the connectors is bulkhead mounted to the satellite and weighs approximately 3.5 pounds, which includes the weight of the connector mounting flange plus the inclined ramp mechanism.

The design requires no external power, (no drive mechanisms/motors, etc.) and depends only upon positioning/aligning the fluid connector mating halves by manipulating the PFMA into position, and then wrist roll to engage and pull together the connector halves.

The mechanism consists of rollers on an inclined plane that translates rotational movement to axial force to complete the coupling. The fluid connector tool was fabricated and demonstration tests with the PFMA were successfully performed during this reporting period.

The actual force moment (torque) in the wrist roll mode of the PFMA required to pull the connector mating halves together was measured to be 2.0 ft-lbs. The angle of the inclined ramp (plane) is 11° from the horizontal.

4.4.4 Storage Concepts

Background: A multiple tool system requires a storage system to hold the tools which are not being used. This storage system must be designed so that the tools are readily accessible to the manipulator while under teleoperated or computer control while in the remote working area. The tool storage system must firmly hold the tools to prohibit their loss during the manipulator operations and during all mission phases including launch and ascent. It must also allow relatively easy insertion and extraction of the tools from the holder.

The design requirements for launch and on-orbit operations will differ greatly, and may not be compatible. For instance, the manipulator may not have the strength to remove a tool if it is held sufficiently rigid to comply with launch requirements. It is anticipated that separate systems will be required for tool holding in these two different conditions.

Design: Each tool (see drawing 500) will be stored in an individual bin that is attached to a bolt-on framework. An advantage to this type of bolt-on, individual bin storage system is that only the specific tools required for a given mission would be carried, thus greatly saving space and weight. In addition, those tools most frequently used for a given mission would be advantageously placed for easy manipulator access. As additional tools are developed for the manipulator system, individual bins would be designed and fabricated rather than redesigning the entire storage system.

A stiff brush material has been considered as a means of providing a firm hold on the tools while still allowing relatively easy manipulator access for operations on-orbit. The brushes would be positioned around the inside perimeter of the tool storage box, and would conform to the shape of the tool to assist in holding it while also centering the tool in the storage bin. This type of a system is shown in drawings 501 and 502 for the FCT and RPT.

Possible methods for accommodating launch loads would be to utilize positive lock mechanisms which could be actuated either by individual motors located on each storage bin or by the manipulator end effector. The complexity of such a system would be great as redundancy would have to be built into the mechanism.

An alternative method, which is recommended if mission logistics allow, would be to incorporate a support cover over the entire tool storage bin. The cover would be designed to assist in rigidly holding the tools, and would be installed prior to each launch. After arriving at an intermediate on-orbit location, such as the Space Station, the cover could be manually removed to provide easy manipulator access.

A passive system could also be included to assist in holding the tools during the subsequent orbital transfer. With this system, the tool storage bin would be positioned so that the major loads on the tools would force them down into the bottom of the bin rather than from side-to-side. With this type of system, the tool could be positively held in only one position, and held less rigidly by the brushes in the other directions.

In addition to the storage bins for the FCT and RPT, an additional storage mechanism is required for the interchangeable collets. The collet holder (shown in drawing 106) is made of four retaining springs which hold the collet in position. An internal hex head and allen head are used to keep the collets from spinning during installation and removal. The alignment device is required to line up the collet groove with the anti-rotation pins located on the Fastener Gripping Mechanism. The actual tool storage designs selected for fabrication were position locking devices for each tool as described in Section 5.2.

4.4.5 Controls

A simple circuit to control the tool motors (excluding the main RPT drive motor) is shown in Table 5. This circuit is adequate for each of the three motors. However, it is not suitable for altitudes above approximately 50,000 feet due to arcing considerations. This means that a different circuit will be needed when the motors are to be used in space. Table 6 shows a block diagram of a proposed control arrangement for use in space.

In the circuit of Table 5, it has been assumed that control for the motor is to be manual. Thus a double pole, double throw switch is shown for turning the motor on and selecting the direction of operation. The circuit is simple, and if point-to-point wiring is used, only three wires need be brought for the motor/limit switch area. Subminiature switches are specified for shutting off the motor when the limits of the slide travel have been reached. It is recommended that the limit switch used for this application be a 1SX1-T manufactured by Micro Switch Division of Honeywell Corporation. This switch will safely handle the inductive loads imposed by the motors. A wire size for the motor circuit should be selected on the basis of ease of handling and mechanical strength. Electrical requirements can be handled by any wire that is 30 gauge or larger.

No limit switches are needed in the circuit of Table 6 because the motor is shut off anytime the motor current exceeds a set limit. This circuit will not only control the motor when the slide reaches the end of its travel but will also stop the motor should the slide meet excessive resistance anywhere in its travel. It should be noted, however, that this circuit assumes that the end of the slide travel is characterized by a hard stop.

The comparator in the circuit continually monitors the motor current and sends a signal to a flip-flop should the current exceed a certain amount. When activated, the flip-flop turns off a solid state switch (SSS). With the solid state switch off, the current to the motor is interrupted and the motor stops. The delay element in the circuit is intended to allow the motor to come up far enough in speed so that the starting current is below the trip point set at the comparator. The delay element would be set to a time close to the time constant for the motor in the circuit. In the motor circuit the solid state switch is probably no more than a transistor with diode protection. Again, in this circuit, it has been assumed that control for the motor is to be manual and a double pole, double throw switch has been indicated for power and direction control Resistor R1 is low resistance and will not influence the motor characteristics. Overall, the motor control circuit need not be complex.

TABLE 5. LIMIT SWITCH MOTOR CONTROL

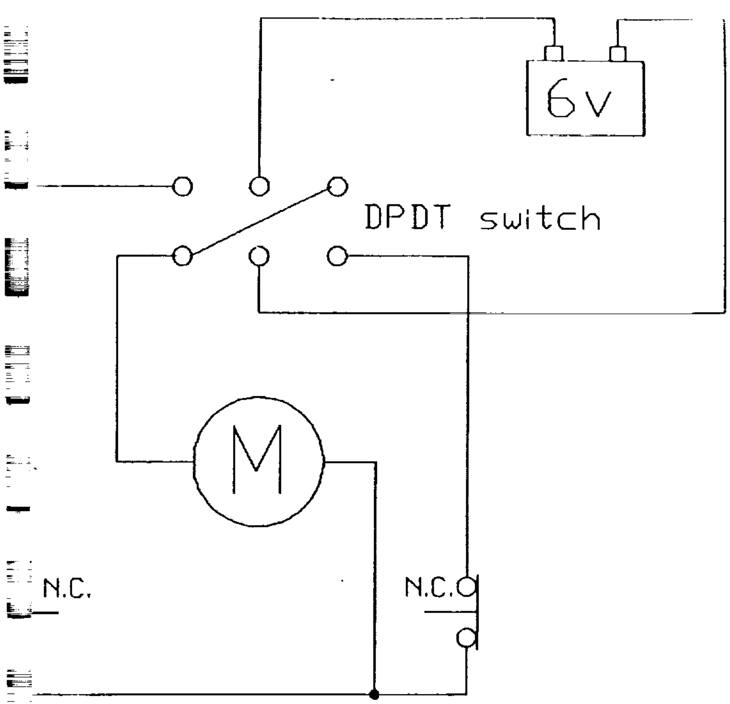
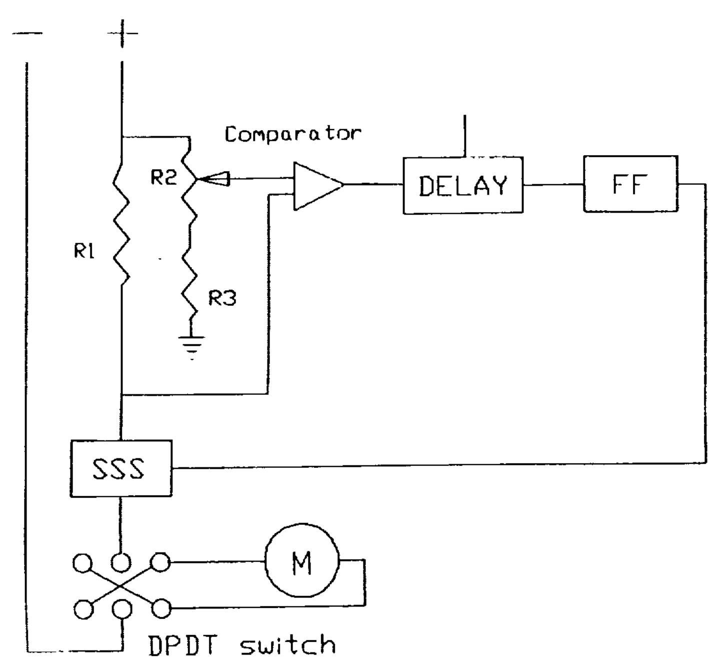


TABLE 6. CURRENT LIMITING MOTOR CONTROL



5.0 TOOLS DESIGN/CONSTRUCTION

5.1 Tool Design

Final tool design and manufacturing drawings were prepared by New Technology of the following:

- o Rotary Power Tool
- o Fairchild Fluid Connector Tool
- o Purolator Fluid Connector Tool
- o Self Aligning Standard Electrical Interface
- o PFMA End Effector Standard Mechanical Interface

The rotary power tool was developed from the Battelle concept discussed previously in Section 3.3.3. Final design is shown in the attached drawings NT-RT-30-001 through NT-RT-30-013.

The Fairchild and Purolator fluid connector tools are shown in drawings NT-RT-20-001 through NT-RT-20-002 and NT-RT-10-001 through NT-RT-10-002, respectively. Both the Fairchild and Purolator connector tools were developed from the New Technology concept described in Section 3.3.2.

A Standard Electrical Interface (SEI) mechanism for transfer of power from the PFMA to tools or devices requiring external power was developed from a New Technology concept that is self aligning as the PFMA end effector mates with the Standard Mechanical Interface (SMI) tool base (Drawing NT-RT-30-005 and NT-RT-30-007). The female receptacle is PFMA wrist mounted while the male probe is an integral part of the power tool or may be mounted separately on the SMI. The electric drive motors are required.

The SMI, as shown on drawing NT-RT-40-001, is very similar to the customer furnished design with slight modifications to reduce weight and the addition of upper and lower guide flanges to aid in alignment with the end effector.

5.2 Tool Storage Rack Design

A tool storage rack was designed to accommodate functional demonstration of the PFMA's capabilities with the entire tool set. After evaluation of each tool, storage design concepts, and existing equipment at the PFMA facility, a storage system was designed to make each tool easily accessible to the PFMA during task function operations while providing firm locking receptacles for each tool. These receptacles provide convenient insertion and extraction by the PFMA. Holding forces are provided by friction, springs, and ball locks without relying on gravity for tool retention. Drawings NT-RT-50-001 through NT-RT-50-010 illustrate the storage rack components listed below.

Storage Rack Components

- Rotary Power Tool Storage Fixture
- Torque Adjustment Fixture
- Collet/Fastener Fixture
- Service Module/Receptacle (with bolting flange)
- Fairchild Fluid Coupler Holder (with low pressure air supply and guage)
- Purolator Fluid Coupler Holder (with high pressure air supply and guage)

5.3 Tools/Storage Rack Construction

5.3.1 Tools Fabrication

All tools and components were manufactured and/or assembled at the New Technology Prototype Engineering Machine Shop. Material and components selection was based on the functional requirements and capabilities of the PFMA as well as applicability to flight hardware for possible future use in the space environment.

5.3.2 Storage Rack Construction

The construction, materials, and location of components of the Storage Rack were dictated by the requirements for durability, simplicity, and ease of operation during demonstration of the PFMA facility. The rack is a basic box structure with all tool storage receptacles located on a single vertical face. Appropriate spacing and alignment margins are provided to aid the PFMA operator when removing or replacing the tools, fasteners, etc. With minor hardware modifications and strategies orientation of the components relative to the launch loads, the storage rack could be adapted for flight use.

5.4 Fit/Function Verification

Fit of all tool parts was verified during assembly and operational function was tested.

Fit of tools to storage rack and simulation board was verified.

It was verified that the rotary power tool can be picked up by the end effector, connect itself electrically, connect to a chosen collet, grip a chosen fastener, rotate forward and reverse at varying speeds, release the fastener, and disconnect from the collet.

Both fluid connectors have been verified to be capable, while being grippled by the PFMA end effector, of easily mating, locking, and demating its appropriate fluid connector using approximately 2 ft/lbs of PFMA wrist roll torque.

6.0 TOOL FUNCTION SIMULATOR

The following sections describe the simulation requirements, design and construction, and functional testing of the tool functional simulator (task board).

6.1 Simulation Requirements

The task board is designed to require specific tool operations similar to those required to perform maintenance services typical of those determined to be of highest priority in Task 1. Since unplanned maintenance may involve removal of spacecraft panels and/or inspection covers, and the removal of components held by threaded fasteners, the task board includes a test panel held in place by threaded fasteners that must be removed before the test panel can be removed or replaced. In this case the PFMA and storage rack simulates the servicing craft and the task board simulates the craft needing maintenance. Removing and storing the fasteners, and removing the test panel from the task board to the storage rack simulates the required operations using the rotary power tool and the PFMA.

Fluid transfer was also determined to be a high priority servicing requirement in Task 1. This operation is simulated with PFMA and the fluid connect/disconnect tools. Two types of fluid connectors can be mated/demated and the operation is similar for each. As before, the storage rack simulates the servicing craft, and the task board simulates the craft needing service. The PFMA picks up the fluid connect/disconnect tool, which is integrated with the servicing half of the fluid connector, and mates it with the spacecraft half to simulate an in orbit fluid umbilical connection. Disconnection and storage is done in the reverse order. The task board and storage rack must have clearly visible alignment marks to aid the operator in aligning the mating halves and in determining the correct rotation to assure the halves have been properly connected.

6.2 Simulator Design

The simulator design included components for demonstration of all tools delivered plus a simulated module exchange function. Both the Fairchild and Purolator fluid couplers are incorporated with gas/fluid storage and gauges.

The rotary power tool is demonstrated with two different fastener sizes and types as an integral requirement of simulated module removal and replacement.

6.3 Simulator Construction

Based on existing task board construction and definition of simulator requirements, a modular task simulator was constructed. A basic box structure was built with all task functions performed on a front vertical face and other components such as gas/fluid piping contained within the structure with door access from the rear. The task simulator model is mounted adjacent to the tools storage rack with attachment hardware which allows convenient removal from any appropriate location or orientation for variation of PFMA demonstration schemes.

6.4 Functional Testing

Fit and function verification testing was performed utilizing all the servicing tools and equipment with the task simulator before and after delivery and installation at the PFMA facility.

7.0 EVALUATION/DEMONSTRATION PLAN

The following plan is designed to demonstrate the capabilities of the tool set provided as part of this contract.

7.1 Test Objectives/Requirements

The objectives of this demonstration are to demonstrate tool capability to perform functions/tasks representative of tasks required for spacecraft on-orbit maintenance and/or servicing. Fluid transfer from one spacecraft to another via teleoperator will be demonstrated by the fluid connector tools for both the Purolator and Fairchild connectors. The remote manipulator will perform all operations anticipated for demating and mating these types of fluid connectors. These operations utilize a simulation of flight-type hardware mounted on a task board that interfaces with the remote manipulator (PFMA) standard gripper mechanism and the end effector tool.

The rotary power tool with interchangeable collets will demonstrate the removal and installation of hex head and socket head type fasteners. These operations simulate typical tasks required for scheduled and unscheduled on-orbit maintenance of spacecraft. The objective is to demonstrate the remote installation and removal of these fasteners without losing control (i.e., dropping the fastener) or cross threading the fastener. These operations also require a task board to simulate flight-type operations. All tools require a tool and parts storage system which is part of the hardware that was delivered.

7.2 Functions/Operations Descriptions

Tool Set

The tool set provided for demonstration purposes consists of the Fairchild Fluid Coupling Tool, the Purolator Fluid Coupling Tool, and the Rotary Power Tool, including interchangable collets. The collets accommodate both 1/4-28 hex head fasteners and #10-32 socket head cap screws. Both fastener types can be demonstrated.

Stowage Mechanism

Individual stowage mechanisms are provided for the rotary power tool and two collets, for the Fairchild fluid connector, and for the Purolator fluid connector. A stowage system is also provided for fasteners, both used and spares. These stowage mechanisms are of prototype design, and with minor redesign, could be expected to sustain shuttle flight loads. The tool stowage mechanisms are mounted on a separate board, adjacent to the demonstration task board, simulating transfer of tools from stowage on a remote manipulator spacecraft module to a spacecraft being serviced.

Task Board

The task board was constructed and mounted to the basic structure of an existing MSFC task board. The task board includes the female mating halves of the two fluid coupling mechanisms, and a test module (TM) which allows the demonstration of removal and installation of fasteners, which is typical of operations used in removing access panels, and/or components of spacecraft requiring service.

A pneumatic source is provided to demonstrate fluid transfer through the mated connectors. The test module consists of a sheet metal panel with box attached, typical of a spacecraft orbital replacement unit (ORU). The panel is equipped with two 1/4-28 hex head screws, and two #10-32 socket head cap screws, that must be removed in order to remove the panel from the task board. A cavity in the test board provides structural mounting for the TM. Nut plates allow fastening of the panel to the task board with the threaded fasteners. A standard interface handle is fastened to the front of the panel for interfacing with the PFMA intermeshing jaws.

Demonstration of Rotary Power Tool

The following operations demonstrate typical operations encountered in on-orbit removal/replacement of ORU's, access panels, and/or inspection panels. These are typical tasks required for scheduled and/or unscheduled on-orbit maintenance of spacecraft. These operations demonstrate the capability of performing these tasks with a remotely operated robotic arm equipped with special end effector tools. Specifically this operation will demonstrate the removal of two 1/4" hex head screws, and two #10 allen head cap screws, storage of the fasteners, removal of the test module, and storage of the test module at the servicing station. Specific operations are as follows:

- The PFMA retrieves the rotary power tool from the storage bin - verifies the electrical connection and adjusts the torque.
- The PFMA translates the rotary power tool to collet storage, and retrieves a 1/4" collet.
- The PFMA translates the rotary power tool with collet to the test module, removes 1/4" screws and stores each screw at the servicing station, then stores the 1/4" collet.
- The PFMA translates the rotary power tool to collet storage and repeats the operation for removal of the #10 screws from the test module, storing each screw and storing the collet at the servicing station.
- The PFMA returns the rotary power tool to storage.
- The PFMA translates to the test module, removes the test module, translates to the servicing station, and stores the test module.
- To install the test module, a reverse of the above sequence would be performed.

Demonstration of Fluid Connect/Disconnect Tools

The following operations demonstrate the capability of the PFMA and end effector tool to transfer fluid from one station to the other simulating the remote operations involved in transfer of fluids from one spacecraft to the other. These operations are typical of those that would involve transfer through fluid umbilicals. The specific operations demonstrated are as follows:

- The PFMA retrieves the fluid connect/disconnect tool from storage.
- The tool is transferred to the task board and mates the fluid connector halves.
- The connection is verified by reading the pressure gauge.
- The PFMA returns the tool to storage.

8.0 REFERENCES

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3. "End Effector and Task Board Development for the Protoflight Manipulator Assembly," Essex Report No. H-84-03, MSFC Contract - 35320, April, 1984.
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5. "Satellite Services Handbook Interface Guidelines," JSC 19212, Lockheed, 23 December 1983.
6. MSFC-RQMT-691.7, "Space Telescope On-Orbit Maintenance Mission Space Support Equipment Human Engineering Design Criteria," October, 1982.
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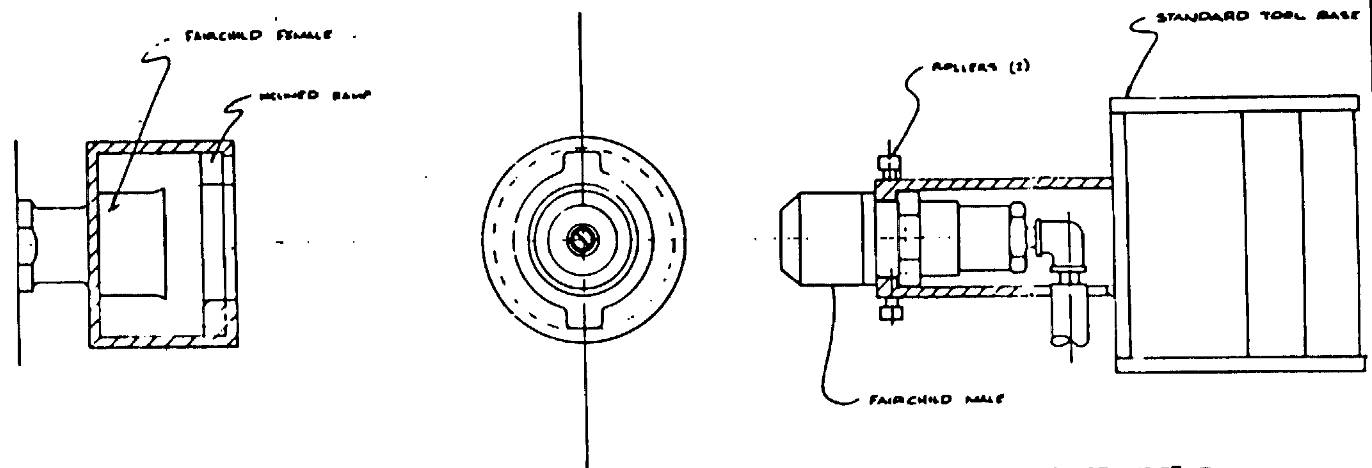

FEMALE PART

MALE FLUID CONNECTOR

OPERATION

1. END EFFECTOR GRIPS TOOL BASE.
2. INSERTS MALE INTO FEMALE, PASSING ROLLERS THRU SLOTS.
3. ROTATES EFFECTOR WRIST 45-90°.
4. ROLLERS ENGAGE INCLINED PLANE INSIDE FEMALE HOUSING.
5. CONNECTOR IS PULLED TOGETHER (MOVES .390)
6. ROLLERS MOVE ON TO A SLIGHT DECLINE, WHICH HOLDS CONNECTOR IN COUPLED POSITION
7. TO UNCOUPLE, MALE PART IS ROTATED 45-90° OPPOSITE DIR

N.T.I. CONCEPT FOR FLUID LINE CONNECTION USING FAIRCHILD CONNECTOR

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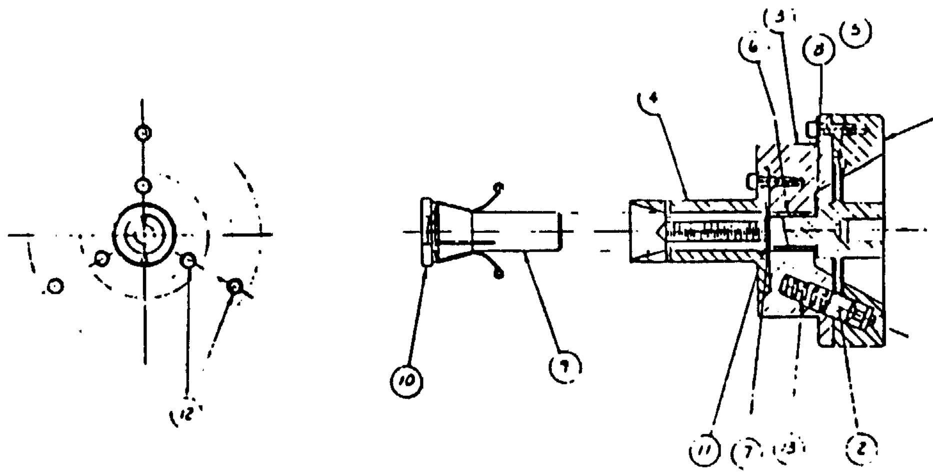

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12	6	#5-40UNC	-	SOCKET HEAD MACH. SCREW		
11	1	5100 25	-	RETAINING RING	WALDES	
10	1	106	B	COLLET HOLDER		
9	1	105	B	COLLET		
8	1	104.3	B	THRUST WASHER		
7	1	104.2	B	THRUST WASHER		
6	1	104.1	B	BUSHING		
5	1	104	B	LOCK SHAFT		
4	1	103	B	COLLET SUPPORT FLANGE		
3	1	102	B	CENTER FLANGE		
2	1	101.1	B	LOCK PIN		
1	1	101	B	REAR FLANGE		

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Battelle — Columbus Laboratories

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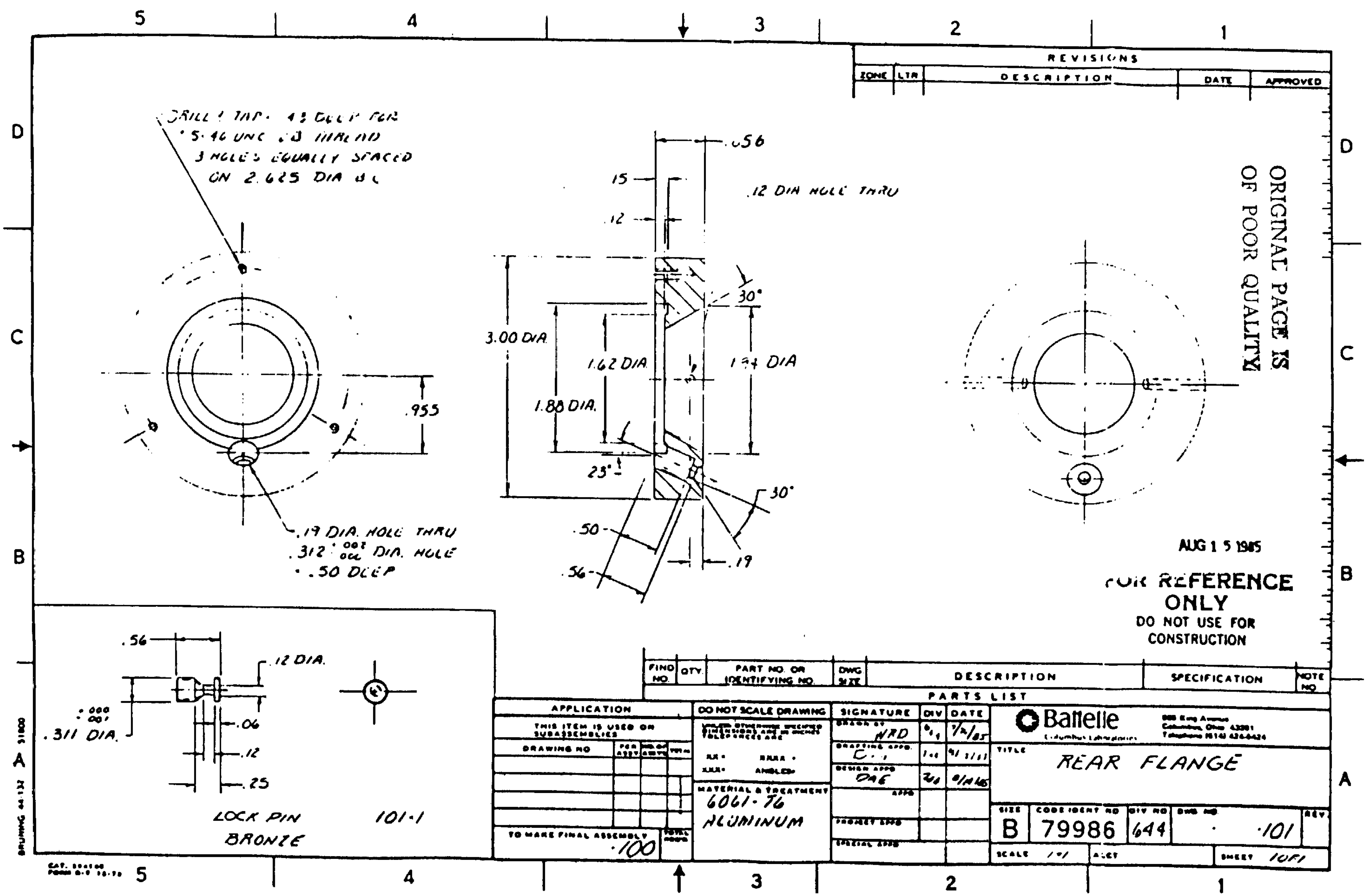
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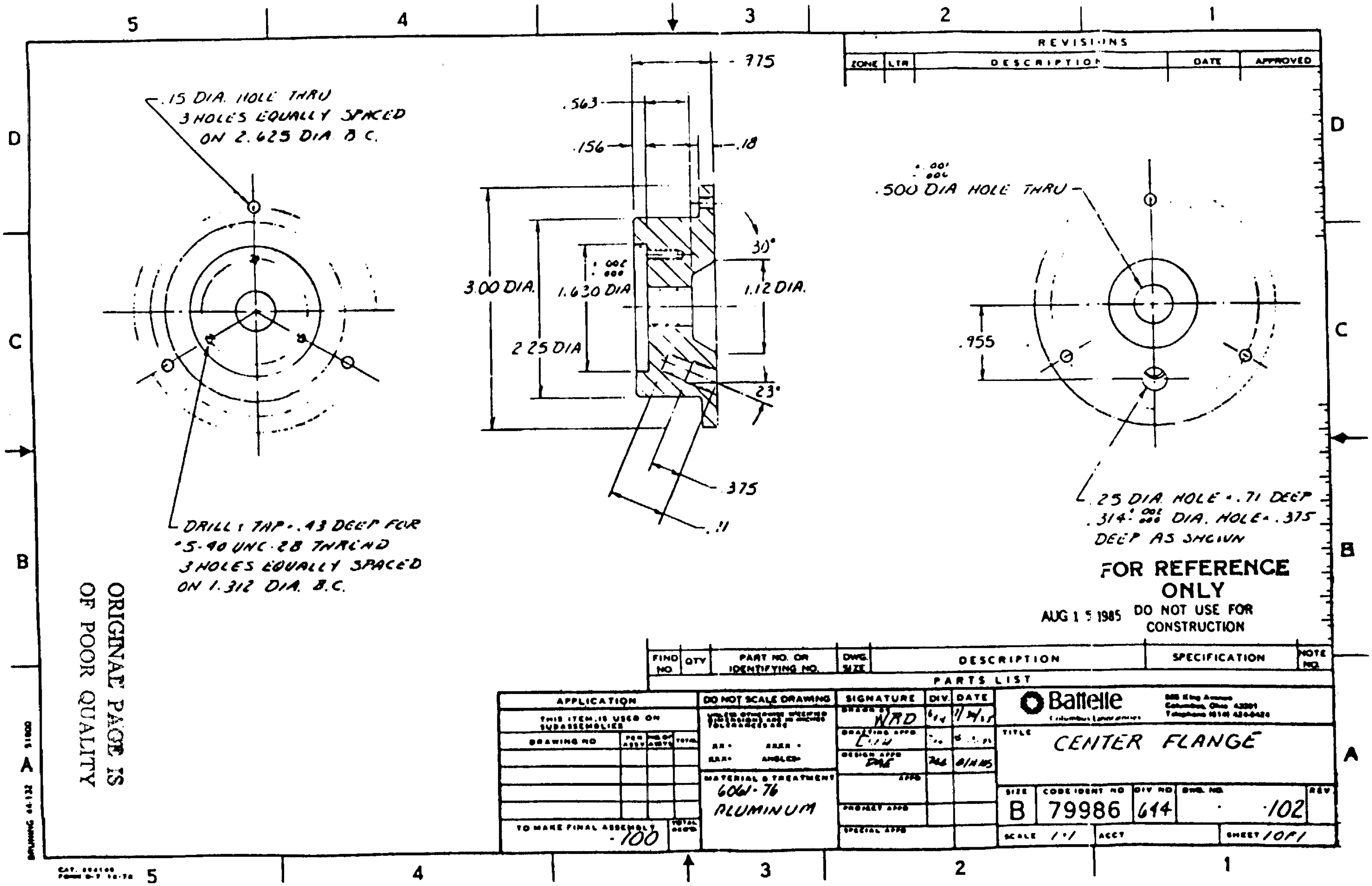

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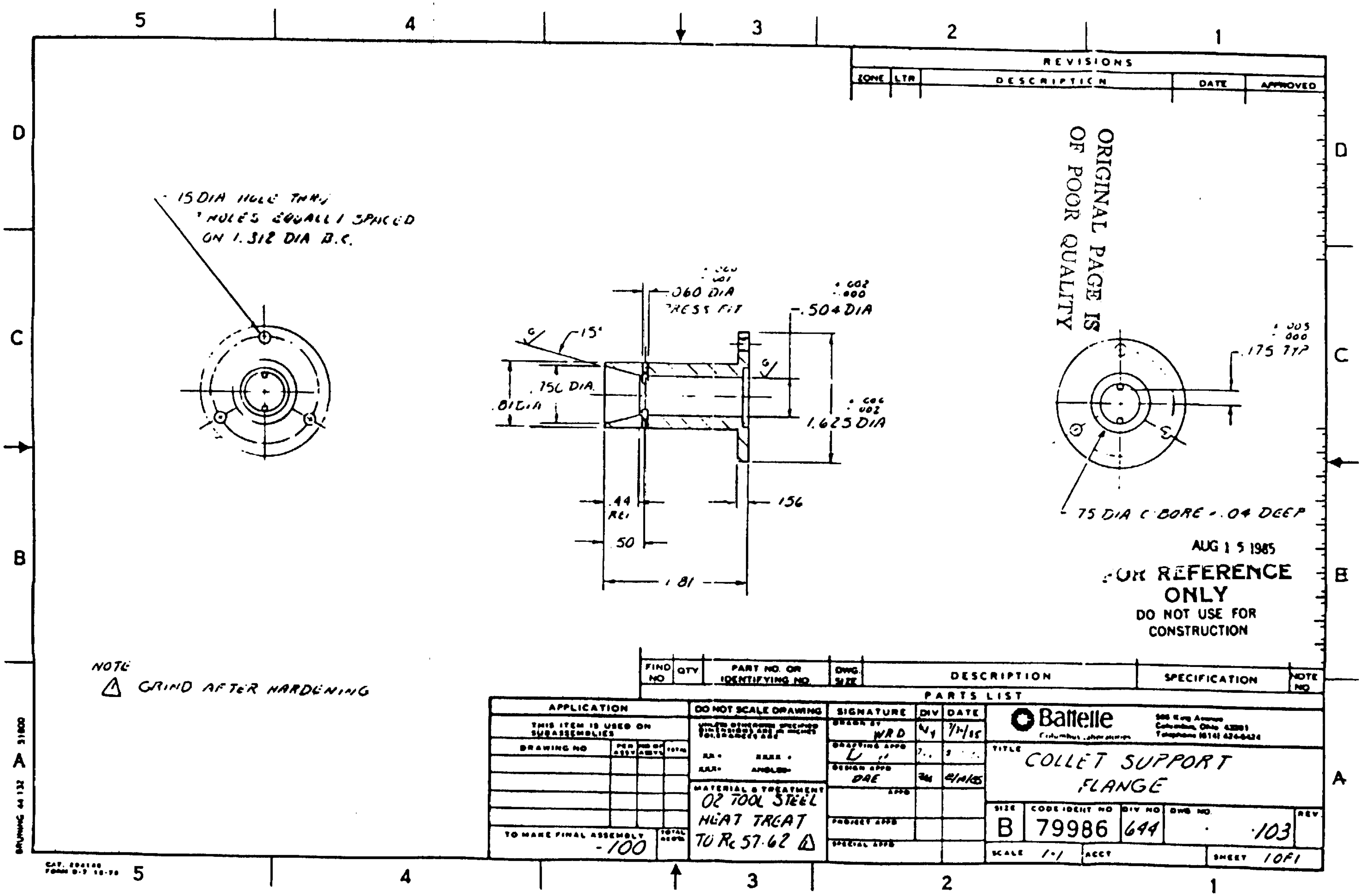
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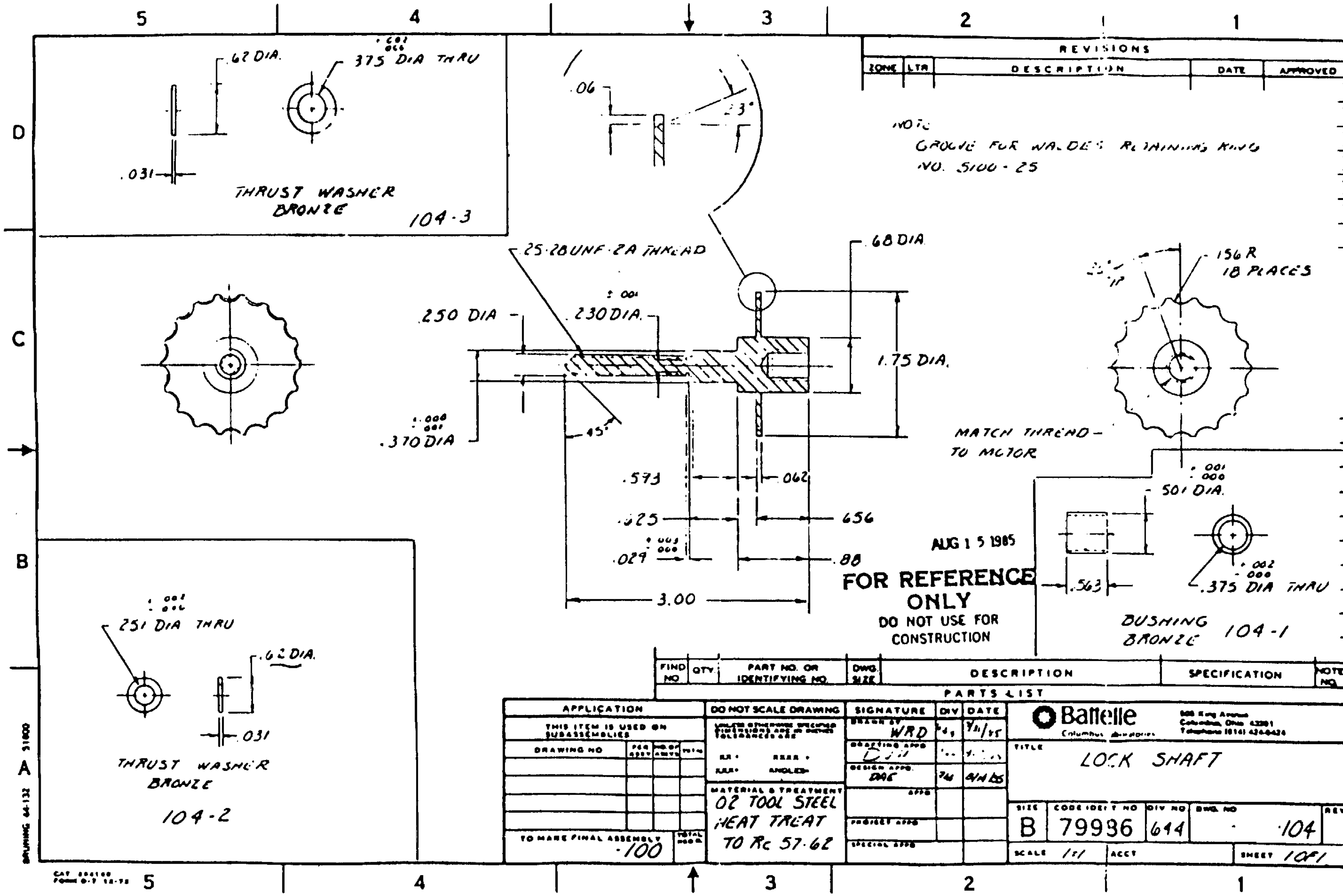
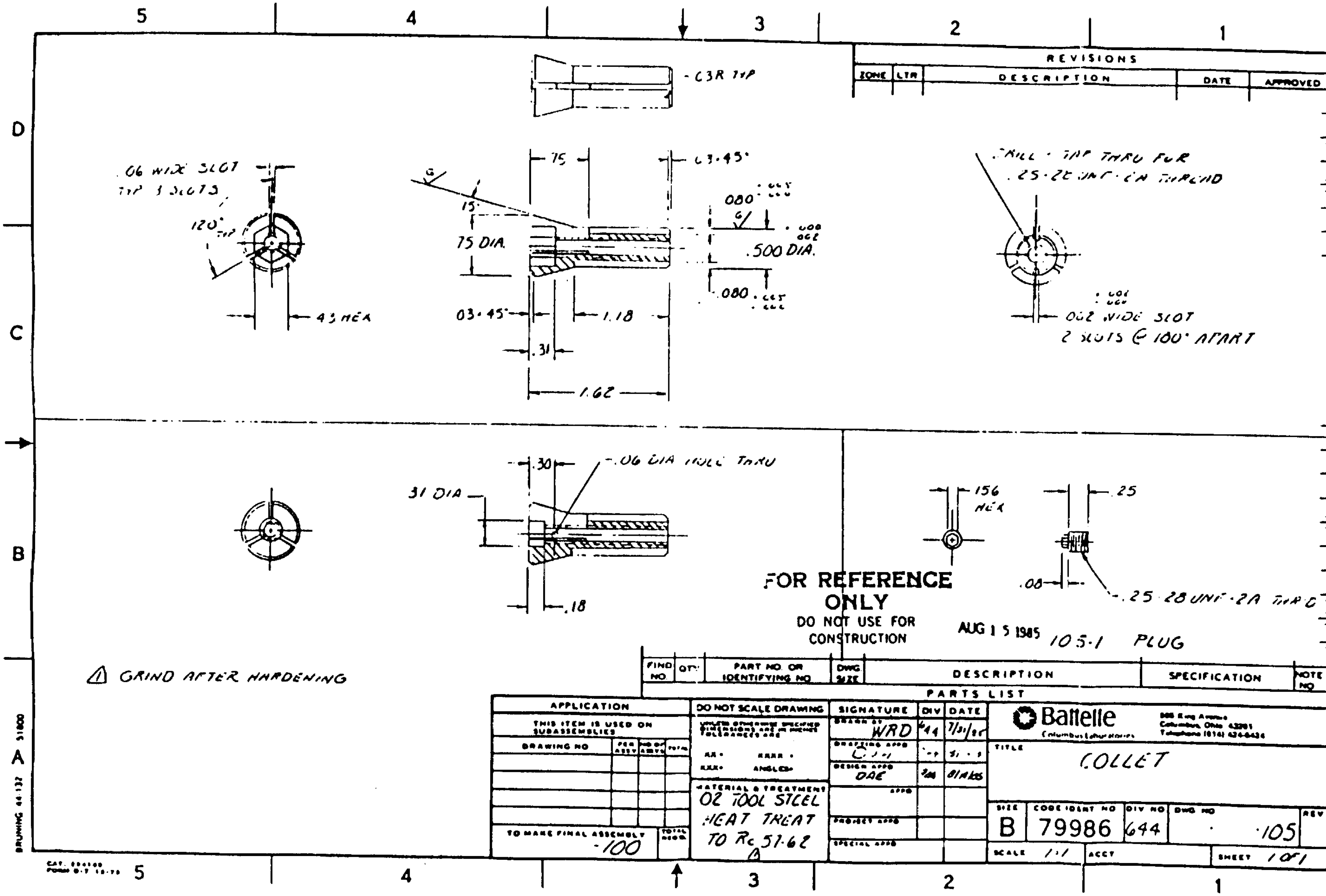
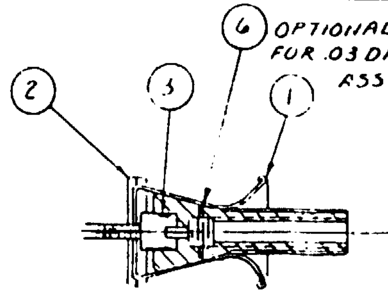



.06 WIDE SLOT
TYP 3 SLOTS
120° TYP
.43 HEX
C3R TYP
.75
C3 • 45°
15°
.75 DIA.
.080
.500 DIA.
.080
03 • 45°
1.18
.31
1.62
DRILL + TAP THRU FOR
.25-28 UNF-2B THREAD
.002 WIDE SLOT
2 SLOTS @ 180° APART
.30
.06 DIA HOLE THRU
.31 DIA
.18
.156 HEX
.25
.08
.25-28 UNF-2A THRD
FOR REFERENCE ONLY
DO NOT USE FOR CONSTRUCTION
AUG 1 5 1985
105-1 PLUG
GRIND AFTER HARDENING
REVISIONS
ZONE
LTR
DESCRIPTION
DATE
APPROVED
FIND NO
QTY
PART NO. OR IDENTIFYING NO
DWG SIZE
DESCRIPTION
SPECIFICATION
NOTE NO
PARTS LIST
APPLICATION
THIS ITEM IS USED ON SUBASSEMBLIES
DRAWING NO
TO MAKE FINAL ASSEMBLY
-100
DO NOT SCALE DRAWING
MATERIAL & TREATMENT
02 TOOL STEEL
HEAT TREAT
TO Rc 57-62
SIGNATURE
DIV
DATE
WRD
DAE
Battelle
Columbus Laboratories
TITLE
COLLET
SIZE
B
CODE IDENT NO
79986
DIV NO
644
DWG NO
105
REV
SCALE
1/1
SHEET
1 OF 1
BRUNING 44-132 51800



HOLDER FOR #10 COLLET

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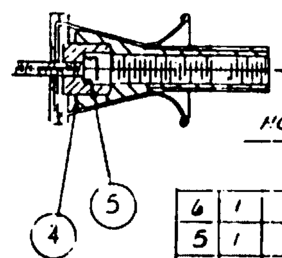
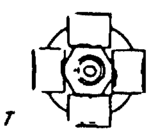


HOLDER FOR 7/16 HEX COLLET



AUG 15 1985

...EFERENCE ONLY
DO NOT USE FOR CONSTRUCTION

FIND NO.	QTY	PART NO. OR IDENTIFYING NO.	DWG. SIZE	DESCRIPTION	SPECIFICATION	NOTE NO.
6	1	105-1	B	PLUG		
5	1	#5-40UNC	-	SOCKET HEAD SCREW		
4	1	107-4	B	CENTER (7/16 HEX COLLET)		
3	1	107-3	B	CENTER (#10 COLLET)		
2	1	107-2	B	BASE		
1	2	107-1	B	SPRING CLIP		

PARTS LIST

REVISIONS: ZONE | LTR | DESCRIPTION | DATE | APPROVED

APPLICATION — THIS ITEM IS USED ON SUBASSEMBLIES — DRAWING NO — TO MAKE FINAL ASSEMBLY 107

DO NOT SCALE DRAWING — MATERIAL & TREATMENT

SIGNATURE / DIV. / DATE: DRAWN BY WRD 7/1/85; DRAFTING APPD. D... ; DESIGN APPD. DAE 8/14/85; PROJECT APPD; SPECIAL APPD

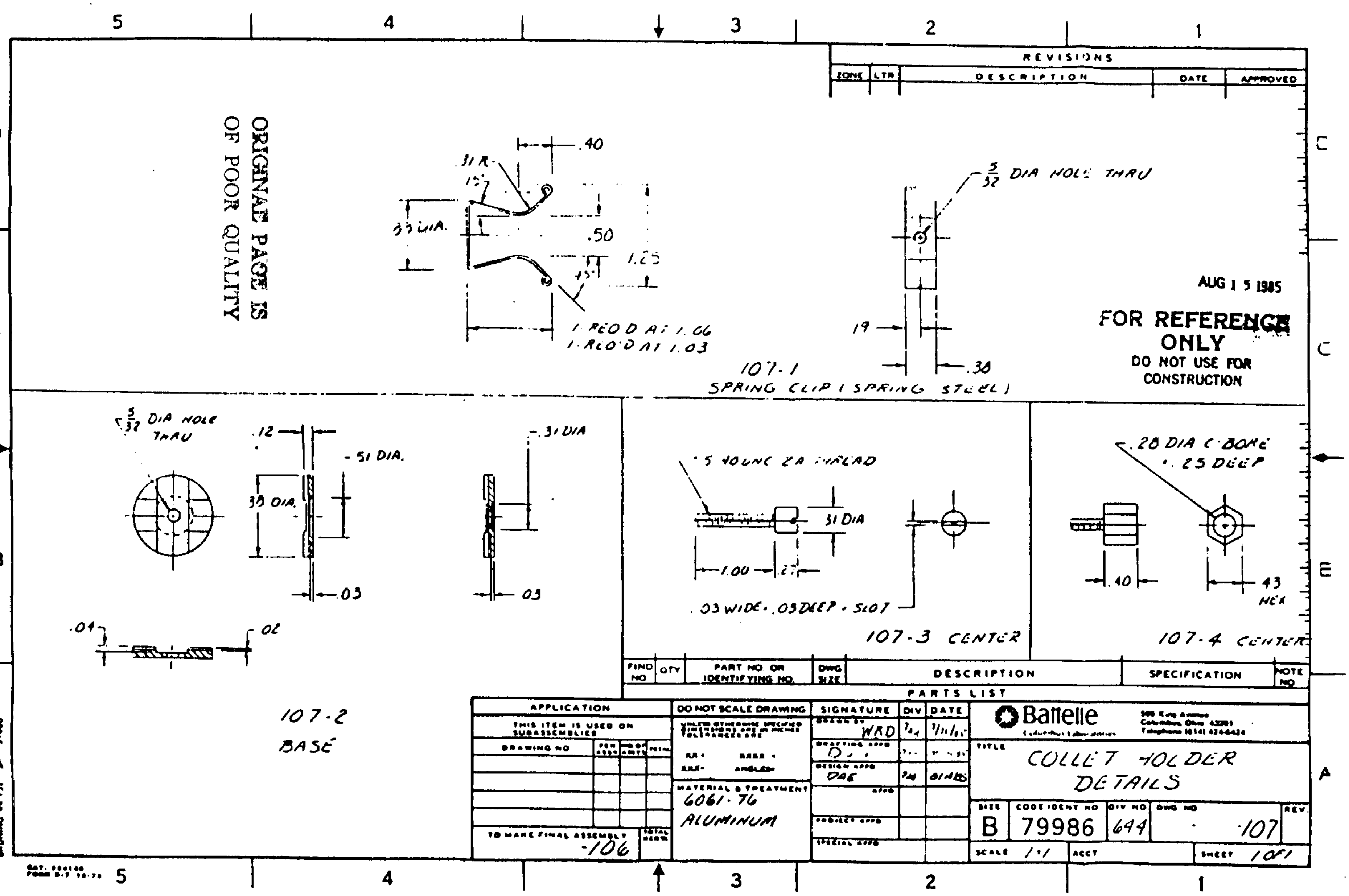
Battelle Columbus Laboratories, 505 King Avenue, Columbus, Ohio 43201, Telephone (614) 424-6424

TITLE: COLLET HOLDER

SIZE B | CODE IDENT NO 79986 | DIV NO 644 | DWG. NO. ·106 | REV

SCALE 1/1 | ACCT | SHEET 1 OF 1

DRAWING 44 132 51800



REVISIONS
ZONE
LTR
DESCRIPTION
DATE
APPROVED
ORIGINAL PAGE IS
OF POOR QUALITY
.40
.31 R.
15°
.33 DIA.
.50
1.25
45°
1 REQ'D AT 1.06
1 REQ'D AT 1.03
5/32 DIA HOLE THRU
19
.38
107-1
SPRING CLIP (SPRING STEEL)
AUG 1 5 1985
FOR REFERENCE ONLY
DO NOT USE FOR CONSTRUCTION
5/32 DIA HOLE THRU
.12
.51 DIA.
.33 DIA.
.03
.31 DIA
.03
.04
.02
107-2
BASE
5 40UNC 2A THREAD
.31 DIA
1.00
.27
.03 WIDE, .03 DEEP, SLOT
107-3 CENTER
.28 DIA C'BORE
.25 DEEP
.40
.43
HEX
107-4 CENTER
FIND NO
QTY
PART NO OR IDENTIFYING NO.
DWG SIZE
DESCRIPTION
SPECIFICATION
NOTE NO
PARTS LIST
APPLICATION
THIS ITEM IS USED ON SUBASSEMBLIES
DRAWING NO
TO MAKE FINAL ASSEMBLY
-106
DO NOT SCALE DRAWING
MATERIAL & TREATMENT
6061-T6
ALUMINUM
SIGNATURE
DIV
DATE
DRAWN BY
WRD
DRAFTING APPD
DESIGN APPD
DAE
PROJECT APPD
SPECIAL APPD
Battelle
TITLE
COLLET HOLDER
DETAILS
SIZE
B
CODE IDENT NO
79986
DIV NO
644
DWG NO
107
REV
SCALE
1/1
SHEET
1 OF 1

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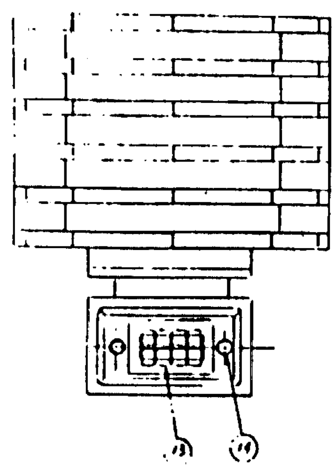
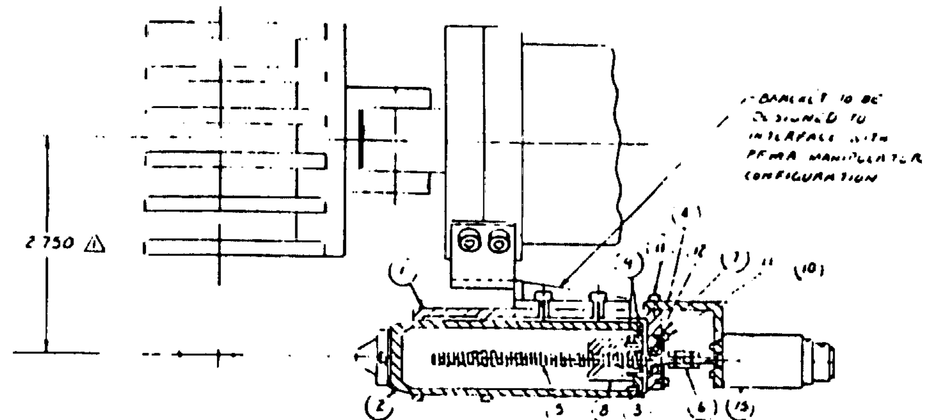




NOTES

1. △ IF 2.750 DIMENSION IS CHANGED DUE TO NEW PACKET DESIGN THIS DIMENSION MUST ALSO BE CHANGED ON DWGS. 300 - FLUID CONNECTOR 400 - ROTARY TOOL
2. MOUNT MICRO - SWITCH * 1SX1-T TO LIMIT BOTH IN AND OUT TRAVEL
3. MATCH DRILL AT ASS 1 TO PIN BOTH MOTOR AND SHAFT TO COUPLING

FIND NO.	QTY.	PART NO. OR IDENTIFYING NO.	DWG. SIZE	DESCRIPTION	SPECIFICATION	NOTE NO.
15	1	[illegible]	-	GEAR MOTOR	MICRO MO	
14	2	*4 40UNC	-	SOC HEAD BOLT - 3/8 LG		
13	1	26 4100 8P	-	PLUG	AMPHENOL	
12	1	R-2	-	BALL BEARING	NEW DEPART	
11	4	*5 40UNC	-	SOC HEAD BOLT - 3/8 LG		
10	4	*2 56UNC	-	SOC HEAD BOLT - 3/8 LG		
9	6	*2 56UNC	-	FLAT HEAD SCREW - .25 LG		
8	1	207	B	LEAD SCREW NUT MODIF		
7	1	206	B	BEARING RETAINER		
6	1	205-1	D	COUPLING		
5	1	205	B	SHAFT		
4	1	204	B	MOTOR MOUNT		
3	1	203	B	END PLATE		
2	1	202	B	CONNECTOR PROBE		
1	1	201	B	GUIDE HOUSING		

PARTS LIST

AUG 1 9 1985

APPLICATION: THIS ITEM IS USED ON SUBASSEMBLIES

DO NOT SCALE DRAWING — UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES. TOLERANCES ARE:

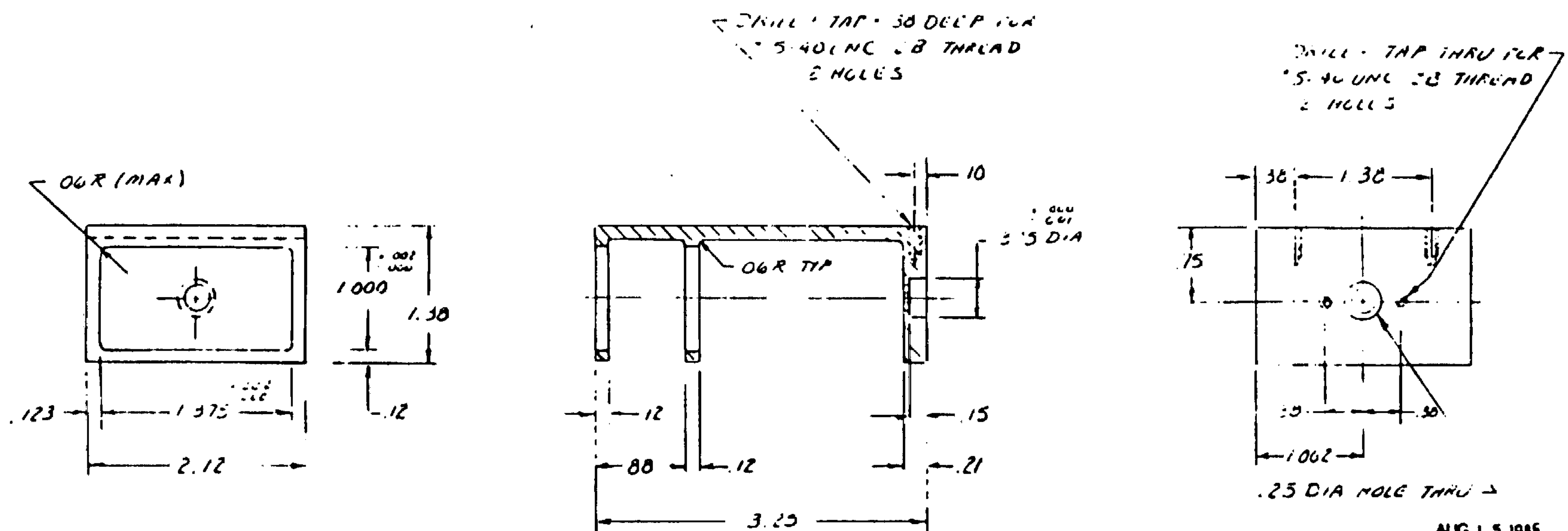
SIGNATURE	DIV	DATE
DRAWN BY WRD		8 7 85
CHECKED		
DESIGN ENG. PAC		

Battelle

TITLE: STANDARD ELECTRICAL INTERFACE

SIZE	CODE IDENT NO.	DIV. NO.	DWG. NO.	REV
C	79986	744	- .200	

SCALE 1:1 — G-0560 — SHEET 1 OF 1



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REFERENCE ONLY
DO NOT USE FOR CONSTRUCTION

ORIGINAL PAGE IS OF POOR QUALITY

REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED

FIND NO	QTY	PART NO. OR IDENTIFYING NO	DWG SIZE	DESCRIPTION	SPECIFICATION	NOTE NO

PARTS LIST

APPLICATION: THIS ITEM IS USED ON SUBASSEMBLIES — DRAWING NO / PER ASSY / NO OF ASSYS / TOTAL

TO MAKE FINAL ASSEMBLY 200 — TOTAL REQD 1

DO NOT SCALE DRAWING

MATERIAL & TREATMENT: 6061-T6 ALUMINUM

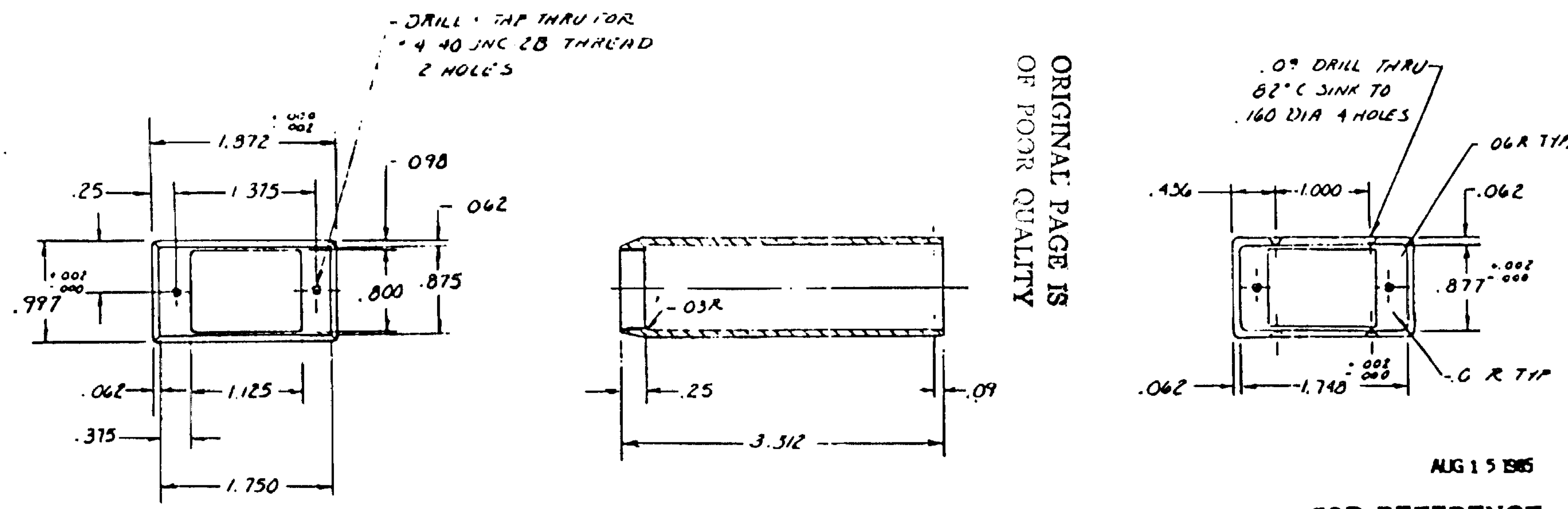
SIGNATURE	DIV	DATE
DRAWN BY WRD		7/11/85
DRAFTING APPD		
DESIGN APPD LWS		7/11/85

Battelle

TITLE: GUIDE HOUSING

SIZE	CODE IDENT. NO	DIV NO	DWG NO	REV
B	79986	647	.201	

SCALE 1:1 — SHEET 1 OF 1



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AUG 1 5 1985

FOR REFERENCE ONLY
DO NOT USE FOR CONSTRUCTION

NOTE:
1. BREAK ALL SHARP CORNERS & EDGES .01 R MIN
2. FAO ✓
3. HARD COAT ANODIZE EXTERIOR SURFACE WITH NIMET IND. NITUFF PROCESS
4. DIMENSIONS ARE PRIOR TO ANODIZING

PARTS LIST

FIND NO	QTY	PART NO. OR IDENTIFYING NO	DWG SIZE	DESCRIPTION	SPECIFICATION	NOTE NO.

APPLICATION

THIS ITEM IS USED ON SUBASSEMBLIES

DRAWING NO	PER ASSY	NO. OF ASSY	TOTAL

TO MAKE FINAL ASSEMBLY: 200 | TOTAL: 1

DO NOT SCALE DRAWING

MATERIAL & TREATMENT: 6061-T6 ALUMINUM

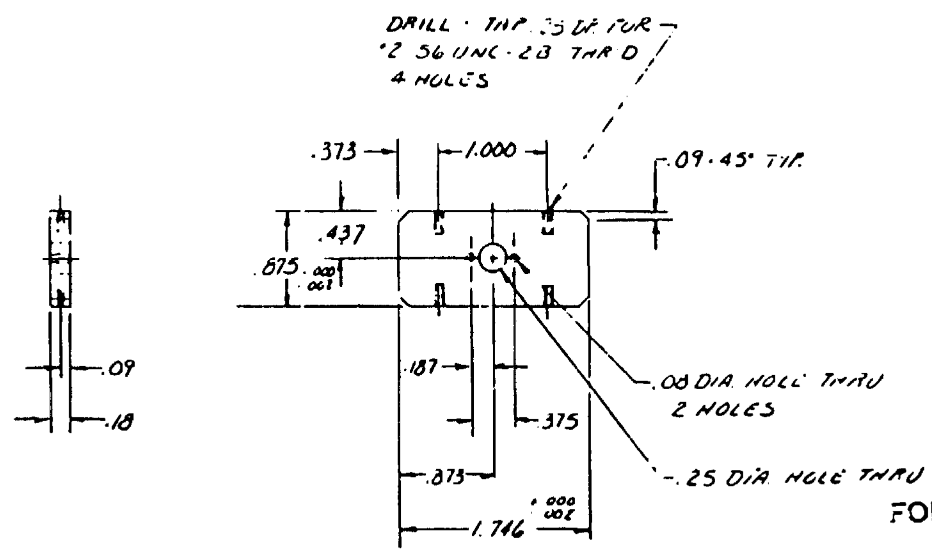
SIGNATURE	DIV	DATE
DRAWN BY: WRD		
DRAFTING APPD: D. J.		
DESIGN APPD: DWE		
APPD		
PROJECT APPD		
SPECIAL APPD		

Battelle
Columbus Laboratories

TITLE: CONNECTOR PROBE

SIZE	CODE IDENT. NO	DIV NO	DWG. NO.	REV
B	79986	644	202	

SCALE: 1/1 | ACCT | SHEET: 1 OF 1



AUG 15 1985

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REVISIONS

ZONE	LTR	DESCRIPTION	DATE	APPROVED

PARTS LIST

FIND NO	QTY	PART NO OR IDENTIFYING NO	DWG SIZE	DESCRIPTION	SPECIFICATION	NOTE NO

APPLICATION: THIS ITEM IS USED ON SUBASSEMBLIES — DRAWING NO — TO MAKE FINAL ASSEMBLY 200 — TOTAL REQD 1

DO NOT SCALE DRAWING

MATERIAL & TREATMENT: 6061-T6 ALUMINUM

SIGNATURE: DRAWN BY WRD — DATE 7/15/85
DESIGN APPD DAE — 7/16/85

Battelle Columbus Laboratories

TITLE: END PLATE

SIZE B — CODE IDENT NO 79986 — DIV NO 644 — DWG NO 203

SCALE 1/1 — SHEET 1 OF 1

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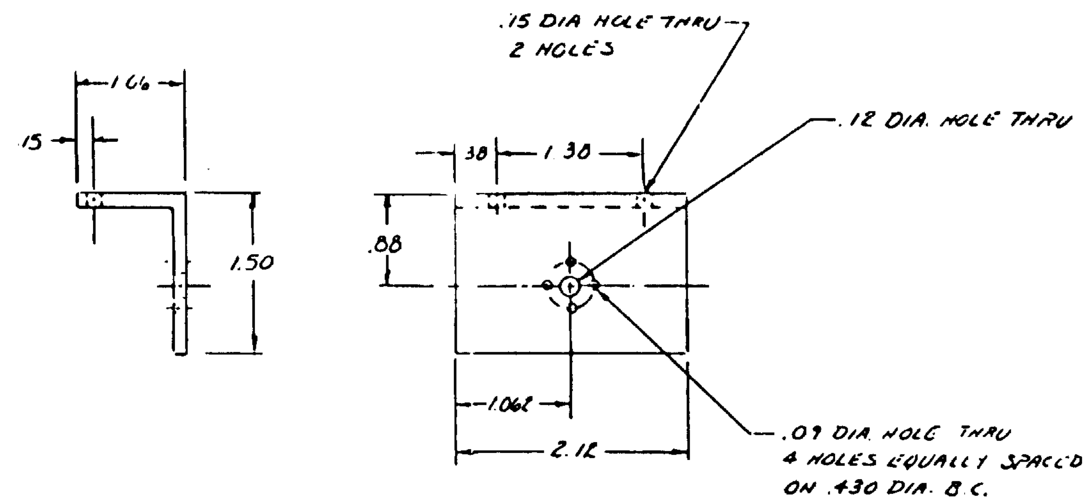

AUG 1 5 1985

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DO NOT USE FOR CONSTRUCTION

REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED

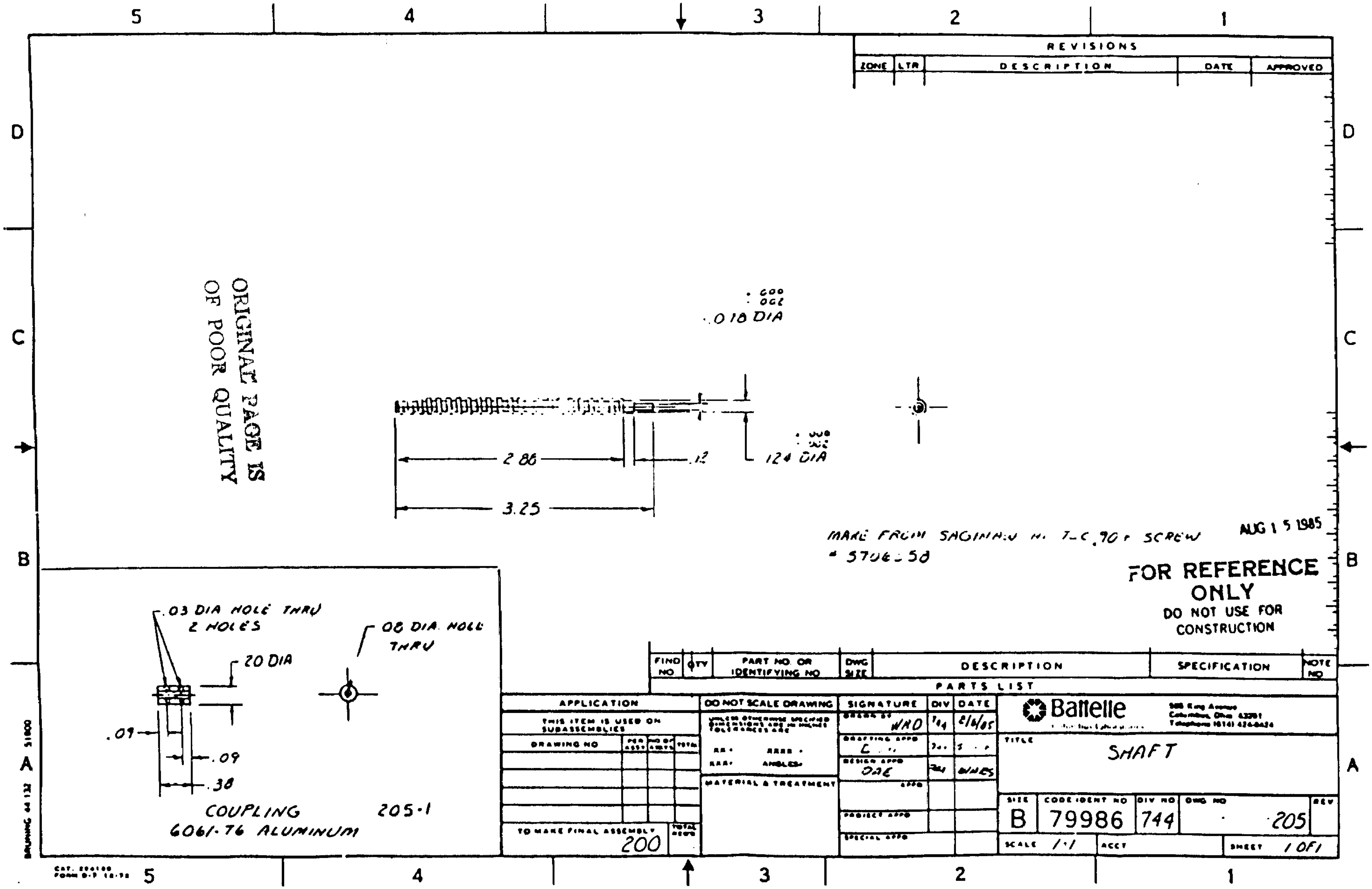
PARTS LIST

FIND NO	QTY	PART NO OR IDENTIFYING NO.	DWG. SIZE	DESCRIPTION	SPECIFICATION	NOTE NO

APPLICATION	THIS ITEM IS USED ON SUBASSEMBLIES
TO MAKE FINAL ASSEMBLY	200
DO NOT SCALE DRAWING	
MATERIAL & TREATMENT	1.00 · 1.50 · .12 6061-T6 ALUM. ANGLE
DRAWN BY	WAD
DRAFTING APPR.	DJ
DESIGN APPR.	DWE

Battelle
Columbus Laboratories

TITLE	MOTOR MOUNT
SIZE	B
CODE IDENT. NO	79986
DIV NO	644
DWG. NO.	204
SCALE	1:1
SHEET	1 OF 1



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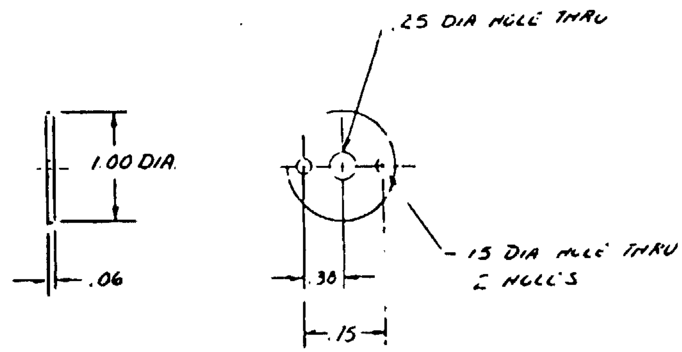

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.UR REFERENCE ONLY
DO NOT USE FOR CONSTRUCTION

REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED

PARTS LIST

FIND NO	QTY	PART NO OR IDENTIFYING NO	DWG SIZE	DESCRIPTION	SPECIFICATION	NOTE NO

APPLICATION			
THIS ITEM IS USED ON SUBASSEMBLIES			
DRAWING NO	PER ASSY	NO OF ASSYS	TOTAL
TO MAKE FINAL ASSEMBLY: 200			TOTAL REQD: 1

DO NOT SCALE DRAWING

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ARE

MATERIAL & TREATMENT: 6061-T6 ALUMINUM

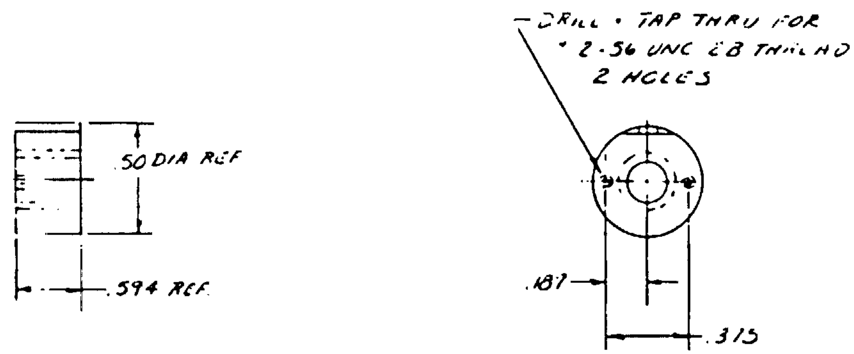
SIGNATURE	DIV	DATE
DRAWN BY: WRD		
DRAFTING APPD:		
DESIGN APPD: DAE		8/…
APPD		
PROJECT APPD		
SPECIAL APPD		

Battelle
Columbus Laboratories
505 King Avenue
Columbus, Ohio 43201
Telephone (614) 424-6424

TITLE: BEARING RETAINER

SIZE	CODE IDENT NO	DIV NO	DWG NO	REV
B	79986	694	206	

SCALE 1/1 ACCT SHEET 1 OF 1



AUG 1 5 1985

FOR REFERENCE ONLY
DO NOT USE FOR CONSTRUCTION

REVISIONS

ZONE	LTR	DESCRIPTION	DATE	APPROVED

PARTS LIST

FIND NO	QTY	PART NO. OR IDENTIFYING NO	DWG SIZE	DESCRIPTION	SPECIFICATION	NOTE NO

APPLICATION: THIS ITEM IS USED ON SUBASSEMBLIES — DRAWING NO — TO MAKE FINAL ASSEMBLY 200 — TOTAL 1

DO NOT SCALE DRAWING

MATERIAL & TREATMENT: MAKE FROM SAGINAW NUT # 5709729

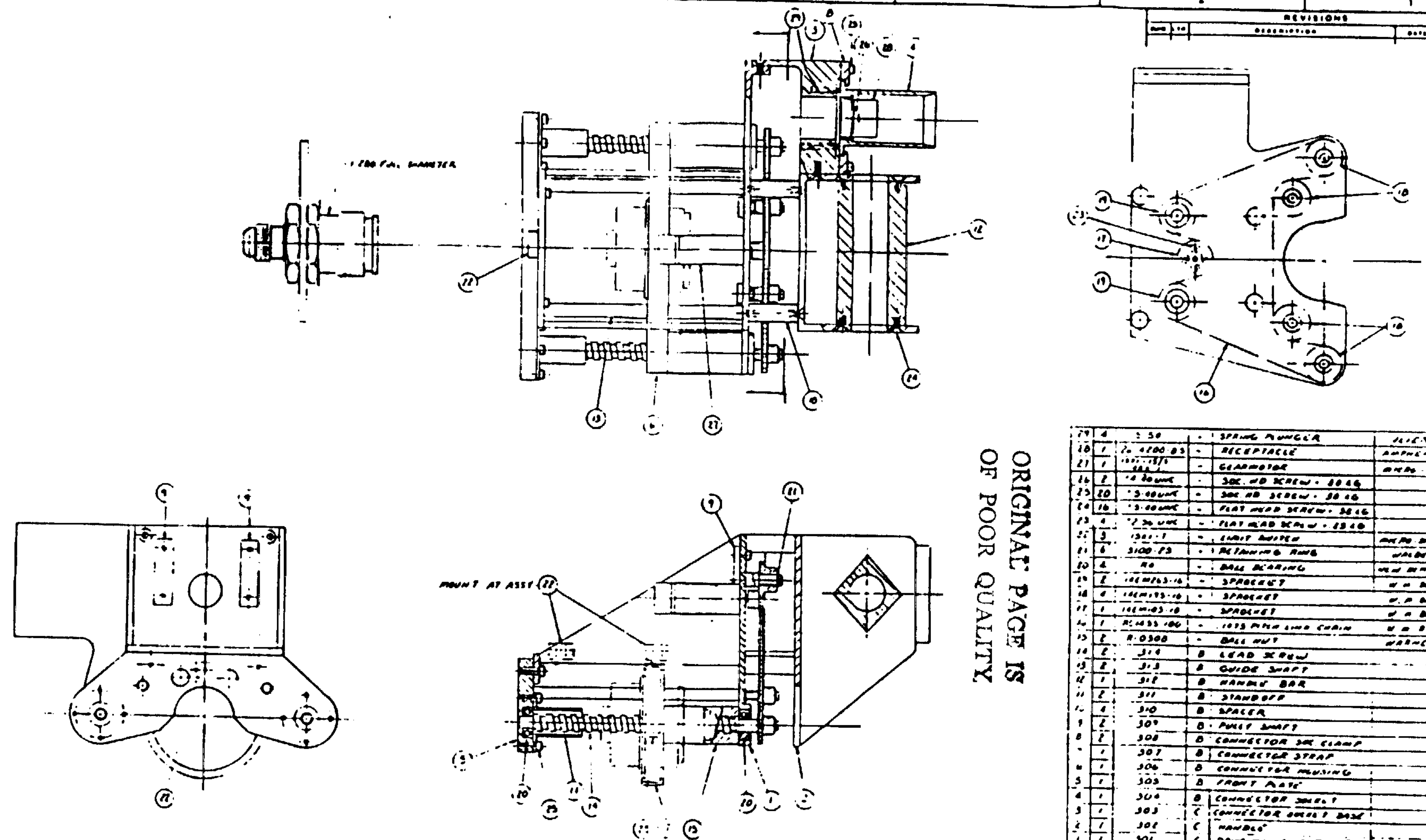
SIGNATURE	DIV	DATE
DRAWN BY WRD		7/15/85
DRAFTING APPD D		
DESIGN APPD VAE		9/4/85

Battelle

TITLE: LEAD SCREW NUT MODIF.

SIZE	CODE IDENT NO	DIV NO	DWG NO	REV
B	79986	644	207	

SCALE 1/1 — SHEET 1 OF 1



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OF POOR QUALITY

FIND NO	QTY	PART NO OR IDENTIFYING NO	DWG SIZE	DESCRIPTION	SPECIFICATION	NOTE NO
29	4	3 50	-	SPRING PLUNGER	[illegible]	
28	1	[illegible] 4100 83	-	RECEPTACLE	AMPHENOL	
27	1	[illegible]	-	GEARMOTOR	[illegible]	
26	2	[illegible]	-	SOC. HD SCREW - 18-8 SS		
25	20	[illegible]	-	SOC HD SCREW - 18-8 SS		
24	16	[illegible]	-	FLAT HEAD SCREW - 18-8 SS		
23	4	[illegible]	-	FLAT HEAD SCREW - 18-8 SS		
22	3	[illegible]	-	LIMIT SWITCH	MICRO SWITCH	
21	6	5100-75	-	RETAINING RING	WALDES	
20	4	R6	-	BALL BEARING	NEW DEPARTURE	
19	2	[illegible]	-	SPROCKET	W M BERG	
18	4	[illegible]	-	SPROCKET	W. M. BERG	
17	1	[illegible]	-	SPROCKET	W M BERG	
16	1	[illegible]	-	.1875 PITCH LINK CHAIN	W M BERG	
15	2	R-0308	-	BALL NUT	WARNER	
14	2	314	B	LEAD SCREW		
13	2	313	B	GUIDE SHAFT		
12	1	312	B	HANDLE BAR		
11	2	311	B	STANDOFF		
10	4	310	B	SPACER		
9	2	309	B	PULLEY SHAFT		
8	2	308	B	CONNECTOR SOCK CLAMP		
7	1	307	B	CONNECTOR STRAP		
6	1	306	B	CONNECTOR HOUSING		
5	1	305	B	FRONT PLATE		
4	1	304	B	CONNECTOR SOCKET		
3	1	303	C	CONNECTOR SOCKET BASE		
2	1	302	C	HANDLE		
1	1	301	C	DRIVE MOUNTING PLATE		

PARTS LIST

DO NOT SCALE DRAWING

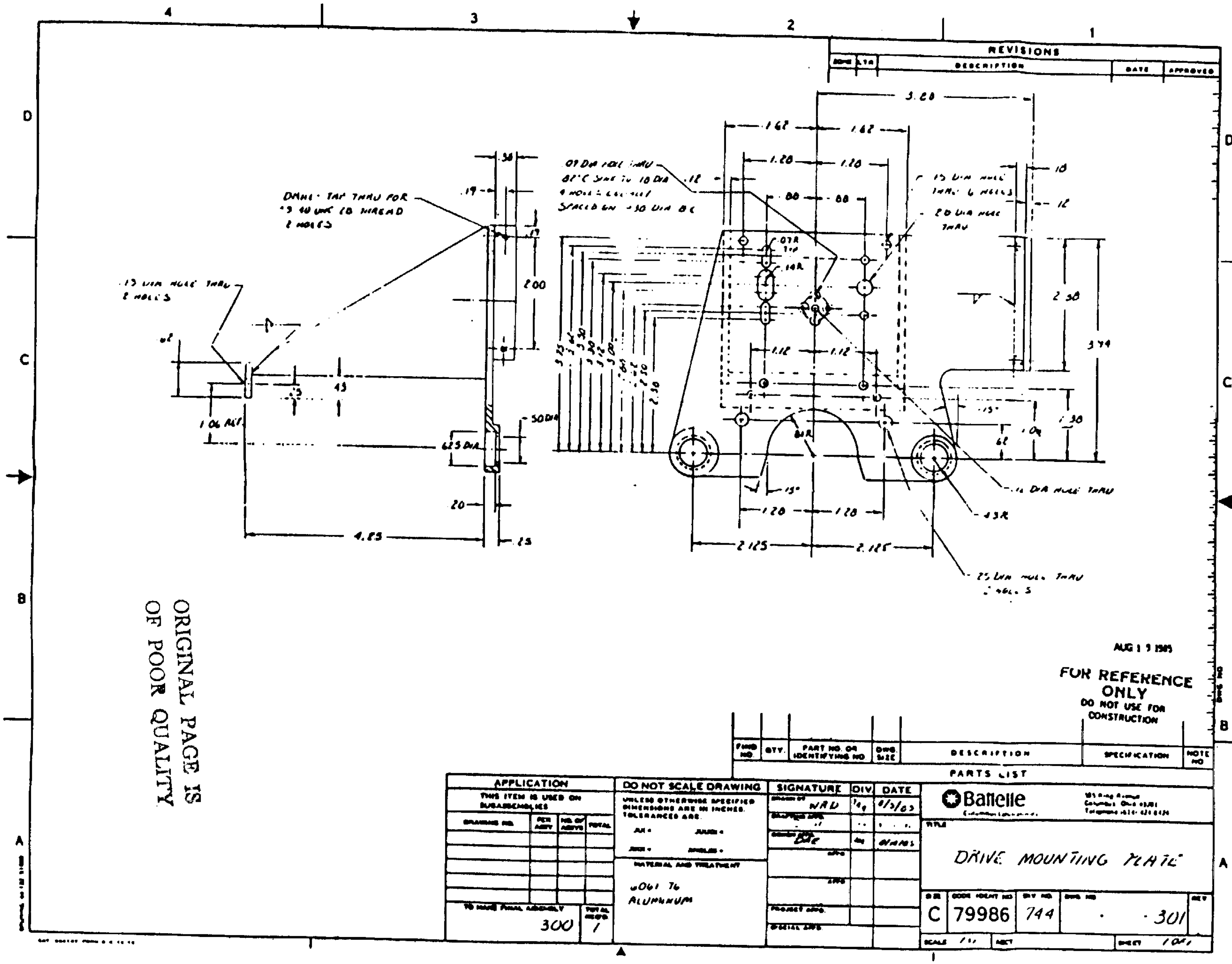
SIGNATURE	DIV	DATE
NRD		[illegible]/85

Battelle

FLUID COUPLING TOOL

D 79986 744 - 300

SCALE 1:1



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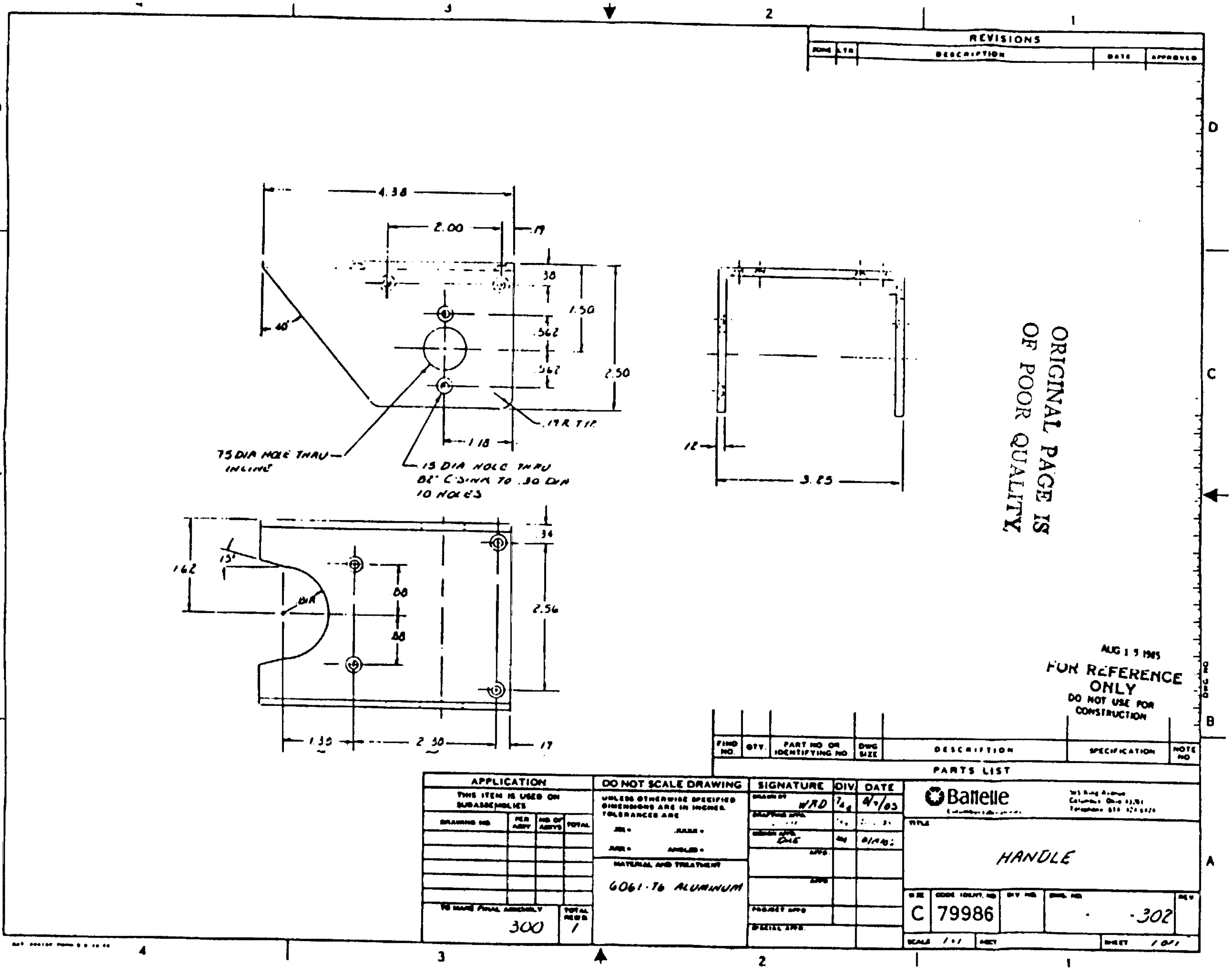
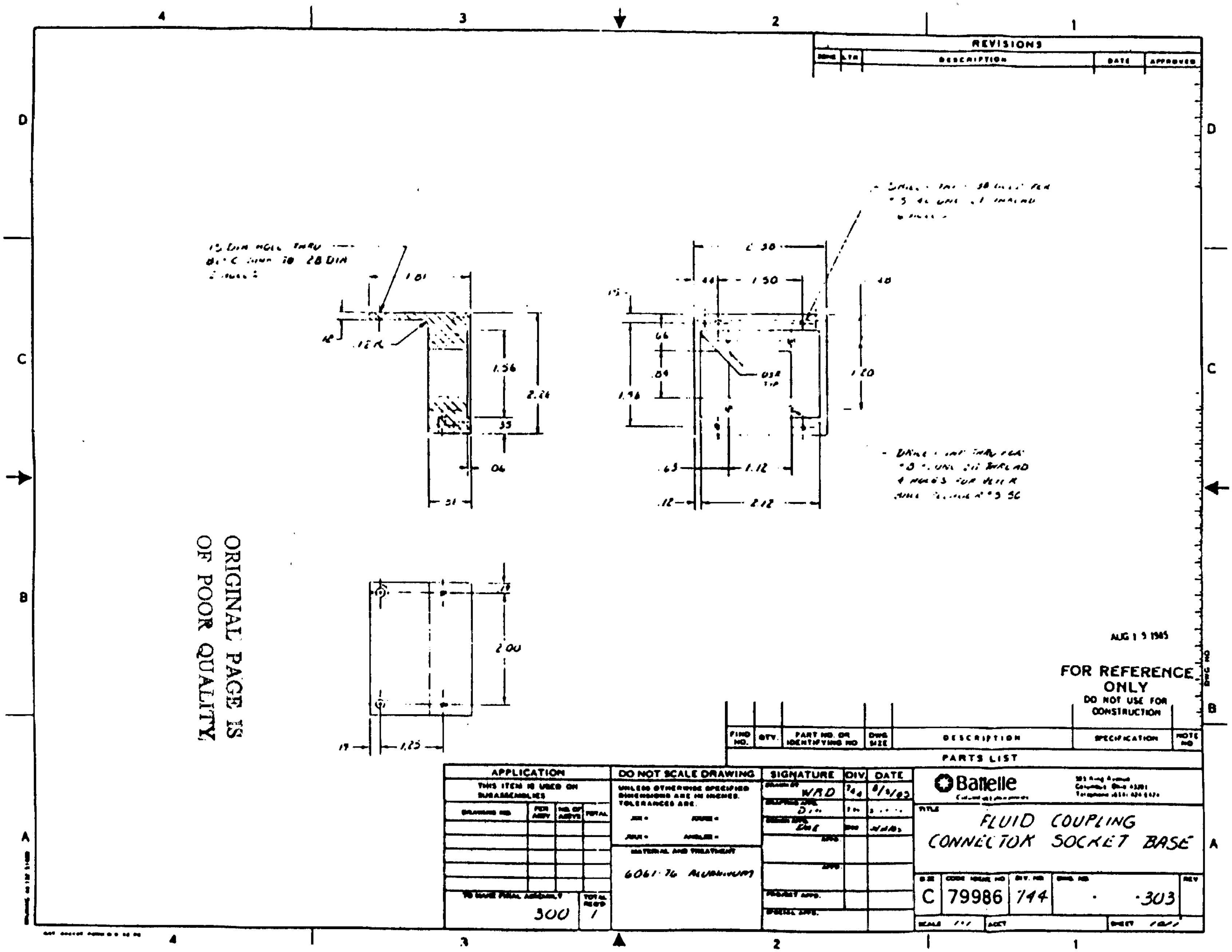
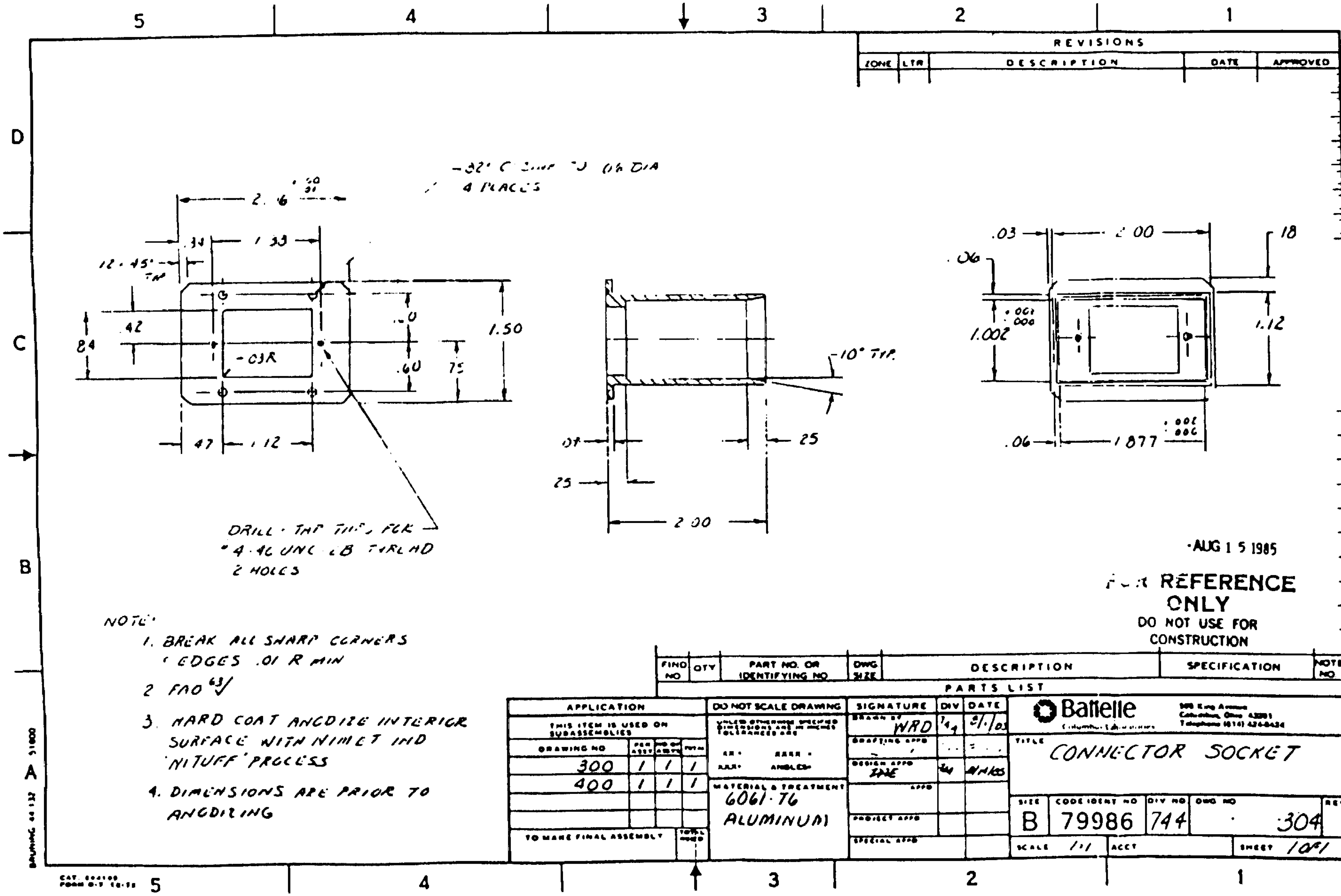
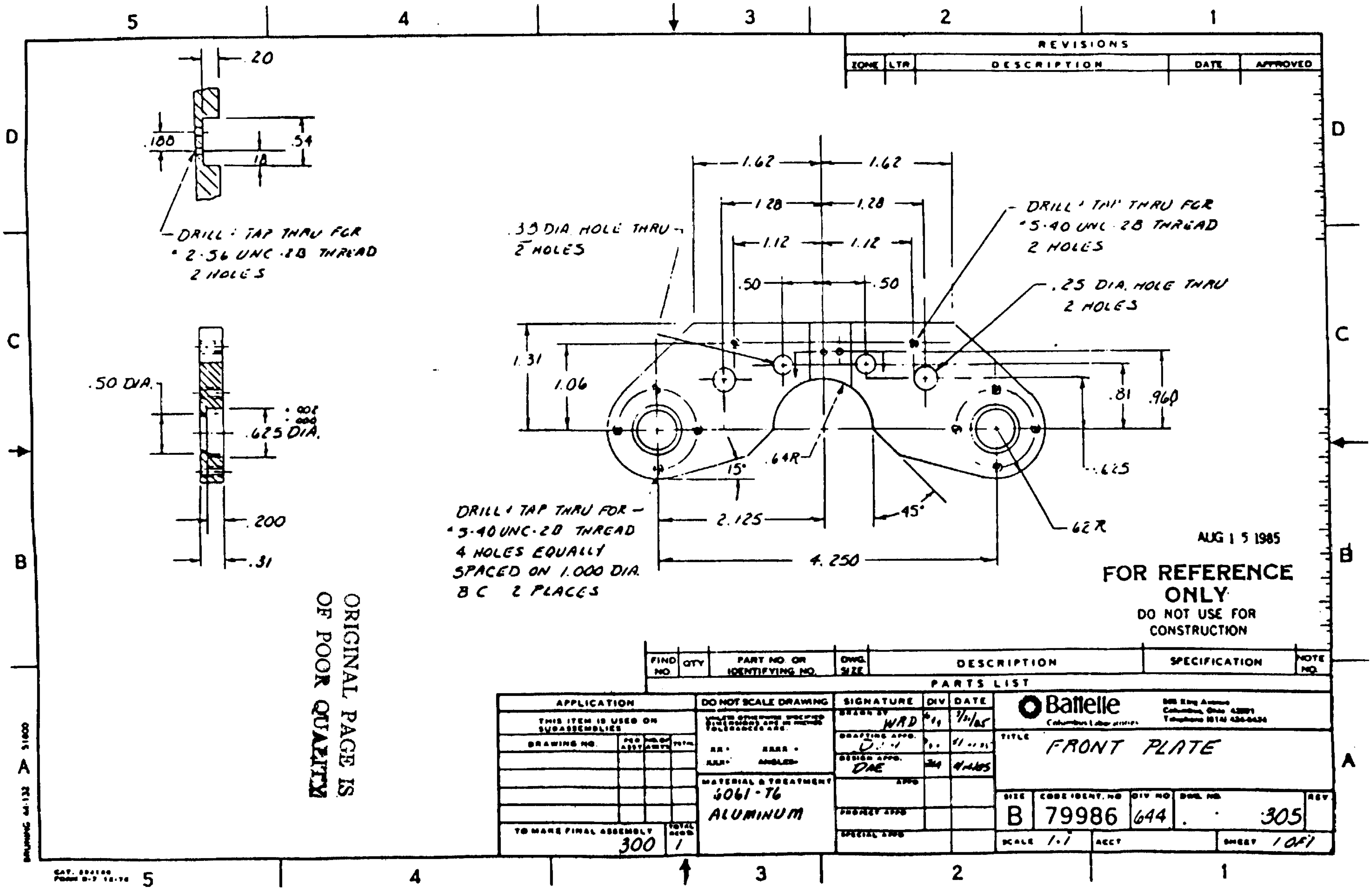


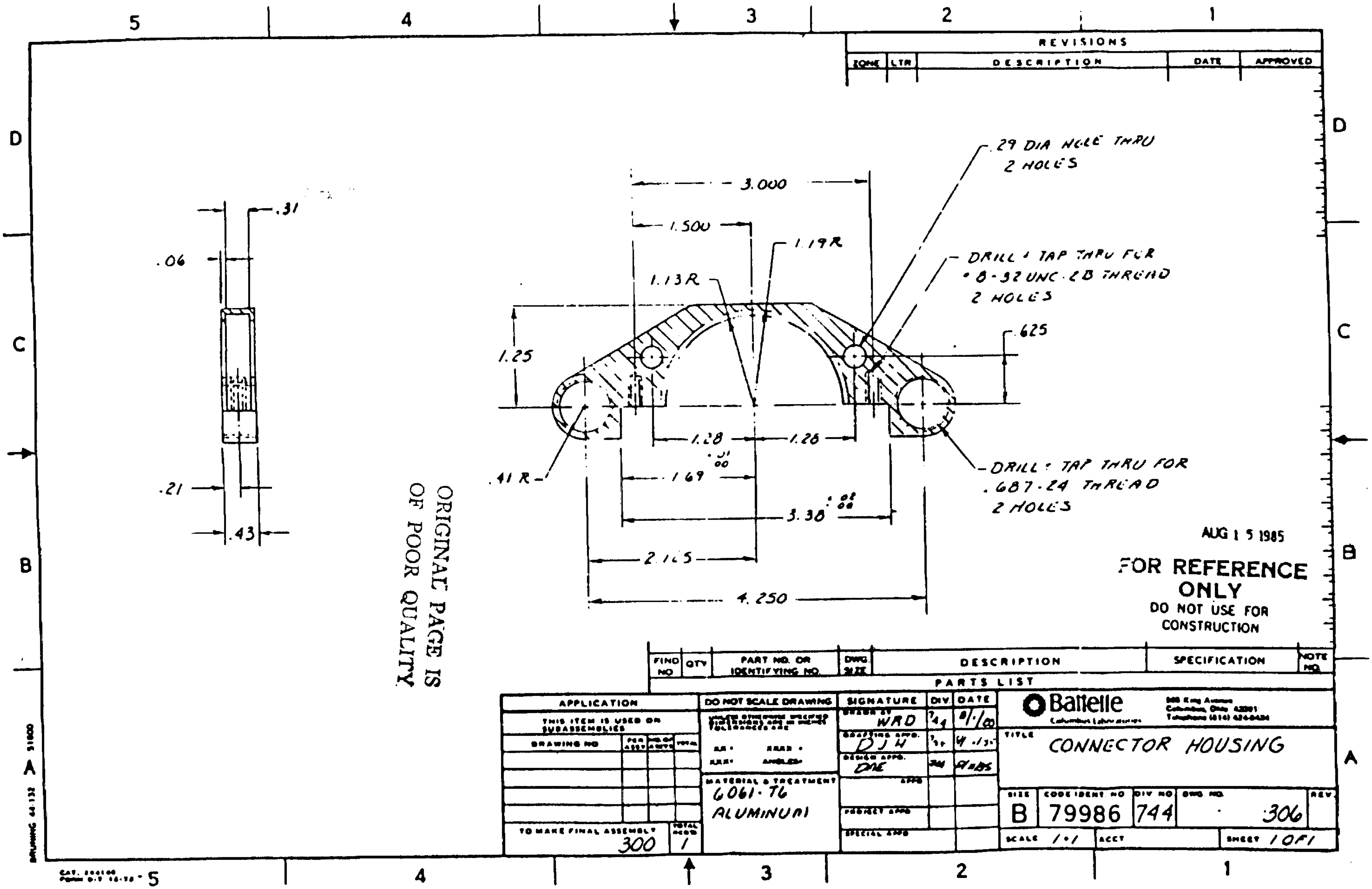
REVISIONS
ZONE
LTR
DESCRIPTION
DATE
APPROVED
4.38
2.00
.19
.38
1.50
.562
.562
2.50
40°
.19 R TYP
1.18
.75 DIA HOLE THRU INLINE
.15 DIA HOLE THRU 82° C'SINK TO .30 DIA 10 HOLES
.12
3.25
.34
1.62
15°
DIA
.88
.88
2.56
1.35
2.30
.17
ORIGINAL PAGE IS OF POOR QUALITY
AUG 1 5 1985
FOR REFERENCE ONLY
DO NOT USE FOR CONSTRUCTION
FIND NO.
QTY.
PART NO OR IDENTIFYING NO
DWG SIZE
DESCRIPTION
SPECIFICATION
NOTE NO
PARTS LIST
APPLICATION
THIS ITEM IS USED ON SUBASSEMBLIES
DRAWING NO
PER ASSY
NO OF ASSYS
TOTAL
300
TOTAL REQ'D
1
DO NOT SCALE DRAWING
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ARE
MATERIAL AND TREATMENT
6061-T6 ALUMINUM
SIGNATURE
DIV
DATE
WRD
4/4/85
Battelle
TITLE
HANDLE
SIZE
C
79986
-302
SCALE 1/1
SHEET 1 OF 1

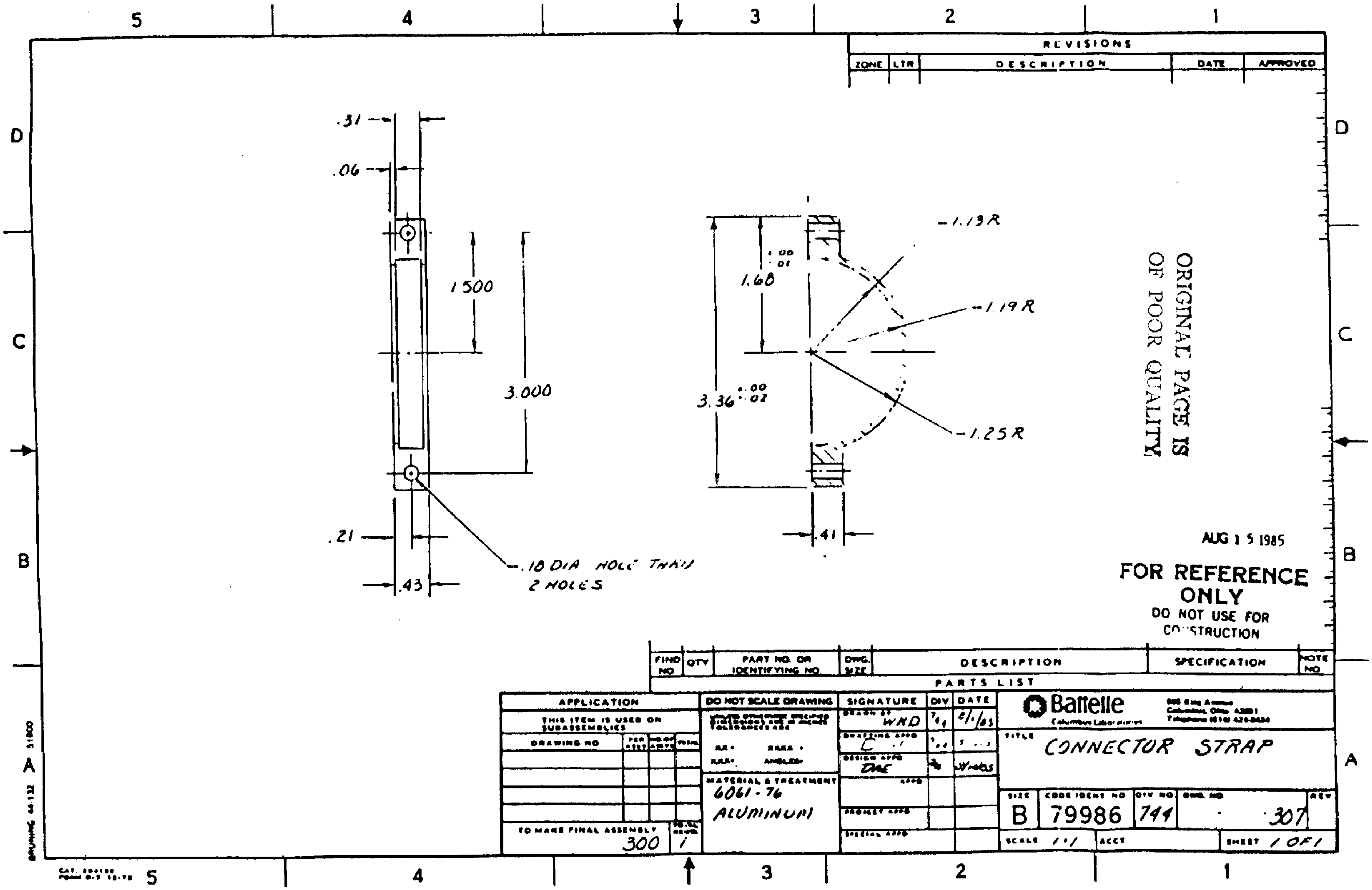

REVISIONS
DESCRIPTION
DATE
APPROVED
AUG 1 9 1985
FOR REFERENCE ONLY
DO NOT USE FOR CONSTRUCTION
FIND NO.
QTY.
PART NO. OR IDENTIFYING NO
DWG SIZE
DESCRIPTION
SPECIFICATION
NOTE NO
PARTS LIST
APPLICATION
THIS ITEM IS USED ON SUBASSEMBLIES
DRAWING NO.
TO MAKE FINAL ASSEMBLY
300
TOTAL REQD
1
DO NOT SCALE DRAWING
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES. TOLERANCES ARE:
MATERIAL AND TREATMENT
6061-T6 ALUMINUM
SIGNATURE
DIV
DATE
WRD
PROJECT APPD.
SPECIAL APPD.
Battelle
TITLE
FLUID COUPLING
CONNECTOR SOCKET BASE
SIZE
C
79986
744
303
SCALE
SHEET
1.81
1.56
2.26
.35
.06
.51
.12 R
2.30
1.50
.44
.66
.84
1.96
.63
1.12
.12
2.12
1.20
.48
2.00
1.25
.19


REVISIONS
ZONE
LTR
DESCRIPTION
DATE
APPROVED
4 PLACES
1.50
1.33
.42
.84
.60
.75
.47
1.12
-.03R
-10° TYP.
.25
2.00
.03
.06
18
1.12
1.002
.06
1.877
DRILL · TAP
2 HOLES
NOTE:
1. BREAK ALL SHARP CORNERS
EDGES .01 R MIN
3. HARD COAT ANODIZE INTERIOR
SURFACE WITH NIMET AND
'NITUFF' PROCESS
4. DIMENSIONS ARE PRIOR TO
ANODIZING
AUG 15 1985
REFERENCE
ONLY
DO NOT USE FOR
CONSTRUCTION
FIND NO
QTY
PART NO. OR IDENTIFYING NO
DWG SIZE
DESCRIPTION
SPECIFICATION
NOTE NO
PARTS LIST
APPLICATION
THIS ITEM IS USED ON SUBASSEMBLIES
DRAWING NO
300
400
TO MAKE FINAL ASSEMBLY
DO NOT SCALE DRAWING
MATERIAL & TREATMENT
6061-T6
ALUMINUM
SIGNATURE
DIV
DATE
WRD
Battelle
TITLE
CONNECTOR SOCKET
SIZE
B
CODE IDENT NO
79986
DIV NO
744
DWG NO
304
REV
SCALE 1/1
SHEET 1 OF 1



REVISIONS
ZONE
LTR
DESCRIPTION
DATE
APPROVED
.20
.188
.54
.18
DRILL : TAP THRU FOR
• 2-56 UNC-2B THREAD
2 HOLES
.50 DIA.
.625 DIA.
.200
.31
.33 DIA. HOLE THRU
2 HOLES
1.62
1.28
1.12
.50
DRILL & TAP THRU FOR
• 5-40 UNC-2B THREAD
2 HOLES
.25 DIA. HOLE THRU
2 HOLES
1.31
1.06
.81
.960
.625
15°
.64R
45°
2.125
4.250
.62R
DRILL & TAP THRU FOR
• 5-40 UNC-2B THREAD
4 HOLES EQUALLY
SPACED ON 1.000 DIA.
B C 2 PLACES
AUG 1 5 1985
FOR REFERENCE ONLY
DO NOT USE FOR CONSTRUCTION
FIND NO
QTY
PART NO. OR IDENTIFYING NO.
DWG. SIZE
DESCRIPTION
SPECIFICATION
NOTE NO.
PARTS LIST
APPLICATION
THIS ITEM IS USED ON SUBASSEMBLIES
DRAWING NO.
TO MAKE FINAL ASSEMBLY
300
TOTAL
1
DO NOT SCALE DRAWING
MATERIAL & TREATMENT
6061-T6
ALUMINUM
SIGNATURE
DIV
DATE
DRAWN BY
WRD
DRAFTING APPD.
DESIGN APPD.
DAE
PROJECT APPD
SPECIAL APPD
Battelle
Columbus Laboratories
TITLE
FRONT PLATE
SIZE
B
CODE IDENT. NO
79986
DIV NO
644
DWG. NO.
305
REV
SCALE 1:1
ACCT
SHEET 1 OF 1


REVISIONS
ZONE LTR DESCRIPTION DATE APPROVED
.29 DIA HOLE THRU 2 HOLES
DRILL & TAP THRU FOR 8-32 UNC-2B THREAD 2 HOLES
DRILL & TAP THRU FOR .687-24 THREAD 2 HOLES
3.000
1.500
1.19R
1.13R
.625
1.25
.41 R
1.28
1.26
1.69
3.38
2.125
4.250
.31
.06
.21
.43
AUG 1 5 1985
FOR REFERENCE ONLY
DO NOT USE FOR CONSTRUCTION
FIND NO
QTY
PART NO. OR IDENTIFYING NO.
DWG SIZE
DESCRIPTION
SPECIFICATION
NOTE NO.
PARTS LIST
APPLICATION
THIS ITEM IS USED ON SUBASSEMBLIES
DRAWING NO
TO MAKE FINAL ASSEMBLY 300
TOTAL REQ'D 1
DO NOT SCALE DRAWING
MATERIAL & TREATMENT
6061-T6 ALUMINUM
SIGNATURE
DIV
DATE
WRD
DJH
DAE
PROJECT APPD
SPECIAL APPD
Battelle
Columbus Laboratories
TITLE
CONNECTOR HOUSING
SIZE B
CODE IDENT NO 79986
DIV NO 744
DWG NO 306
REV
SCALE 1/1
ACCT
SHEET 1 OF 1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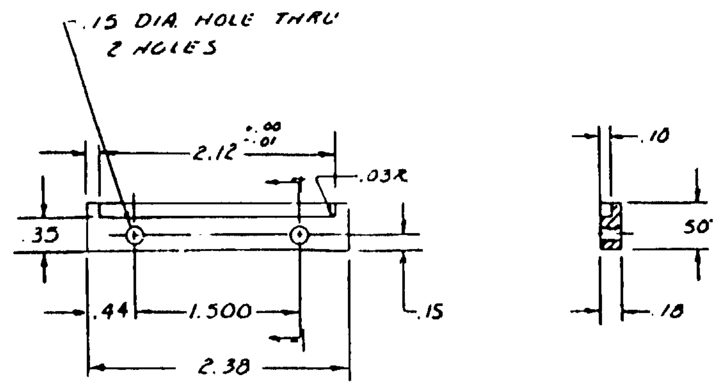
ZONE LTR DESCRIPTION DATE APPROVED
.31
.06
1.500
3.000
.21
.43
.10 DIA HOLE THRU
2 HOLES
1.68 +.00 -.01
3.36 +.00 -.02
-1.13R
-1.19R
-1.25R
.41
ORIGINAL PAGE IS
OF POOR QUALITY
AUG 1 5 1985
FOR REFERENCE ONLY
DO NOT USE FOR CONSTRUCTION
FIND NO QTY PART NO. OR IDENTIFYING NO. DWG. SIZE DESCRIPTION SPECIFICATION NOTE NO.
PARTS LIST
APPLICATION
THIS ITEM IS USED ON SUBASSEMBLIES
DRAWING NO
TO MAKE FINAL ASSEMBLY 300 1
DO NOT SCALE DRAWING
MATERIAL & TREATMENT
6061-T6
ALUMINUM
SIGNATURE DIV DATE
WHD
Battelle
Columbus Laboratories
TITLE CONNECTOR STRAP
SIZE B
CODE IDENT NO 79986
DIV NO 744
DWG NO 307
SCALE 1/1
SHEET 1 OF 1

C-2



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DO NOT USE FOR CONSTRUCTION

REVISIONS

ZONE	LTR	DESCRIPTION	DATE	APPROVED

PARTS LIST

FIND NO.	QTY.	PART NO. OR IDENTIFYING NO.	DWG. SIZE	DESCRIPTION	SPECIFICATION	NOTE NO.

APPLICATION

THIS ITEM IS USED ON SUBASSEMBLIES

DRAWING NO.	PER ASSY	NO. OF ASSYS	TOTAL
300	2	1	2
400	2	1	2

TO MAKE FINAL ASSEMBLY — TOTAL REQ'D

DO NOT SCALE DRAWING

MATERIAL & TREATMENT: 6061-T6 ALUMINUM

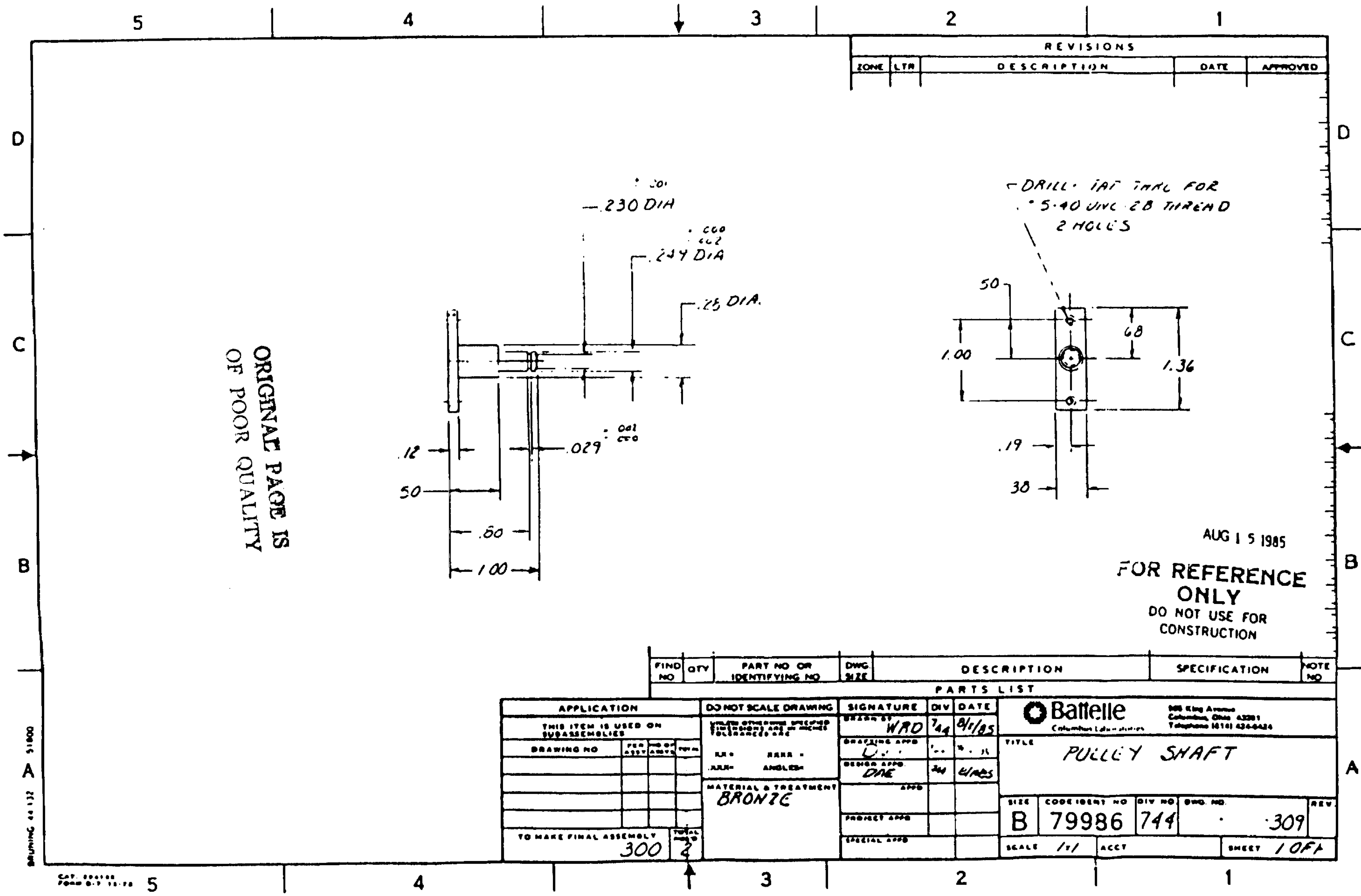
SIGNATURE	DIV.	DATE
DRAWN BY WRD	744	8/1/85
DRAFTING APPD. DJN		
DESIGN APPD. DAE	744	8/14/85

Battelle
Columbus Laboratories

TITLE: CONNECTOR SOCKET CLAMP

SIZE	CODE IDENT. NO.	DIV. NO.	DWG. NO.	REV
B	79986	744	308	

SCALE 1/1 — SHEET 1 OF 1


REVISIONS
ZONE
LTR
DESCRIPTION
DATE
APPROVED
DRILL · TAP THRU FOR
5-40 UNC 2B THREAD
2 HOLES
.50
1.00
.68
1.36
.19
.38
.230 DIA
.249 DIA
.25 DIA.
.12
.50
.029
.60
1.00
ORIGINAL PAGE IS
OF POOR QUALITY
AUG 1 5 1985
FOR REFERENCE
ONLY
DO NOT USE FOR
CONSTRUCTION
FIND NO
QTY
PART NO OR IDENTIFYING NO
DWG SIZE
DESCRIPTION
SPECIFICATION
NOTE NO
PARTS LIST
APPLICATION
THIS ITEM IS USED ON SUBASSEMBLIES
DRAWING NO
TO MAKE FINAL ASSEMBLY
300
2
DO NOT SCALE DRAWING
MATERIAL & TREATMENT
BRONZE
SIGNATURE
DIV
DATE
DRAWN BY
WRD
744
8/1/85
DESIGN APPD
DAE
PROJECT APPD
SPECIAL APPD
Battelle
Columbus Laboratories
TITLE
PULLEY SHAFT
SIZE
CODE IDENT NO
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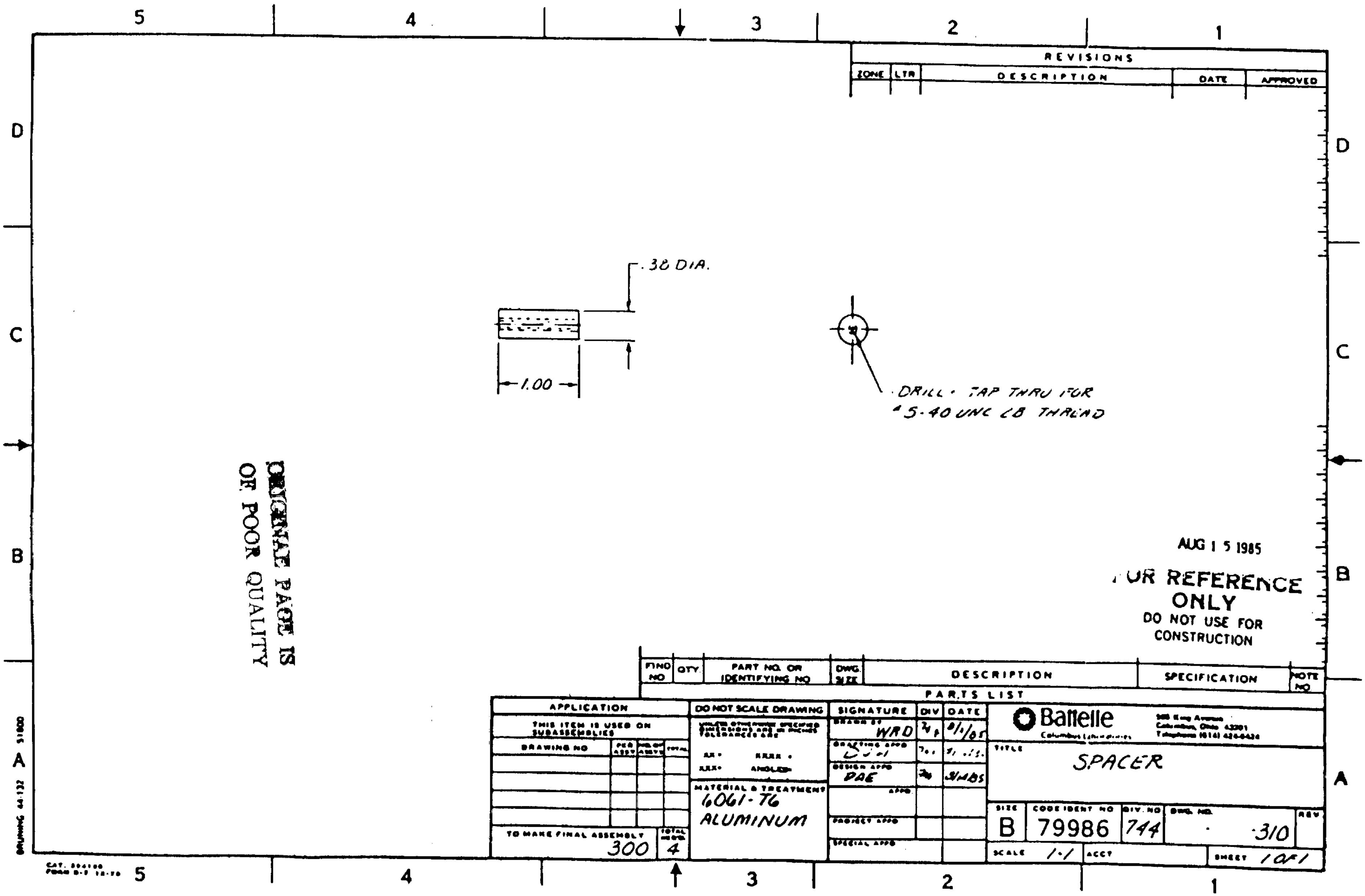
DWG NO
REV
B
79986
744
.309
SCALE
1/1
ACCT
SHEET
1 OF 1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DESCRIPTION
DATE
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.38 DIA.
1.00
DRILL & TAP THRU FOR
#5-40 UNC 2B THREAD
AUG 1 5 1985
FOR REFERENCE ONLY
DO NOT USE FOR CONSTRUCTION
FIND NO
QTY
PART NO. OR IDENTIFYING NO
DWG. SIZE
DESCRIPTION
SPECIFICATION
NOTE NO
PARTS LIST
APPLICATION
THIS ITEM IS USED ON SUBASSEMBLIES
DRAWING NO
TO MAKE FINAL ASSEMBLY
300
4
DO NOT SCALE DRAWING
MATERIAL & TREATMENT
6061-T6
ALUMINUM
SIGNATURE
DIV
DATE
WRD
DESIGN APPD
DAE
PROJECT APPD
SPECIAL APPD
Battelle
Columbus Laboratories
TITLE
SPACER
SIZE
B
CODE IDENT NO
79986
DIV. NO
744
DWG. NO.
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REV
SCALE
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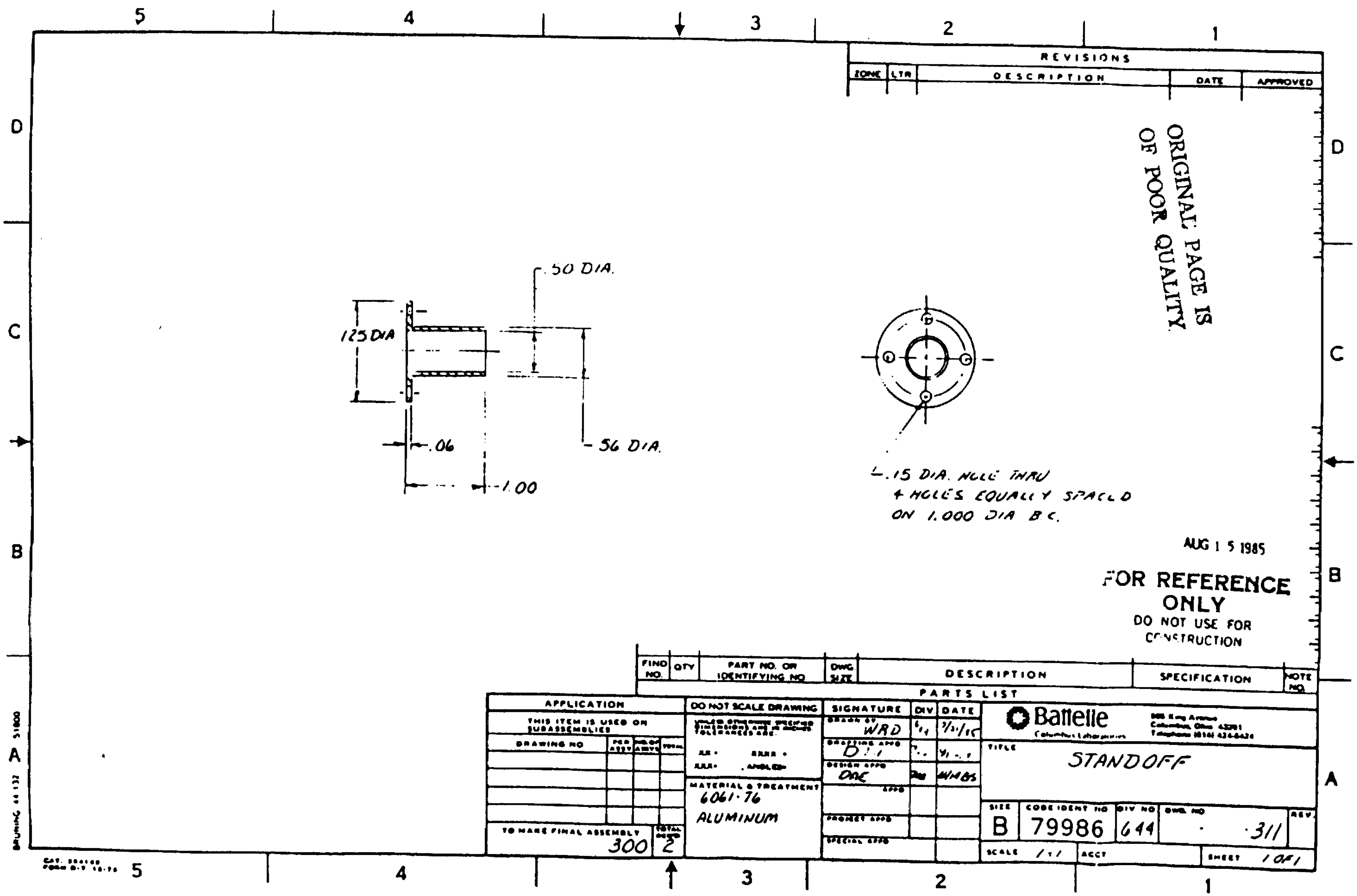
SHEET
1 OF 1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LTR
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DATE
APPROVED
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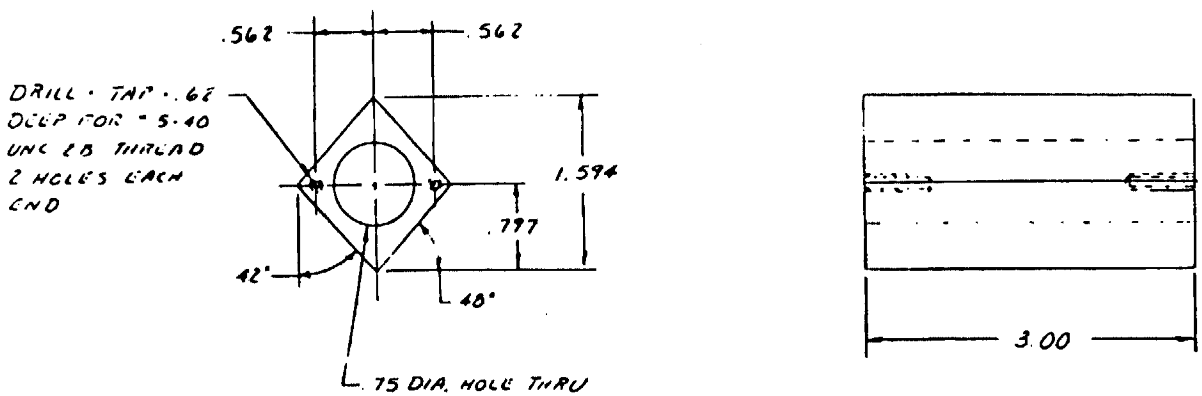
.50 DIA.
125 DIA
.06
1.00
.56 DIA.
.15 DIA. HOLE THRU
4 HOLES EQUALLY SPACED
ON 1.000 DIA B.C.
AUG 15 1985
FOR REFERENCE
ONLY
DO NOT USE FOR
CONSTRUCTION
FIND NO.
QTY
PART NO. OR IDENTIFYING NO
DWG SIZE
DESCRIPTION
SPECIFICATION
NOTE NO.
PARTS LIST
APPLICATION
THIS ITEM IS USED ON SUBASSEMBLIES
DRAWING NO
TO MAKE FINAL ASSEMBLY
300
TOTAL
2
DO NOT SCALE DRAWING
MATERIAL & TREATMENT
6061-T6
ALUMINUM
SIGNATURE
DIV
DATE
WRD
Battelle
TITLE
STANDOFF
SIZE
B
CODE IDENT NO
79986
DIV NO
644
DWG NO
311
REV
SCALE
1/1
ACCT
SHEET
1 OF 1



AUG 1 5 1985

FOR REFERENCE ONLY
DO NOT USE FOR CONSTRUCTION

REVISIONS

ZONE	LTR	DESCRIPTION	DATE	APPROVED

PARTS LIST

FIND NO.	QTY	PART NO. OR IDENTIFYING NO.	DWG SIZE	DESCRIPTION	SPECIFICATION	NOTE NO.

APPLICATION — THIS ITEM IS USED ON SUBASSEMBLIES

DRAWING NO.	PER ASSY	NO. OF ASSYS	TOTAL
300	1	1	1
400	1	1	1

TO MAKE FINAL ASSEMBLY — TOTAL REQD.

DO NOT SCALE DRAWING

MATERIAL & TREATMENT: 6061-T6 ALUMINUM

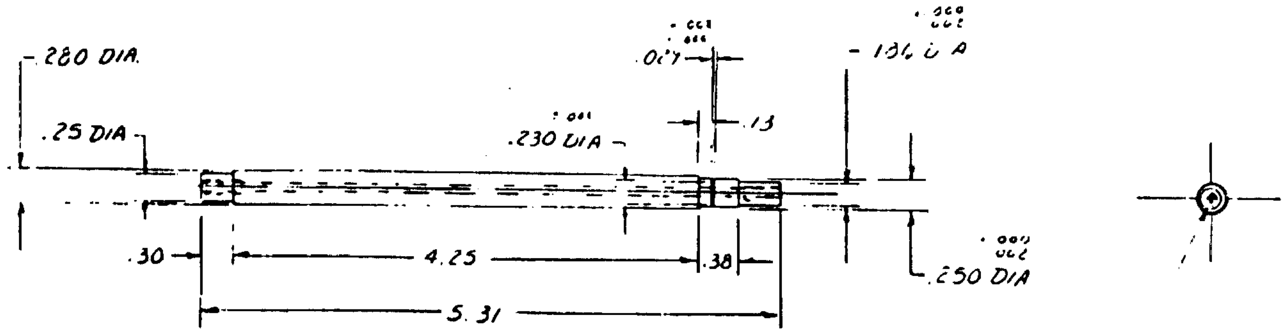
SIGNATURE	DIV.	DATE
DRAWN BY WRD		
DRAFTING APPD DJH		
DESIGN APPD DAE		4/4/85
APPD		
PROJECT APPD		
SPECIAL APPD		

Battelle Columbus Laboratories

TITLE: HANDLE BAR

SIZE: B | CODE IDENT. NO.: 79986 | DIV NO.: 744 | DWG. NO.: 312 | REV.:

SCALE: 1/1 | ACCT: | SHEET: 1 OF 1



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*38 ..101, DIA HOLE THRU
*5-40 UNC-2B TAP .38
DEEP BOTH ENDS

AUG 15 1985

FOR REFERENCE ONLY
DO NOT USE FOR CONSTRUCTION

REVISIONS

ZONE	LTR	DESCRIPTION	DATE	APPROVED

PARTS LIST

FIND NO	QTY	PART NO. OR IDENTIFYING NO	DWG SIZE	DESCRIPTION	SPECIFICATION	NOTE NO

APPLICATION — THIS ITEM IS USED ON SUBASSEMBLIES — TO MAKE FINAL ASSEMBLY 300 — TOTAL REQ'D 2

DO NOT SCALE DRAWING

MATERIAL & TREATMENT: BRONZE

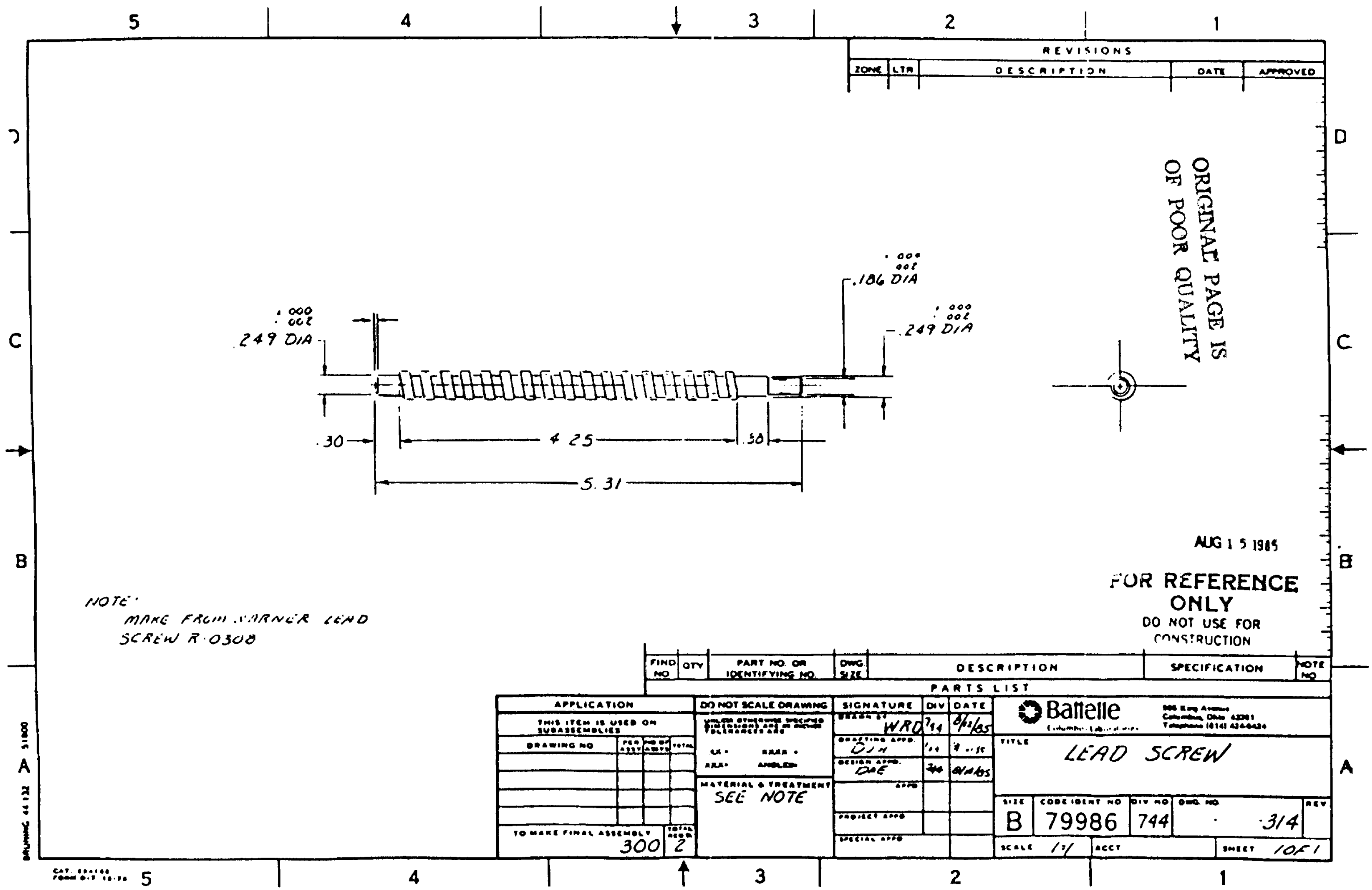
SIGNATURE	DIV	DATE
DRAWN BY WRD	744	8/1/85
DRAFTING APPD DJ		
DESIGN APPD DAE		

Battelle — Columbus Laboratories

TITLE: GUIDE SHAFT

SIZE	CODE IDENT NO	DIV NO	DWG NO	REV
B	79986	744	313	

SCALE 1/1 — SHEET 1 OF 1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REVISIONS
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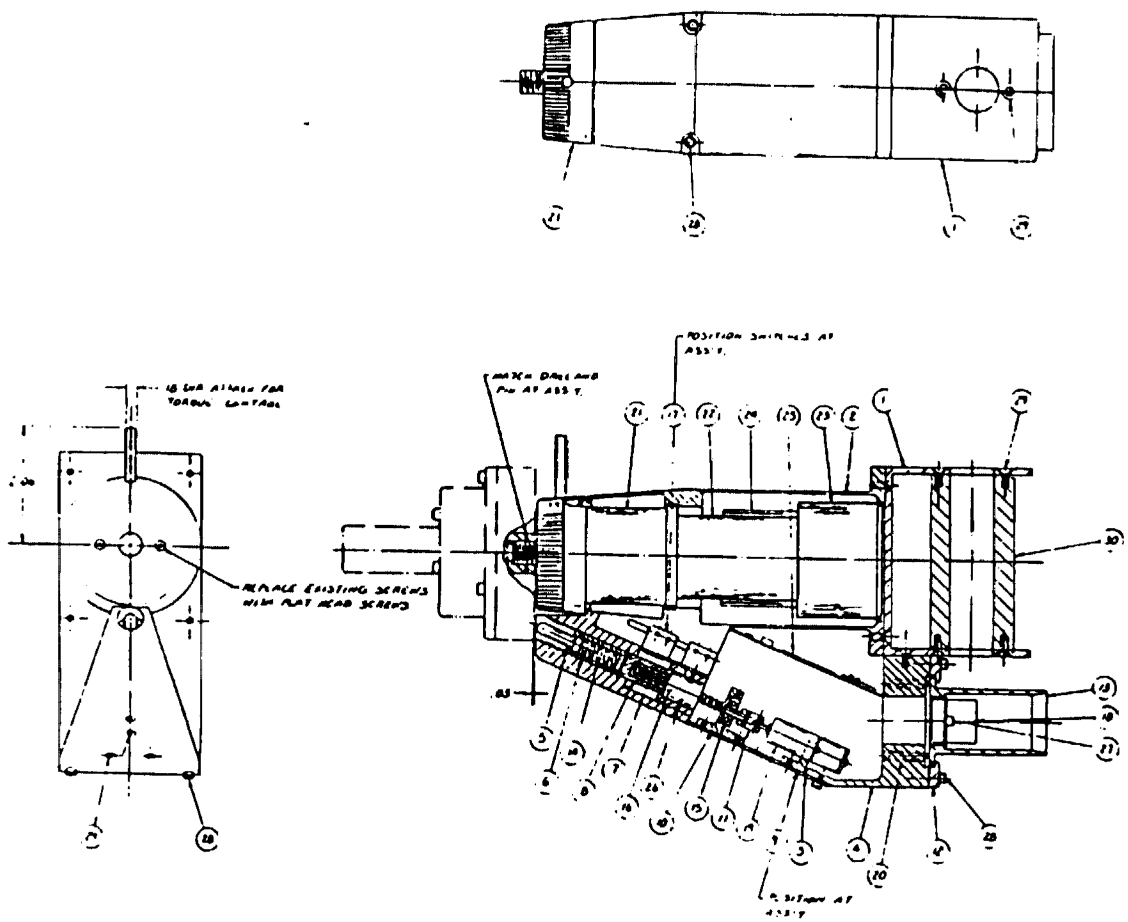
LTR
DESCRIPTION
DATE
APPROVED
.186 DIA
.249 DIA
.249 DIA
.30
4 25
.30
5. 31
AUG 1 5 1985
FOR REFERENCE
ONLY
DO NOT USE FOR
CONSTRUCTION
NOTE:
MAKE FROM WARNER LEAD
SCREW R-0308
FIND NO
QTY
PART NO. OR IDENTIFYING NO.
DWG SIZE
DESCRIPTION
SPECIFICATION
NOTE NO
PARTS LIST
APPLICATION
THIS ITEM IS USED ON SUBASSEMBLIES
DRAWING NO
TO MAKE FINAL ASSEMBLY
300
2
DO NOT SCALE DRAWING
MATERIAL & TREATMENT
SEE NOTE
SIGNATURE
DIV
DATE
WRD
Battelle
Columbus Laboratories
TITLE
LEAD SCREW
SIZE
B
CODE IDENT NO
79986
DIV NO
744
DWG. NO
314
REV
SCALE
1/1
ACCT
SHEET
1 OF 1



FIND NO	QTY	PART NO OR IDENTIFYING NO	DWG SIZE	DESCRIPTION	SPECIFICATION	NOTE NO
30	1	312	B	HANDLE BAR		
29	14	3-48UNC	-	FLAT HEAD SCREW - 1316		
28	8	3-48UNC	-	SOC HEAD SCREW - 1316		
27	8	10-40UNC	-	SOC HEAD SCREW - 3016		
26	2	2-56UNC	-	FLAT HEAD SCREW - 1316		
25	1	G10 607	-	MODULE BLOCK	AEG EE306	
24	1	G10 606	-	FET BLOCK	AEG EE306	
23	1	G10 604	-	SWITCH BLOCK	AEG EE306	
22	1	G10 603	-	MOTOR BLOCK	AEG EE306	
21	1	G10 602	-	GEAR BLOCK	AEG EE306	
20	4	3-30	-	SPRING PLUNGER	VLIER	
19	1	[illegible]	-	CONNECTOR	MICRO-MO	
18	1	[illegible]	-	RECEPTACLE	AMPHENOL	
17	2	[illegible]	-	LIMIT SWITCH	MICRO-SWITCH	
16	1	5709729	-	LEAD SCREW NUT	SAGINAW	
15	1	R2-A	-	BALL BEARING	[illegible]	
14	1		-	SPRING		
13	1	300	B	CONNECTOR SOCKET		
12	2	160	B	CONNECTOR SOCKET CLAMP		
11	1	403-7	B	COUPLING		
10	1	403-6	B	BEARING HOUSING		
9	1	403-5	B	MOTOR MOUNT		
8	1	403-4	B	NUT HOUSING		
7	1	403-3	B	LEAD SCREW		
6	1	403-2	B	SPRING HOUSING		
5	1	403-1	B	PLUNGER		
4	1	404	C	CONNECTOR SOC. BASE		
3	1	403	C	MOTOR BASE		
2	1	402	C	MOTOR COVER		
1	1	401	B	HANDLE		

PARTS LIST

APPLICATION

DO NOT SCALE DRAWING

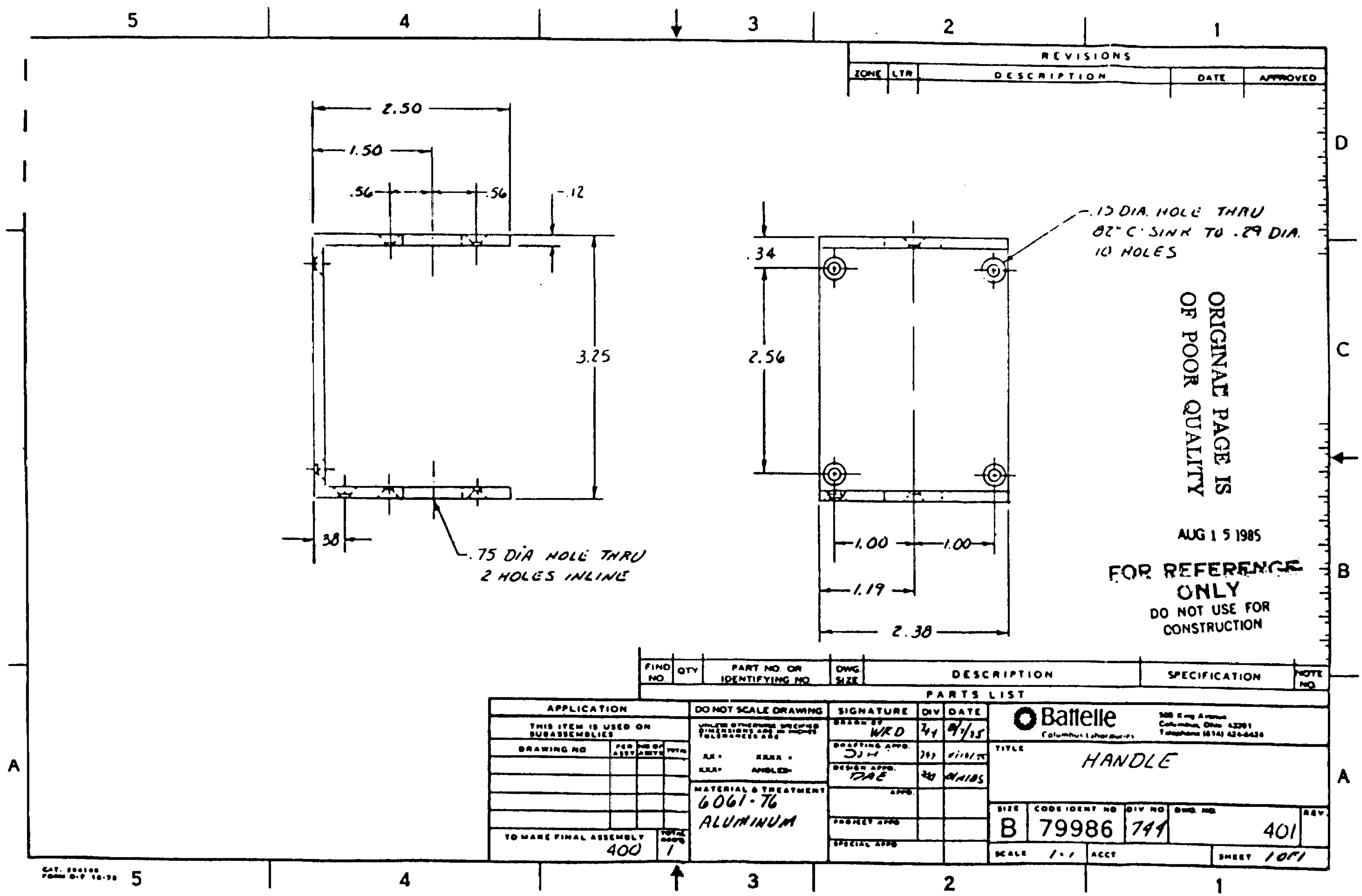
SIGNATURE	DIV	DATE
WRG		8/10/83

Battelle

ROTARY POWER HEAD

D 79986 744 .400

SCALE 1:1 6-0300 SHEET 1 OF 1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LTR
DESCRIPTION
DATE
APPROVED
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1.50
.56
.56
.12
3.25
.38
.75 DIA HOLE THRU
2 HOLES INLINE
.34
2.56
.13 DIA. HOLE THRU
82° C'SINK TO .29 DIA.
10 HOLES
1.00
1.00
1.19
2.38
ORIGINAL PAGE IS
OF POOR QUALITY
AUG 1 5 1985
FOR REFERENCE
ONLY
DO NOT USE FOR
CONSTRUCTION
FIND NO
QTY
PART NO. OR IDENTIFYING NO.
DWG. SIZE
DESCRIPTION
SPECIFICATION
NOTE NO.
PARTS LIST
APPLICATION
THIS ITEM IS USED ON SUBASSEMBLIES
DRAWING NO
TO MAKE FINAL ASSEMBLY
400
1
DO NOT SCALE DRAWING
MATERIAL & TREATMENT
6061-T6
ALUMINUM
SIGNATURE
DIV
DATE
WRD
DJH
DAE
Battelle
Columbus Laboratories
TITLE
HANDLE
SIZE
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744
DWG. NO.
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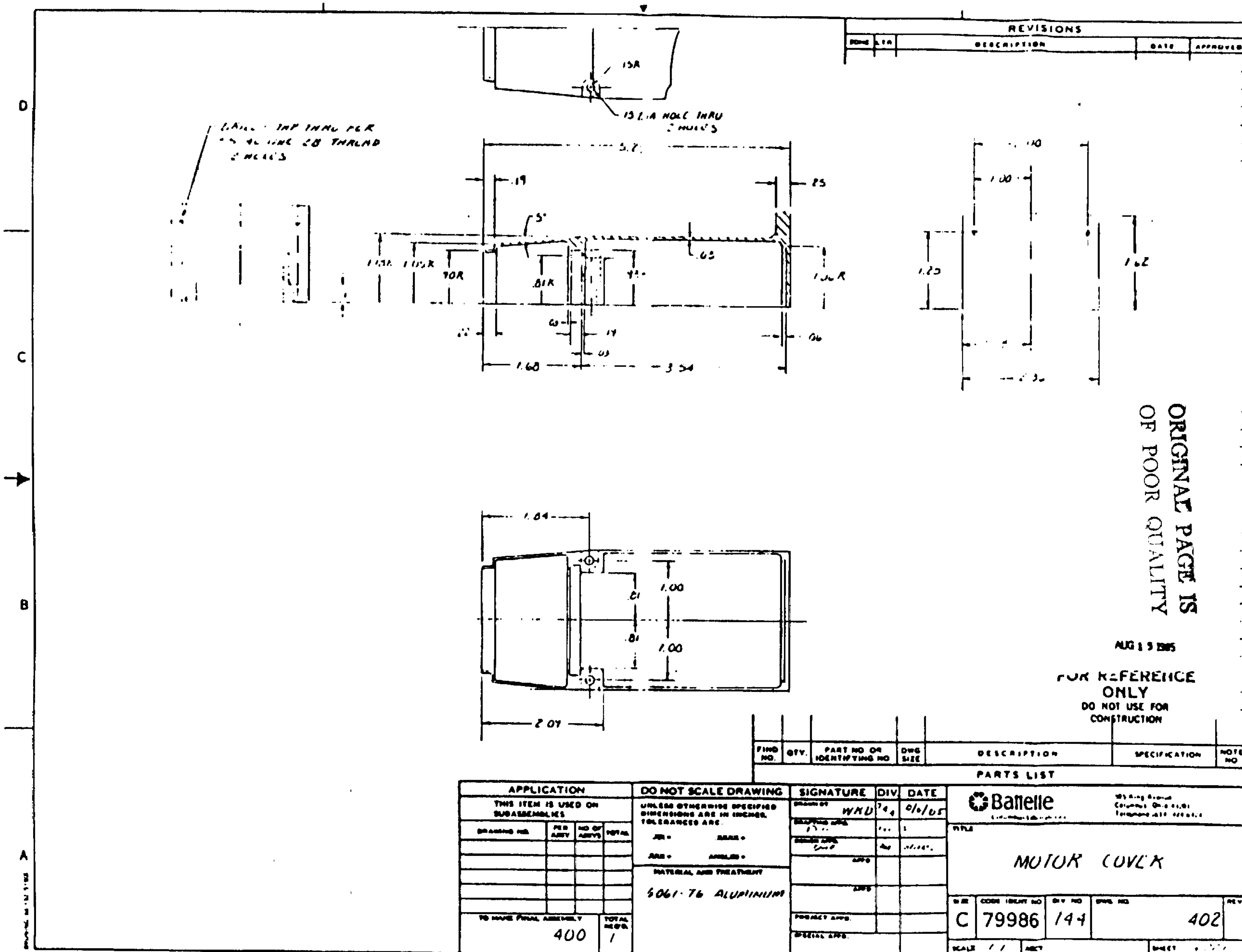
SHEET
1 OF 1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AUG 1 5 1985
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ONLY
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CONSTRUCTION
PARTS LIST
APPLICATION
DO NOT SCALE DRAWING
SIGNATURE
DIV
DATE
Battelle
MOTOR COVER
6061-T6 ALUMINUM
C
79986
144
402
400

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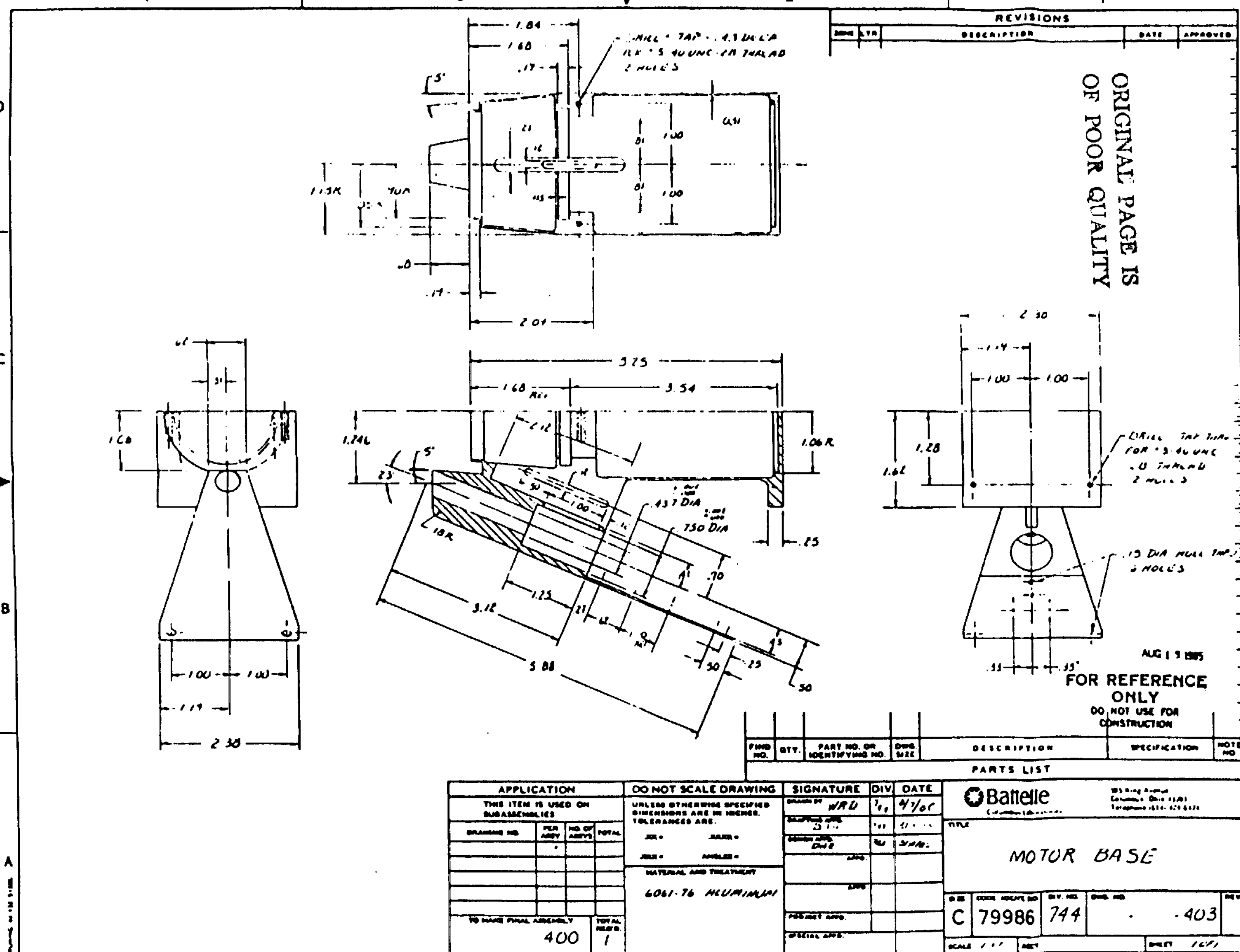

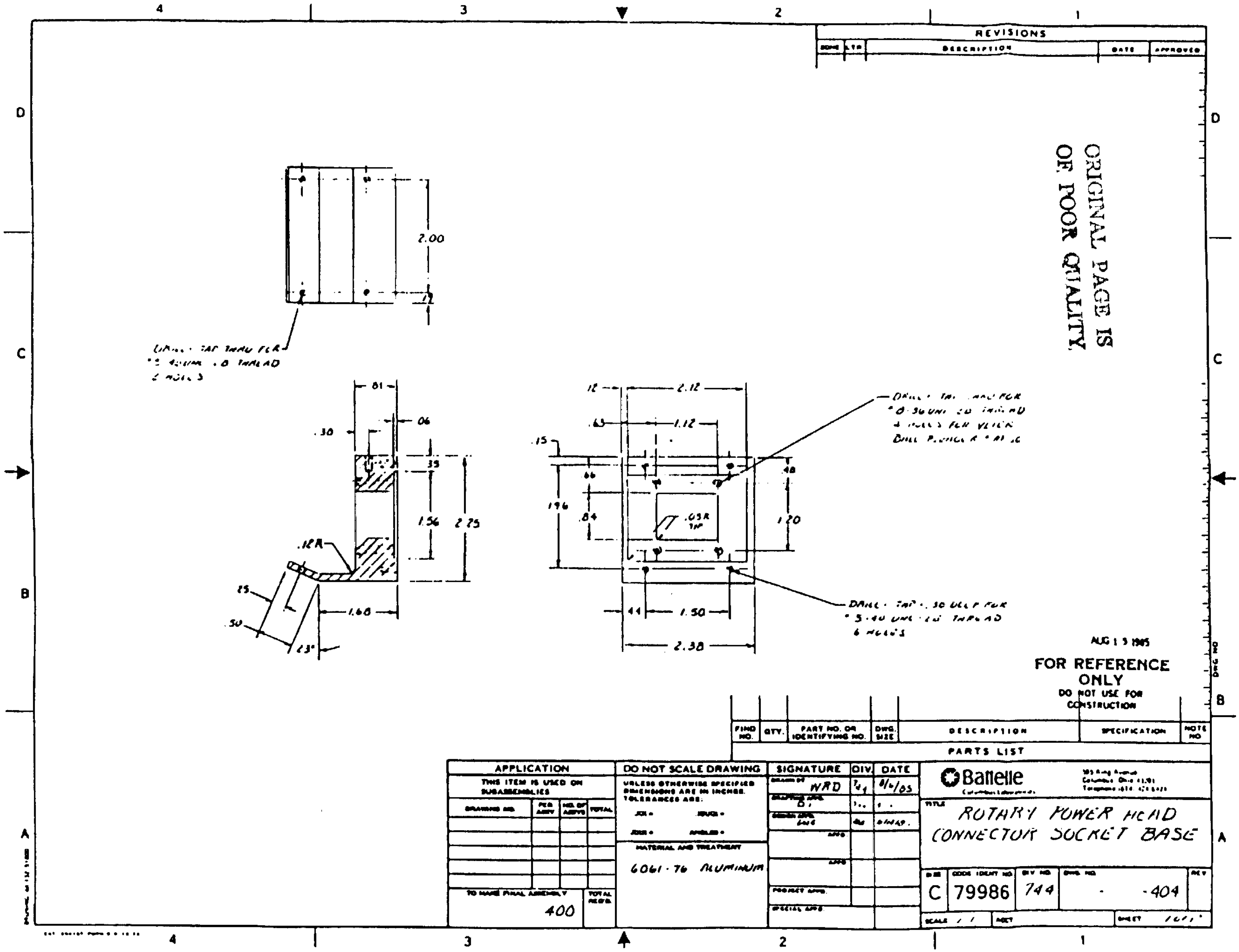

REVISIONS
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2.00
2.12
1.12
1.50
2.38
1.56
2.75
1.68
1.20
.12R
23°
FOR REFERENCE ONLY
DO NOT USE FOR CONSTRUCTION
AUG 1 5 1985
PARTS LIST
FIND NO.
QTY.
PART NO. OR IDENTIFYING NO.
DWG. SIZE
DESCRIPTION
SPECIFICATION
NOTE NO.
APPLICATION
THIS ITEM IS USED ON SUBASSEMBLIES
TO MAKE FINAL ASSEMBLY
400
DO NOT SCALE DRAWING
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES. TOLERANCES ARE:
MATERIAL AND TREATMENT
6061-T6 ALUMINUM
SIGNATURE
DIV
DATE
WRD
Battelle
ROTARY POWER HEAD
CONNECTOR SOCKET BASE
C
79986
744
-404

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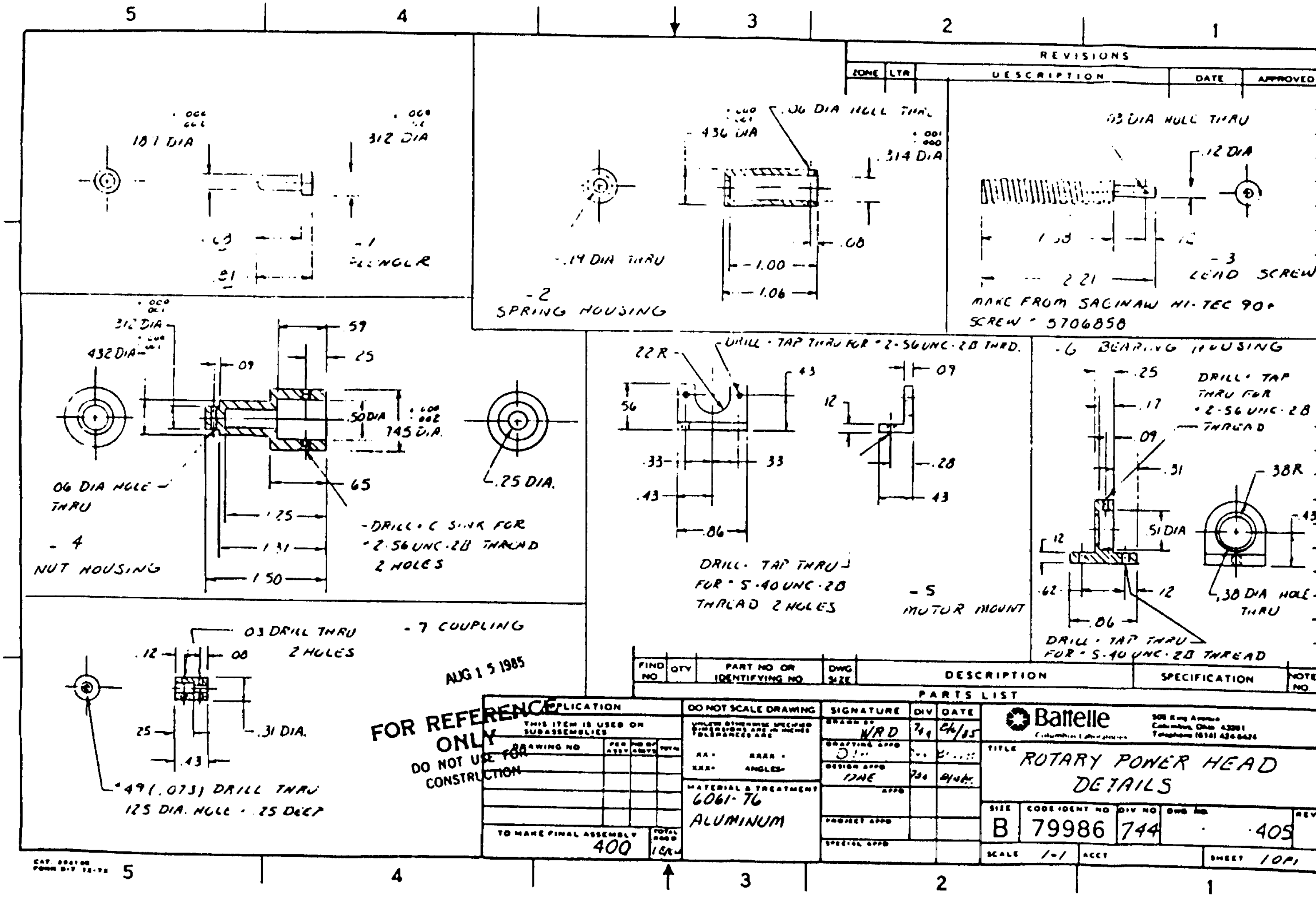

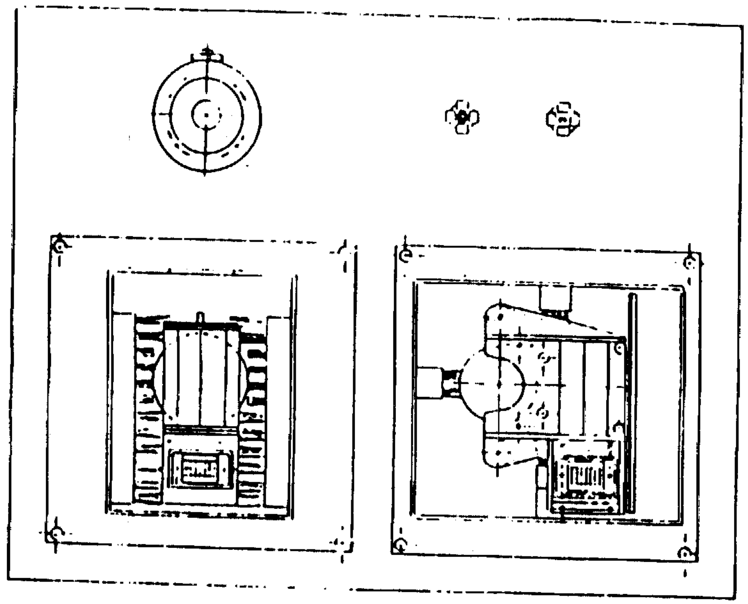

REVISIONS

AUG 1 5 1985

PARTS LIST

FIND NO.	QTY.	PART NO. OR IDENTIFYING NO.	DWG. SIZE	DESCRIPTION	SPECIFICATION	NOTE NO.

APPLICATION

DO NOT SCALE DRAWING

Battelle

TYPICAL LAYOUT FOR
TOOL SUIT

C 79986 744 -500

SHEET 1 OF 1

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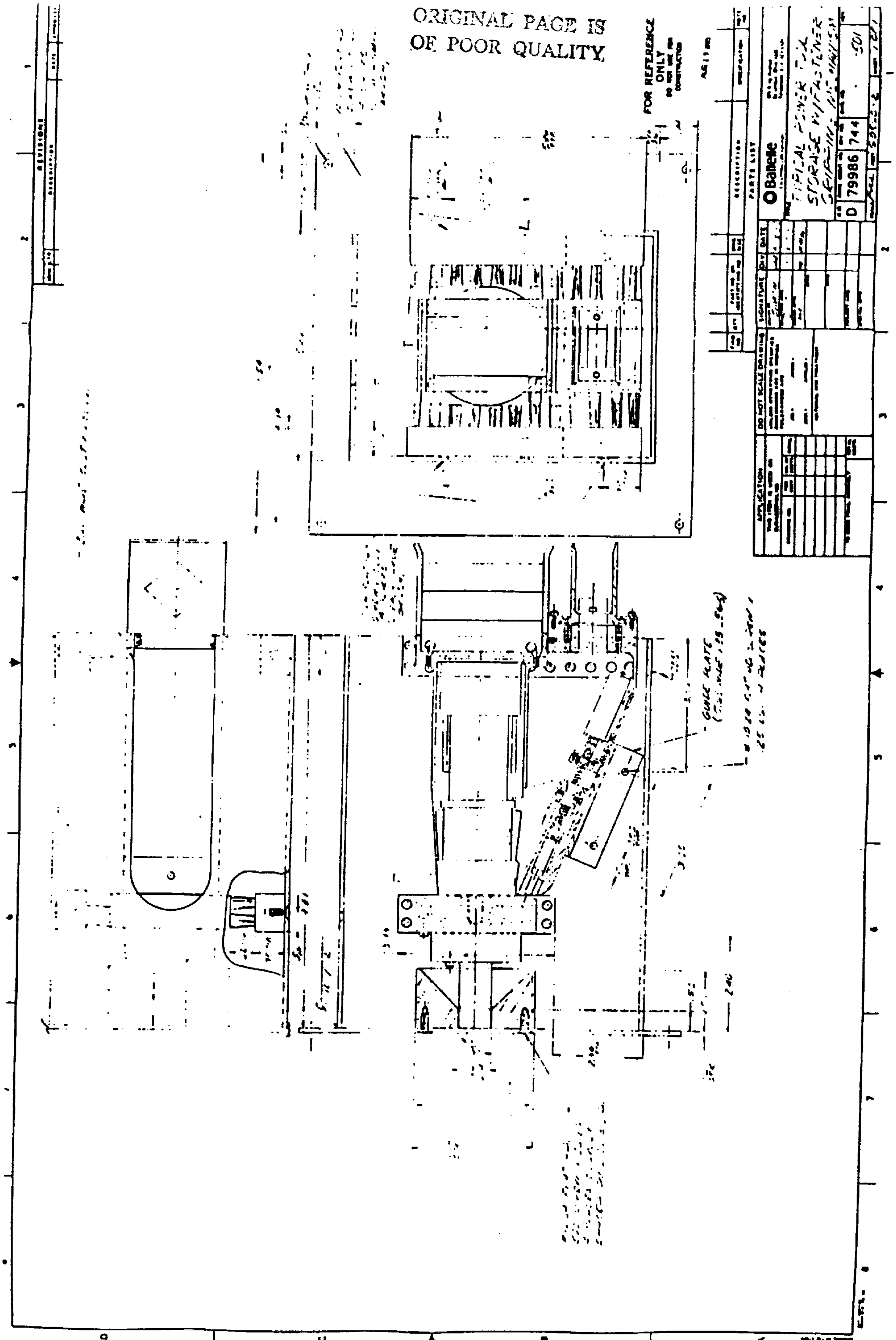

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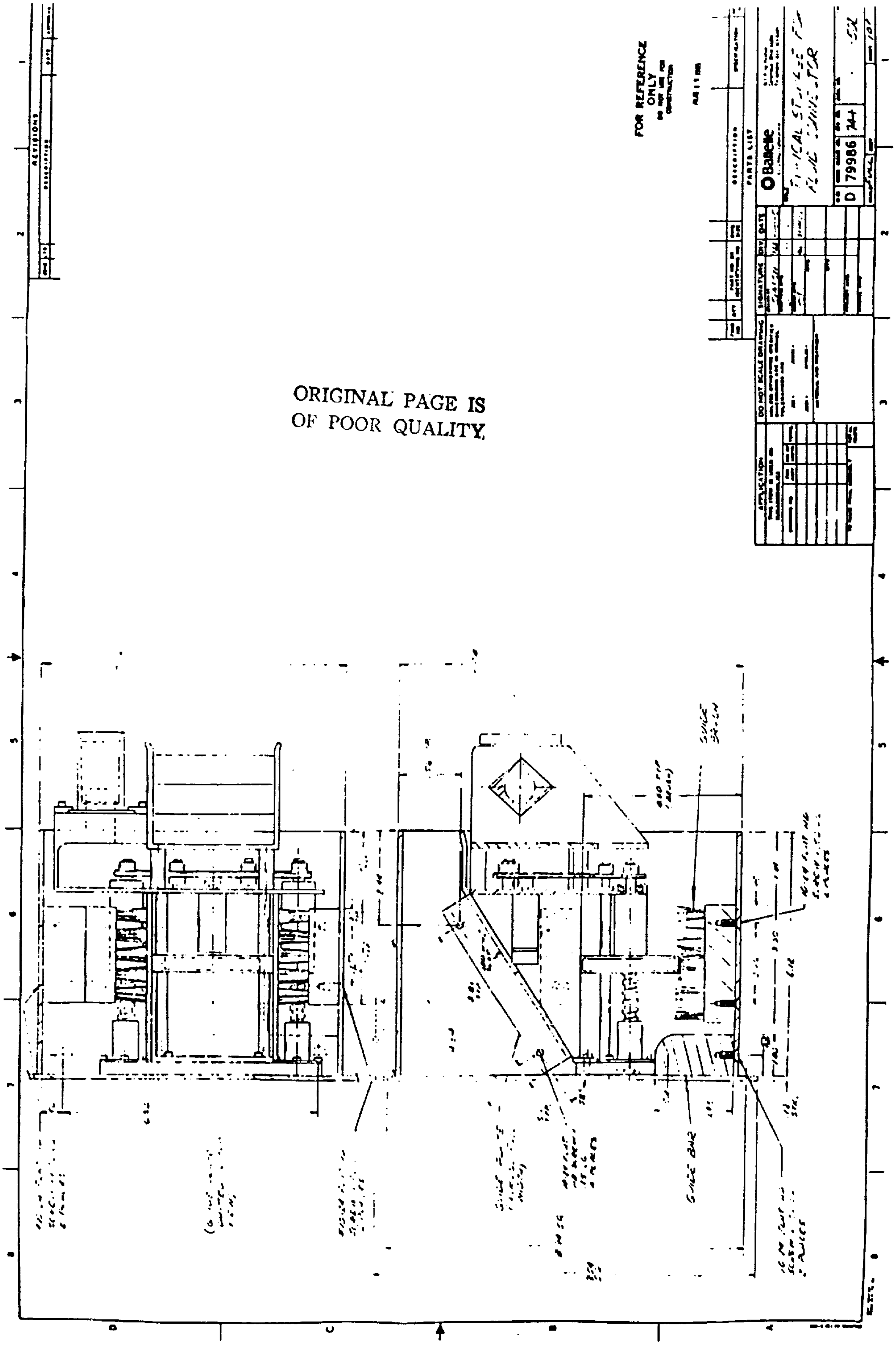

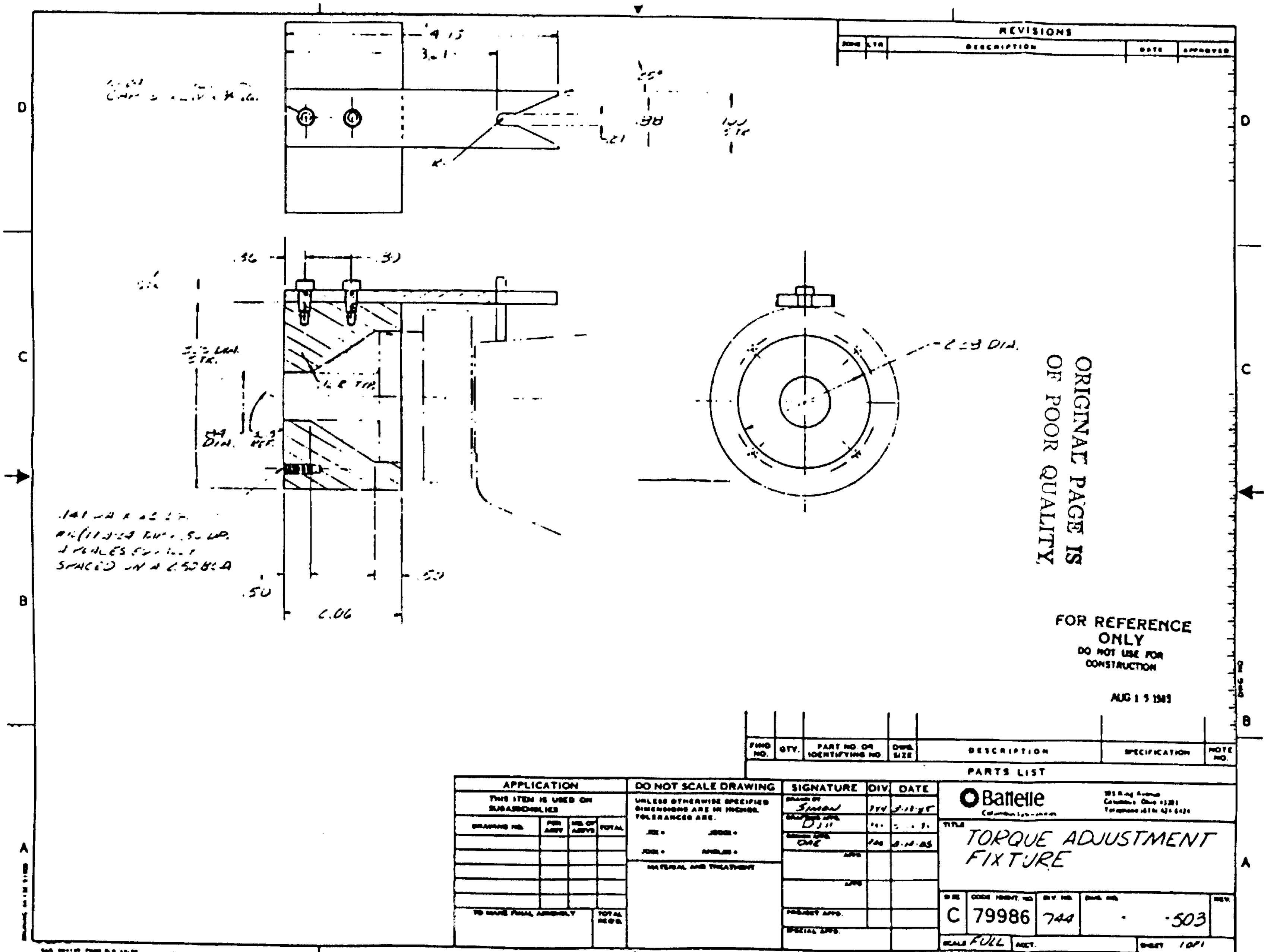
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FOR REFERENCE ONLY
DO NOT USE FOR CONSTRUCTION
AUG 1 9 1985
2.23 DIA.
2.06
.50
.30
.36
.88
.21
25°
PARTS LIST
APPLICATION
DO NOT SCALE DRAWING
SIGNATURE
DIV
DATE
Battelle
TORQUE ADJUSTMENT FIXTURE
C
79986
744
-503
FULL
1 OF 1

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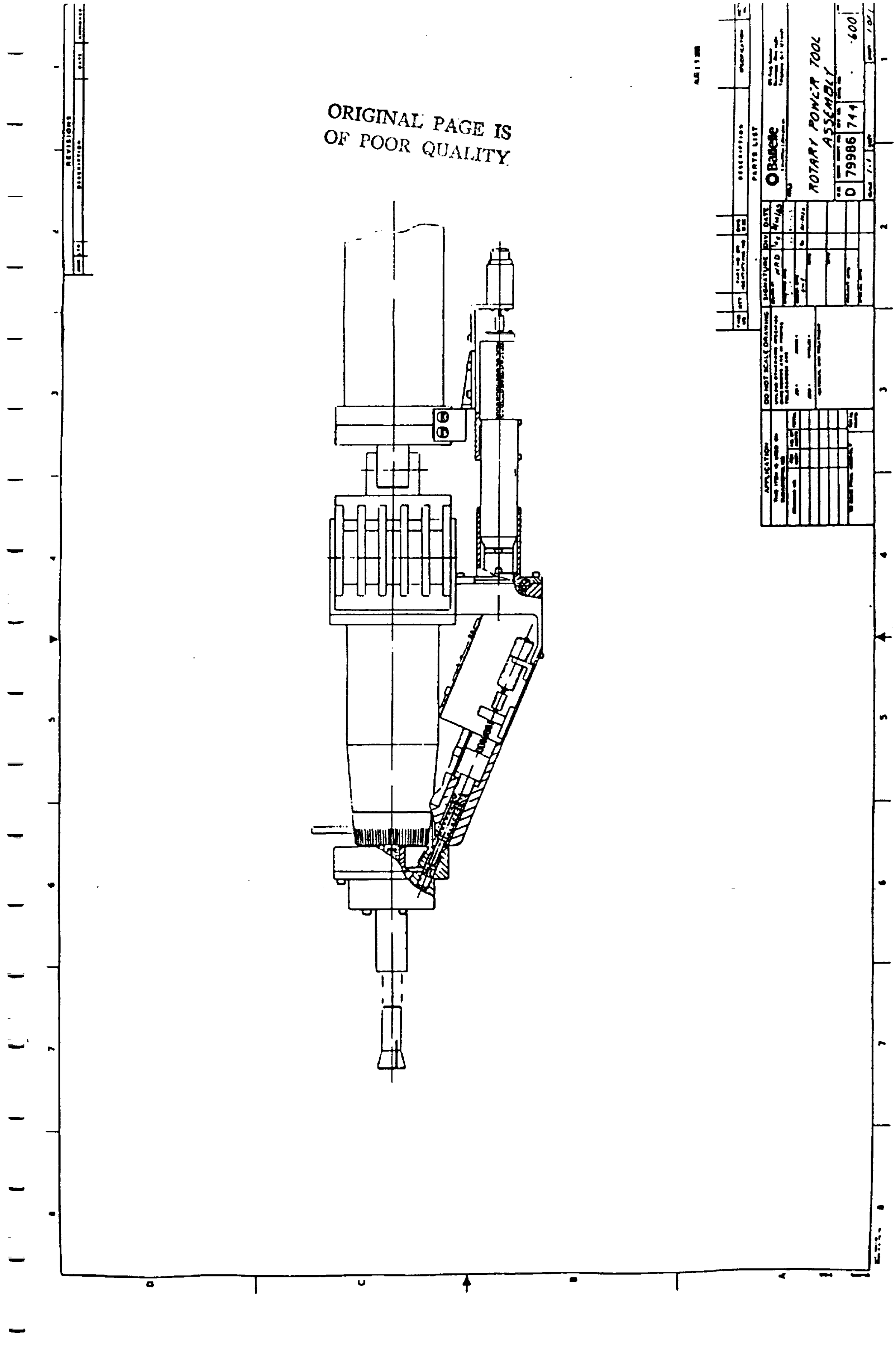

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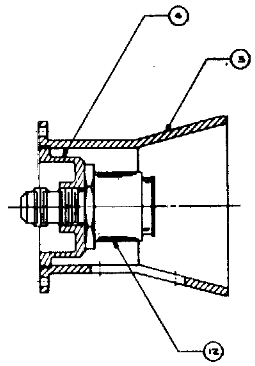

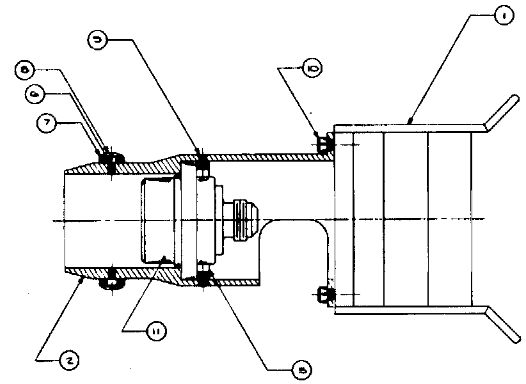

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11	1	PUROLATOR FLUID CONN - MALE		
10	4	10-24 UNC-2A X .50 LG SHCS		
9	4	6-32 UNC-2A X .25 LG. FLAT HD 82°		
8	2	6-32 UNC 2A X .25 LG. PAN HD		
7	2	WHEEL - NYLON	NT-RT-10-002-007	
6	2	SPACER	NT-RT-10-002-005	
5	1	RING	NT-RT-10-002-006	
4	1	COUPLING BUSHING	NT-RT-10-002-001	
3	1	FEMALE HOUSING	NT RT 10-002-011	
2	1	MALE HOUSING	NT-RT-10-002-003	
1	1	TOOL BASE	NT-RT-40-001-003	

BILL OF MATERIAL

MATERIAL: NOTED

NTI
New Technology, Inc.

DATE: 20 DEC 1985
PREPARED: R.H.C.
CHECKED
ENGINEER
APPROVED

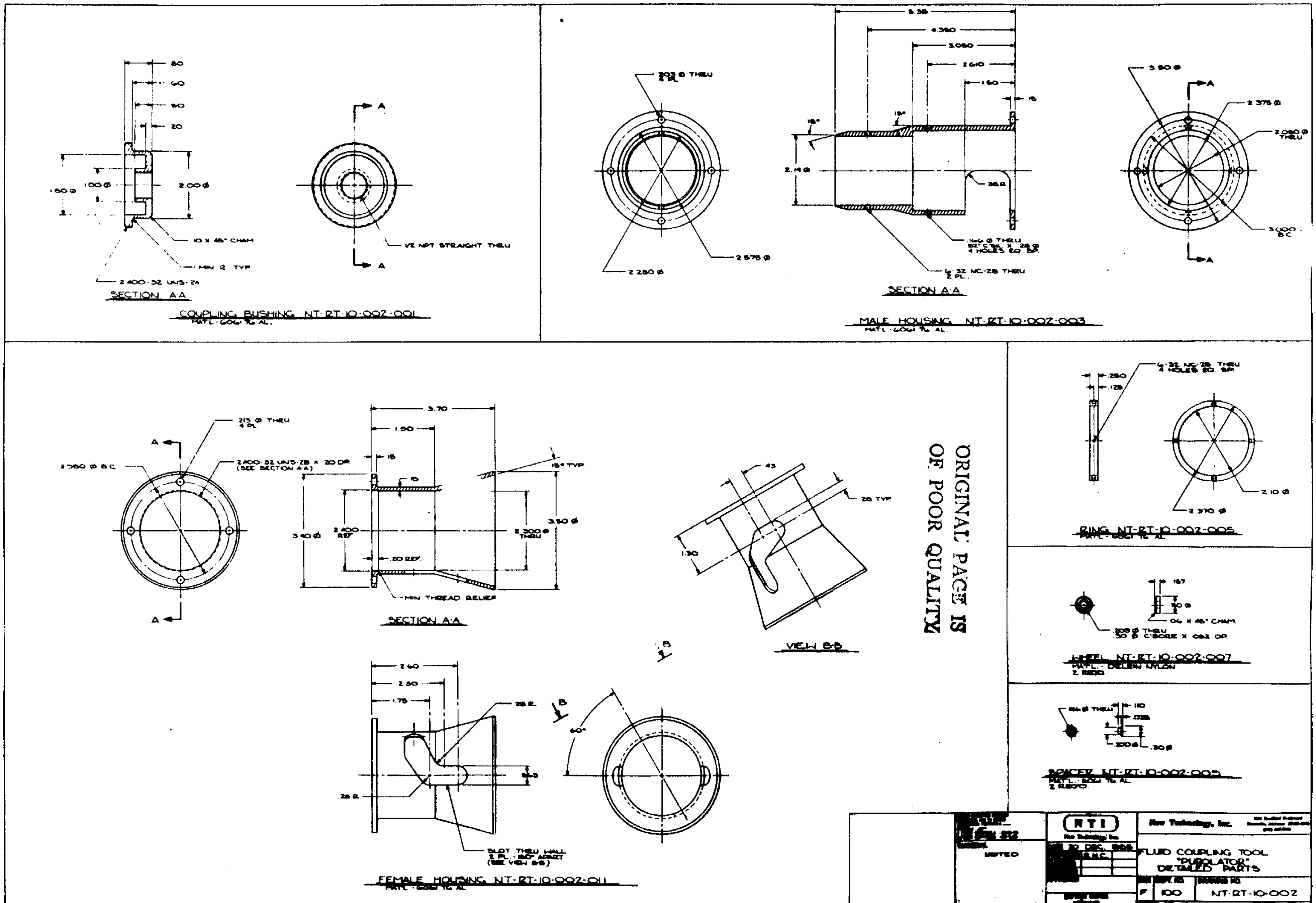
DO NOT SCALE DRAWING

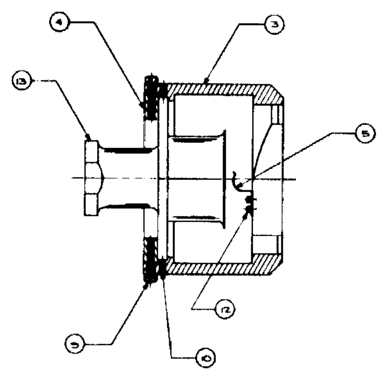
New Technology, Inc.

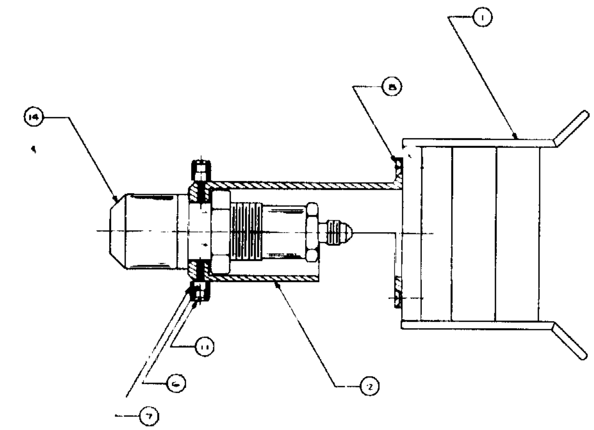
FLUID COUPLING TOOL ASS'Y "PUROLATOR"

SIZE	DEPT. NO.	DRAWING NO.
F	100	NT-RT-10-001

SCALE 1/1 SHEET 1 OF 1


SECTION A-A
COUPLING BUSHING NT-RT-10-002-001
MAT'L - 6061 T6 AL.
1/2 NPT STRAIGHT THRU
10 X 45° CHAM
MIN .12 TYP
2.400-32 UNS-2A
MALE HOUSING NT-RT-10-002-003
MAT'L - 6061 T6 AL.
SECTION A-A
.203 Ø THRU 4 PL
2.280 Ø
2.575 Ø
5.38
4.360
3.050
2.610
1.50
.15
2.14 Ø
.36 R
.166 Ø THRU 82° C'SK X .28 Ø 4 HOLES EQ. SP.
6-32 NC-2B THRU 2 PL.
3.90 Ø
2.375 Ø
2.080 Ø THRU
3.000 B.C.
RING NT-RT-10-002-005
MAT'L - 6061 T6 AL.
6-32 NC-2B THRU 4 HOLES EQ. SP.
2.10 Ø
2.370 Ø
WHEEL NT-RT-10-002-007
MAT'L - DELRIN NYLON
2 REQ'D.
.04 X 45° CHAM.
SPACER NT-RT-10-002-009
MAT'L - 6061 T6 AL.
2 REQ'D.
FEMALE HOUSING NT-RT-10-002-011
MAT'L - 6061 T6 AL.
2.560 Ø B.C.
.213 Ø THRU 4 PL
2.400-32 UNS-2B x .20 DP (SEE SECTION A-A)
SECTION A-A
3.70
1.50
3.40 Ø
2.400 REF
.20 REF.
2.300 Ø THRU
3.50 Ø
15° TYP
MIN THREAD RELIEF
VIEW B-B
.43
.28 TYP
1.30
2.60
2.30
1.75
.28 R.
SLOT THRU WALL 2 PL. - 180° APART (SEE VIEW B-B)
60°
NTI
New Technology, Inc.
FLUID COUPLING TOOL "DUDDLATOR" DETAILED PARTS
NT-RT-10-002





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ITEM	QTY	DESCRIPTION	PART OR DRWG NO	NOTES
14	1	FAIRCHILD FLUID CONN MALE		
13	1	FAIRCHILD FLUID CONN FEMALE		
12	4	2-56 UNC-2A X 1/4 LG SHCS		
11	2	4-40 UNC-2A X 1/2 LG PAN HD		
10	4	6-32 UNC-2A X .25 LG CUP POINT SET SCREW		
9	4	4-32 UNC-2A X .50 LG SHCS		
8	4	10-24 UNC-2A X 3/8 LG FLAT HD 82°		
7	2	ROLLER - NYLON	NT-RT-20-002-007	
6	2	AXLE	NT-RT-20-002-005	
5	2	SPRING	NT-RT-20-002-005	
4	1	FEMALE ADAPTER END PLATE	NT-RT-20-002-011	BLK ANOD
3	1	FEMALE ADAPTER	NT-RT-20-002-001	BLK ANOD
2	1	MALE ADAPTER	NT-RT-20-002-003	BLK ANOD
1	1	TOOL BASE	NT-RT-40-001-001	

BILL OF MATERIAL

MATERIAL
NOTED

NTI
New Technology, Inc.

DATE 20 DEC 1985
PREPARED R.H.C.
CHECKED
ENGINEER
APPROVED

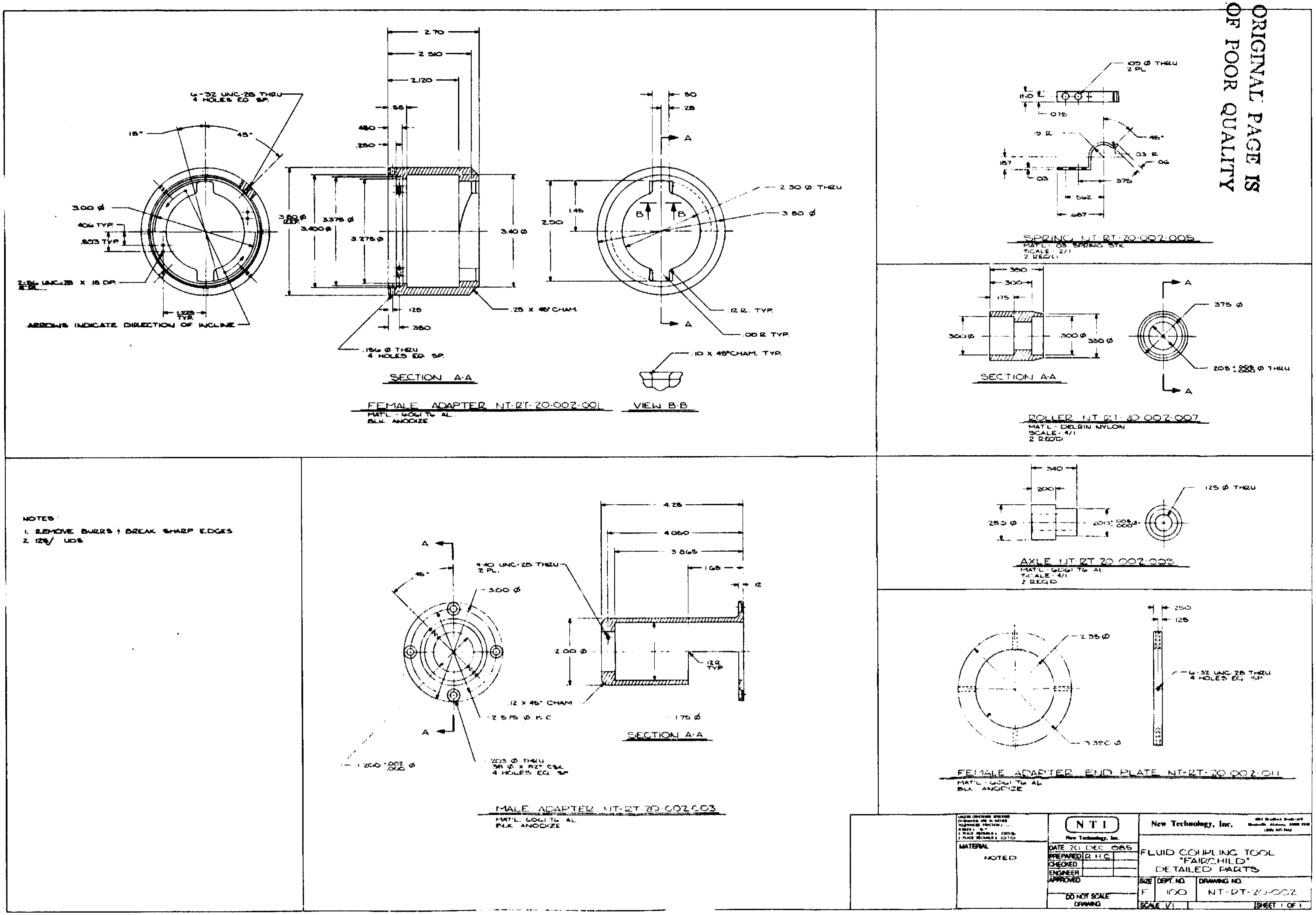
DO NOT SCALE DRAWING

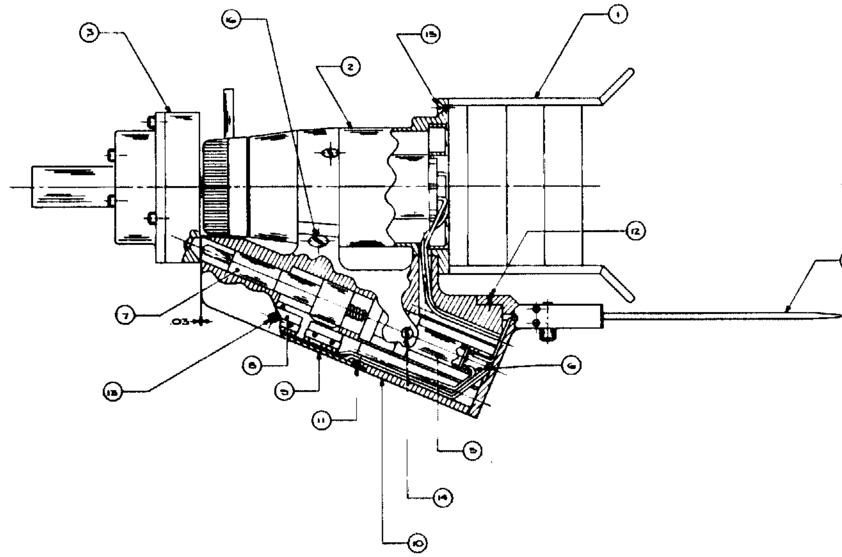
New Technology, Inc.

FLUID COUPLING TOOL ASSY
"FAIRCHILD"

SIZE	DEPT. NO.	DRAWING NO.
F	100	NT-RT-20-001

SCALE 1/1 SHEET 1 OF 1


SECTION A-A
FEMALE ADAPTER NT-RT-20-002-001
MAT'L - 6061 T6 AL.
BLK. ANODIZE
VIEW B-B
ARROWS INDICATE DIRECTION OF INCLINE
SPRING NT-RT-20-002-005
SCALE: 2/1
2 REQ'D
SECTION A-A
ROLLER NT-RT-20-002-007
MAT'L - DELRIN NYLON
SCALE: 4/1
2 REQ'D
AXLE NT-RT-20-002-009
MAT'L - 6061 T6 AL.
SCALE: 4/1
2 REQ'D
FEMALE ADAPTER END PLATE NT-RT-20-002-011
MAT'L - 6061 T6 AL.
BLK. ANODIZE
SECTION A-A
MALE ADAPTER NT-RT-20-002-003
MAT'L 6061 T6 AL.
BLK. ANODIZE
NOTES:
1. REMOVE BURRS & BREAK SHARP EDGES.
2. 125/ UOS
MATERIAL
NOTED
New Technology, Inc.
DATE 20 DEC 1985
PREPARED R.H.C.
CHECKED
ENGINEER
APPROVED
DO NOT SCALE DRAWING
FLUID COUPLING TOOL
"FAIRCHILD"
DETAILED PARTS
SIZE F
DEPT. NO. 100
DRAWING NO. NT-RT-20-002
SCALE 1/1
SHEET 1 OF 1



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NOTE
FOR COLLET DETAILS SEE DWG NO NT-RT-30-013

ITEM	QTY	DESCRIPTION	PART OR IDENT NO	NOTES
16	4	8-32 UNC 2A X .25 LG FLAT HD - 82°		
15	4	10-24 UNC-2A X .38 LG FLAT HD - 82°		
14	1	4-40 UNC-2A X .25 LG FLAT HD - 82°		
13	4	2-56 UNC-2A X .62 LG PAN HD		
12	6	2-56 UNC-2A X .25 LG FLAT HD - 82°		
11	2	2-56 UNC 2A X .18 LG FLAT HD - 82°		
10	1	ACTUATOR HOUSING	NT-RT-30-008-001	
9	1	SWITCH COVER	NT-RT-30-010-017	
8	2	LIMIT SWITCH	1S X 1-T	
7	1	PLUNGER ASS'Y	NT-RT-30-003	
6	—	16 GA WIRE		
5	1	ACT MOTOR ASS'Y	NT-RT-30-004	
4	1	MALE ELECT CONN ASS'Y	NT-RT-30-00E	
3	1	FASTENER GRIPPING MECHANISM	NT-RT-30-006	
2	1	DRIVE MOTOR ASS'Y	NT-RT-30-002	
1	1	TOOL BASE	NT-RT-40-001-005	

BILL OF MATERIAL

MATERIAL

NTI
New Technology, Inc.

DATE 20 DEC 1985
PREPARED R.H.C.
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ENGINEER
APPROVED

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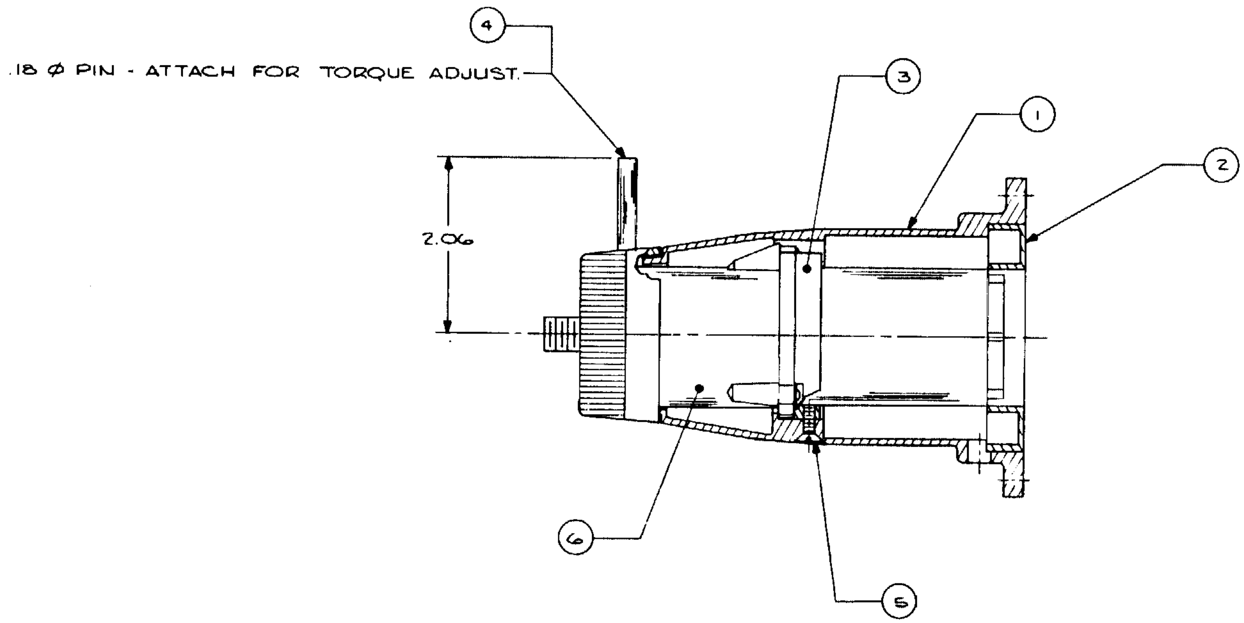
New Technology, Inc.

ROTARY POWER TOOL ASSEMBLY

SIZE F | DEPT. NO. 100 | DRAWING NO. NT-RT-30-001
SCALE 1/1 | SHEET 1 OF



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ITEM	QTY	DESCRIPTION	PART OR IDENT. NO.	NOTES
6	1	AEG GEARMOTOR ASSEMBLY	013838 / 013837	
5	3	6-32 UNC-2A X .25 LG. FLAT HD.-82°		
4	1	TORQUE ADJUSTER		
3	1	MOTOR POSITIONING RING	NT-RT-30-009-003	
2	1	MOTOR BACKING RING	NT-RT-30-009-005	
1	1	GEARMOTOR HOUSING	NT-RT-30-009-001	

BILL OF MATERIAL

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
TOLERANCES: FRACTION ± —
ANGLES ± —
3 PLACE DECIMALS ± —
2 PLACE DECIMALS ± —

MATERIAL

NTI
New Technology, Inc.

DATE 20 DEC. 1985
PREPARED R.H.C.
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ENGINEER
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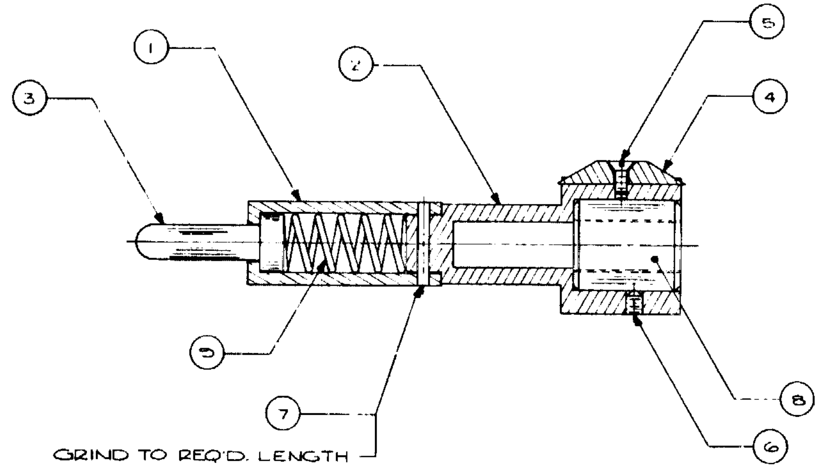
New Technology, Inc. 4811 Bradford Boulevard Huntsville, Alabama 35805-1948 (205) 837-7663

DRIVE MOTOR ASSEMBLY

SIZE	DEPT. NO.	DRAWING NO.
C	100	NT-RT-30-002

SCALE 1/1 SHEET 1 OF



ITEM	QTY	DESCRIPTION	PART OR IDENT NO.	NOTES
9	1	SPRING		
8	1	BALL NUT - SAGINAW	5709729	
7	1	.062 ⌀ ROLL PIN X .50 LG.		
6	3	2-56 UNC-2A X .12 LG. CUP POINT SET SCREW		
5	1	0-80 UNF-2A X .18 LG. FLAT HD. - 82°		
4	1	NUT GUIDE - NYLON	NT-RT-30-010-019	
3	1	PLUNGER	NT-RT-30-010-003	
2	1	NUT HOUSING	NT-RT-30-010-001	
1	1	SPRING HOUSING	NT-RT-30-010-009	

BILL OF MATERIAL

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
TOLERANCES FRACTION ± ——
ANGLES ± ——
3 PLACE DECIMALS ± ——
2 PLACE DECIMALS ± ——

MATERIAL

NTI
New Technology, Inc.

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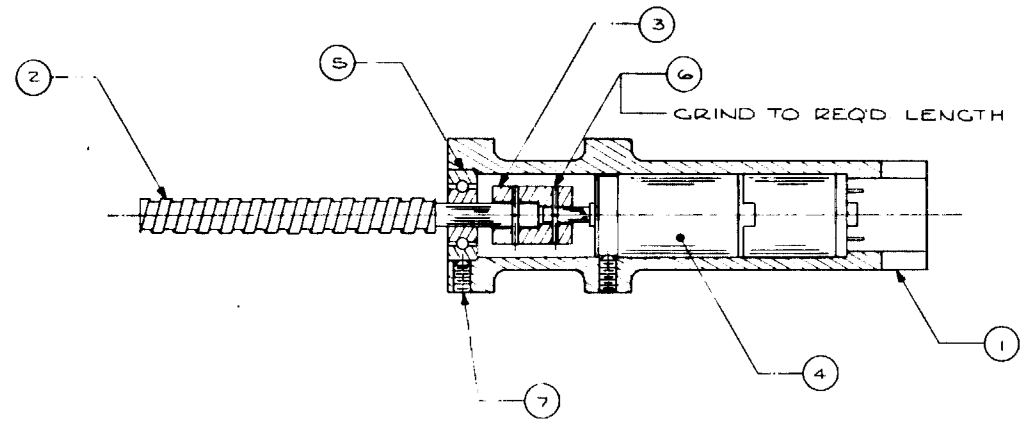
PLUNGER ASSEMBLY

SIZE	DEPT. NO.	DRAWING NO.
C	100	NT-RT-30-003

SCALE 2/1 SHEET 1 OF



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ITEM	QTY.	DESCRIPTION	PART OR IDENT NO.	NOTES
7	6	2-56 UNC-2A X .12 LG. CUP POINT SET SCREW		
6	2	.031 Ø X .38 LG. ROLL PIN		
5	1	BALL BEARING	R2-A	
4	1	GEARMOTOR	1212-12 / 3-104:1	
3	1	COUPLING	NT-RT-30-010-005	
2	1	LEAD SCREW - SAGINAW	NT-RT-30-010-011	
1	1	ACT MOTOR HOUSING - NYLON	NT-RT-30-010-015	

BILL OF MATERIAL

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
TOLERANCES: FRACTION ± ——
ANGLES ± ——
3 PLACE DECIMALS ± ——
2 PLACE DECIMALS ± ——

MATERIAL

NTI
New Technology, Inc.

DATE	20 DEC. 1985
PREPARED	R. H. C.
CHECKED	
ENGINEER	
APPROVED	

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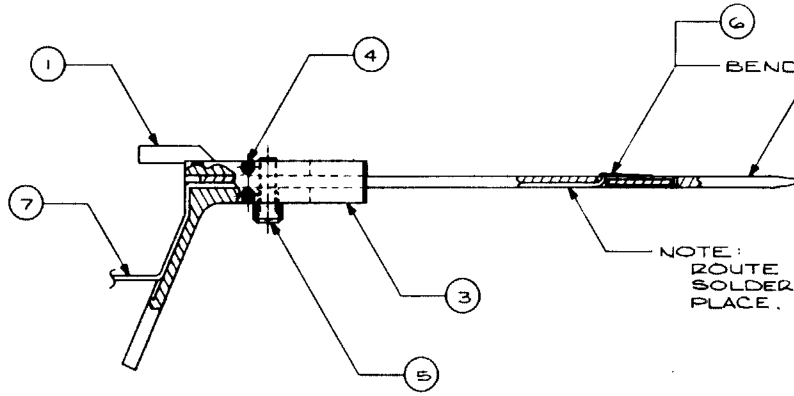
ACT. MOTOR ASSEMBLY

SIZE	DEPT. NO.	DRAWING NO.
C	100	NT-RT-30-004

SCALE 2/1 SHEET 1 OF



ITEM	QTY	DESCRIPTION	PART OR IDENT. NO.	NOTES
7	—	16 GA. WIRE		
6	5	MALE CONN. CONTACT	NT-RT-30-011-005	
5	1	10-24 UNC-2A X .50 LG. SHCS		
4	8	2-56 UNC-2A X .25 LG. SHCS		
3	2	SPRING	NT-RT-30-011-009	
2	1	MOTOR CAP	NT-RT-30-011-001	
1	1	MALE ELECT. CONN.-NYLON	NT-RT-30-011-007	

BILL OF MATERIAL

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
TOLERANCES: FRACTION ± ——
ANGLES ± ——
3 PLACE DECIMALS ± ——
2 PLACE DECIMALS ± ——

MATERIAL

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DATE	20 DEC. 1985
PREPARED	R. H. C.
CHECKED	
ENGINEER	
APPROVED	

DO NOT SCALE DRAWING

MALE ELECTRICAL CONN. ASSEMBLY

SIZE	DEPT. NO.	DRAWING NO.
C	100	NT-RT-30-005

SCALE 1/1 SHEET 1 OF

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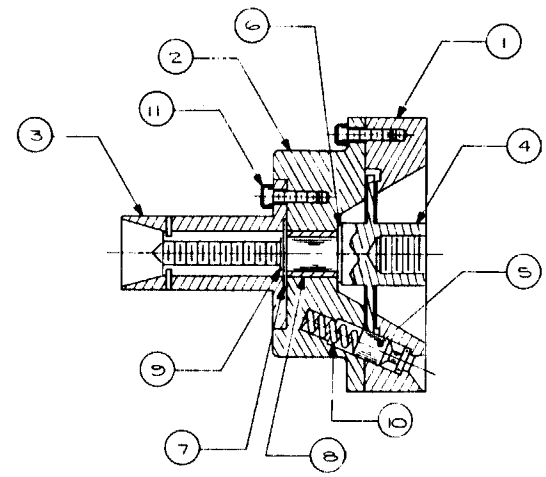

ITEM	QTY	DESCRIPTION	PART OR IDENT. NO.	NOTES
11	6	5-40 UNC-2A x .50 LG. SHCS		
10	1	SPRING		
9	1	RETAINING RING - WALDES	5100-25	
8	1	BUSHING	NT-RT-30-012-001	
7	1	THRUST WASHER	NT-RT-30-012-009	
6	1	THRUST WASHER	NT-RT-30-012-011	
5	1	LOCK PIN	NT-RT-30-012-003	
4	1	LOCK SHAFT	NT-RT-30-012-007	
3	1	COLLET SUPPORT FLANGE	NT-RT-30-012-005	
2	1	CENTER FLANGE	NT-RT-30-012-015	
1	1	REAR FLANGE	NT-RT-30-012-013	

BILL OF MATERIAL

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
TOLERANCES: FRACTION ± ___
ANGLES ± ___
3 PLACE DECIMALS ± ___
2 PLACE DECIMALS ± ___

MATERIAL

NTI
New Technology, Inc.

DATE 20 DEC. 1985
PREPARED R.H.C.
CHECKED
ENGINEER
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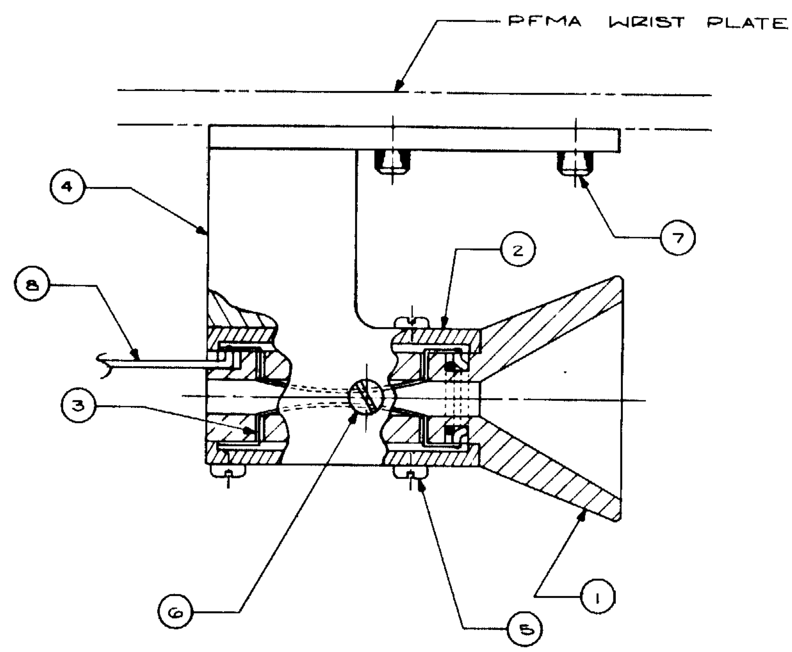
FASTENER GRIPPING MECHANISM

SIZE	DEPT. NO.	DRAWING NO.
C	100	NT-RT-30-006

SCALE 1/1 | SHEET 1 OF



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ITEM	QTY	DESCRIPTION	PART OR IDENT. NO.	NOTES
8	—	16 GA. WIRE		
7	5	4-40 UNC-2A X .25 LG. SHCS		
6	4	4-40 UNC-2A X .25 LG. PAN HD.		
5	8	2-56 UNC-2A X .25 LG. PAN HD.		
4	1	FEMALE CONN. BRACKET	NT-RT-30-011-003	
3	10	FEMALE CONN. CONTACT	NT-RT-30-010-013	
2	2	FEMALE CONN. CAP - NYLON	NT-RT-30-010-023	
1	1	FEMALE CONN. HOUSING - NYLON	NT-RT-30-010-021	

BILL OF MATERIAL

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
TOLERANCES: FRACTION ± ——
ANGLES ± ——
3 PLACE DECIMALS ± ——
2 PLACE DECIMALS ± ——

MATERIAL

NTI
New Technology, Inc.

DATE 20 DEC. 1985
PREPARED R.H.C.
CHECKED
ENGINEER
APPROVED

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New Technology, Inc.
4611 Bradford Boulevard
Huntsville, Alabama 35805-1948
(205) 837-7663

FEMALE ELECTRICAL
CONN. ASSEMBLY

SIZE C | DEPT. NO. 100 | DRAWING NO. NT-RT-30-007

SCALE 2/1 | SHEET 1 OF

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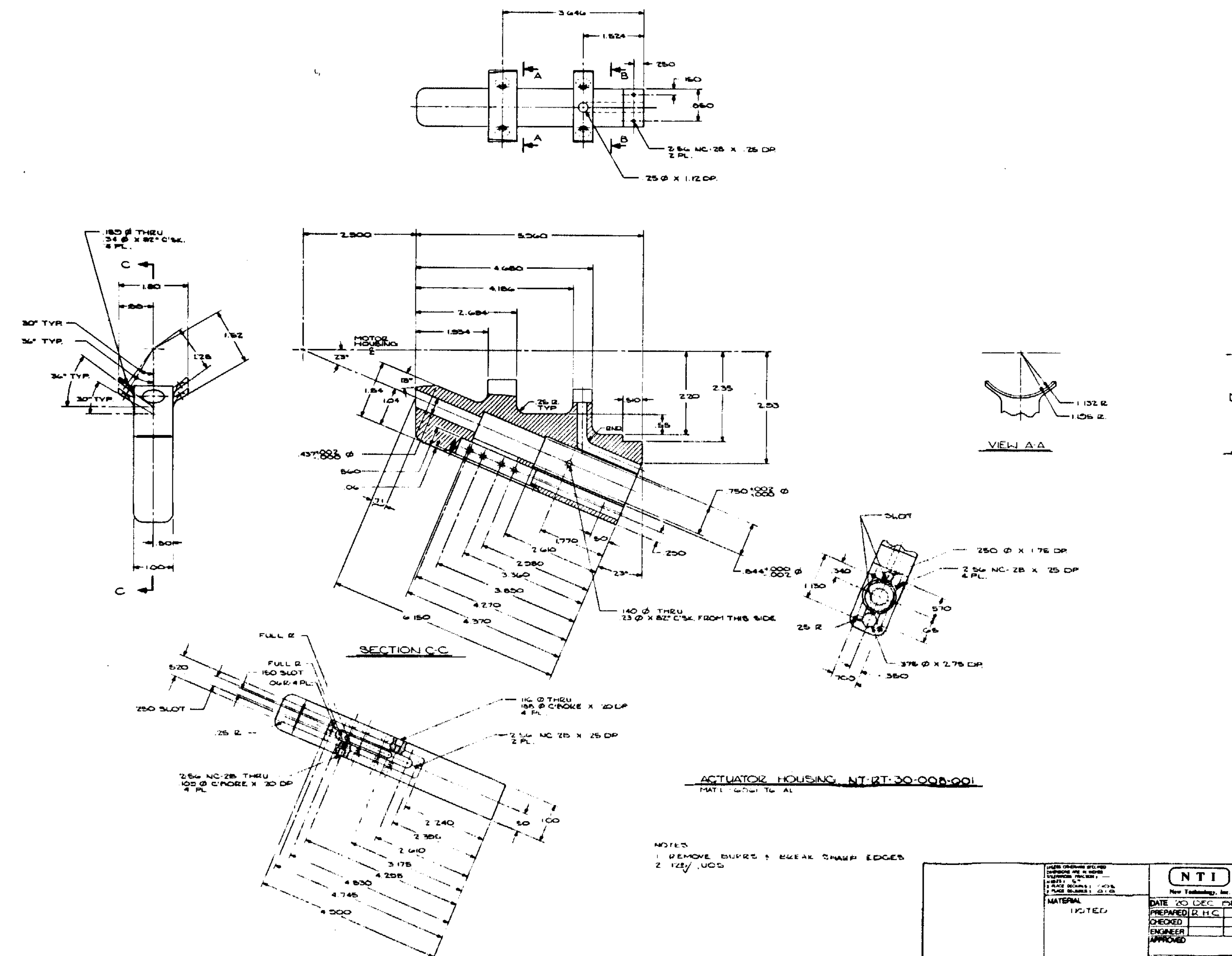

NOTES
1. REMOVE BURRS & BREAK SHARP EDGES
2. 125/ UOS

MATERIAL	NOTED
DATE	20 DEC 1985
PREPARED	R.H.C.
CHECKED	
ENGINEER	
APPROVED	
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ROTARY POWER TOOL
DETAILED PARTS

SIZE	DEPT. NO.	DRAWING NO.
F	100	NT-RT-30-008
SCALE 1/1		SHEET 1 OF

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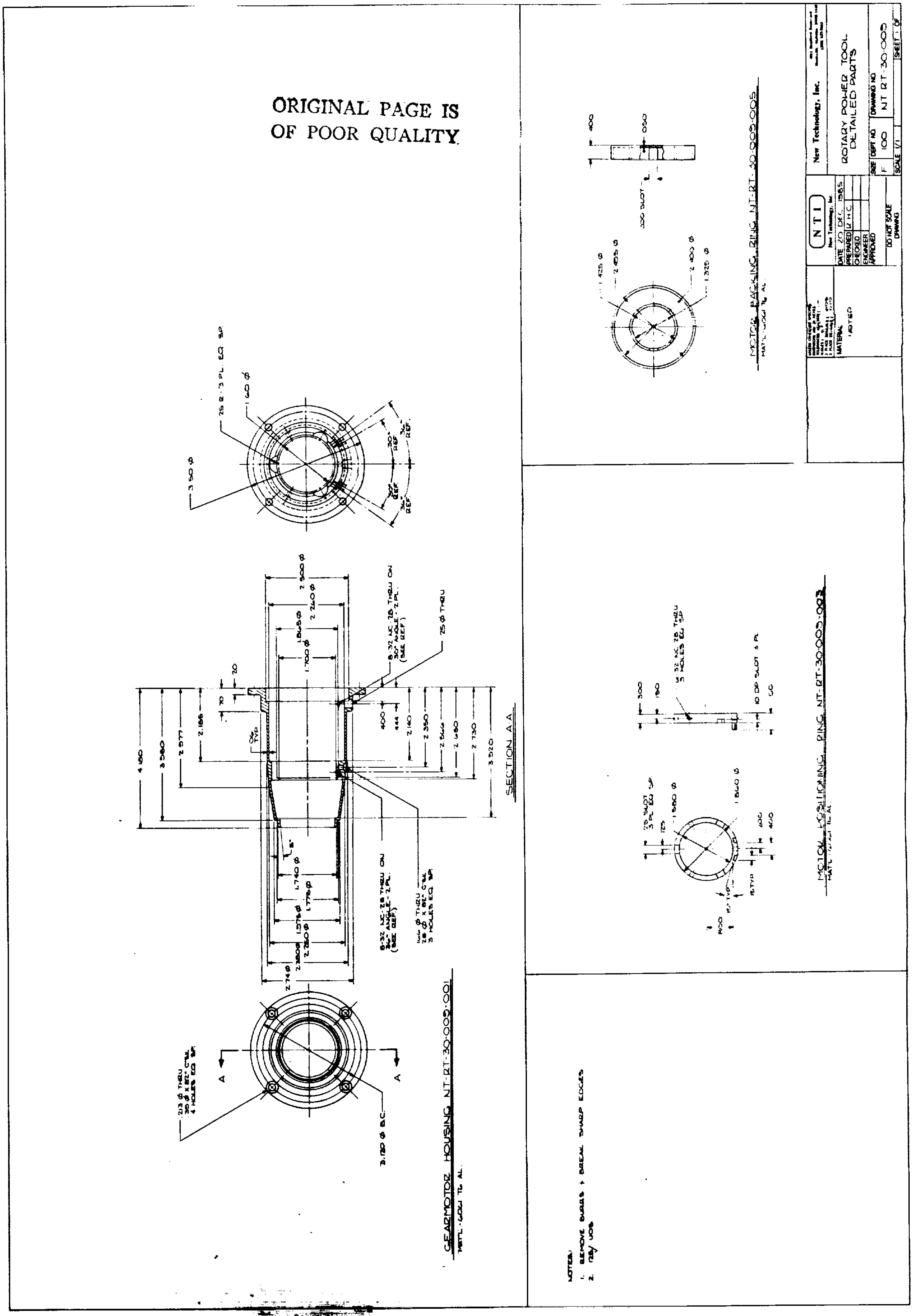

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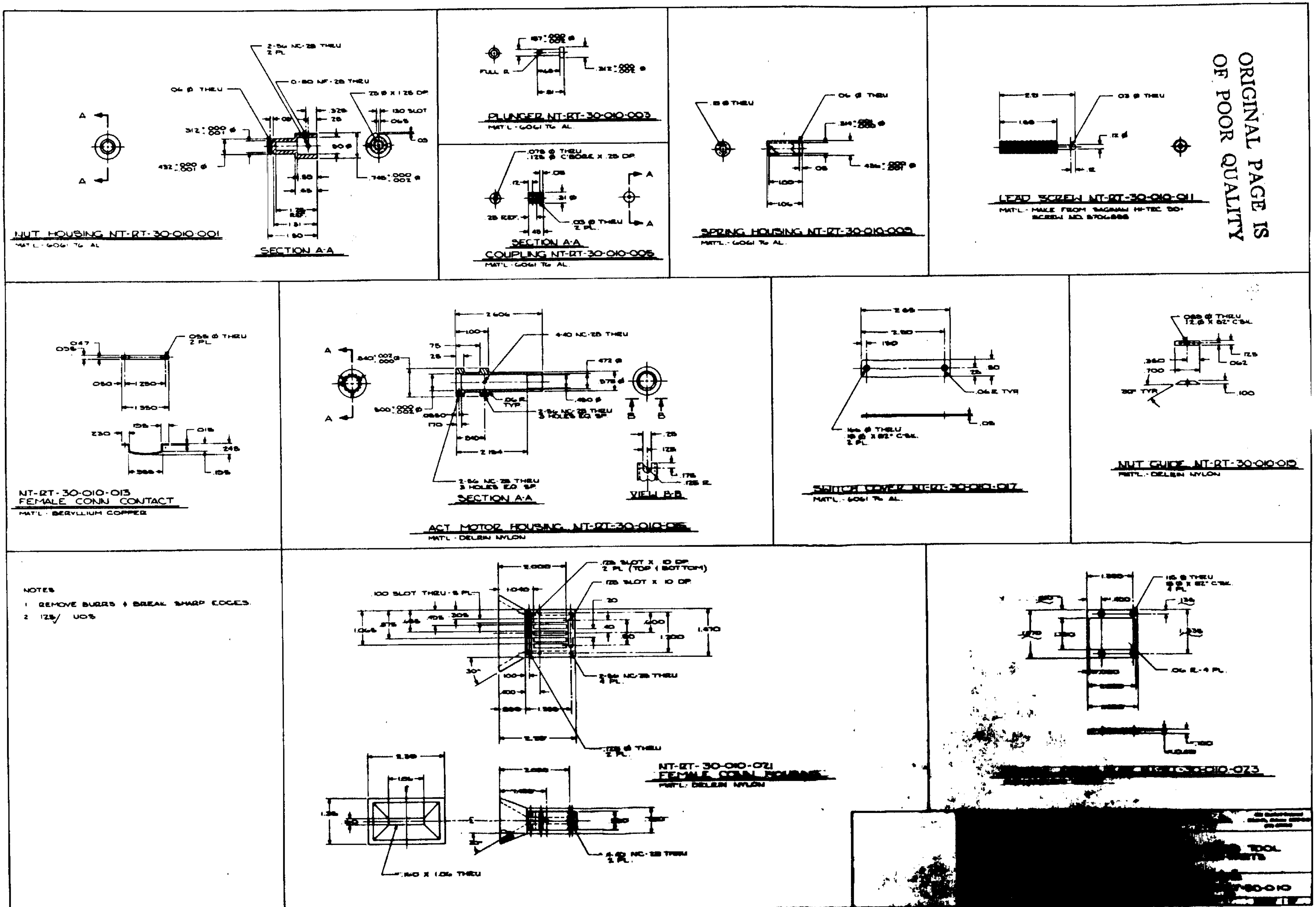

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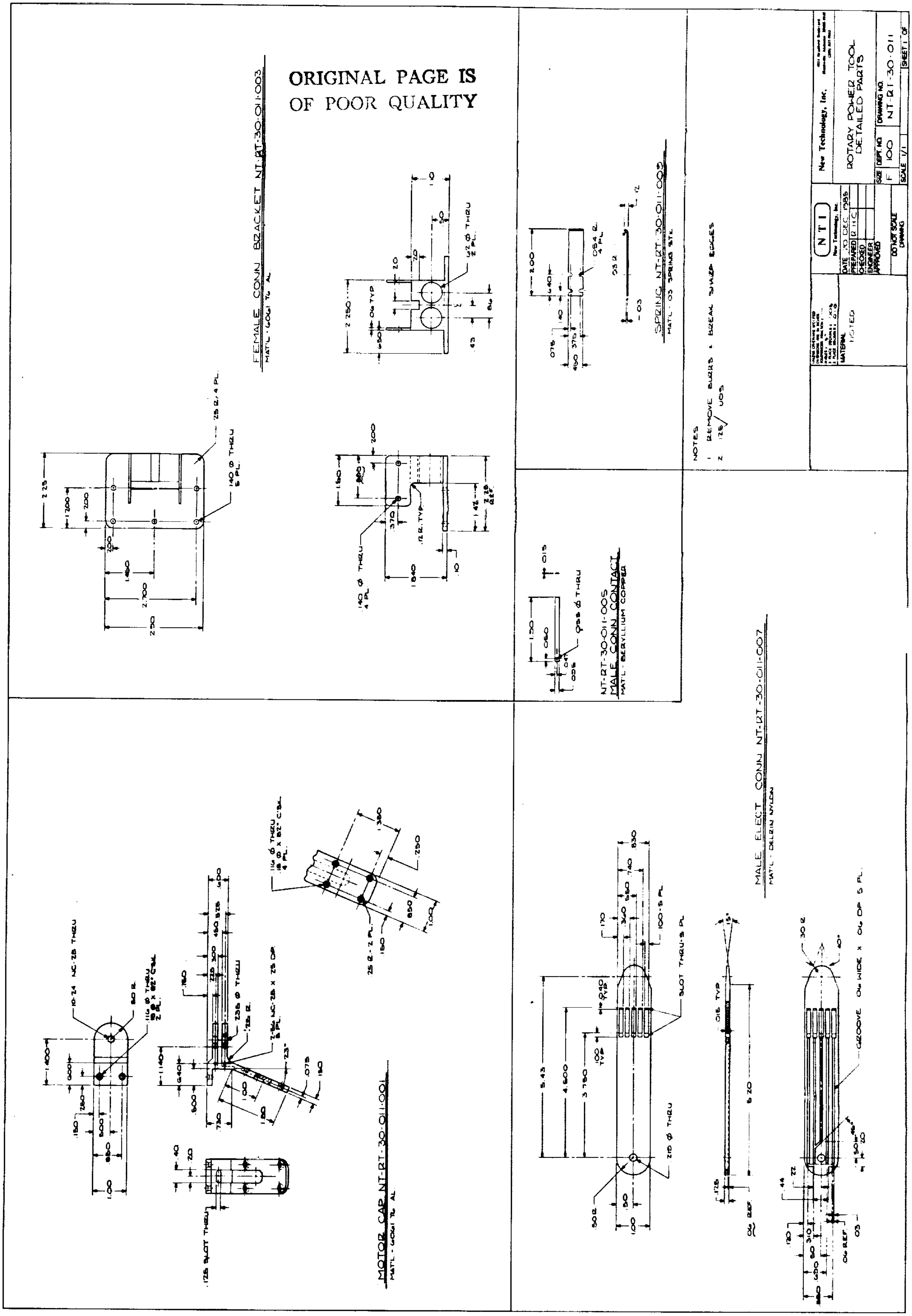
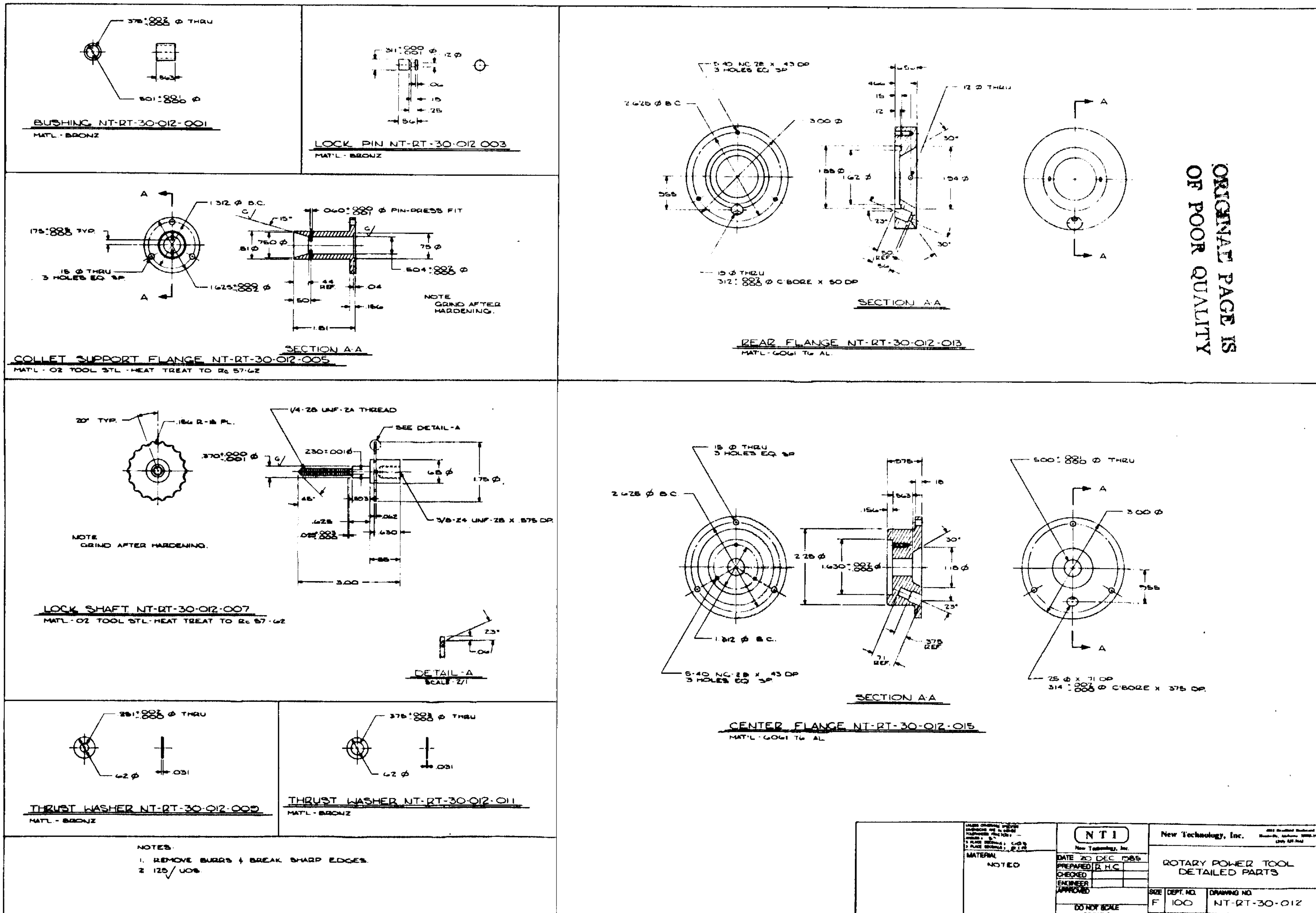
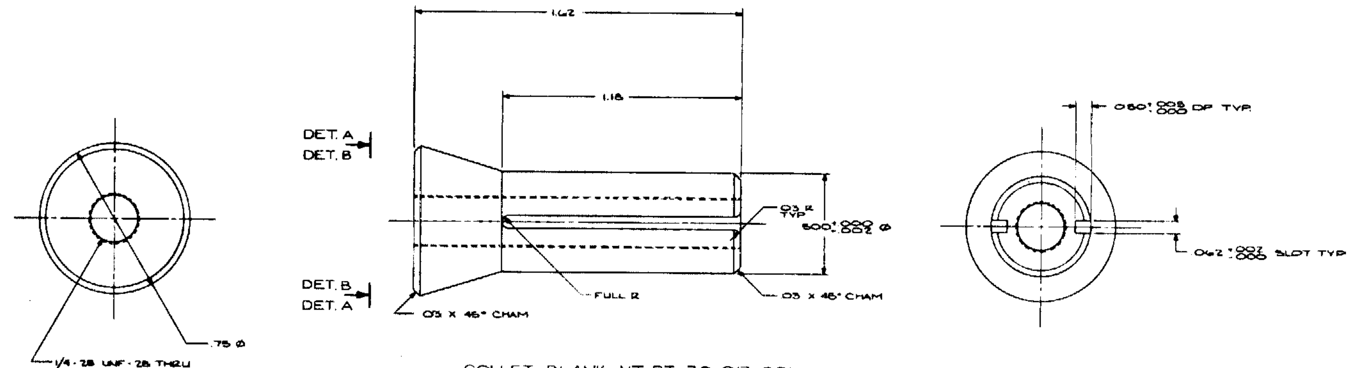
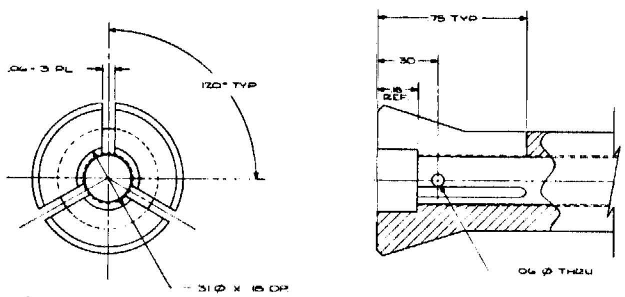



BUSHING NT-RT-30-012-001
MAT'L - BRONZ
LOCK PIN NT-RT-30-012 003
MAT'L - BRONZ
COLLET SUPPORT FLANGE NT-RT-30-012-005
MAT'L - O2 TOOL STL - HEAT TREAT TO Rc 57-62
SECTION A-A
NOTE
GRIND AFTER HARDENING.
REAR FLANGE NT-RT-30-012-013
MAT'L - 6061 T6 AL.
SECTION A-A
LOCK SHAFT NT-RT-30-012-007
MAT'L - O2 TOOL STL - HEAT TREAT TO Rc 57-62
NOTE
GRIND AFTER HARDENING.
1/4-28 UNF-2A THREAD
SEE DETAIL-A
3/8-24 UNF-2B X .875 DP.
DETAIL-A
SCALE 2/1
CENTER FLANGE NT-RT-30-012-015
MAT'L - 6061 T6 AL
SECTION A-A
THRUST WASHER NT-RT-30-012-009
MAT'L - BRONZ
THRUST WASHER NT-RT-30-012-011
MAT'L - BRONZ
NOTES
1. REMOVE BURRS & BREAK SHARP EDGES.
2. 125/ UOS.
NTI
New Technology, Inc.
ROTARY POWER TOOL
DETAILED PARTS
DATE 20 DEC 1985
PREPARED R.H.C.
CHECKED
ENGINEER
APPROVED
MATERIAL
NOTED
DO NOT SCALE DRAWING
SIZE F
DEPT. NO. 100
DRAWING NO. NT-RT-30-012
SCALE 1/1
SHEET 1 OF



COLLET BLANK NT-RT-30-013-001
MAT'L - O2 TOOL STL. - HEAT TREAT TO Rc 57-62
SCALE - 4/1

NOTE:
SEE DET. A OR B FOR PIECE COMPLETION



DETAIL A NT-RT-30-013-003
MAT'L - USE COLLET BLANK
SCALE - 4/1

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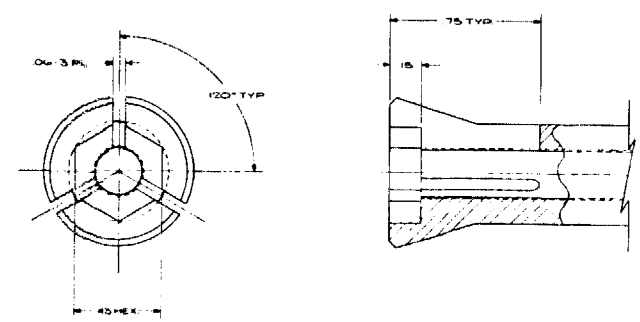

DETAIL B NT-RT-30-013-005
MAT'L - USE COLLET BLANK
SCALE - 4/1

NOTES
1. REMOVE BURRS & BREAK SHARP EDGES
2. 125/ USO

MATERIAL: NOTED

NTI — New Technology, Inc.

DATE: 20 DEC 1985
PREPARED: R H C
CHECKED
ENGINEER
APPROVED
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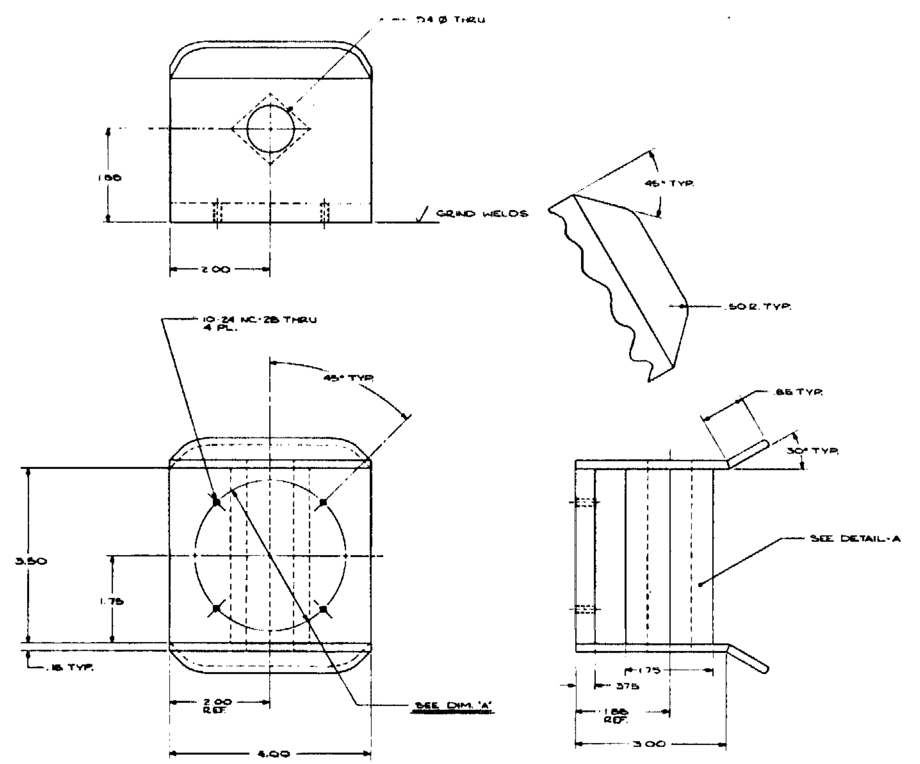
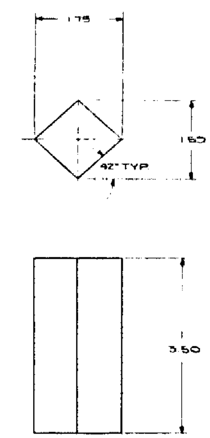
New Technology, Inc.

ROTARY POWER TOOL
COLLET DETAILS

SIZE	DEPT. NO.	DRAWING NO.
F	100	NT-RT-30-013

SCALE 1/1 SHEET 1 OF





DETAIL-A

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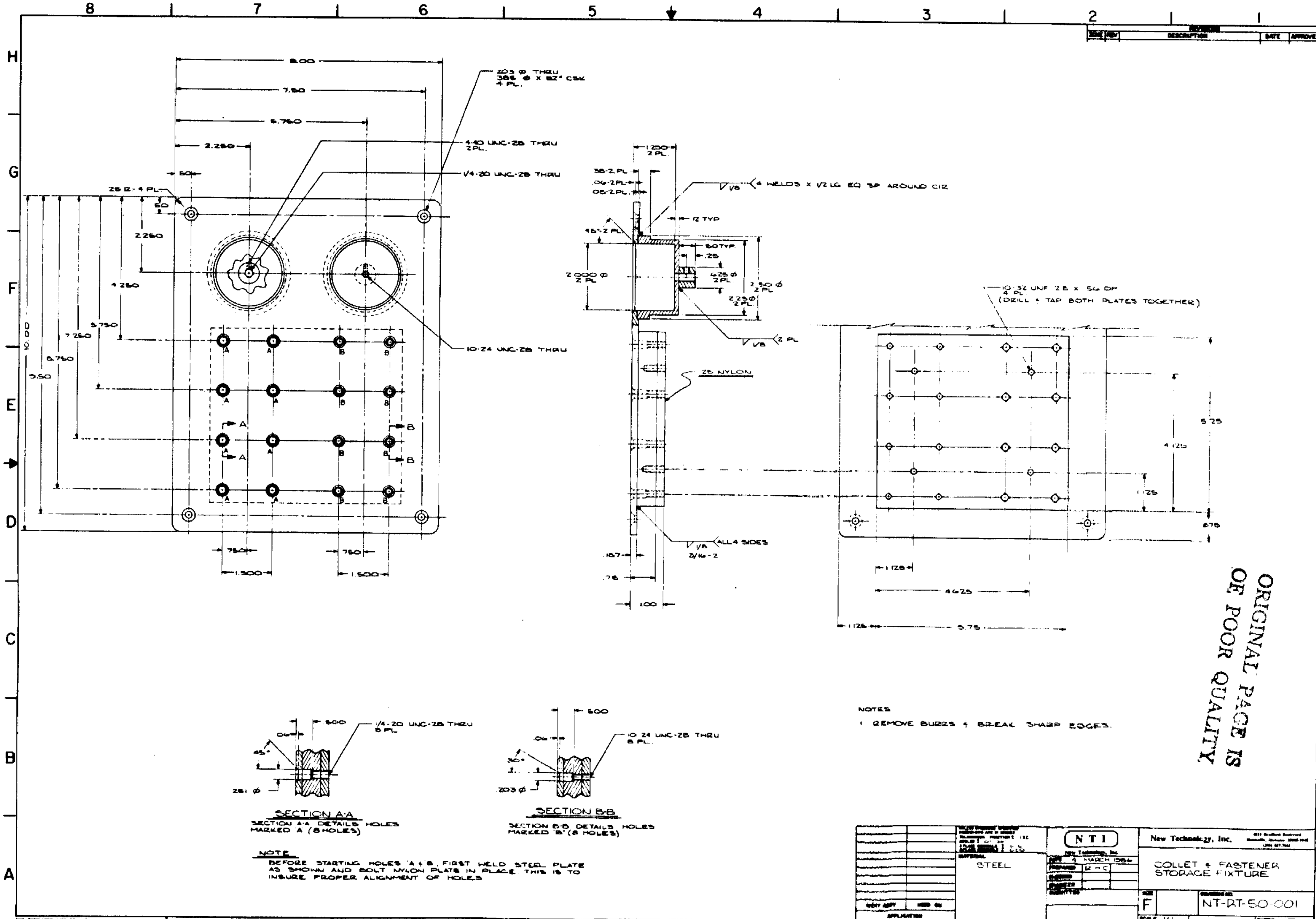
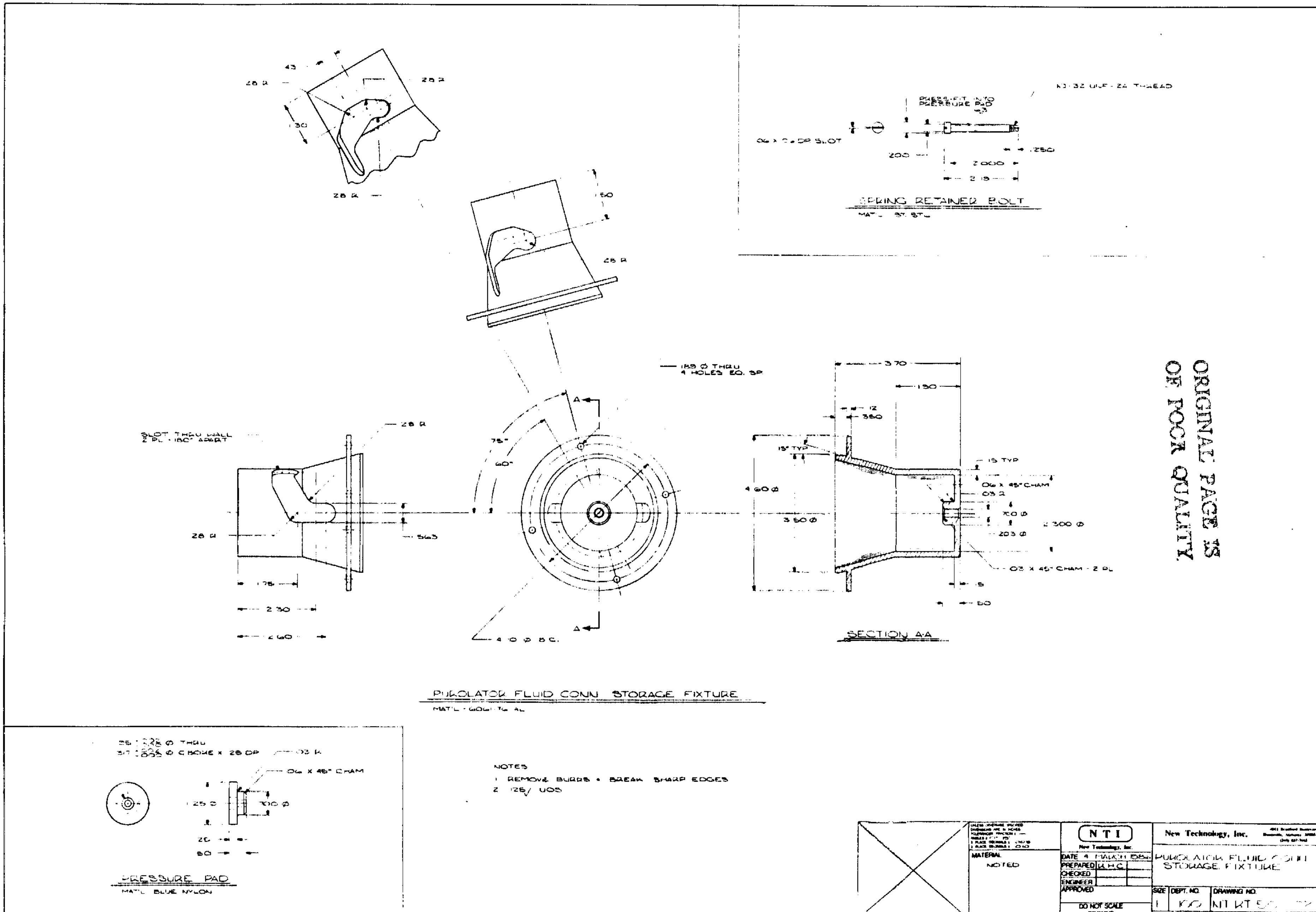
NOTES
1. REMOVE BURRS & BREAK SHARP EDGES
2. 125/ UOS
3. WELDED CONST.

PART NO	DIM 'A'
NT-RT-40-001-001	2.875 Ø BC
NT-RT-40-001-003	3.000 Ø BC
NT-RT-40-001-005	3.120 Ø BC

TOOL BASE ASSEMBLY
MAT'L - 6061 T6 AL

MATERIAL: NOTED	NTI New Technology, Inc.	New Technology, Inc.
	DATE 20 DEC 1985	UNIVERSAL TOOL BASE
	PREPARED R. H. C.	
	CHECKED	
	ENGINEER	SIZE F / DEPT. NO. 100 / DRAWING NO. NT-RT-40-001
	APPROVED	
	DO NOT SCALE DRAWING	SCALE 1/1 / SHEET 1 OF 1


203 Ø THRU
386 Ø X 82° CSK
4 PL.
4-40 UNC-2B THRU
2 PL.
1/4-20 UNC-2B THRU
10-24 UNC-2B THRU
4 WELDS X 1/2 LG EQ SP AROUND CIR
25 NYLON
ALL 4 SIDES
10-32 UNF 2B X .56 DP
4 PL
(DRILL & TAP BOTH PLATES TOGETHER)
NOTES
1 REMOVE BURRS & BREAK SHARP EDGES.
1/4-20 UNC-2B THRU
8 PL
SECTION A-A
SECTION A-A DETAILS HOLES
MARKED A (8 HOLES)
10-24 UNC-2B THRU
8 PL.
SECTION B-B
SECTION B-B DETAILS HOLES
MARKED B (8 HOLES)
NOTE
BEFORE STARTING HOLES A & B, FIRST WELD STEEL PLATE
AS SHOWN AND BOLT NYLON PLATE IN PLACE. THIS IS TO
INSURE PROPER ALIGNMENT OF HOLES
STEEL
NTI
4 MARCH 1984
New Technology, Inc.
COLLET & FASTENER
STORAGE FIXTURE
F
NT-RT-50-001
SCALE 1/1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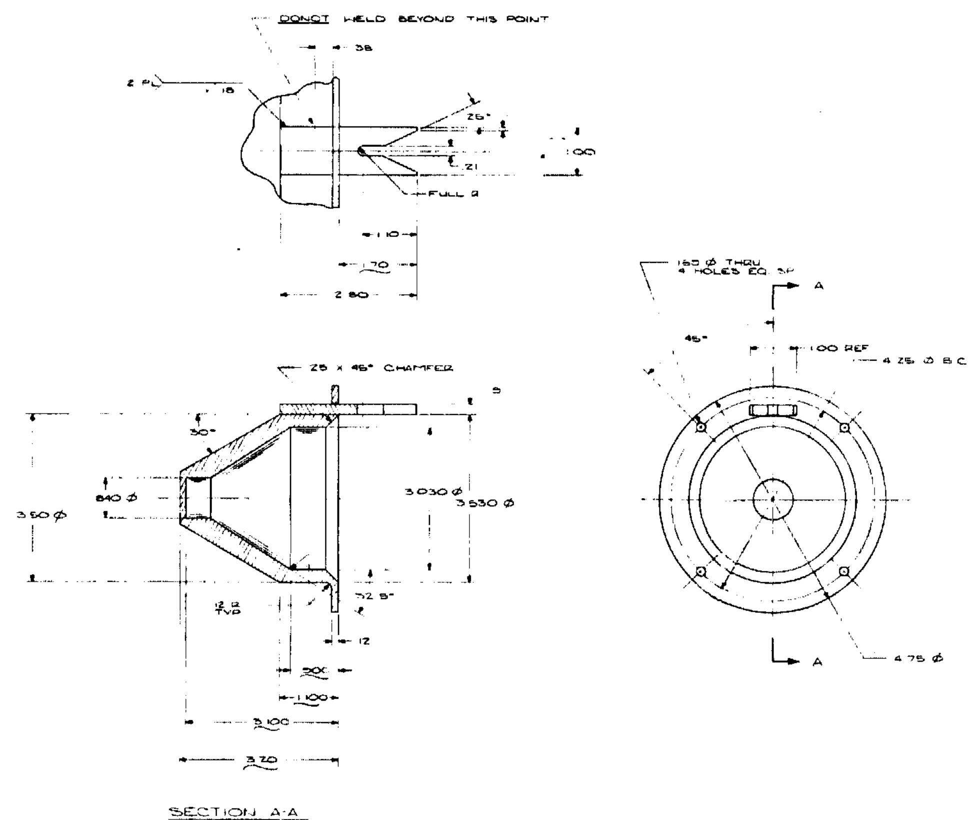
SPRING RETAINED BOLT
MAT'L - ST. STL
PRESS-FIT INTO PRESSURE PAD
.06 x .04 DP SLOT
2.000
2.15
.250
.200
.189 Ø THRU 4 HOLES EQ. SP
SLOT THRU WALL 2 PL - 180° APART
28 R
.563
1.75
2.30
2.60
75°
60°
4.00 Ø B.C.
SECTION A-A
3.70
1.50
.12
.380
15° TYP
4.60 Ø
3.50 Ø
.15 TYP
.06 x 45° CHAM
.03 R
.700 Ø
.203 Ø
2.300 Ø
.03 x 45° CHAM - 2 PL
.60
PUROLATOR FLUID CONN. STORAGE FIXTURE
MAT'L - 6061-T6 AL
NOTES
1. REMOVE BURRS + BREAK SHARP EDGES
2. 125/ UOS
.06 x 45° CHAM
.700 Ø
1.25 Ø
.20
.60
PRESSURE PAD
MAT'L - BLUE NYLON
MATERIAL
NOTED
NTI
New Technology, Inc.
DATE
PREPARED
CHECKED
ENGINEER
APPROVED
DO NOT SCALE DRAWING
PUROLATOR FLUID CONN
STORAGE FIXTURE
SIZE
DEPT. NO
DRAWING NO
SCALE 1/1
SHEET 1 OF 1



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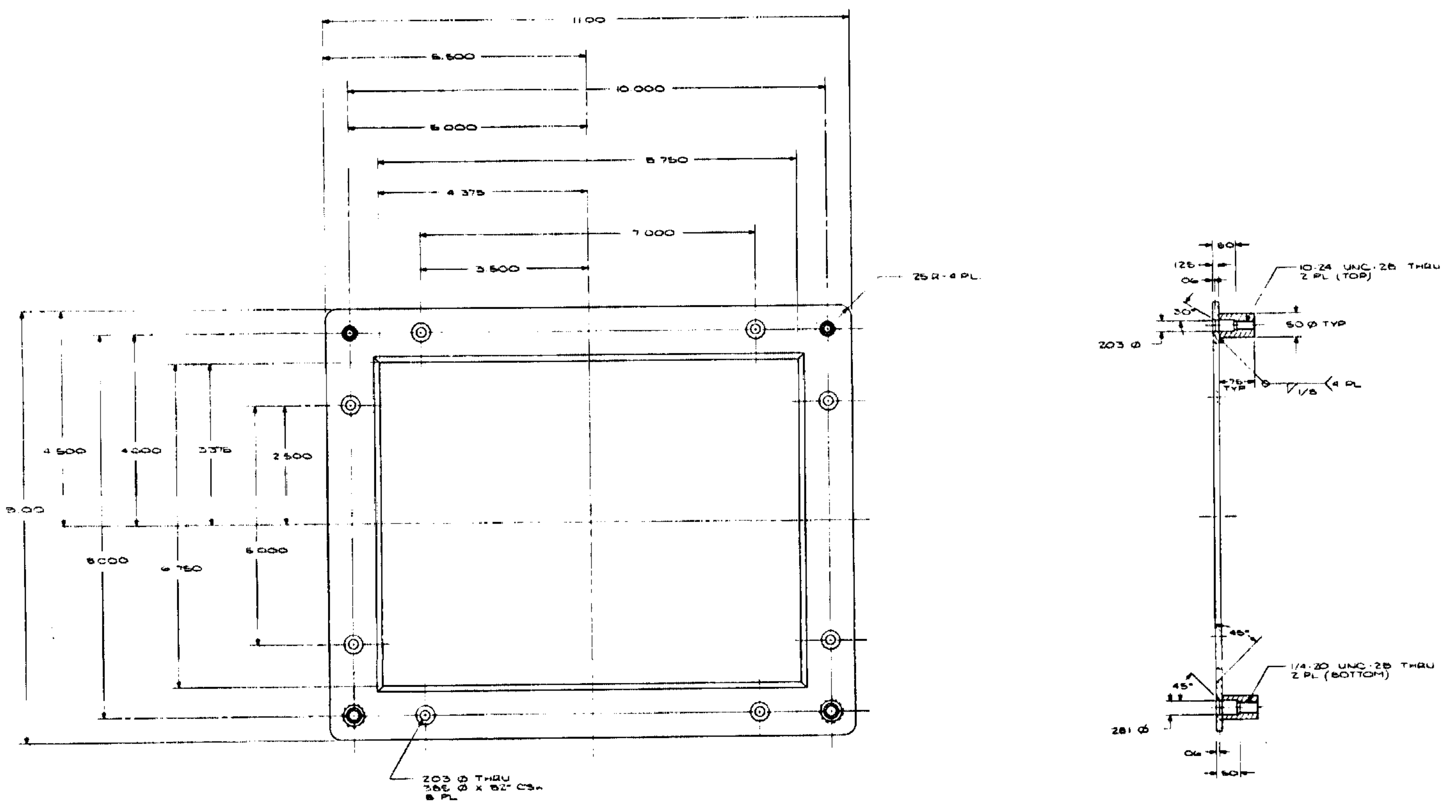
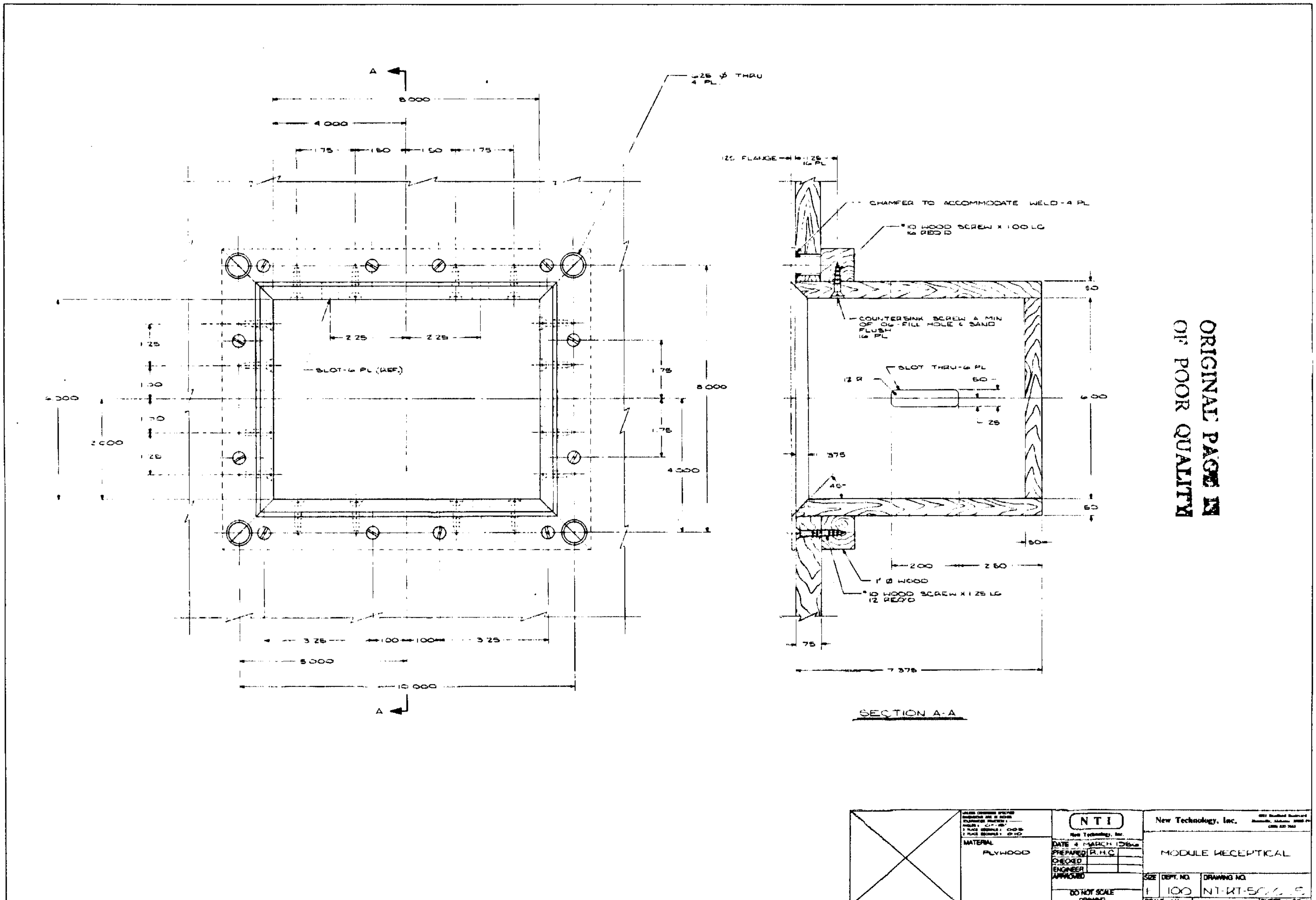
NOTES
1. REMOVE BURRS & BREAK SHARP EDGES
2. 25/ USE

MATERIAL 6061-T6 AL.	NTI New Technology, Inc.	New Technology, Inc.	
	DATE 4 MARCH 1986	TORQUE ADJUST FIXTURE	
	PREPARED R.H.C.		
	CHECKED		
	ENGINEER APPROVED	SIZE E / DEPT. NO. 100	DRAWING NO. NT-RT-50-003
	DO NOT SCALE DRAWING	SCALE 1/1	SHEET 1 OF 1



NOTES
1 REMOVE BURRS & BREAK SHARP EDGES

MATERIAL: STEEL	NTI New Technology, Inc.	New Technology, Inc.	
	DATE 4 MARCH 1986	MODULE MOUNTING FLANGE	
	PREPARED R.H.C.		
	CHECKED		
	ENGINEER		
	APPROVED	SIZE F	DEPT. NO. 100 — DRAWING NO. NT-KT-5C004
	DO NOT SCALE DRAWING	SCALE 1/1	SHEET 1 OF 1


.25 Ø THRU 4 PL
SLOT-6 PL (REF.)
125 FLANGE
CHAMFER TO ACCOMMODATE WELD-4 PL
#10 WOOD SCREW X 1.00 LG 16 REQ'D
COUNTERSINK SCREW A MIN OF .06 - FILL HOLE & SAND FLUSH 16 PL
SLOT THRU-6 PL
1" Ø WOOD
#10 WOOD SCREW X 1.25 LG 12 REQ'D
SECTION A-A
MATERIAL
PLYWOOD
NTI
New Technology, Inc.
DATE 4 MARCH 1986
PREPARED R.H.C.
CHECKED
ENGINEER
APPROVED
DO NOT SCALE DRAWING
MODULE RECEPTICAL
SIZE
DEPT. NO. 100
DRAWING NO.
SCALE 1/1
SHEET 1 OF 1

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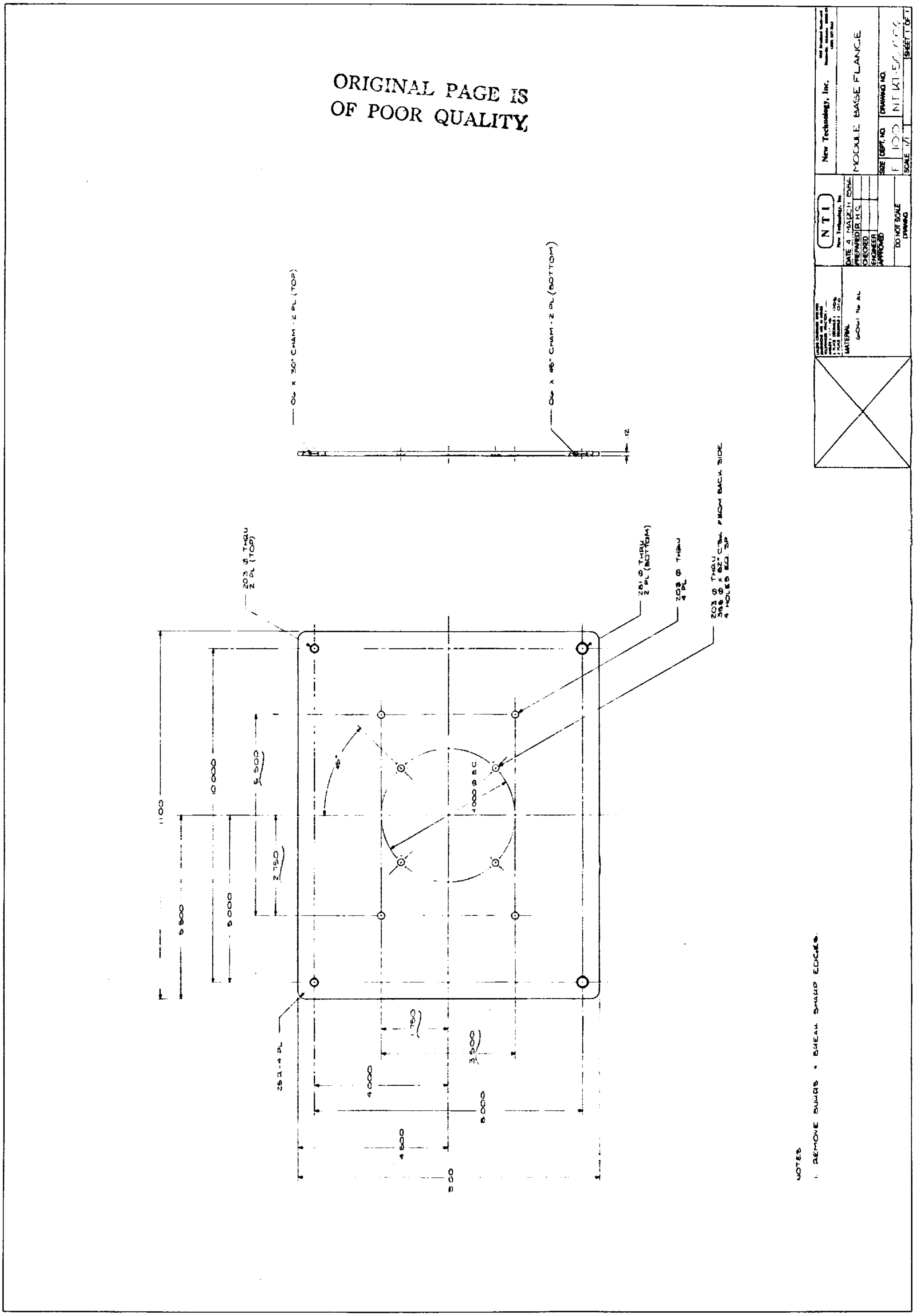

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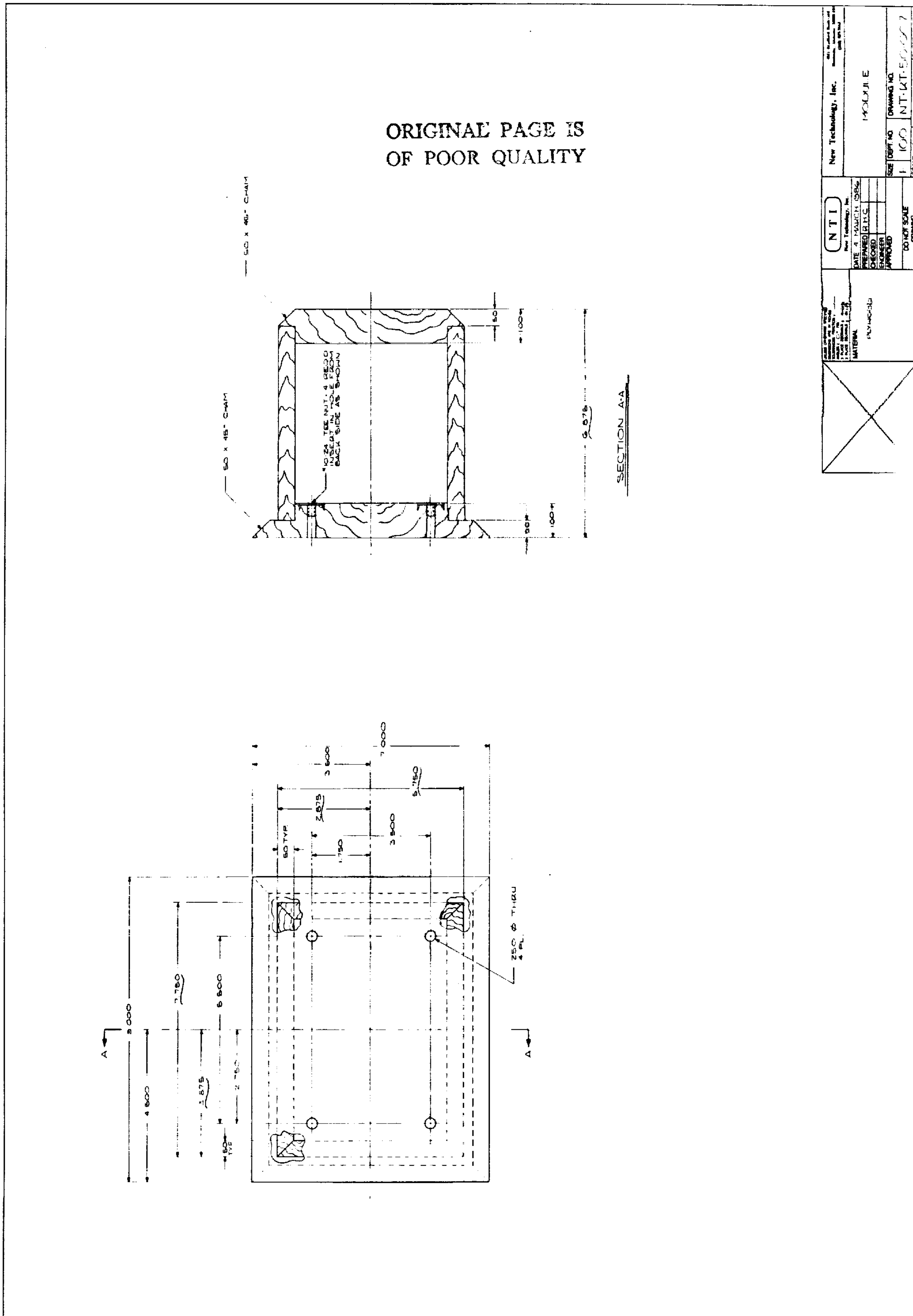

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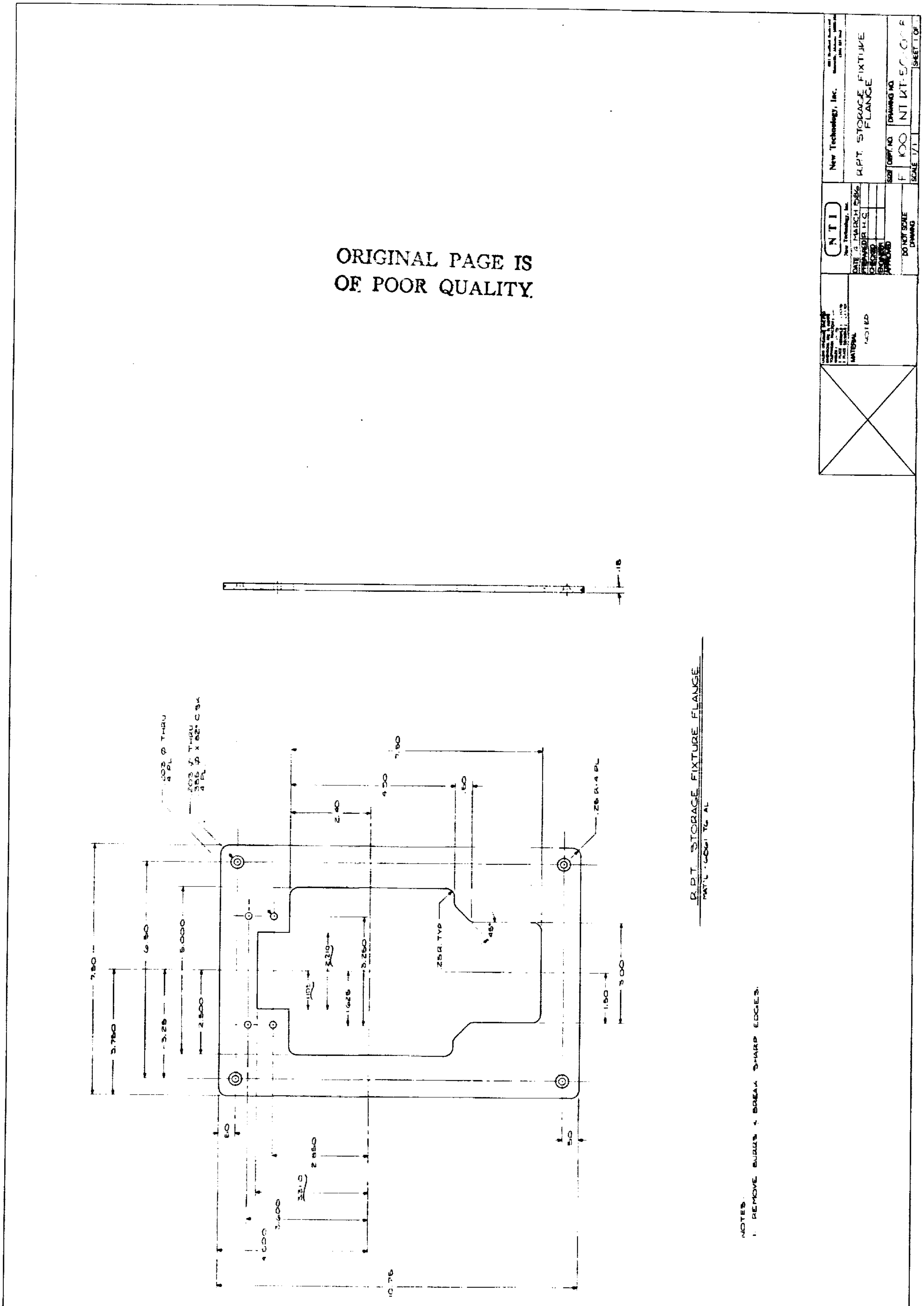

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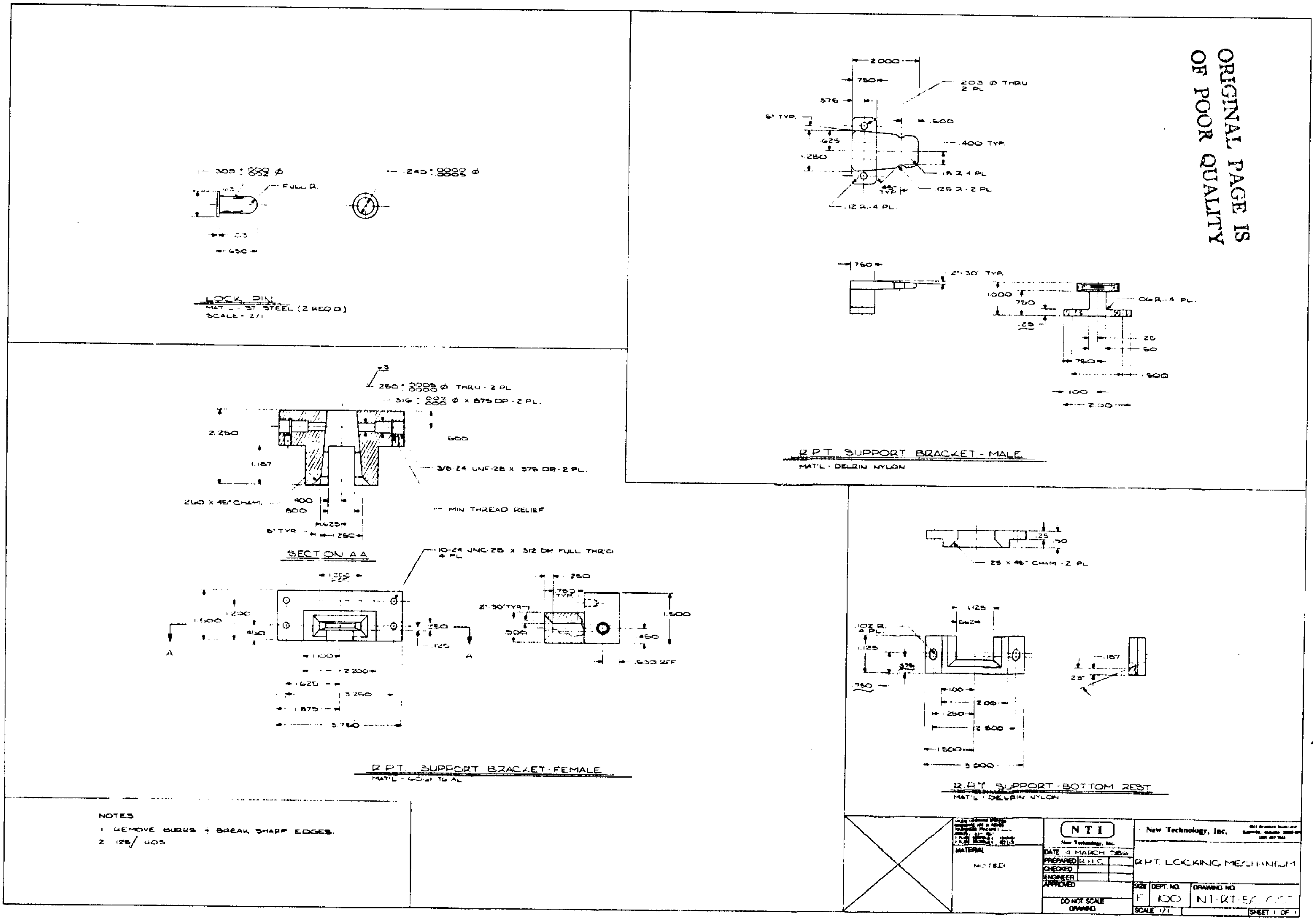

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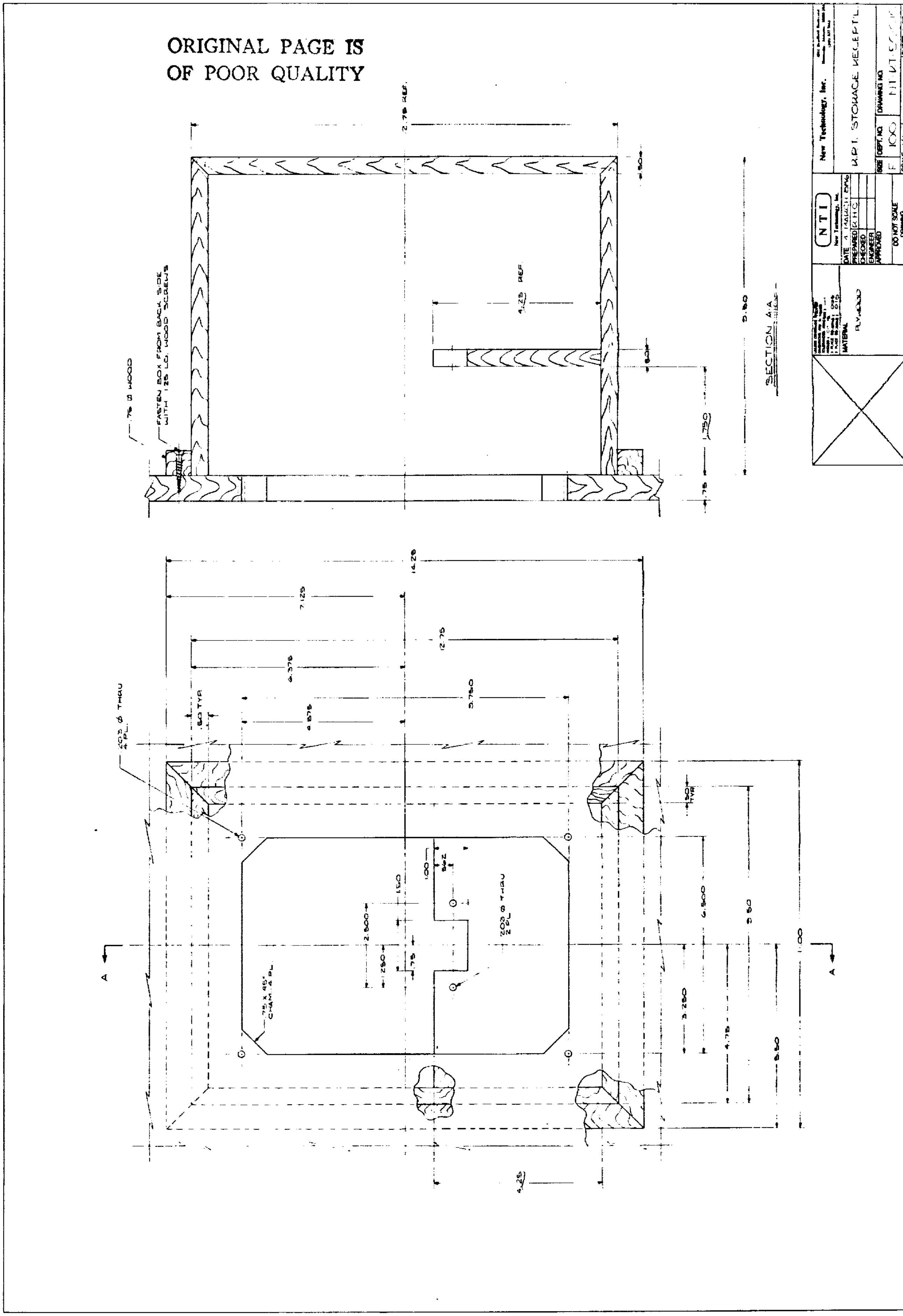
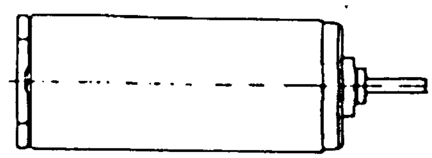


MicroMo MOTORS

DC MicroMotors Series 1331

- 1-oz.-in Stall Torque
- Samarium Cobalt Magnet
- Fits Our 15/5 Series Heavy Duty Gearhead
- Platinum Brushes Standard



Continuous Duty Ratings:[1]

Speeds up to 12,000 RPM
Torque up to .35 oz-in.
Output Power up to 2 Watts

Electrical Specifications:

For Model 1331T — @ 72°F (22°C)

	4.5S	006S	012S	024S
Nominal Voltage nom. (Volts)	4.5	6	12	24
Armature Resistance (Ohm) ± 12%	2.2	3.6	13.3	55
Max. Power Output (Watts)[2]	2.3	2.5	2.7	2.6
Max. Efficiency (%)[2]	73	73	72	72
No Load Speed (RPM) ± 12%[2]	11,700	12,000	12,000	12,000
No Load Current (mA) ± 50%[3]	43	35	21	10
Friction Torque (@ No Load Speed) (oz.-in.)	.021	.023	.028	.027
Velocity Constant (RPM/Volt)	2,656	2,043	1,024	512
Torque Constant (oz.-in/Amp)	.51	.66	1.32	2.64
Armature Inductance (mH)	.04	.08	.3	1.1
Back EMF Constant (mV/RPM)	.377	.490	.977	1.954
Stall Torque (oz.-in.)[2]	1.02	1.08	1.16	1.12

Mechanical Specifications:

	4.5S	006S	012S	024S
Mechanical Time Constant (mS)[2]	9	9	9	9
Armature Inertia ($x10^{-4}$ oz.-in.-Sec^2)	.075	.078	.084	.071
Radial Acceleration ($x10^3$ Rad/Sec^2)[2]	136	139	139	139

Bearing Play (measured at Bearing)
- Radial: Less than .03 mm (.0012")
- Axial: Less than 2 mm (.0079")

Thermal Resistances (°F/W)	4.5S	006S	012S	024S
Rotor to Case	6	6	6	6
Case to Ambient	43	43	43	43

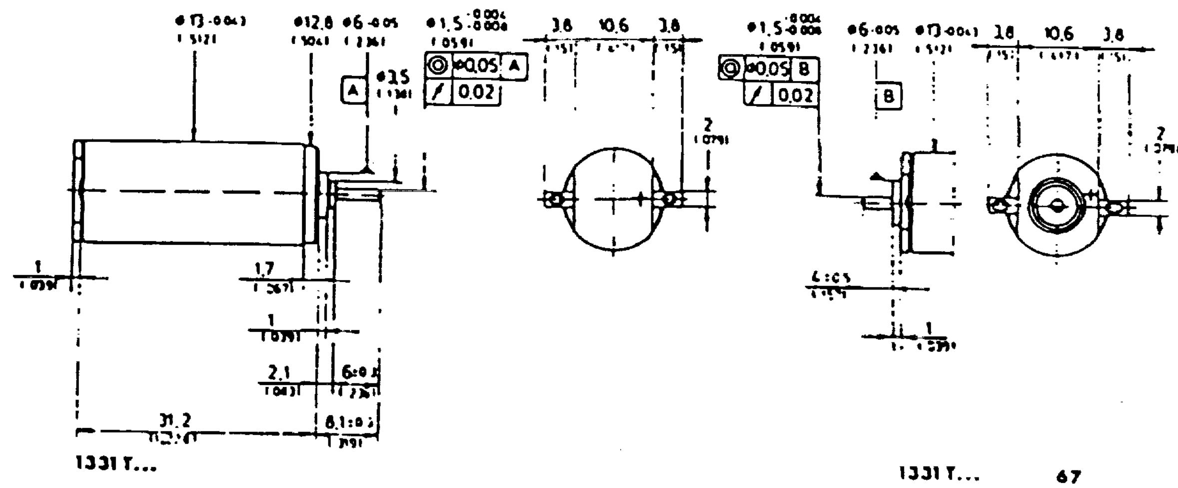
Max. Shaft Loading (oz.)[4]
- Radial (@ 3000 RPM): 3.58 All Types
- Axial (Standing Still): 35.8 All Types

Weight (oz.): .71 All Types
Rotor Temperature Range: Std. −22°F to 212°F
Special High Temperature Rotor: −67°F to 257°F

(1) Life Expectancy Greater Than 1,000 Hrs. if these Ratings are Observed Ratings are Presented Independent of Each Other.
(2) Specified at Nominal Supply Voltage.
(3) Specified with Shaft Diameter = 1.5 mm at No-Load Speed.
(4) Bearing Life Expectancy Greater Than 1,000 Hrs. if Loading Data is Observed.
(5) Direction of Rotation is Reversible and Clockwise as seen from Shaft End if Red Lead or Solder Tab Marked + is Connected to Positive Side of Voltage Supply.

— Specifications Subject to Change —

Dimensional Outlines:



Dimensions are given in mm. (in)

Dimensions with no tolerance indicated are as follows:

For Dimensions:	Tolerance
Less than or equal to 6 mm.	±.1 mm. (.0039")
Less than or equal to 30 mm.	±.2 mm. (.0079")
Less than or equal to 120 mm.	±.3 mm. (.0118")

Ordering Information:

Example: To Order a 6 Volt, 1331 Motor intended to fit our 15/5 Gearheads, specify:

Motor 13 31 E 006 S ... + 15/5 . 485:1

- Motor Diameter (13)
- Motor Length (31)
- Output Shaft Configuration: (E)
  - E – Pinion for 15/5 Gearheads (9 Teeth, Metric Module – .2 mm., Modified Involute, DIN 58400, Pressure Angle – 20°)
  - T – 1.5 mm. Diam. x 6 mm. Shaft End
- Nominal Voltage (006)
- Commutator Plating Material: S – Silver, G – Gold (S)
- Special Order Numbers (where applicable) (...)
- Gearhead Type. (15/5)
- Desired Gear Ratio (485:1)

Micro Mo ELECTRONICS INC.
742 Second Avenue S. / St. Petersburg, Florida 33701 / Phone: 813/822-2529 / Telex: 807-982

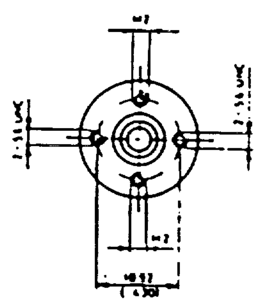
MicroMo GEARHEADS

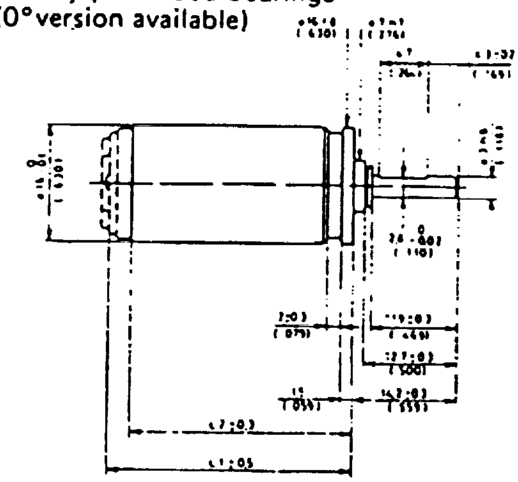
Gearhead Series 15/5 and 16/5

- For Motor Type 1331, 1516, 1524, 1616 and 1624
- 3 mm Output Shaft
- 2 Pre-Loaded Ball Bearings (Standard)
- 42.6 oz-in Max Output Torque
- Continuous Output Torque 14.2 oz-in
- Zero Backlash Version Available

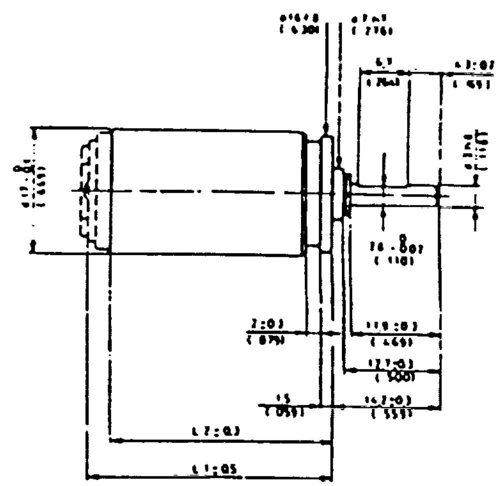
Maximum Ratings:

Shaft Loading: Dynamic: Radial 89.9 oz max, Axial 18.0 oz max,
Static: Radial 89.9 oz max.
Maximum Push-On Pressure: 18.0 oz
Shaft Play: Eliminated by preloaded bearings
Backlash: 3° max (0° version available)





type 15/5



type 16/5

1 reduction ratio	2 weight without motor 1)		3 length without motor		4 length with motors 1516 E .... 1616 E		length with motors 1524 E .... 1624 E		5 output torque, max. permissible continuous operation		intermittent operation		6 direct. of rotation	7 efficiency 2)
			L 2	L 2	L 1	L 1	L 1	L 1	M max.	M max	M max.	M max	R = cw	
	g	oz	mm	in	mm	in	mm	in	Nm 10⁻⁴	oz-in	Nm 10⁻⁴	oz-in	L = ccw	%
6,3 :1	17	0,53	27,8	1,094	29,1	1,146	37,1	1,461	600	8,52	2000	28,4	R	83
11,8 :1	17	0,53	27,8	1,094	29,1	1,146	37,1	1,461					R	83
22 :1	18	0,56	29,9	1,177	32,8	1,291	40,8	1,606					L	75
41 :1	18	0,56	29,9	1,177	32,8	1,291	40,8	1,606					L	75
76 :1	19	0,61	32,0	1,260	34,9	1,347	42,9	1,689	1000	14,2	3000	42,6	R	68
141 :1	19	0,61	32,0	1,260	34,9	1,374	42,9	1,689					R	68
~~262 :1~~	~~20~~	~~0,67~~	~~34,1~~	~~1,343~~	~~37,0~~	~~1,457~~	~~45,0~~	~~1,772~~					L	61
485 :1	20	0,67	34,1	1,343	37,0	1,457	45,0	1,772					L	61
900 :1	21	0,74	36,2	1,425	39,1	1,539	47,1	1,854					R	54
1670 :1	21	0,74	36,2	1,425	39,1	1,539	47,1	1,854					R	54
3101 :1	22	0,77	38,3	1,508	41,2	1,622	49,2	1,937					L	49
5752 :1	22	0,77	36,3	1,508	41,2	1,622	49,2	1,937					L	49
683 :1	23	0,81	40,4	1,591	43,3	1,705	51,3	2,020					R	44
.813 :1	23	0,81	40,4	1,591	43,3	1,705	51,3	2,020					R	44
36796 :1	24	0,85	42,5	1,673	45,4	1,787	53,4	2,102					L	40
68245 :1	24	0,85	42,5	1,673	45,4	1,787	53,4	2,102					L	40
125741 :1	25	0,90	44,6	1,756	47,5	1,870	55,5	2,185					R	39
235067 :1	25	0,90	44,6	1,756	47,5	1,870	55,5	2,185					R	39

1) by standard lubrication
2) at 30 % nominal torque

GEARHEADS

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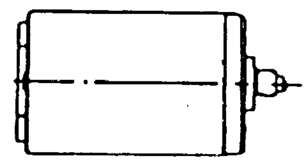
MicroMo MOTORS

DC MicroMotors Series 1624

- .6 oz-in. Typ. Stall Torque in a 16 mm Diameter Motor Package.
- Fits Our Slip-On Gearhead Series 16/1 (Plastic Case, Ratios 11.8:1 to 5752:1)
  16/2 (Metal Case, Ratios 3.45:1 to 235,067:1)
  16/3 (Metal Case, Ratios 6.3:1 to 235,067:1)
  16/5 (Metal Case, Ratios 6.3:1 to 235,067:1)
- Available with Integral Optical Rate Encoders (15 Pulses per Revolution)
- Available in 3, 6, 12 and 24 Volt Types.



Continuous Duty Ratings:(1)

Speeds up to 12,000 RPM
Torque up to .21 oz-in
Output Power up to .9 Watts

Electrical Specifications:

@ 72°F (22°C)

For Motor Type 1624 E	003S	006S	012S	024S
Supply Voltage nom. (Volts)	3	6	12	24
Armature Resistance (Ohm) ± 12%	1.6	8.6	24	75
Max. Power Output (Watts)(2)	1.41	1.05	1.50	1.92
Max. Efficiency (%)(2)	76	72	74	74
No Load Speed (RPM) ± 12%(2)	12,000	10,600	13,000	14,400
No Load Current (mA) ± 50%(3)	30	16	10	6
Friction Torque (@ No Load Speed) (oz-in)	.010	.011	.013	.013
Stall Torque (oz-in)(2)	.613	.510	.600	.694
Velocity Constant (RPM/Volt)	4,065	1,808	1,105	611
Back EMF Constant (mV/RPM)	.246	.553	.905	1.635
Torque Constant (oz-in/Amp)	.333	.748	1.223	2.212
Armature Inductance (mH)	.085	.20	.75	3.00

Mechanical Specifications:

	003S	006S	012S	024S
Mechanical Time Constant (mS)(2)	19	16	19	24
Armature Inertia ($x10^{-4}$ oz-in-Sec^2)	.111	.071	.082	.091
Radial Acceleration ($x10^3$ Rad/Sec^2)(2)	66.1	69.4	71.6	62.8
Bearing Play (measured at Bearing)				
Radial	Less Than .03 mm (.0012")			
Axial	Less Than .2 mm (.0079")			
Thermal Resistances (°F/W)				
Rotor to Case	8	9	9	8
Case to Ambient	43	54	47	47
Max. Shaft Loading (oz)(4)				
Radial (@ 3,000 RPM)	4.3 All Types			
Axial (Standing Still)	72 All Types			
Weight (oz)	.75 All Types			
Rotor Temperature Range (Special Models for −67°F to +257°F Available on Request)	−22°F to +150°F			

Direction of Rotation is Reversible and Clockwise as Seen From Shaft End if Red Lead or Solder Tab Marked + is Connected to Positive Side of Voltage Supply

(1) Life Expectancy Greater Than 1,000 Hrs. if These Ratings are Observed. Ratings are Presented Independent of Each Other
(2) Specified at Nominal Supply Voltage.
(3) Specified with Shaft Diameter = 1.5 mm. At No-Load Speed.
(4) Bearing Life Expectancy Greater Than 1,000 Hrs. if Loading Data is Observed.

— Specifications Subject to Change —

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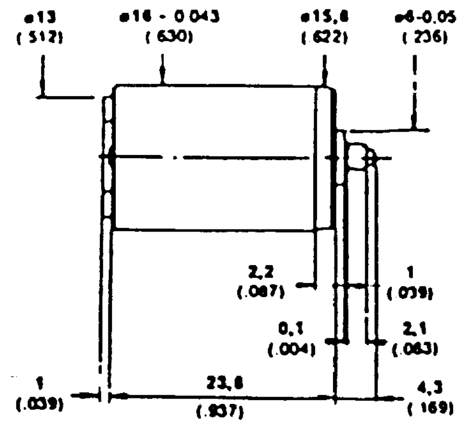
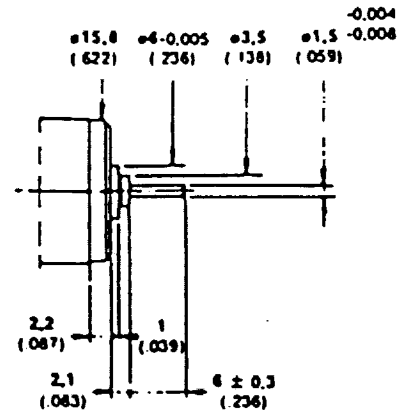
DC MicroMotors Series 1624

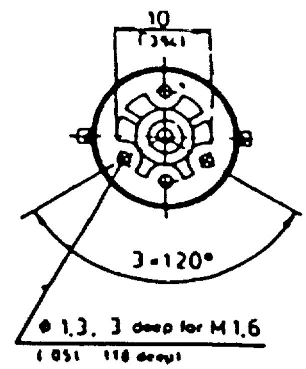
Dimensional Outlines:



Motor 1624 E...S



Motor 1624 T...S

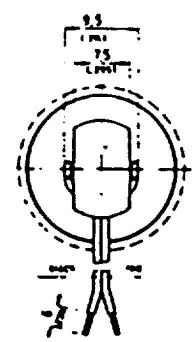


Front View

Dimensions are given in mm. (in)

Dimensions with no tolerance indicated are as follows:

For Dimensions:	Tolerance
Less than or equal to 6 mm.	±.1 mm. (.0039")
Less than or equal to 30 mm.	±.2 mm. (.0079")
Less than or equal to 120 mm.	±.3 mm. (.0118")



Rear View (Optional Leads)

Ordering Information:

Example: To Order a 6 Volt, 1624 Motor intended to fit our 16/2 Gearheads, specify:

Motor 16 24 E 006 S .... + 16/2 , 485:1

- **Motor Diameter** (16)
- **Motor Length** (24)
- **Output Shaft Configuration:** (E)
  - **E = Pinion for 16/1, 2, 3, 5 Gearheads (9 Teeth, Metric Module = .2 mm, Modified Involute Pressure Angle = 20°)**
  - **T = 1.5 mm. Diam. x 6 mm Shaft End**
- Nominal Voltage (006)
- Commutator Plating Material: S – Silver, G – Gold (S)
- Special Order Numbers (where applicable) (....)
- Gearhead Type. For 1624 Motor Gearhead Series 16/1, 16/2, 16/3 & 16/5 are applicable (16/2)
- Desired Gear Ratio (485:1)

Series 1624 is Available with 5.9" Long Leads Instead of Solder Tabs. Specify Letter "L" in Special Order Numbers Slot.

Micro Mo ELECTRONICS INC.
742 Second Avenue S. / St. Petersburg, Florida 33701 / Phone: 813/822-2529 / Telex: 807-982

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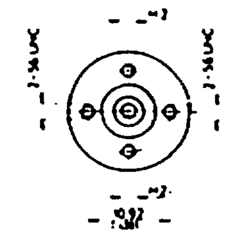
Gearhead Series 15/3 and 15/3 K (Formerly 05/3)
16/3 and 16/3 K (Formerly 05/30)

- Fits Motor Series 1516E . . . (Formerly 050/0 . . .), 1616E . . ., 1524E . . . (Formerly 250/0 . . .) and 1524E. . . .
- Case Material: Brass Alloy.
- 15/3K and 16/3K Contains Ball Instead of Sintered Bearings.



Series 15/3 and 16/3 Gearheads Front View

Maximum Ratings:

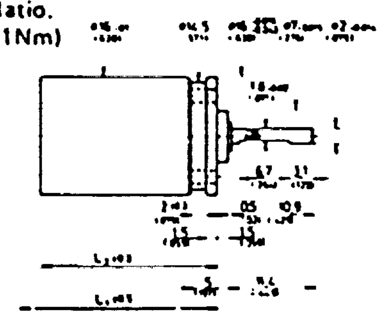
Temperature Range: −22°F to +150°F (−30°C to +65°C)
Special Models: −67°F to +257°F (−55°C to +125°C)
Shaft Loading: Radial 4.7 oz. (1.3N) Axial 7.2 oz. (2N)
Press-Fit Force: 108 oz. (30N)
Bearing Play: Radial .0012 in. (.03 mm), Axial .008 in. (.2 mm)
(Tighter Tolerances Available on Request)
Backlash: 5.4°
Continuous Torque Output: Depends on Ratio.
Intermittent Torque Output. 14.2 oz-in. (.1Nm)

Dimensional Outlines:

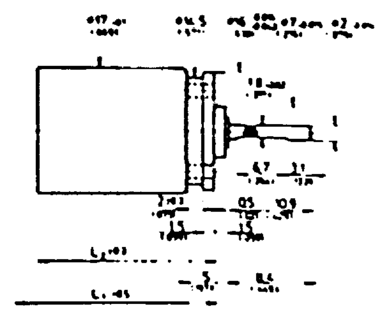
Dimensions are given in mm (in)

Dimensions with no tolerance indicated are as follows:

For Dimensions:	Tolerance
Less than or equal to 6 mm.	±.1 mm. (.0039")
Less than or equal to 30 mm.	±.2 mm. (.0079")
Less than or equal to 120 mm.	±.3 mm. (.0118")



Series 15/3 Gearheads



Series 16/3 Gearheads

1 Gear Ratio	2 Weight Without Motor		3 Length Without Motor		4 Length With Motor 1516E. . or 1616E . . .		Length With Motor 1524E. . or 1624E . . .		5 Max. Continuous Duty Torque Output		6* Rotation Direction	7 Efficiency
			L 2	L 2	L 1	L 1	L 1	L 1			R = CW	
	g	oz.	mm	in	mm	in	mm	in	$Nm10^{-4}$	oz-in.	L=CCW	%
6,3 :1	9,0	0,317	23,6	0,929	26,5	1,043	34,5	1,358	7	1,	R	81
11,8 :1	9,0	0,317	23,6	0,929	26,5	1,043	34,5	1,358	100	1,420	R	81
22 :1	10,0	0,353	25,7	1,012	28,6	1,126	36,6	1,441	100	1,420	L	73
41 :1	10,0	0,353	25,7	1,012	28,6	1,126	36,6	1,441	200	2,840	L	73
76 :1	12,	0,430	27,8	1,094	30,7	1,209	38,7	1,524	200	2,840	R	66
141 :1	12,	0,430	27,8	1,094	30,7	1,209	38,7	1,524	300	4,248	R	66
262 :1	13,0	0,459	29,9	1,177	32,8	1,291	40,8	1,606	300	4,248	L	59
485 :1	13,0	0,459	29,9	1,177	32,8	1,291	40,8	1,606	300	4,248	L	59
900 :1	15,0	0,529	32,0	1,260	34,9	1,374	42,9	1,689	300	4,248	R	53
1670 :1	15,0	0,529	32,0	1,260	34,9	1,374	42,9	1,689	300	4,248	R	53
3101 :1	16,0	0,557	34,0	1,339	37,0	1,457	45,0	1,772	300	4,248	L	48
5752 :1	16,0	0,557	34,0	1,339	37,0	1,457	45,0	1,772	300	4,248	L	48
10683 :1	17,0	0,600	36,2	1,425	39,1	1,539	47,1	1,854	300	4,248	R	43
19813 :1	17,0	0,600	36,2	1,425	39,1	1,539	47,1	1,854	300	4,248	R	43
36796 :1	18,0	0,635	38,3	1,508	41,2	1,622	49,2	1,937	300	4,248	L	39
68245 :1	18,0	0,635	38,3	1,508	41,2	1,622	49,2	1,937	300	4,248	L	39
126741 :1	19,0	0,688	40,4	1,591	43,3	1,705	51,3	2,020	300	4,248	R	35
235067 :1	19,0	0,688	40,4	1,591	43,3	1,705	51,3	2,020	300	4,248	R	35

*R = Clockwise. L = Counterclockwise as Viewed from Shaft End with Driving Motor Turning Clockwise.

—Specifications Subject to Change —

Micro Mo ELECTRONICS INC.
742 Second Avenue S. / St. Petersburg, Florida 33701 / Phone: 813/822-2529 / Telex: 807-982

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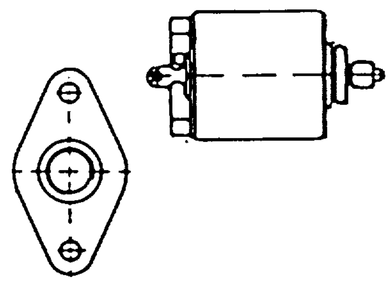
MicroMo MOTORS

DC MicroMotors Series 1212

- Our Smallest Motor: Only 12 mm Long with 12 mm Diameter.
- Fits Screw-On Gearhead Series 12/2 and 12/3 High Torque (Ratios from 9:1 to 154368:1)
- Available in 1.8, 2.7, 4 and 6 Volt Types.



Continuous Duty Ratings:[1]

Speeds up to 15,000 RPM
Torque up to .014 oz-in
Output Power up to .1 Watts

Electrical Specifications:

@ 72°F (22°C)

For Motor Type 1212E (Formerly Type 060/...)	01.8G	02.7G	004G	006G
Supply Voltage nom. (Volts)	1.8	2.7	4	6
Armature Resistance (Ohm) ±12%	6	12	20	79
Max. Power Output (Watts)[2]	.14	.15	.20	.11
Max. Efficiency (%)[2]	50	51	50	43
No Load Speed (RPM) ±12%[2]	18000	17300	20300	17400
No Load Current (mA) ±50%[3]	24	17	16	8
Friction Torque (@ No Load Speed) (oz-in)	.003	.003	.004	.003
Stall Torque (oz-in)[2]	.034	.041	.045	.028
Velocity Constant (RPV/Volt)	10870	6931	5516	3241
Back EMF Constant (mV/RPM)	.092	.144	.181	.309
Torque Constant (oz-in/Amp)	.125	.196	.245	.418
Armature Inductance (mH)	.03	.1	.18	1.6

Mechanical Specifications:

	01.8G	02.7G	004G	006G
Mechanical Time Constant (mS)[2]	140	100	75	115
Armature Inertia ($x10^{-4}$ oz-in-Sec^2)	.026	.023	.016	.019
Radial Acceleration ($x10^3$ Rad/Sec^2)[3]	13.5	18.1	28.3	15.8

Bearing Play (measured at Bearing)	
Radial	Less Than .03 mm (.0012")
Axial	Less Than .2 mm (.0079")
Thermal Resistances (°F/W)	
Rotor to Case	54 All Types
Case to Ambient	108 All Types
Max. Shaft Loading (oz)[4]	
Radial (@ 3,000 RPM)	1.8 All Types
Axial (Standing Still)	72 All Types
Weight (oz)	.23 All Types
Rotor Temperature Range (Special Models for −67°F to +257°F Available on Request)	−22°F to +150°F

Direction of Rotation is Reversible and Clockwise as Seen From Shaft End if Red Lead or Solder Tab Marked + is Connected to Positive Side of Voltage Supply

(1) Life Expectancy Greater Than 1,000 Hrs. if These Ratings are Observed. Ratings are Presented Independent of Each Other.
(2) Specified at Nominal Supply Voltage.
(3) Specified with Shaft Diameter − .8 mm. At No-Load Speed.
(4) Bearing Life Expectancy Greater Than 1,000 Hrs. if Loading Data is Observed.

— Specifications Subject to Change —

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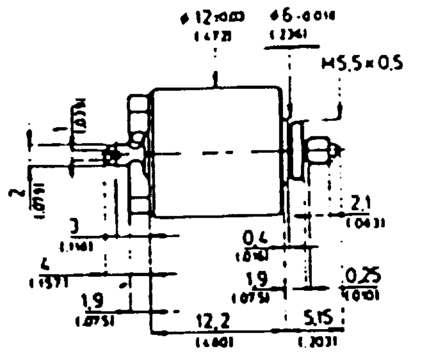
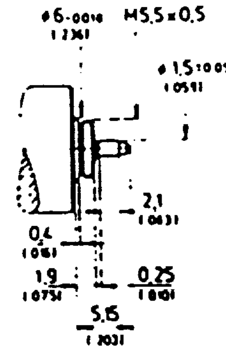
DC MicroMotors Series 1212

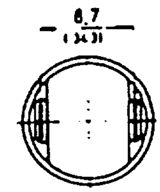
Dimensional Outlines:



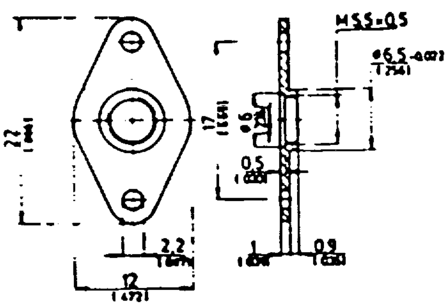
Motor 1212 E...



Motor 1212 N...



Motor 1212...
Lead Configuration



Mounting Plate

Dimensions are given in mm. (in)

Dimensions with no tolerance indicated are as follows:

For Dimensions:	Tolerance
Less than or equal to 6 mm.	±.1 mm. (.0039")
Less than or equal to 30 mm.	±.2 mm. (.0079")
Less than or equal to 120 mm.	±.3 mm. (.0118")

Ordering Information:

Example: To Order a 6 Volt, 1212 Motor intended to Fit our 12/3 Gearheads, specify:

Motor 12 12 E 006 G ... + 12/3 20.6:1

- Motor Diameter — 12
- Motor Length — 12
- **Output Shaft Configuration:** — E
  - **E = Pinion for 12/3 Gearheads (9 Teeth, Metric Module = .2 mm. Modified Involute)**
  - **N = 1.5 mm. Diam. x 2.1 mm. Sleeve on 0.8 mm. Diam. Shaft.**
- Nominal Voltage — 006
- Brushes/Commutator Plating Material: G = Gold. — G
- Special Order Numbers (where applicable) — ...
- Gearhead Type — 12/3
- Desired Gear Ratio — 20.6:1

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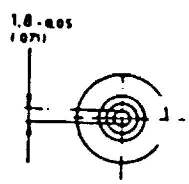
MicroMo GEARHEADS

Gearhead Series 12/3 and 12/3K

- Fits Motor Series 1212E and 1219E
- Case Material: German Silver
- 12/3 Contains Sleeve Bearings, 12/3K Contains Preloaded Ball Bearings.

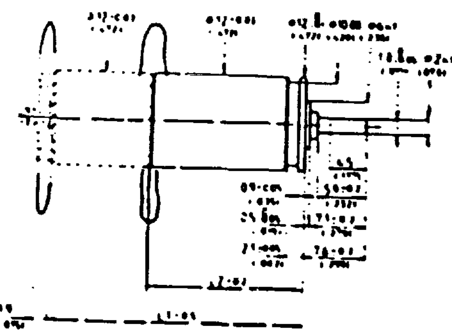
Maximum Ratings:

Temperature Range: −22°F to +150°F (−30°C to +65°C)
Special Models: −67°F to +257°F (−55°C to +125°C)
Shaft Loading: Radial 10.8 oz (3N), Axial 36 oz (10N)
Press Fit Force: 36 oz (10N)
Bearing Play: Radial .0012 in. (.03mm), Axial .004 in. (.1mm)
(Tighter Tolerances Available on Request)
Backlash: 3° Unloaded
Continuous Torque Output: 5.64 oz-in.
Intermittent Torque Output: 14.1 oz-in.



Front View

Gearhead 12/3 shown with 1212E Motor



1	2		3		4				5		6*	7
Ratios	Weight Without Motor		Length Without Motor		Length With Motor 1212E		Length With Motor 1219E		Maximum Torque Output		Rotation Direction	Efficiency
			L2		L1		L1		Continuous	Intermittent	R = CW	
	g	oz	mm	in	mm	in	mm	in	oz-in	oz-in	L = CCW	%
9.17 : 1	9.1	0.321	15.5	0.610	27.7	1.091	34.2	1.346	5.64	14.1	L	90
20.6 : 1	10.0	0.353	17.6	0.693	29.8	1.173	36.3	1.429	5.64	14.1	R	86
46.4 : 1	10.9	0.385	19.7	0.776	31.9	1.256	38.4	1.512	5.64	14.1	L	81
104.4 : 1	11.8	0.416	21.8	0.858	34.0	1.339	40.5	1.594	5.64	14.1	R	77
235 : 1	12.7	0.448	23.9	0.941	36.1	1.421	42.6	1.677	5.64	14.1	L	74
529 : 1	13.6	0.480	26.0	1.024	38.2	1.504	44.7	1.760	5.64	14.1	R	70
1190 : 1	14.5	0.511	28.1	1.106	40.3	1.587	46.8	1.843	5.64	14.1	L	66
2677 : 1	15.4	0.543	30.2	1.189	42.4	1.669	48.9	1.925	5.64	14.1	R	63
6023 : 1	16.3	0.575	32.3	1.272	44.5	1.752	51.0	2.008	5.64	14.1	L	60
13552 : 1	17.2	0.607	34.4	1.354	46.6	1.835	53.1	2.091	5.64	14.1	R	57
30492 : 1	18.1	0.638	36.5	1.437	48.7	1.917	55.2	2.173	5.64	14.1	L	54
68608 : 1	19.0	0.674	38.6	1.520	50.8	2.000	57.3	2.256	5.64	14.1	R	51
154368 : 1	19.9	0.702	40.7	1.602	52.9	2.083	59.4	2.339	5.64	14.1	L	49

*R = Clockwise, L = Counterclockwise, as viewed from Shaft End with Driving Motor Turning Clockwise.
Note: Gearheads are Fully Reversible. From Ratio 9.17 (9.16667) on, Subsequent Ratios are Multiples of 27/12 = 2.25.

— Specifications Subject to Change —

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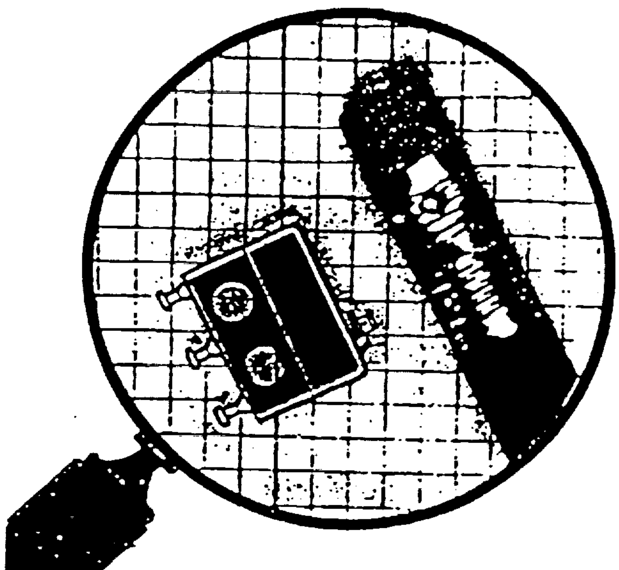
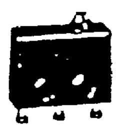


Catalog Listings
1SX1-T (MS24547-1)
and 3SX1-T



Actual Size

FEATURES

These smallest available single-pole double-throw snap-action switches open a new world of possibilities for the designer of compact devices. Where switch reliability, space-saving and weight-saving are important, these switches set new standards of compactness, combining this new small size with ample electrical capacity.

Not just a "shrinkage" of an existing design—it is a completely new concept resulting from a long period of engineering development and laboratory testing, coupled with years of basic experience in precision switching.

Case, cover and plunger are made of high-strength plastic. The unique, snap-action spring is fabricated of beryllium copper.

Turret-type terminals are used, permitting easy wiring and strong wrap-around lead wire connections. Terminals are plated for ease of soldering.

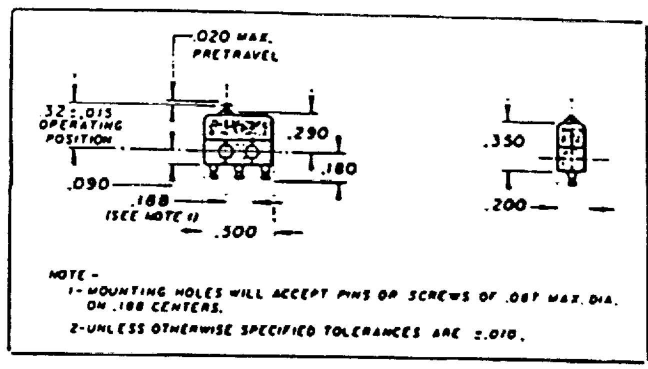
These switches will withstand temperatures from −100° to +250°F.

CONTACT ARRANGEMENT

Contact arrangement is single-pole double-throw, allowing either normally open or normally closed wiring.

TWO-HOLE MOUNTING

The two mounting holes will accept No. 2 screws. One hole is slightly elongated to simplify positioning of the switch.



AVAILABLE WITH SILVER OR GOLD CONTACTS

Catalog Listings 1SX1-T (MS24547-1) has silver contacts, while the 3SX1-T has gold contacts. They are dimensionally identical.

Gold contacts allow switching of milli-volt, milli-amp dry circuits, providing contact surety and stabilized contact resistance at low energy levels.

1SX1-T AND 3SX1-T CHARACTERISTICS

Operating Force	5 oz. max.
Release Force	1 oz. min.
Pretravel	.020 in. max.
Overtravel	.004 in. min.
Differential Travel	.005 in. max.
Weight	1/32 oz.

1SX1-T ELECTRICAL RATING
(Silver Contacts)

*28 vdc: 7 amps., resistive;
4 amps., inductive (sea level);
2.5 amps., inductive (50,000 feet);
4 amps. motor load; 2.5 amps., lamp load;
24 amps., maximum inrush.

Underwriters Laboratories' Listing.

*115/230 vac, 60 cycles: 7 amps., resistive and inductive; 15 amps., inrush.

*For 25,000 operations minimum.

3SX1-T ELECTRICAL RATING
(Gold Contacts)

28 vdc: 2 amps., inrush.
.5 amp. inductive; 1 amp., resistive.

Dimensions shown are for reference only and are subject to change without notice. Current drawings will be supplied upon request.