NOTICE: When government or other drawings, specifications or other data are used for any purpose other than in connection with a definitely related government procurement operation, the U. S. Government thereby incurs no responsibility, nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use or sell any patented invention that may in any way be related thereto.
ULTRASONIC WELDING PROCESS AND EQUIPMENT FOR CONSTRUCTION OF ELECTRON-TUBE MOUNTS

Second Quarterly Progress Report
For the Period
October 1 through December 31, 1962

Contract No. DA-36-039-sc86741
Order No. 19063-PP-62-8181

Placed by
Industrial Preparedness Activity
United States Army Electronics Material Agency

AEROPROJECTS INCORPORATED
West Chester, Pennsylvania

MAY 29 1963
ULTRASONIC WELDING PROCESS AND EQUIPMENT
FOR CONSTRUCTION OF ELECTRON-TUBE MOUNTS

Second Quarterly Progress Report
For the Period
October 1 through December 31, 1962

The object of this program is to design and construct prototype welding equipments and their associated accessories to perform by ultrasonic techniques the welding operations required in the assembly of electron tubes under Specifications SCS-114A and SCIPR-15.

Contract No. DA-36-039-sc86741
Order No. 19063-PP-62-81-81

Report Prepared by: [Signature]
Report Approved by: [Signature]
ABSTRACT

Results of welding eighty-two combinations of materials and geometries are presented. An evaluation program for all successfully welded combinations has been established. Progress in the effort to use ultrasonic welding in the manufacture of three specific electron tubes is reported.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>ABSTRACT</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>PURPOSES</td>
<td>1</td>
</tr>
</tbody>
</table>

## NARRATIVE AND DATA

<table>
<thead>
<tr>
<th>WELDING STUDY</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Material Procurement</td>
<td>2</td>
</tr>
<tr>
<td>2. Tooling</td>
<td>3</td>
</tr>
<tr>
<td>3. Welding</td>
<td>6</td>
</tr>
<tr>
<td>4. Weld Evaluation</td>
<td>9</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>WELD-EVALUATION PROGRAM FOR WIRE-TO-COUPON WELDMENTS</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>I Basic Data</td>
<td>12</td>
</tr>
<tr>
<td>II Shock Test</td>
<td>13</td>
</tr>
<tr>
<td>III Vibration and Fatigue Tests</td>
<td>13</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TEST-EXPOSURE SPECIFICATIONS FOR WIRE-TO-COUPON WELDMENTS</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>14</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ELECTRON-TUBE STUDY</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>14</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CHATHAM ELECTRONICS CORRELATIVE ACTIVITY</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>15</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CONCLUSIONS</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>16</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PROGRAM FOR THE NEXT REPORTING PERIOD</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>16</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>REFERENCES</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>17</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PROJECT SCHEDULE</th>
<th></th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>IDENTIFICATION OF TECHNICAL PERSONNEL</th>
<th></th>
</tr>
</thead>
</table>

**APPENDIX A**

111
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Successfully Welded Combinations of Fine and Heavy Wire to Coupon</td>
</tr>
<tr>
<td>2</td>
<td>Typical Welding Tip Used on the 100-Watt and 20-Watt Ultrasonic Welding Machines</td>
</tr>
<tr>
<td>3</td>
<td>Fixturing for the 20-Watt Welder (Pictured) and 100-Watt Welder</td>
</tr>
<tr>
<td>4</td>
<td>Modified Welding Fixture Installed on 4-KW Spot Welder</td>
</tr>
<tr>
<td>5</td>
<td>Anvil-Tip Configuration</td>
</tr>
<tr>
<td>6</td>
<td>Spherical-Radius Sonotrode Tips</td>
</tr>
<tr>
<td>7</td>
<td>3-Inch Grooved Spherical-Radius Sonotrode Tip</td>
</tr>
<tr>
<td>8</td>
<td>Notch Produced at Joint by Spherical-Radius Tip</td>
</tr>
<tr>
<td>9</td>
<td>Gold Wire (0.060-Inch) Welded to Nickel Plate (0.060-Inch)</td>
</tr>
<tr>
<td>10</td>
<td>Threshold Curve</td>
</tr>
<tr>
<td>11</td>
<td>Jaw Arrangement Permits Tensile-Shear Testing of Side-By-Side Ultrasonic Welds of 0.060-Inch Diameter Wire to the Same Coupon</td>
</tr>
<tr>
<td>12</td>
<td>Commercial Ultrasonic 20-Watt Welder</td>
</tr>
<tr>
<td>13</td>
<td>Wire-End Handling Technique for Hard and Soft Wires</td>
</tr>
<tr>
<td>14</td>
<td>Upside Down Position of Jaw Arrangement Used for Tensile-Shear Testing of High-Strength Wire-to-Coupon Welds</td>
</tr>
<tr>
<td>15</td>
<td>Specification for Weld Specimen and Test Planes</td>
</tr>
<tr>
<td>16</td>
<td>Sonotrode Tip for 600-Watt Welder</td>
</tr>
</tbody>
</table>
LIST OF TABLES

Table
1  Test Results of Fine-Wire-to-Coupon Junctures
2  Test Results of Heavy-Wire-to-Coupon Junctures
3  Weldment Materials Description
4  Tube Type 6080WB Assembly Sequence for Ultrasonic Welding
The objectives of this Production Engineering Measure (PEM) are to:

1. Demonstrate the capability limits of ultrasonic welding to join combinations of metallic materials of interest to the electron-tube industry. This part of the work will be limited in that it will not continue exhaustive attempts to weld those combinations which might prove particularly difficult to join.

2. Analyze the welding requirements for three specific electron tubes. The three tube types selected are the Type 6080WB, 5814WB and 6205. These were selected by the U. S. Army Electronics Material Agency because they are widely used in military equipment, and have a record of failures due to improperly welded joints.

3. Prepare fixturing and tooling for the specific electron tubes, so that ultrasonic welding may be used in the manufacturing process.

4. Weld the parts required to assemble electron-tube mounts for the three tube types, and evaluate.

5. Build production ultrasonic welding equipment which will enable an electron-tube manufacturer to make the welded connections in a broad range of electron-tube types.

6. Install the ultrasonic welding equipment in a production company, and produce on a pilot basis with that company's personnel, a limited lot size of each of the three tubes for subsequent evaluation in accordance with applicable military specifications.
NARRATIVE AND DATA

WELDING STUDY

The welding study was directed toward the accomplishment of the following objectives: (a) demonstration of the capability of ultrasonic welding to join 51 metal combinations in wire to flat sheet material (b) define tooling requirements and material surface preparation necessary to accomplish satisfactory welds in these combinations (c) development of an evaluation method for the welds that is sufficiently determinate to indicate successful application of ultrasonic welding to production manufacturing.

Figure 1 indicates a total of 91 weld specimens to be attempted (in two wire sizes for a total of 182) and incorporates the 51 similar and dissimilar metal combinations required to be ultrasonically welded under the program. Although welding was done on all of these 182 combinations during the period of this report, only 82 successful selected combinations (41 x 2) are shown by shaded blocks in the Figure. These combinations represent a group wherein satisfactory joint efficiencies had been obtained in both fine and heavy wire weldments in the same material combination. Joint efficiency (in percent) is calculated from the failure load of the specimen divided by the failure load of the unwelded wire multiplied by 100. Whenever a welded combination was obtained which could be considered satisfactory for practical purposes, no additional improvement was sought. Additional study of surface preparation, welding parameters, and fixturing will improve tensile-shear strengths, reduce strength variations, and decrease deformation, and there is little doubt that all of the combinations are satisfactorily weldable for the end uses here under consideration.

Effort was expended in literature research, and contacts with technical sources during this report provided assistance in joining various of the difficult-to-weld combinations. Published data relevant to the welding of refractory metals are generally inadequate, and information covering manufacturing or processing techniques difficult to secure. Technical cooperation in these areas has, however, been obtained from the General Electric Company in Cleveland, Ohio during a visit there on December 11, 1962, but a complete report thereon is being withheld until a later report.

1. Material Procurement

The material initially ordered for use in the program has been received. In many cases it was necessary to search for satisfactory substitutes, due to difficulties encountered in the condition of the material, and the presence of contaminants therein. For instance, molybdenum free from contaminants was unobtainable. It is contemplated that a discussion of these difficulties, together with their impact upon the work and with pertinent solutions, will be included in the next report.
2. Tooling

a) Fine-Wire Tooling

A typical welding tip used on the 100-watt and the 20-watt (used for reasons explained subsequently) ultrasonic welding machines is shown in Figure 2. A hardened-steel welding-pin tip is brazed into the end of the contoured shank which is attached to the transducer-coupler assembly by a threaded stud. Both ends of the pin tip are ground to a spherical radius. The welding of wires is sometimes facilitated by the placement of a semi-cylindrical groove in the end of the tip, which not only assists in the locating of the workpieces, but also reduces wire deformation and the level of energy required. The groove is usually parallel to the axis of the exponential shank because in the transverse position the wire tends to roll during welding.

Other pin-tip configurations, for application to relatively inaccessible places, can be designed and readily manufactured. Critical aspects of such fabrication include the problem of physical strength, to prevent breakage when required power is applied, and the avoidance of resonance in a mode which will not permit welding. It is important in the design of tips that the resonant frequency of the entire system be not changed so that the system will deliver power in accordance with system calibration.

For fixturing, two spring-loaded clamps (Figure 3) firmly fasten the coupons to the welding anvil. In all cases, this arrangement met all welding requirements for fine wires.

On the 100-watt and 20-watt welding machines, the level of ultrasonic energy is low compared to the thickness of the coupons, and is not sufficient to penetrate the heavy coupon and affect the anvil tip. Thus, for the fine-wire weldments, anvil tip materials were not a consideration.

b) Heavy-Wire Tooling

Difficulties were experienced with the first welding fixture for the 4-kw spotwelder (described in the First Quarterly Progress Report), and its performance was regarded as unsatisfactory. It was found that the eccentric clamping lever did not permit adequate latitude in welding a sufficient number of wires to the same coupon, nor did it hold coupons securely enough. In addition, the restraining lips (phenolic laminate-Micarta) deteriorated in use, necessitating the substitution of metal lips. In an effort to overcome the fact that the adjustable base complied at the frequency of the applied ultrasonic energy, slots were cut into the periphery of the flanges thereof, with the view of altering its natural frequency. Despite the achievement of a reduction in vibratory response,
the action remained inadequate, and a Micarta base was substituted for the steel base, to avoid resonant vibrations. However, this base pulled the copper anvil flange out of position, preventing good contact between the copper anvil and its support. Subsequently, the adjustable base was eliminated, and no problems were experienced.

A welding fixture was evolved to surmount the limitations of the previously used designs, and is shown in Figure 4.

Several materials were used for anvil tips in the heavy-wire-to-coupon welding, and their performance is indicated in the table below. It will be noted that tip life and anvil life are related to the physical properties of materials to be welded. All anvil tips were made to the configuration shown in Figure 5.

<table>
<thead>
<tr>
<th>Type of Tip</th>
<th>Condition</th>
<th>Performance of Tip Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Astroloy, cast</td>
<td>As-cast</td>
<td>Satisfactory, but the tip spalled. Tip is not reclaimable.</td>
</tr>
<tr>
<td>Astroloy, fabricated</td>
<td>As-received</td>
<td>Very Good</td>
</tr>
<tr>
<td>from rolled-plate stock</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type M-2 Tool Steel</td>
<td>Heat-treated</td>
<td>Good</td>
</tr>
</tbody>
</table>

Sonotrode tips of various materials and geometries were used. A heat-treated Inconel-X sonotrode tip (Figure 6A) gave satisfactory results on soft-metal wires.

Cast Astroloy, in the "as-cast" condition with a 3-inch spherical-radius tip (Figure 6B) cracked and chipped.

Sonotrode tips made from extruded Astroloy* stock and forged Udiment 700** bar stock (heat-treated by Aeroprojects) proved to be quite satisfactory. They are shown in Figure 6C. Longer than standard tips (as an economy measure to permit regrinding) produced high stresses at the brazed joint between the reed and the tip, due to a high bending moment and to greater stiffness. Since the brazed fillet showed evidences of cracking,

---

* A superalloy developed originally by General Electric Company. Currently manufactured by Wyman Gordon Co.
** A superalloy developed and manufactured by Special Metals Incorporated.
modifications were made to the tip, to decrease stresses by reducing the
degree of stiffness. The modified geometry is shown in Figure 6D. Proving
satisfactory after this change, tips of this type were used initially for
all heavy-wire combinations. Regrinding to restore surface contour and
condition had no adverse effect on tip performance. It should be noted
parenthetically here that there is presently no yardstick which can be
universally applied in determining the extent of tool life. Under con-
ditions of operation there is a degree of tool abuse existent. There is
evidence to indicate, however, that when optimum welding conditions have
been established, long tool life may be expected. For instance, produc-
tion reports show the making of over 1 million welds in aluminum, about
12,000 in beryllium copper, without any tip maintenance.

Sonotrode tips made from Astroloy and Udimet 700 in heat-treated
condition with 3-inch spherical radius and grooved as shown in Figure 7,
were used for welding material combinations considered either partly satis-
factory or impossible to be joined with an ungrooved spherical-radius tip.
These tips were also used for welding soft wires to hard coupons when ex-
cessive wire deformation occurred. The grooved tip reduced deformation and
produced higher joint efficiency, and in some instances produced joints
which could not be made with the plain, spherical-radius tip. For welding
hard, brittle wires, in materials such as molybdenum and tungsten, which
cracked due to the high deformation associated with a spherical tip, a tip
groove provided restraint and virtually eliminated wire cracking. The
groove is parallel to the direction of vibration.

The grooved tip is useful also in reducing the notch produced at
the joint (Figure 8) by spherical-radius tips. Figure 9 compares the re-
sults of welding gold wires to nickel plate by spherical-radius tips, and
by grooved tips. It has been determined that the groove width should be
about 0.005 inch larger than the diameter of the wire.

The performance of Astroloy and Udimet 700 sonotrode tips was
superior to that of Inconel-X alloy tips, possibly due to the superior
high-temperature properties of the former alloys. When used on hard metals
and alloys, Inconel-X tips may crack and chip at the work-interface. Such
cracks as occur are usually deep, to the end that such tips cannot be sal-
vaged by grinding. Astroloy and Udimet 700 tips offer much higher resis-
tance to cracking than Inconel-X tips, and do not chip. Moreover, cracks
in the Astroloy and Udimet 700 tips are usually shallow, and the tips can
ordinarily be reclaimed by grinding to a depth of 0.020 inch to 0.030 inch.
Regrinding may be continued as required until no material structural strength
remains.

Despite the superior weldment characteristics from the grooved tip,
it is not uncommonly preferable to use a standard spherical-radius tip be-
cause of the economies which can be effected. Tip damage is more readily
discernible, regrinding or redressing is easier, and positioning of weldment
components is less critical.
3. Welding

Of the number of generally controllable variables in the ultrasonic welding process (sonotrode-tip radius, anvil radius, clamping force, power, and time) only the last three of these are readily adjustable by the operator.

In most applications, the anvil tip is flat. The passive anvil is essentially non-compliant, thus concentrating the vibratory energy in the weldment. The sonotrode-tip spherical radius contacting the work (such as shown on Figure 7) is governed by the thickness and the properties of the material being welded. Although welding has been accomplished with a range of tip radii, experience with flat material has shown that the tip radius should ordinarily be between 50 and 100 times the thickness of the material adjacent to the sonotrode tip (1).

The clamping force, power, and weld interval (or time) are under the immediate control of the operator. These are adjusted to near optimum values for each combination of materials being welded. Equations have been derived from which estimates of the energy (and therefore power and time) required to make a weld can be deduced (1). To date, no straightforward analytical method for determining clamping force has been determined, and its value is established empirically.

There does exist a clamping force for which the energy required to produce a weld is minimum. This clamping force is important in that if welding is attempted at a clamping force setting much different (greater or less) than this optimum value, more energy will be required to make a satisfactory weld, and much more heating of the weldment will result (1).

The level of power delivered by the power source to the welder controls the amplitude of the vibration of the sonotrode tip and, hence, the magnitude of the dynamic stresses at the weld interface between the parts being welded. A certain minimum value of cyclic stress must be achieved before welding will occur. Thus, there is a lower limit, or "threshold", for the amount of applied power, which must be exceeded.

Finally, the length of the pulse of ultrasonic power determines the energy supplied to the weld. The product of the power (watts) multiplied by the time (seconds) is the amount of energy (watt-seconds) actually utilized. The thickness and hardness of the parts being welded primarily determine the energy required to create welds. Other factors also govern the energy requirement, but generally as either thickness or hardness of the parts increases, the energy required for welding also increases (1).

Previous experimental data are useful in determining machine settings which will be reasonably satisfactory. Probably the most practical and the most reliable method to determine correct welding machine settings for power, clamping force, and weld time is to ascertain the threshold curve (4).
A typical threshold curve is shown in Figure 10. There is an optimum clamping force at which bonding of a given material combination is accomplished with least vibratory energy. To produce a threshold curve as shown in Figure 10, the procedure is first to select a weld time interval that appears reasonable on the basis of previous experience or available data. Second, select a power setting that appears reasonable on the same basis. Then make welds progressively, increasing the clamping force only from a low value by modest steps through some high value. At the low values essentially no bonding will be observed, as can be determined by manual peeling of the weldment and observing if, or if not, a nugget is pulled from one of the pieces. But at some level of clamping force bonding will be observed, and bonding will continue as clamping force is increased to some point where no further bonding will occur. If no bonding whatever is observed, it can be assumed that the power setting is too low and/or the weld time interval is too short. By repeating the above procedure at several power and/or time settings, when the bond or no-bond formation is noted on suitable graph paper with the ordinate stepped off in increments of power and the abscissa stepped off in increments of clamping force, it is straightforward to quickly observe the envelope of power-clamping force relationship at any fixed weld time interval, inside of which bonding occurs and outside of which no bonding occurs.

The proper clamping force will be the value at which the threshold curve is minimum. The proper power setting will be somewhat higher than the minimum value indicated by the threshold curve, so as to be within the "good bond" envelope.

As previously pointed out, the total energy utilized is the product of power and weld time. Excessive weld time causes surface damage and sometimes cracking. Thus, as a general rule, welding should be carried out with the shortest practical weld time interval and at a proper power level indicated by the threshold curve.

To conserve material, a maximum number of wires was welded to one coupon. The positioning of these welds was dictated by considerations of space required both for tool application and test procedures. Specially designed welding fixtures and tensile-testing machine jaws were devised (Figure 11), as reported in the First Quarterly Progress Report.

a. Fine-Wire Welding

Ultrasonic welding of fine wires requires close control of the power level and the clamping force. For most fine-wire-to-tab combinations, the 100-watt, 40-kc welding machine was satisfactory. For extra-fine, soft wires, such as 0.0003-inch gold, the 20-watt, 60-kc welding machine had to be used, as referenced under fine-wire tooling. On the 100-watt unit, the clamping force is applied by a mechanical spring through a range of zero to 15 pounds. The necessary precision of this clamping force exceeds the capability of the 100-watt welder used for some of the fine, soft wires.
Additionally, control of power with the 100-watt welder was also insufficiently precise at the low values required for the welding of extra-fine, soft wires. With the 20-watt welder, clamping force is applied by adjustable counter-weights providing a range from zero to 250 grams with a variation in any particular setting of ± 1 gram. Power is also more accurately controllable in the low range with the 20-watt unit. The 100-watt unit was pictured in the previous report. The 20-watt unit is shown in Figure 12.

Because of the number of specimens to be welded, and the difficulty in handling the fine wires, it was decided to locate and hold the fine wires during welding by the use of tweezers and a microscope, rather than by a clamping and locating fixture. A 60-power Bausch & Lomb binocular stereo zoom microscope was used. Similar instruments are in general use throughout the electronic industry to assist with problems of this nature.

Figure 13 shows the handling technique used for hard and soft wires. One end portion of the wire was to be subjected to tensile-shear testing. The use of tweezers to hold and position the wire during welding exerted some tension against the holding force of the welding tip at the weld point. Such tension was not critical with the harder wires and did not affect weld or wire strength. On soft wires, however, such as gold, silver, and copper, the tension weakened the wire at the edge of the weld, giving unreliable tensile-shear values. Accordingly, tweezer handling of soft wires was restricted to that section of the wire not used for tensile-shear testing.

Extreme care was necessary in lowering the welding tip onto the wire, to avoid flattening the wire prior to welding. Such deformation reduces joint strength, and changes the welding conditions.

When welding very fine wires with a standard spherical-radius tip, the wire must be placed almost exactly under the center of the radius. Should the wire lie eccentrically under the tip, a poor joint will result, because the tip would have greater contact with the tab than with the wire, or the wire will roll during the weld pulse.

A semi-cylindrical groove in the tip helps to locate the wire, but it does not appear practical to use a grooved tip for wires less than about 0.0005-inch diameter. Grooved tips do make stronger welds with some materials such as gold, copper, nickel and tungsten.

Specifics of the tip design contribute to weld quality. To optimize these details, it would be necessary to study the effect of such specifics as the length, depth, and radius of the groove in the tips, or of various spherical radii on the standard tips.
The joining of hard wires to hard coupons caused tip deteriora-
tion and pitting. Consequently, some of the tips required frequent honing
and redressing. Tip wear is drastically reduced when the machine is op-
erated constantly at the optimum machine settings.

It is important that the joint area on the coupon be smooth, flat,
and reasonably parallel to the anvil surface. It is necessary to occasionally
burnish the coupon to insure smoothness and flatness by using the tweezer
ends or by moving the welding tip approximately 1 mil to each side of the
weld area. Titanium and molybdenum required such attention. Burnishing had
little effect on tungsten because of its high hardness.

Materials with a rough surface texture are unsuitable for fine-
wire bonding without additional surface preparation. In the procurement
of materials, no surface conditions were specified, and several of the ma-
terials, e.g., tungsten and molybdenum, had a rough texture. In the present
case, auxiliary surface preparation, such as surface grinding and electro-
etching, was required to insure a surface condition appropriate for fine-
wire bonding.

"White room" conditions should be used in the bonding of very
low-strength fine wires such as gold and copper. Particles of foreign
matter on the coupon or wire were found equal to or larger than the wire
diameter. In these instances, the materials should be located so that

Most wires were welded in the "as-received" condition. The cou-
pons were wiped with acetone. The fine copper wire could not be welded
satisfactorily until it was cleaned by dipping into a 50 percent solution
of nitric acid (HNO₃) for two or three seconds, and then flushed with
water.

b. Heavy-Wire Welding

All heavy-wire weldments were made using a laboratory model of
the 4-kw ultrasonic welder. Tooling and techniques previously described
were used to make the weldments.

h. Weld Evaluation

a. Evaluation Program

Pertinent military specifications and electron-tube industry
practices were reviewed with representatives of Chatham Electronics and
the U. S. Army Electronics Material Agency. The following comments are
provided by way of background and general information for the specifics
of the several tests outlined in later paragraphs.
a) Shock, vibration, and fatigue are the primary mechanical test exposures for electron tubes.

b) Specific details of test specifications vary according to the electron-tube type. Each test is conducted on a separate group of electron tubes and not sequentially on the same tube. The ability of the electron tube to withstand test exposure is usually determined by a comparison of electrical measurements, such as transconductance and noise, which are made both before and after testing. A change in electrical characteristics usually results from deformation of tube components or by particles being shaken loose. Such particles generally result from weld spatter (not present from ultrasonic welds). Such particles are jarred loose during tests. Tests are made upon completed electron tubes because the glass envelope supports the electron tube mount.

c) Tests are not made under low temperature or temperature cycling conditions. In many cases tests are conducted when the tube heaters or filaments are hot with electrical current as normal in operation. Heaters and cathodes are prone to failure because of their lack of strength at elevated temperatures. They not uncommonly fail by breaking or by distorting beyond usable limits, rather than by failing at the weld. Standard shock and vibration test equipment permits only room temperature and heated tests as just mentioned.

d) Gas filled electron tubes are first evacuated to very low pressure prior to the introduction of atmosphere. The atmosphere in both gas filled and vacuum tubes is inert and has no effect on weld performance. Completed electron tubes are tested for reasons other than the effect of vacuum or gas on the mechanical assembly.

Vibration tests at varying frequency are made to determine failures because of resonance in the completed tubes. After such exposure, evaluation is electrical. X-ray examination is not used or stipulated to evaluate weld quality.

Chatham Electronics is preparing a quotation to cover the fixturing and the work necessary for shock and vibration tests of specimens welded by Aeroprojects.
b. **Strength Testing**

Handling of the fine-wire weldments is difficult. Wires of .0015-inch diameter and smaller often fail before, during, or after welding from looping and kinking. For tensile-shear testing, small pieces of masking tape should be affixed to the free ends of the wires, and the weldments so manipulated that the weight of the tape keeps the wire in tension at all times.

Care must be exercised to prevent the masking tape from sticking to surfaces other than the wire (such as the fixture), because the welded assembly can not then be removed without breaking. As a safeguard, the wire ends can be sandwiched between a small square of paper and a smaller piece of tape so that no free edges of the tape are exposed.

Figure 14 shows the testing of these fine wire weldments in an inverted position. This technique is utilized where the parent metal strength of the wire is measured in pounds (the load cell of the Instron machine does not support the weight of the coupon and fixture when the gram scale was used.)

No particular difficulties are encountered in tensile-shear testing the heavy-wire weldments. The jaw arrangement for tensile-shear testing the heavy wire-coupon assemblies is shown in Figure 11. Note the several welds per coupon.

The tensile-shear data obtained for the combinations here reported are tabulated in Tables 1 and 2, together with the computed values of joint efficiency, strength variation, and other pertinent data.

c. **Metallurgical Evaluation**

Metallographic procedures for the preparation of dissimilar metal junctions of this configuration are complex, requiring extraordinary manipulative skill to ensure that the specimen represents accurately the structure and character of the bond. Since each material combination presents individual problems of preparation and interpretation, a complete discussion of the metallographic evaluation will be withheld until all combinations have been examined.
WELD-EVALUATION PROGRAM FOR WIRE-TO-COUPON WELDMENTS

I Basic Data

1. .060-inch diameter wire weldments
   A. Tensile-shear test of a minimum of three specimens.
      1. Compute average, range, and variation of strengths.
      2. Compare average tensile-shear strength with ultimate
tensile strength of wire, and compute joint efficiency.
   B. Examine external weld surface for defects.
   C. Microsection one specimen.
      1. Examine from 30X to 500X.
      2. Photograph for report purposes at approximately 30X
         and 250X.
         (Note: Transverse and longitudinal sections are being
         taken. Photos are of transverse and longitudinal
         sections.)

2. .0003-inch diameter wire range weldments
   A. Same as 1A
   B. Same as 1B
   C. Microsection one specimen whenever -
      (a) during welding it is evident from external inspection
          that such examination would be valuable,
      (b) a successful small-wire weld has been obtained in a
          combination where a large-wire configuration has not
          been successfully joined.
      1. Examine to 1000X.
      2. Photograph for report purposes at a suitable magnifica-
         tion.
II  Shock Test

1. Expose 3 specimens of each successfully welded combination obtained under the Basic Data evaluation to the Shock Test described under Test Specifications.
   a. Test exposures are to be made at room temperature.
   b. Test exposures are to be made without special atmospheres.

2. Tensile-shear test all surviving welds.

III  Vibration and Fatigue Tests

1. Expose 3 specimens of each successfully welded combination obtained under the Basic Data evaluation to the Fatigue Test described under Test Specifications.
   a. Test exposures are to be made at room temperature.
   b. Test exposures are to be made without special atmospheres.

2. Examine specimens after 60 seconds exposure in Z plane, and note failures. Resume exposure for 32 hours.

3. Expose specimens for 32 hours in Y plane.

4. Examine specimens after 60 seconds exposure in X plane, and note failures. Resume exposure for 32 hours.

5. Tensile-shear test all surviving welds.
TEST-EXPOSURE SPECIFICATIONS FOR WIRE-TO-COUPON WELDMENTS

In all the tests, the coupons will be clamped to the fixtures so that the wire is unrestricted. Applicable test specimen dimensions and test planes are shown in Figure 15.

Shock Test

The shock test shall be conducted on a high-impact shock machine for electronic devices. Each weldment shall be subjected to a total of 21 hammer blows of 30° (450 G) angular displacement; that is, seven blows in each of the positions X, Y and Z in any sequence.

Fatigue Test

The weldments shall be rigidly mounted on a table vibrating with simple harmonic motion at a frequency of 25 ± 2 cps with an amplitude of 0.040 ± 0.005 inch (total excursion 0.080 ± 0.005 inch). The weldments shall be vibrated for a total of 96 hours, 32 hours in each of the three positions X, Y and Z.

ELECTRON-TUBE STUDY

At the beginning of the report period, a contract was executed with Chatham Electronics providing for technical service, electron-tube parts, and the electron-tube evaluation specified for the last phase of the program.

The major effort during this report period was associated with the welding study.

Electron tube Type 6080WB was studied and the assembly sequence thereof revised to facilitate accessibility for the ultrasonic welding tooling. The new sequence, shown in Table 4, was approved by Chatham. Design work on the tooling for this tube has been initiated.

The contact area between the sonotrode tip and the workpiece is normally within the area of the tip diameter. To reach some of the weld areas in the 6080WB electron tube, it was necessary to design a tip, shown in Figure 16,
which will have the contact area outside the diameter of the tip. Several of these tips will have to be designed with the contact surface of each contoured to suit the specific joint geometry. The experimental tip was evaluated on flat material with good results.

Test welds, using the 100-watt welder, were made between the tungsten heater wire and the nickel heater connectors so that the nickel tubing previously welded to the tungsten heater wire could be eliminated. However, satisfactory welds were not obtained as the hard tungsten wire embedded into the nickel without forming a true bond.

All junctions on the Type 6205 electron tube were attempted with the 100-watt welder. These welds were evaluated together with Chatham, and it would appear that only the cathode tab can be welded with this machine. It should be possible to make all other welds on the 600-watt welder. It was not possible to weld the stem lead to the plate, as the plate material (identified as Alclad iron) crumbled during welding. Further investigation will be made into this problem.

No work was done on electron tube Type 5814WB.

CHATHAM ELECTRONICS CORRELATIVE ACTIVITY

Chatham Electronics performed advisory services during Phase 1 of the program.

Conferences were held at the Chatham plant, and their assistance was enlisted in various areas of the work: (a) Establishing specialized refinements to sequential production operations in electron-tube manufacture. (b) Detailing representative historical aspects of weld failures in electron tubes. (c) Isolating difficulties encountered in molybdenum and tungsten. (d) Establishing weld evaluation procedures and undertaking preliminary evaluation of some ultrasonically welded parts. (e) Supplying electron-tube components and samples.

Currently, Chatham is preparing a quotation covering fixturing and work necessary to subject specimens ultrasonically welded by Aeroprojects to shock and vibration exposures.

In the later phases of the program, Chatham will more specifically direct its efforts to the evaluation of ultrasonic welding applicable to electron-tube manufacture.
CONCLUSIONS

Junctions in most of the desired combinations have already been successfully effected, demonstrating conclusively that ultrasonic welding produces satisfactory welds in a wide range of material combinations of interest to the electron-tube industry. The effect of tooling and surface preparation on welding has been indicated. Generally, surface preparation is less critical than that required for resistance welding. However, in some materials, such as tungsten and molybdenum, surface condition and contaminations are significant.

It will be possible without recourse to substantial research to ultrasonically weld nearly all of the required junctions in the three specific electron tubes. Assembly sequencing of the electron tubes can be varied to minimize accessibility problems.

PROGRAM FOR THE NEXT REPORTING PERIOD

Welding the remaining combinations will be completed. All successfully welded combinations will be subjected to the test exposures outlined, and subsequently evaluated. Junctions for the three electron tubes will be welded.
REFERENCES


**WIRE MATERIAL**

<table>
<thead>
<tr>
<th></th>
<th>AU</th>
<th>AG</th>
<th>CU</th>
<th>&quot;A&quot;Ni</th>
<th>MILD STEEL</th>
<th>STAIN. STEEL</th>
<th>TI</th>
<th>TA</th>
<th>MO</th>
<th>W</th>
<th>RE</th>
</tr>
</thead>
<tbody>
<tr>
<td>AU</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AG</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CU</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&quot;A&quot;Ni</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MILD STEEL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>STAIN. STEEL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TI</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MO</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>W</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Successful Welds

**Figure 1**  
X Not required in program

SUCCESSFULLY WELDED COMBINATIONS OF FINE AND HEAVY WIRE TO COUPON
Figure 2

TYPICAL WELDING TIP USED ON THE 100-WATT AND 20-WATT ULTRASONIC WELDING MACHINES
Figure 3

Fitting for the 20-watt welder (pictured) and 100-watt welder
Figure 4

MODIFIED WELDING FIXTURE INSTALLED ON 4-KW SPOT WELDER
Figure 5

ANVIL-TIP CONFIGURATION
**Figure 6**

SPHERICAL-RADIUS SONOTRODE TIPS
Figure 7

3-INCH GROOVED SPHERICAL-RADIUS SONOTRODE TIP
Figure 8

NOTCH PRODUCED AT JOINT BY SPHERICAL-RADIUS TIP
Figure 9

GOLD WIRE (0.060 INCH) WELDED TO NICKEL PLATE (0.060 INCH)

Left: Welds Made with Ungrooved 3-Inch Spherical-Radius Tip

Right: Made with Grooved Tip
Figure 10

THRESHOLD CURVE

(Welds produced at conditions above curve are satisfactory. Those below curve are unsatisfactory.)
Figure 11

JAW ARRANGEMENT PERMITS TENSILE-SHEAR TESTING
OF SIDE-BY-SIDE ULTRASONIC WELDS
OF 0.060-INCH DIAMETER WIRE TO THE SAME COUPON
Figure 12

COMMERCIAL ULTRASONIC 20-WATT WELDER
Wire End Used For Hard Wire Positioning

Welding Tip

Weld Point

Wire End Used For Soft Wire Positioning

Coupon

This End Used For Tensile-Shear Testing

Figure 13

WIRE-END HANDLING TECHNIQUE
FOR HARD AND SOFT WIRES
Figure 14

UPSIDE DOWN POSITION OF JAW ARRANGEMENT
USED FOR TENSILE-SHEAR TESTING OF
HIGH-STRENGTH WIRE-TO-Coupon WELDS
Figure 15
SPECIFICATION FOR WELD SPECIMENS
AND TEST PLANES
Figure 16
SONOTRODE TIP FOR 600-WATT WELDER
Table 1
TEST RESULTS OF FINE-WIRE-TO-COUPON JUNCTIONS

<table>
<thead>
<tr>
<th>Weld Combination Materials</th>
<th>Joint Efficiency (percent)</th>
<th>Tensile-Shear Strengths</th>
<th>Variation**</th>
<th>Welder Used (Watts)</th>
<th>Welding Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wire</td>
<td>Coupon</td>
<td>(2) Base Wire*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gold</td>
<td>Gold</td>
<td>96</td>
<td>2.7 gm</td>
<td>2.6 gm</td>
<td>0.538</td>
</tr>
<tr>
<td>Silver</td>
<td></td>
<td>100</td>
<td>22.3 gm</td>
<td>22 gm</td>
<td>0.076</td>
</tr>
<tr>
<td>Silver: Copper</td>
<td>Copper</td>
<td>94</td>
<td>20.96 gm</td>
<td>22 gm</td>
<td>0.124</td>
</tr>
<tr>
<td>Silver</td>
<td>Silver</td>
<td>70</td>
<td>6.15 gm</td>
<td>4.3 gm</td>
<td>0.581</td>
</tr>
<tr>
<td>Copper</td>
<td>Gold</td>
<td>92</td>
<td>6.15 gm</td>
<td>5.7 gm</td>
<td>0.035</td>
</tr>
<tr>
<td>&quot;A&quot; Nickel</td>
<td></td>
<td>95</td>
<td>6 gm</td>
<td>0.133</td>
<td></td>
</tr>
<tr>
<td>&quot;A&quot; Nickel</td>
<td>St. Steel</td>
<td>98</td>
<td>6.18 gm</td>
<td>0.056</td>
<td></td>
</tr>
<tr>
<td>&quot;A&quot; Nickel</td>
<td>Titanium</td>
<td>92</td>
<td>5.8 gm</td>
<td>0.155</td>
<td></td>
</tr>
<tr>
<td>&quot;A&quot; Nickel</td>
<td>Tantalum</td>
<td>94</td>
<td>5.9</td>
<td>0.203</td>
<td></td>
</tr>
<tr>
<td>Titanium</td>
<td>Silver</td>
<td>92</td>
<td>5.81 gm</td>
<td>0.104</td>
<td></td>
</tr>
<tr>
<td>&quot;A&quot; Nickel</td>
<td>Rhenium</td>
<td>92</td>
<td>5.78</td>
<td>0.043</td>
<td></td>
</tr>
<tr>
<td>&quot;A&quot; Nickel</td>
<td>&quot;A&quot; Nickel</td>
<td>98</td>
<td>6.2</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>&quot;A&quot; Nickel</td>
<td>Molybdenum</td>
<td>93</td>
<td>5.85</td>
<td>0.196</td>
<td></td>
</tr>
<tr>
<td>&quot;A&quot; Nickel</td>
<td>Gold</td>
<td>90</td>
<td>5.69</td>
<td>0.084</td>
<td></td>
</tr>
<tr>
<td>&quot;A&quot; Nickel</td>
<td>Copper</td>
<td>95</td>
<td>6.01 gm</td>
<td>0.05</td>
<td></td>
</tr>
<tr>
<td>Mild Steel</td>
<td></td>
<td>98</td>
<td>0.26 lb</td>
<td>0.083</td>
<td></td>
</tr>
<tr>
<td>&quot;A&quot; Nickel</td>
<td>St. Steel</td>
<td>92</td>
<td>0.22</td>
<td>0.348</td>
<td></td>
</tr>
<tr>
<td>&quot;A&quot; Nickel</td>
<td>Mild Steel</td>
<td>83</td>
<td>0.25</td>
<td>0.078</td>
<td></td>
</tr>
<tr>
<td>&quot;A&quot; Nickel</td>
<td>Gold</td>
<td>81</td>
<td>0.211 lb</td>
<td>0.450</td>
<td></td>
</tr>
<tr>
<td>St. Steel</td>
<td></td>
<td>92</td>
<td>0.263 lb</td>
<td>0.114</td>
<td></td>
</tr>
<tr>
<td>&quot;A&quot; Nickel</td>
<td>St. Steel</td>
<td>79</td>
<td>0.231</td>
<td>0.952</td>
<td></td>
</tr>
<tr>
<td>&quot;A&quot; Nickel</td>
<td>Mild Steel</td>
<td>70</td>
<td>0.32</td>
<td>0.093</td>
<td></td>
</tr>
<tr>
<td>&quot;A&quot; Nickel</td>
<td>Rhenium</td>
<td>93</td>
<td>0.31</td>
<td>0.064</td>
<td></td>
</tr>
<tr>
<td>&quot;A&quot; Nickel</td>
<td>Tantalum</td>
<td>88</td>
<td>0.295</td>
<td>0.338</td>
<td></td>
</tr>
<tr>
<td>&quot;A&quot; Nickel</td>
<td>Tungsten</td>
<td>76</td>
<td>0.256 lb</td>
<td>0.058</td>
<td></td>
</tr>
<tr>
<td>Titanium</td>
<td>&quot;A&quot; Nickel</td>
<td>81</td>
<td>12.9 gm</td>
<td>0.263</td>
<td></td>
</tr>
<tr>
<td>Titanium</td>
<td>Copper</td>
<td>96</td>
<td>52.5 gm</td>
<td>0.124</td>
<td></td>
</tr>
<tr>
<td>Titanium</td>
<td>Titanium</td>
<td>98</td>
<td>51.6 gm</td>
<td>0.096</td>
<td></td>
</tr>
<tr>
<td>Titanium</td>
<td></td>
<td>100+</td>
<td>0.493 lb</td>
<td>0.010</td>
<td></td>
</tr>
<tr>
<td>Tantalum</td>
<td>&quot;A&quot; Nickel</td>
<td>87</td>
<td>0.48 lb</td>
<td>0.302</td>
<td></td>
</tr>
<tr>
<td>Tantalum</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Material</td>
<td>% A Nickel</td>
<td>% Tantalum</td>
<td>Copper</td>
<td>% Nickel</td>
<td>% Steel</td>
</tr>
<tr>
<td>------------</td>
<td>------------</td>
<td>------------</td>
<td>--------</td>
<td>----------</td>
<td>---------</td>
</tr>
<tr>
<td>Titanium</td>
<td>62</td>
<td>98</td>
<td>96</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Tantalum</td>
<td>89</td>
<td>87</td>
<td>96</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Tungsten</td>
<td>93</td>
<td>88</td>
<td>100</td>
<td>93</td>
<td>83</td>
</tr>
<tr>
<td>St. Steel</td>
<td>100+</td>
<td>100+</td>
<td>100+</td>
<td>100</td>
<td>100+</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rhenium</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Titanium</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tantalum</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Average of three specimens.  ** Variation = \ \text{highest shear-strength value - lowest shear-strength value} \ / \ \text{average of individual shear strengths}

\# = \ \frac{\text{Col. (2)}}{\text{Col. (1)}} \times 100
<table>
<thead>
<tr>
<th>Weld Combination Materials</th>
<th>Joint Efficiency (percent)</th>
<th>Tensile-Shear Strengths</th>
<th>Variance**</th>
<th>Welding Comments</th>
<th>Metallography and Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wire</td>
<td>Coupon</td>
<td>Base Wire* (lbs)</td>
<td>Welded Wire* (lbs)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gold</td>
<td>Gold</td>
<td>100+</td>
<td>53</td>
<td>54</td>
<td>0.019</td>
</tr>
<tr>
<td>Silver</td>
<td>Gold</td>
<td>93</td>
<td>76</td>
<td>73.7</td>
<td>0.0135</td>
</tr>
<tr>
<td>Silver</td>
<td>Copper</td>
<td>100+</td>
<td>80</td>
<td>0</td>
<td>b,g,k,m</td>
</tr>
<tr>
<td>Copper</td>
<td>Silver</td>
<td>95</td>
<td>114</td>
<td>107.7</td>
<td>0.009</td>
</tr>
<tr>
<td>Copper</td>
<td>Gold</td>
<td>100+</td>
<td>114</td>
<td>119</td>
<td>0</td>
</tr>
<tr>
<td>Titanium</td>
<td>Silver</td>
<td>94</td>
<td>159</td>
<td>148.7</td>
<td>0.08</td>
</tr>
<tr>
<td>Tungsten***</td>
<td></td>
<td>100</td>
<td>165</td>
<td>0</td>
<td>b,w</td>
</tr>
<tr>
<td>Tantalum</td>
<td>98</td>
<td>155.8</td>
<td>0.025</td>
<td>s,aa,bb,cc</td>
<td></td>
</tr>
<tr>
<td>St. Steel</td>
<td>97</td>
<td>155</td>
<td>0.006</td>
<td>r,s</td>
<td></td>
</tr>
<tr>
<td>Mild Steel</td>
<td>73</td>
<td>116</td>
<td>0.0603</td>
<td>l</td>
<td></td>
</tr>
<tr>
<td>Silver</td>
<td>Rhenium</td>
<td>98</td>
<td>124</td>
<td>0.0217</td>
<td>d,g,s</td>
</tr>
<tr>
<td>Nickel</td>
<td>99</td>
<td>158.7</td>
<td>0.057</td>
<td>c,v</td>
<td></td>
</tr>
<tr>
<td>Molybdenum</td>
<td>100</td>
<td>164</td>
<td>0.012</td>
<td>t</td>
<td></td>
</tr>
<tr>
<td>Gold</td>
<td>Copper</td>
<td>95</td>
<td>152</td>
<td>0.223</td>
<td>p</td>
</tr>
<tr>
<td>Mild Steel</td>
<td>St. Steel</td>
<td>100+</td>
<td>160</td>
<td>0</td>
<td>b,g</td>
</tr>
<tr>
<td>Mild Steel</td>
<td></td>
<td>100</td>
<td>157</td>
<td>157</td>
<td>0.0317</td>
</tr>
<tr>
<td>Nickel</td>
<td></td>
<td>100</td>
<td>153</td>
<td>0.026</td>
<td>p</td>
</tr>
<tr>
<td>Gold</td>
<td></td>
<td>97</td>
<td>160</td>
<td>0.088</td>
<td>b,j</td>
</tr>
<tr>
<td>St. Steel</td>
<td>St. Steel</td>
<td>100+</td>
<td>280</td>
<td>0.05</td>
<td>a</td>
</tr>
<tr>
<td>Mild Steel</td>
<td></td>
<td>95</td>
<td>255</td>
<td>0.0231</td>
<td>b</td>
</tr>
<tr>
<td>Nickel</td>
<td></td>
<td>92</td>
<td>218</td>
<td>0.0615</td>
<td>c</td>
</tr>
<tr>
<td>Rhenium</td>
<td></td>
<td>94</td>
<td>253</td>
<td>0.0276</td>
<td>c</td>
</tr>
<tr>
<td>Tantalum</td>
<td></td>
<td>89</td>
<td>239</td>
<td>0.625</td>
<td>d,f,h,s</td>
</tr>
<tr>
<td>Tungsten***</td>
<td></td>
<td>93</td>
<td>250</td>
<td>0.096</td>
<td>c,w</td>
</tr>
<tr>
<td>Titanium</td>
<td>Nickel</td>
<td>94</td>
<td>256</td>
<td>252</td>
<td>0.045</td>
</tr>
<tr>
<td>Titanium</td>
<td>Copper</td>
<td>100+</td>
<td>256</td>
<td>264</td>
<td>0.95</td>
</tr>
<tr>
<td>Titanium</td>
<td></td>
<td>100</td>
<td>257</td>
<td>0.0194</td>
<td>c,u</td>
</tr>
<tr>
<td>Tantalum</td>
<td>Titanium</td>
<td>100</td>
<td>151</td>
<td>150</td>
<td>0.02</td>
</tr>
<tr>
<td>Tantalum</td>
<td>Tantalum</td>
<td>100</td>
<td>161.3</td>
<td>0.062</td>
<td>aa,bb,cc,dd</td>
</tr>
<tr>
<td>Tantalum</td>
<td>Nickel</td>
<td>94</td>
<td>112</td>
<td>0.035</td>
<td>b</td>
</tr>
</tbody>
</table>

**Appendix A #1**
**Appendix A #2**
**Appendix A #3**
**Appendix A #4**
**Appendix A #5**
**Appendix A #6**
**Appendix A #7**
**Appendix A #8**
**Appendix A #9**
**Appendix A #10**
### All combinations were welded on Hkw spot welder.

<table>
<thead>
<tr>
<th>Material</th>
<th>Specimen</th>
<th>Average Shear Strength (ksi)</th>
<th>Variation</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Titanium</td>
<td>Copper</td>
<td>100*</td>
<td>256</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td>Titanium</td>
<td>100</td>
<td>257</td>
<td>0.019</td>
</tr>
<tr>
<td></td>
<td>Tantalum</td>
<td>100</td>
<td>150</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td>Tantalum</td>
<td>94</td>
<td>110</td>
<td>0.035</td>
</tr>
<tr>
<td></td>
<td>St. Steel</td>
<td>100*</td>
<td>145</td>
<td>0.052</td>
</tr>
<tr>
<td></td>
<td>Copper</td>
<td>91</td>
<td>138</td>
<td>0.32</td>
</tr>
<tr>
<td>Tungsten</td>
<td>Nickel</td>
<td>85</td>
<td>660</td>
<td>0.132</td>
</tr>
<tr>
<td></td>
<td>Tantalum</td>
<td>72</td>
<td>660</td>
<td>0.498</td>
</tr>
<tr>
<td>Rhenium</td>
<td>St. Steel</td>
<td>100*</td>
<td>360</td>
<td>0.033</td>
</tr>
<tr>
<td></td>
<td>Nickel</td>
<td>100</td>
<td>360</td>
<td>0.056</td>
</tr>
<tr>
<td></td>
<td>Titanium</td>
<td>100</td>
<td>360</td>
<td>0.075</td>
</tr>
<tr>
<td></td>
<td>Tantalum</td>
<td>72</td>
<td>360</td>
<td>0.0321</td>
</tr>
</tbody>
</table>

#### **Variation**

\[ \text{Variation} = \frac{\text{highest shear-strength value} - \text{lowest shear-strength value}}{\text{average of individual shear strengths}} \]

* Average of three specimens.

** After surface preparation of base wire.
Table 3
WELDMENT MATERIALS DESCRIPTION

<table>
<thead>
<tr>
<th>Material</th>
<th>Gage (inch)</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gold</td>
<td>0.060</td>
<td>Annealed</td>
</tr>
<tr>
<td>Silver</td>
<td>0.060</td>
<td></td>
</tr>
<tr>
<td>Copper</td>
<td>0.055</td>
<td></td>
</tr>
<tr>
<td>&quot;A&quot; Nickel</td>
<td>0.060</td>
<td></td>
</tr>
<tr>
<td>Mild Steel(AISI 1010)</td>
<td>0.060</td>
<td></td>
</tr>
<tr>
<td>Stainless Steel(AISI 304)</td>
<td>0.060</td>
<td></td>
</tr>
<tr>
<td>Titanium</td>
<td>0.068</td>
<td>Annealed</td>
</tr>
<tr>
<td>Tantalum</td>
<td>0.063</td>
<td>Stress-relieved</td>
</tr>
<tr>
<td>Molybdenum</td>
<td>0.060</td>
<td>Stress-relieved</td>
</tr>
<tr>
<td>Tungsten</td>
<td>0.063</td>
<td></td>
</tr>
<tr>
<td>Rhenium</td>
<td>0.060</td>
<td>Annealed</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fine Wires</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gold</td>
<td>0.0003</td>
<td>Hard</td>
</tr>
<tr>
<td>Silver</td>
<td>0.0015</td>
<td>99.99% pure - 20% elongation</td>
</tr>
<tr>
<td>Copper</td>
<td>0.0005</td>
<td>Hard</td>
</tr>
<tr>
<td>&quot;A&quot; Nickel</td>
<td>0.0005</td>
<td>Hard</td>
</tr>
<tr>
<td>Mild Steel(AISI 1010)</td>
<td>0.0015</td>
<td>Low Carbon</td>
</tr>
<tr>
<td>Stainless Steel(AISI 304)</td>
<td>0.001</td>
<td>Hard</td>
</tr>
<tr>
<td>Titanium</td>
<td>0.001</td>
<td>Hard</td>
</tr>
<tr>
<td>Tantalum</td>
<td>0.003</td>
<td>14% Stretch</td>
</tr>
<tr>
<td>Tungsten</td>
<td>0.0003</td>
<td>Etched</td>
</tr>
<tr>
<td>Rhenium</td>
<td>0.005</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heavy Wires</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gold</td>
<td>0.060</td>
<td>Annealed</td>
</tr>
<tr>
<td>Silver</td>
<td>0.060</td>
<td></td>
</tr>
<tr>
<td>Copper</td>
<td>0.064</td>
<td></td>
</tr>
<tr>
<td>&quot;A&quot; Nickel</td>
<td>0.060</td>
<td></td>
</tr>
<tr>
<td>Mild Steel(AISI 1010)</td>
<td>0.062</td>
<td>Annealed</td>
</tr>
<tr>
<td>Stainless Steel(AISI 304)</td>
<td>0.0625</td>
<td>Stress-relieved</td>
</tr>
<tr>
<td>Titanium</td>
<td>0.063</td>
<td></td>
</tr>
<tr>
<td>Tantalum</td>
<td>0.062</td>
<td></td>
</tr>
<tr>
<td>Tungsten</td>
<td>0.066 to 0.066</td>
<td>Stress-relieved</td>
</tr>
<tr>
<td>Rhenium</td>
<td>0.060</td>
<td>Annealed</td>
</tr>
</tbody>
</table>

This table lists only those materials reported in Tables 1 and 2.
### Table 4

**TUBE TYPE 608OWB**

**ASSEMBLY SEQUENCE FOR ULTRASONIC WELDING**

<table>
<thead>
<tr>
<th>Sequence No.</th>
<th><em>Old No.</em></th>
<th>Component</th>
<th>to</th>
<th>Component</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>Cathode Tab</td>
<td>Cathode Sleeve</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>Cathode Tab</td>
<td>Itself</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>7</td>
<td>Anode Eyelet</td>
<td>Anode Support</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>6</td>
<td>Grid Eyelet</td>
<td>Grid</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>Anode Connector</td>
<td>Anode Support</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>11</td>
<td>Anode Connector</td>
<td>Anode Support</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>3</td>
<td>Grid Connector</td>
<td>Grid</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>9</td>
<td>Heater</td>
<td>RH and LH Heater Connector</td>
<td>Note 1</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>4</td>
<td>Grid Connector</td>
<td>Grid</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>15</td>
<td>Snubber</td>
<td>Snubber Support</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>10</td>
<td>Grid Radiator</td>
<td>Grid</td>
<td></td>
<td>Note 2</td>
</tr>
<tr>
<td>12</td>
<td>12</td>
<td>Stem Leads</td>
<td>Heater Connector</td>
<td></td>
<td>Note 3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Grid Connector</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Anode Connector</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>13</td>
<td>Cathode Connector</td>
<td>Stem Lead</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>14</td>
<td>Cathode Connector</td>
<td>Snubber Support</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>16</td>
<td>Top Cathode Connector</td>
<td>Snubber Support</td>
<td></td>
<td>Note 4</td>
</tr>
<tr>
<td>16</td>
<td>17</td>
<td>Getter</td>
<td>Snubber Support</td>
<td></td>
<td>Note 5</td>
</tr>
</tbody>
</table>

*These numbers refer to key numbers in Description of Welding Junctures presented in the First Quarterly Report.*
Note 1. Tungsten heater wire together with the nickel sleeve may be welded directly to the nickel heater connector, thereby eliminating the heater sleeve to heater welding juncture Key #8 as a separate operation.

Note 2. These joints will be resistance welded. Ultrasonic welding can join these materials and geometries, but accessibility is limited beyond a practical solution for tooling or tube redesign.

Note 3. The heater connectors will be formed to attach to the outside of the stem leads, rather than to the inside to facilitate ultrasonic welding. A small hand tool may be required.

Note 4. The splash spacer supports will be assembled on the snubber supports so that the welding will occur on the outside, rather than the inside of the splash spacer to facilitate accessibility for ultrasonic welding.

Note 5. The weld required between the getter and the snubber support is a crossed-wire weld. Welds will be attempted, although no activity in the program has provided a basis for ultrasonically welding this geometrical configuration.
### PROJECT SCHEDULE

<table>
<thead>
<tr>
<th>Phase</th>
<th>Activities</th>
<th>Dates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase I</td>
<td>Mat'l Proc.</td>
<td>JUL 1962</td>
</tr>
<tr>
<td></td>
<td>Weld Study</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tooling</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Welding &amp; Eval.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Shock &amp; Vibration Testing</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tube Review</td>
<td></td>
</tr>
<tr>
<td></td>
<td>US Weld. Review</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tube Study</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tool Des.&amp; Const.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Welding</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Equip. Const.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Equip. Const.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Equip. Const.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Equip. Const.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Equip. Const.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Equip. Const.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Equipment Set-up</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Chatham Activity</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Training</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tube Assembly</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Age &amp; Test</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Life Test</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Data Compilation</td>
<td></td>
</tr>
</tbody>
</table>

**Note 1:** 30-day period for approval by U. S. Army Electronics Material Agency to proceed with equipment construction.

Schedule allows 30-day period for approval of equipment prior to electron-tube manufacture.
IDENTIFICATION OF TECHNICAL PERSONNEL

Personnel not previously reported who made technical contributions, and the manhours of work performed by all personnel during this report period.

Nicholas Maropis, Physicist

B. A. in Physics and Mathematics from Washington and Jefferson College, 1949, with graduate studies in various aspects of physics, including spectroscopy, microwave techniques, and mathematics. His experience includes both practical engineering background with General Motors and with the U. S. Air Force, and in college-level teaching. Included are 3 years' experience with the Naval Ordnance Laboratory in the application of instrumentation to high-speed shock phenomena.

Mr. Maropis is responsible for ultrasonic transducer development.

William B. Devine, Director of Publications

A. B. in English from the University of Pennsylvania, 1936. For the past 25 years Mr. Devine has been active in the fields of technical and industrial communications, marketing, advertising, and public relations, serving in executive capacities to the level of executive vice-president with several leading corporations.

Mr. Devine is a member of Phi Beta Kappa, and Pi Gamma Mu, national honorary social sciences fraternity. He has been associated with Aeroprojects for the past 7 years as marketing and writing consultant, and has recently joined the Corporation staff as Director of Publications. His duties include active supervision of the editorial function.
### TECHNICAL MAN-HOURS

**EXPENDED DURING THIS REPORT PERIOD**

<table>
<thead>
<tr>
<th>NAME</th>
<th>PROJECT POSITION</th>
<th>HOURS EXPENDED THIS REPORT PERIOD</th>
</tr>
</thead>
<tbody>
<tr>
<td>W. N. Rosenberg</td>
<td>Project Supervisor</td>
<td>176</td>
</tr>
<tr>
<td>J. Koziarski</td>
<td>Director Welding Lab</td>
<td>436</td>
</tr>
<tr>
<td>J. G. Thomas</td>
<td>Metallurgist</td>
<td>332</td>
</tr>
<tr>
<td>G. Sekula</td>
<td>Junior Engineer</td>
<td>393-1/2</td>
</tr>
<tr>
<td>A. L. Fuchs</td>
<td>Chief Design Engineer</td>
<td>37</td>
</tr>
<tr>
<td>C. DePrisco</td>
<td>Chief Electronics</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Engineer</td>
<td></td>
</tr>
<tr>
<td>W. B. Devine</td>
<td>Director of Publications</td>
<td>76</td>
</tr>
<tr>
<td>N. Maropis</td>
<td>Physicist</td>
<td>6</td>
</tr>
</tbody>
</table>
**Metallography**

**Etchant:** NH₄OH + H₂O₂
(Silver unetched)

**Combination:** Silver to Copper
Number 1
(Wire) (Coupon)
0.060 gage 0.055

**Longitudinal**

Magnification: 52X

Magnification: 250X

**Transverse**

Magnification: 63X
Reduced to 3/4 size

**Comments:** The joint shows a high degree of interpenetration and interfacial flow. Bond quality is uneven, but satisfactory bonding was achieved along the center of the wire-sheet contact surface. The longitudinal section illustrates only a small portion of the weld zone.
ETCHANT: Unetched

COMBINATION: Copper to Silver
Number 2 (Wire) (Coupon)
0.064 gage 0.060

LONGITUDINAL

Magnification: 36X
Magnification: 250X

TRANSVERSE

Magnification: 36X
Magnification: 250X
Reduced to 3/4 Size

Comments: The edge-to-edge integrity of the joint and the degree of interpenetration of the mating surfaces exemplify a high degree of bond quality. No voids or unbonded areas were observed in these sections. Eccentric contact of the welding tip and wire resulted in deep indentation into the silver sheet along one edge (see lower left photomicrograph).
**Etchant: Unetched**

**Combination:** Nickel to Tantalum
Number 3 (Wire) (Coupon)
0.060 gage 0.063

**Magnifications**
- Longitudinal
  - Magnification: 36X
  - Reduced to 3/4 Size

- Transverse
  - Magnification: 36X
  - Magnification: 250X

**Comments:** Only a few scattered unjoined areas were observed. As a whole, the joint exhibits good interpenetration and integrity of the mating surfaces.
Etchant: Unetched

Combination: Nickel to Silver
Number h (Wire) (Coupon)

0.060 gage 0.060

Magnifications: 400X
Magnifications: 250X

Longitudinal

Magnification: 400X
Reduced to 3/4 Size

Transverse

Magnification: 250X

Comments: Bonding quality varies. The non-uniform deformation of the wire effected an unbonded area in the center. Edge bonding is satisfactory although numerous small voids are evident. The longitudinal section, taken along the edge of the wire, shows uniformly good bond quality.
**Metallography**

Etchant: KCN + Na₂S₂O₈  
(Gold unetched)

Combination: Nickel to Gold  
(Number 5 (Wire) (Coupon)  
0.060 gage 0.060

**Longitudinal**

Magnification: 36X

Comments: Several small voids are present at the interface, but in general, joint integrity is good. The lack of appreciable interpenetration is to be expected with metals of different hardness. The edges of the flattened wire are not bonded.

**Transverse**

Magnification: 36X

Magnification: 250X
METALLOGRAPHY

Etchant: $\text{NH}_4\text{CN} + \text{H}_2\text{O}_2$

(Nickel unetched)

Combination: Nickel to Copper
Number 6 (Wire) (Coupon)
0.060 gage 0.055

Longitudinal

Magnification: 52X

Magnification: 250X

Transverse

Magnification: 52X
Reduced to $3/4$ Size

Magnification: 250X

Comments: This joint displays excellent bonding characteristics. External deformation is small. The weld interface contains good interpenetration along with associated turbulent flow, uniformity of bond quality, and absence of imperfection such as voids or unbonded areas. The weld edge shows minimum crevasse formation.
**METALLOGRAPHY**

**Etchant:** 1% Nital

**Combination:** Mild Steel to Mild Steel
Number 7 (Wire) (Coupon) 0.062 gage 0.060

**Comments:** Thermal effects are quite apparent. Sub-grain formation and recrystallization have occurred on the surface of the wire and along the bond interface. The recrystallized grains tend to assume a square block-like outline in the longitudinal section. The interface contains clusters of surface debris and small voids.
**METALLORAPHY**

**Etchant:** 1% Nital  
(Stainless steel unetched)

**Combination:** Stainless Steel to Mild Steel  
Number 8 (Wire) (Coupon)  
0.0625 gage 0.060

**Magnification:** 36X  
Reduced to 3/4 Size

**Comments:** This joint exhibits very good bond characteristics. The sub-grain formation and/or recrystallization hold evidence to the thermal effects in the carbon steel.
Etchant: KCN + Na₂S₂O₈
(Stainless steel unetched)

Combination: Stainless Steel to Nickel
Number 9 (Wire) (Coupon)
0.0625 gage 0.060

**Longitudinal**

Magnification: 36x
Reduced to 3/4 Size

**Transverse**

Magnification: 36x

Magnification: 250x

**Comments:** Satisfactory weld characteristics are evident. Mutual interpenetration of the faying surfaces and absence of voids or non-bond areas indicate the integrity of the joint. Note the flow and expulsion of the nickel sheet and recrystallization structure adjacent to the weld interface.
Etchant: HF + HNO₃ + Lactic Acid  
(Nickel unetched)

Combination: Tantalum to Nickel  
Number 10 (Wire) (Coupon)  
0.062 gage 0.060

Comments: Uniform bonding throughout the entire contact area has not occurred, but excellent local bond areas are present. The darkly-etched regions of the wire delineate the heat pattern developed during welding.
Etchant: Unetched

**Metallography**

Combination: Tantalum to Stainless Steel
Number 11 (Wire) (Coupon)
0.062 gage 0.060

**Longitudinal**

Magnification: 36X

Magnification: 250X

**Transverse**

Magnification: 36X
Reduced to 3/4 Size

Magnification: 250X

**Comments:** Small voids and clusters of accumulated oxide decorate the interface; elsewhere, integrity is excellent. Some of the interfacial debris may be non-metallic inclusions within the stainless steel. No positive identification is available.
**METALLOGRAPHY**

**Etchant:** KOH + K$_3$Fe(CN)$_6$  
(Nickel unetched)

**Combination:** Tungsten to Nickel  
Number 12 (Wire) (Coupon)  
0.064 to 0.066 gage 0.060

**Longitudinal**

*Magnification: 48.5X*

**Transverse**

*Magnification: 48.5X*

*Magnification: 250X*

**Comments:** Very good integrity of the mating surfaces is demonstrated. However, evaluation of bond quality must be deferred because of polishing relief at the interface. Note cracking and spalling of tungsten wire.
Etchant: KOH + K$_3$Fe(CN)$_6$
(Tantalum unetched)

Combination: Tungsten to Tantalum
Number 13 (Wire) (Coupon)
0.064 to 0.066 gage 0.063

Comments: Metallographically, bond quality proved difficult to determine because of the interface relief. No large voids were observed; the surfaces appeared to be in intimate contact. Note the crack in the tungsten wire.
<table>
<thead>
<tr>
<th>No. of Copies</th>
<th>No. of Copies</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

**No. of Copies**

1. Advisory Group on Electron Devices  
   346 Broadway - 8th Floor  
   New York 13, New York

2. Commander  
   Aeronautical Systems Division  
   Wright-Patterson Air Force Base  
   Dayton, Ohio

3. Commanding General  
   U. S. Army Electronics Materiel Agency  
   225 South 18th Street  
   Philadelphia 3, Pennsylvania

4. Chief, Quality Assurance Operations Division

5. Commanding Officer  
   Chicago Procurement District, US Army  
   623 S. Wabash Ave.  
   Chicago 5, Illinois


7. Commanding Officer  
   Los Angeles Procurement District,  
   U. S. Army  
   55 South Grand Avenue  
   Pasadena 2, California


9. Chief, Industrial Preparedness Division

10. Commanding Officer  
    U. S. Army Electronics Materiel Support Agency  
    Fort Monmouth, New Jersey

11. Attn: SELMS-PFE

12. Commanding Officer  
    U. S. Army Electronics R&D Agency  
    Fort Monmouth, New Jersey

13. Attn: Chief, Tube Techniques Branch

14. Chief, General Tubes Branch

15. Chief, Gaseous Electronics Section, Bldg. S-53

16. Commander  
    Armed Services Technical Information Agency  
    Arlington Hall Station  
    Arlington 12, Virginia

17. Attn: TIPDR

18. Canadian Liaison Officer  
    Army Materiel Command  
    Tempo 7, Room 1067  
    Washington 25, D. C.

19. Chief, Bureau of Ships  
    Department of the Navy  
    Washington 25, D. C.

20. Attn: 691A

21. Amperex Electronic Corporation  
    230 Duffy Avenue  
    Hicksville, L. I., New York

22. Attn: Mr. Charles Roddy

23. Bell Telephone Laboratories  
    Technical Reports Center  
    Whippany, New Jersey

24. Attn: Miss Nan Farley

25. The Bendix Corporation  
    Red Bank Division  
    Eatontown, New Jersey

26. Attn: Mr. Joseph F. Bozzelli

27. Bomac Laboratories, Inc.  
    Salem Road  
    Beverly, Massachusetts

28. Attn: Mr. Richard S. Briggs

29. Burroughs Corporation  
    Electronic Tube Division  
    P. O. Box 1226  
    Plainfield, New Jersey

30. Attn: Mr. Roger Wolfe
### DISTRIBUTION LIST (Continued)

<table>
<thead>
<tr>
<th>No. of Copies</th>
<th>Company Name and Address</th>
<th>No. of Copies</th>
<th>Company Name and Address</th>
</tr>
</thead>
</table>
| 1             | Allen B. DuMont Laboratories, Inc.  
               750 Bloomfield Avenue  
               Clifton, New Jersey  
               Attn: Mr. Robert Deutsch | 1             | Hughes Aircraft  
               Vacuum Tube Products  
               2020 Short Street  
               Oceanside, California  
               Attn: Mr. James Sutherland |
| 1             | Edgerton, Gershemhausen & Grier, Inc.  
               160 Brookline Avenue  
               Boston 15, Massachusetts  
               Attn: Mr. S. Goldberg | 1             | International Telephone & Telegraph  
               Corporation  
               Components Division  
               P. O. Box 442  
               Clifton, New Jersey  
               Attn: Mr. G. G. Perry |
| 1             | Eitel-McCullough, Inc.  
               301 Industrial Way  
               San Carlos, California  
               Attn: Mr. H. N. Bailey | 1             | Lionel Electronic Laboratories, Inc  
               1226 Flushing Avenue  
               Brooklyn 37, New York  
               Attn: Dr. Gustave Weinberg |
| 1             | Electronic Enterprises, Inc.  
               65-67 Seventh Avenue  
               Newark 1, New Jersey  
               Attn: Mr. Richard Bloemeke | 1             | Litton Engineering Laboratories  
               P. O. Box 949  
               Grass Valley, California  
               Attn: Mr. Charles V. Litton |
| 1             | Electronic Tube & Instrument Division  
               1200 East Mermaid Lane  
               Philadelphia, Pennsylvania  
               Attn: Mr. S. Pearlman | 1             | Litton Industries  
               Electron Tube Division  
               San Carlos, California  
               Attn: Mr. B. D. Kumpfer |
| 1             | Electrons, Inc.  
               127 Sussex Avenue  
               Newark 3, New Jersey  
               Attn: Mr. E. K. Smith | 1             | Machlett Laboratories, Inc.  
               1063 Hope Street  
               Springdale, Connecticut  
               Attn: T. H. Rogers |
| 1             | General Electric Company  
               316 East Ninth Street  
               Owensboro, Kentucky  
               Attn: Mr. W. T. Millis | 1             | Matcom, Inc.  
               76 Lafayette Street  
               Salem, Massachusetts  
               Attn: Mr. Richard Broderick |
| 1             | Gulton Industries, Inc.  
               212 Durham Avenue  
               Metuchen, New Jersey  
               Attn: Mr. Daniel Abrams | 1             | Microwave Associates, Inc.  
               South Street  
               Burlington, Massachusetts  
               Attn: Dr. L. Gould |
| 1             | Huggins Laboratories  
               999 East Argues Avenue  
               Sunnyvale, California  
               Attn: Mr. R. A. Huggins |
<table>
<thead>
<tr>
<th>No. of Copies</th>
<th>Company and Address</th>
<th>No. of Copies</th>
<th>Company and Address</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Microwave Electronics Corporation, 1061 Transport Street, Palo Alto, California, Attn: Dr. Stanley Kaisel</td>
<td>1</td>
<td>S.F.D. Laboratories, Inc., 800 Rahway Avenue, Union, New Jersey, Attn: Dr. Joseph Saloom</td>
</tr>
<tr>
<td>1</td>
<td>Ohio State University, Department of Metallurgy, Columbus, Ohio, Attn: Mr. Frederick J. Fraikor</td>
<td>1</td>
<td>Sonatone Corporation, Box 200, Elmsford, New York, Attn: Dr. L. G. Hector</td>
</tr>
<tr>
<td>1</td>
<td>FEK Laboratories, Inc., 1024 Transport Street, Palo Alto, California, Attn: Mr. H. H. Eaves</td>
<td>1</td>
<td>Sperry Electronic Tube Division, Sperry Rand, Gainesville, Florida, Attn: Mr. John Whitford</td>
</tr>
<tr>
<td>1</td>
<td>Penta Laboratories, Inc., 312 North Nosal Street, Santa Barbara, California, Attn: Mr. R. L. Norton</td>
<td>1</td>
<td>Sylvania Electric Products, Inc., Emporium, Pennsylvania, Attn: Mr. Ralph Clausen</td>
</tr>
<tr>
<td>1</td>
<td>Philco Corporation, Lansdale Division, Church Road, Lansdale, Pennsylvania, Attn: Mr. F. Mayock</td>
<td>1</td>
<td>Tucor, Inc., 59 Danbury Road, Wilton, Connecticut, Attn: Mr. R. White</td>
</tr>
<tr>
<td>1</td>
<td>Polarad Electronics Corporation, 13-20 Thirty-fourth Street, Long Island City 1, New York, Attn: Dr. D. L. Jaffe</td>
<td>1</td>
<td>Tung-Sol Electric, Inc., 1 Summer Avenue, Newark 44, New Jersey, Attn: Mr. William V. Rauscher</td>
</tr>
<tr>
<td>1</td>
<td>Radio Corporation of America, Electron Tube Division, 15 South Fifth Street, Harrison, New Jersey, Attn: Mr. Clarence West</td>
<td>1</td>
<td>United Electronics Company, 12 Spring Street, Newark, New Jersey, Attn: Dr. John Beers</td>
</tr>
<tr>
<td>1</td>
<td>Raytheon Company, Industrial Components Division, 55 Chapel Street, Newton 58, Massachusetts, Attn: Mr. Paul R. Keeler</td>
<td>1</td>
<td>Varian Associates, 611 Hansen Way, Palo Alto, California, Attn: Dr. Richard Nelson</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>The Victoreen Instrument Company, 5806 Hough Avenue, Cleveland 3, Ohio, Attn: Mr. Ben Olson</td>
</tr>
</tbody>
</table>
DISTRIBUTION LIST  (Concluded)

<table>
<thead>
<tr>
<th>No. of Copies</th>
<th>Address</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Watkins-Johnson Company</td>
</tr>
<tr>
<td></td>
<td>3333 Hillview Avenue</td>
</tr>
<tr>
<td></td>
<td>Palo Alto, California</td>
</tr>
<tr>
<td></td>
<td>Attn: Dr. Rolf Peter</td>
</tr>
<tr>
<td>1</td>
<td>Westinghouse Electric Corporation</td>
</tr>
<tr>
<td></td>
<td>Electronic Tube Division</td>
</tr>
<tr>
<td></td>
<td>Box 284</td>
</tr>
<tr>
<td></td>
<td>Elmira, New York</td>
</tr>
<tr>
<td></td>
<td>Attn: Mr. B. W. Sauter</td>
</tr>
<tr>
<td>1</td>
<td>U. S. Army Ordnance</td>
</tr>
<tr>
<td></td>
<td>Frankford Arsenal</td>
</tr>
<tr>
<td></td>
<td>Bridge &amp; Tacony Streets</td>
</tr>
<tr>
<td></td>
<td>Philadelphia, Pennsylvania</td>
</tr>
<tr>
<td></td>
<td>Attn: Mr. Frank Hussey</td>
</tr>
<tr>
<td></td>
<td>Metal Joining Section</td>
</tr>
<tr>
<td></td>
<td>1323, 6H-1</td>
</tr>
<tr>
<td>1</td>
<td>Battelle Memorial Institute</td>
</tr>
<tr>
<td></td>
<td>505 King Avenue</td>
</tr>
<tr>
<td></td>
<td>Columbus 1, Ohio</td>
</tr>
<tr>
<td></td>
<td>Attn: Mr. C. M. Jackson</td>
</tr>
<tr>
<td>1</td>
<td>Westinghouse Electric Corporation</td>
</tr>
<tr>
<td></td>
<td>Youngwood, Pennsylvania</td>
</tr>
<tr>
<td></td>
<td>Attention: Mr. Ozzie Jaeger</td>
</tr>
<tr>
<td>1</td>
<td>Clevite Transistor</td>
</tr>
<tr>
<td></td>
<td>A Division of Clevite Corporation</td>
</tr>
<tr>
<td></td>
<td>200 Smith Street</td>
</tr>
<tr>
<td></td>
<td>Waltham 54, Massachusetts</td>
</tr>
<tr>
<td></td>
<td>Attention: Mr. Sam Rubinovitz</td>
</tr>
<tr>
<td>1</td>
<td>Rome Air Development Center</td>
</tr>
<tr>
<td></td>
<td>Griffiss Air Force Base, New York</td>
</tr>
<tr>
<td></td>
<td>Attention: Mr. L. Cubbins, RASGR</td>
</tr>
<tr>
<td>No. of Copies</td>
<td>Company Name</td>
</tr>
<tr>
<td>--------------</td>
<td>--------------</td>
</tr>
<tr>
<td>1</td>
<td>Philco Corporation</td>
</tr>
<tr>
<td>1</td>
<td>Radio Corporation of America</td>
</tr>
<tr>
<td>1</td>
<td>Raytheon Manufacturing Company</td>
</tr>
<tr>
<td>1</td>
<td>Sprague Electric Company</td>
</tr>
<tr>
<td>1</td>
<td>Texas Instruments, Inc.</td>
</tr>
<tr>
<td>1</td>
<td>Texas Instruments, Inc.</td>
</tr>
<tr>
<td>1</td>
<td>Transitron Electronic Corporation</td>
</tr>
<tr>
<td>2</td>
<td>Western Electric Company</td>
</tr>
<tr>
<td>1</td>
<td>Westinghouse Electric Corporation</td>
</tr>
<tr>
<td>1</td>
<td>Clevite-Transistor Corp.</td>
</tr>
<tr>
<td>1</td>
<td>Delco Radio Division</td>
</tr>
<tr>
<td>1</td>
<td>Bendix Corporation</td>
</tr>
<tr>
<td>1</td>
<td>Motorola, Inc.</td>
</tr>
<tr>
<td>1</td>
<td>Pacific Semiconductors, Inc.</td>
</tr>
<tr>
<td>1</td>
<td>General Electric Company</td>
</tr>
<tr>
<td>1</td>
<td>Bureau of Weapons</td>
</tr>
<tr>
<td>1</td>
<td>The Rembar Company, Inc.</td>
</tr>
<tr>
<td>1</td>
<td>Fairchild Semiconductor Corp.</td>
</tr>
</tbody>
</table>