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MARTIN MARIETTA CORPORATION

FINAL TEST REPORT
(Group 1 and 2 Tests)

SOLDER STUDY CONDUCTED ON APOLLO TELESCOPE MOUNT GYRO PROCESSOR

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FOREWORD

This final report includes the combined test results of Group 1 and Group 2 ATM solder joint tests. These tests were conducted on the Apollo Telescope Mount (ATM) Gyro Processor under contract NAS8-11864 by the Martin Marietta Corporation at Orlando, Florida. A preliminary report on the first group of tests was published in December 1967 as Martin Marietta report OR 9187.

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SUMMARY

Two new thermal cycling machines and an accelerated test technique were developed for these tests. These machines reduce to less than two percent of earlier tests the time required to test new designs of printed circuit (PC) assemblies for resistance to solder joint cracking. Partial test correlation data has been developed and is included in this report.

The Group 2 tests showed no major differences in the solder alloys tested. One part of the test showed the rigid epoxy conformal coating used on some other projects has similar solder joint cracking phenomena as the semi-rigid polyurethane coating. Another group of tests confirmed a resilient spacer does reduce solder joint cracking and that the hardness is not critical when softer than 45 Shore A hardness. The tests showed several solder joint designs are capable of meeting the rigid ATM temperature cycling requirements, and that some of them are more resistant to cracking than the tubelet design. The length the lead extends through the tubelet is critical at least to localized cracking. The tubelet and 96 percent tin and 4 percent silver solder on both resistors and capacitors will enable them to meet the ATM temperature cycling goal. The relay pins with the flanged tubelet will develop minor cracks and there is no significant difference whether the flanged tubelet is soldered only or whether it is crimped, welded and soldered. The special aluminum PC board is several times more resistant to creating solder joint cracking than our standard epoxy-glass PC board.

Table I lists the types of solder joints tested. Also shown is the approximate number of accelerated thermal cycles they can be expected to withstand with ten percent joint cracking. Inspection was accomplished under thirty power magnification. From Group 1 temperature correlation data, these figures can be multiplied by three to give the approximate equivalent number of one hour air cycles. A larger multiplication figure is undoubtedly required to give an equivalent number of ATM thermal cycles of -10° to +55°C air cycles; however, additional testing is necessary to determine this figure.

TABLE I

Accelerated Thermal Test Summary Index

Solder Joint Type	Approximate No. of Cycles to 10 Percent Cracked
Capacitors, Dipped Mica, 0.032 copper-clad steel, 0.062 G10 board	
Formed 0.05-0.1 inch, 60 percent tin, 40 percent lead solder	800
Formed 0.1-0.15 inch, 96 percent tin, 4 percent silver solder	900
Tubelets, heavy solder, 96 percent tin, 4 percent silver solder	>4,700
Resistors, 1/10 watt, hermetically sealed, RNR55 type, 0.062 G10	
Formed 0.05-0.1 inch, 60/40 solder	600
Formed 0.05-0.1 inch, 96/4 solder	950
Formed 0.1-0.15 inch, 97.5 percent lead, 1.5 percent silver, 1 percent tin solder	4,500
Formed 0.1-0.15 inch, 60 percent lead, 37.5 percent tin, 2.5 percent antimony	2,100
Formed 0.1-0.15 inch, 95 percent tin, 5 percent antimony solder	>4,700
Formed 0.1-0.15 inch, 41.4 percent lead, 55 percent tin, 3.6 percent antimony	2,100
Tubelet, 96 percent tin, 4 percent silver solder	>4,100
Relays, half size*, 0.030 inch Ni-Fe-Cr pins, 60/40 sol., G10 boards	
No spacer, 0.062 PC board, plated through holes (full size)*	350
Soft spacer, 0.062 PC board, plated through holes (full size)*	750
No spacer, 0.093 PC board, standard joint	400
Soft spacer, 0.093 PC board, standard joint	900
No spacer, 0.093 PC board, crimped, welded, flanged tubelet	3,300
Soft spacer, 0.093 PC board, crimped, welded, flanged, tubelet	1,400
Soft spacer, 0.093 PC board, soldered flanged tubelet	2,400
Leads only, 0.016-0.020 inch dia, 60/40 solder, 0.062 G10	
Formed 0.1-0.15 inch Kovar	700
Formed 0.1-0.15 inch, nickel-iron	800
Formed 0.1-0.15 inch, dumet (30 percent copper)	1,700
Formed 0.1-0.15 inch copper (OF)	>4,300
Formed plus tubelets, Kovar lead	>3,900

* Refers to crystal can or microminiature size relay, approximately 0.4 by 0.8 by 0.9 inch.

TABLE I (Cont)

Solder Joint Type	Approximate No. of Cycles to 10 Percent Cracked
Transistors, 3 Kovar lead TO-5, formed 0.1-0.15 inch, DAP Spacers	
97.5 percent lead, 1.5 percent silver, 1 percent tin solder	450
96 percent tin, 4 percent silver solder	130
60 percent lead, 37.5 percent tin, 3.5 percent antimony solder	200
95 percent tin, 5 percent antimony solder	90
41.4 percent lead, 55 percent tin, 3.6 percent antimony solder	120
60 percent tin, 40 percent lead solder	50
60 percent tin, 40 percent lead solder except with PC-16 epoxy coating	25
Transistors, 3 lead TO-5, 0.062 G10 boards	
Soft pad, Kovar, straight-squeezed, 96/4 solder	1,900
Soft pad, Kovar, flattened, formed 0.1-0.15, 60/40 solder	1,100
Soft pad, Kovar, gradual form 0.1-0.15, 60/40 solder	1,000
Soft pad, Ni-Fe, flattened, formed 0.1-0.15, 96/4 solder	1,700
Soft pad, Kovar, "D" loop, tubelet, 60/40 solder	3,300
Soft pad, Ni-Fe, "D" loop, tubelet, 96/4 solder	2,800
Soft pad, Ni-Fe, Tubelets, 96/4 solder	3,900
Soft pad, Ni-Fe, mod "D" loop, 96/4 solder	>4,700
DAP pad, Kovar, flattened "D" loop, 41.4Pb, 55Sn, 3.6Sb	3,500
Soft pad, Kovar, cane loop, 96/4 solder	3,800
Soft pad, Kovar, split funnel eyelet, 96/4 solder	3,500
Inverted, Kovar, formed 0.05-0.1, heavy 60/40 solder	3,900
Inverted, Kovar, formed 0.1-0.15, 60/40 solder	1,200
Inverted, Kovar, 1/16 inch straight, heavy 60/40 solder	1,800
Inverted, Kovar, tubelet, long lead, 60/40 solder	1,600
Inverted, Kovar, tubelet, short lead, heavy 60/40 solder	>4,700
Transistors, 3 Kovar lead TO-5, 60/40 solder, 0.062 G-10 board	
Dialyl phthalate spacer, tubelets	410
Polyurethane foam spacer, tubelet	2,100
Polyurethane rubber, 22A shore hardness, tubelets	1,400
Polyurethane rubber, 32A shore hardness, tubelets	1,400
Polyurethane rubber, 45A shore hardness, tubelets	1,600
Neoprene rubber, 40A shore hardness, tubelets	3,800

I. DEVELOPMENT OF AN ACCELERATED TEST

A. EVALUATION OF METHODS

Earlier thermal cycling tests run at Martin Marietta on PC assemblies required that temperature changes be made gradually to avoid thermal shock. Approximately one hour was needed for a complete cycle from -55 to +125 to -55°C. Data was taken on many designs; this information is given in Martin Marietta Report OR 8813.

The requirements for a 12,000 thermal cycle goal from -10° to +55°C on the ATM Gyro Processor precluded the usefulness of such a slow test to prove out ATM designs. Therefore, three methods were evaluated. First, an automatic, dual chamber, air blast thermal cycling machine was monitored. It was found to be unsatisfactory because it required 8 to 10 minutes to saturate thermally a normal size (5- by 5-inch) PC board assembly that had been soaked at the opposite temperature extreme (-65 to +125°C). This evaluation showed that any air cycling machine would be too slow.

Second, small parts of PC assemblies (approximately two inches square) were dipped in hot oil at 300°F and liquid nitrogen at -320°F. Surprisingly, the solder joints withstood these thermal shocks and, after several dozen cycles, began developing the same type of solder joint deterioration and cracking that had been observed previously on gradual air cycling. However, the hot oil began softening the conformal coating, was messy to handle, and was difficult to inspect accurately.

Third, similar parts were alternately dipped in boiling water and isopropyl alcohol cooled by dry ice chunks. These materials maintained constant temperatures and did not affect the PC assemblies. The usual types of deterioration and cracking of the solder joints developed after a few score cycles. The small PC assemblies changed temperature in approximately 10 seconds. Larger assemblies required 20 to 30 seconds.

B. TEST EQUIPMENT

An automated cycling machine was built that would hold sixteen 5- by 5-inch PC assemblies (Figure 1). This machine rotates groups of four assemblies on each of four arms, dipping them alternately into a tank of boiling water and a tank of isopropyl alcohol cooled with dry ice. Each group of boards are in each tank 45 seconds; they then drain 15 seconds before entering the next tank.

Due to the urgency of the requirement for thermal cycling data for other temperatures, another machine was built that would automatically cycle four PC assemblies on each of two arms from one tank to another (Figure 2). One arm moves between one tank of boiling water and one tank

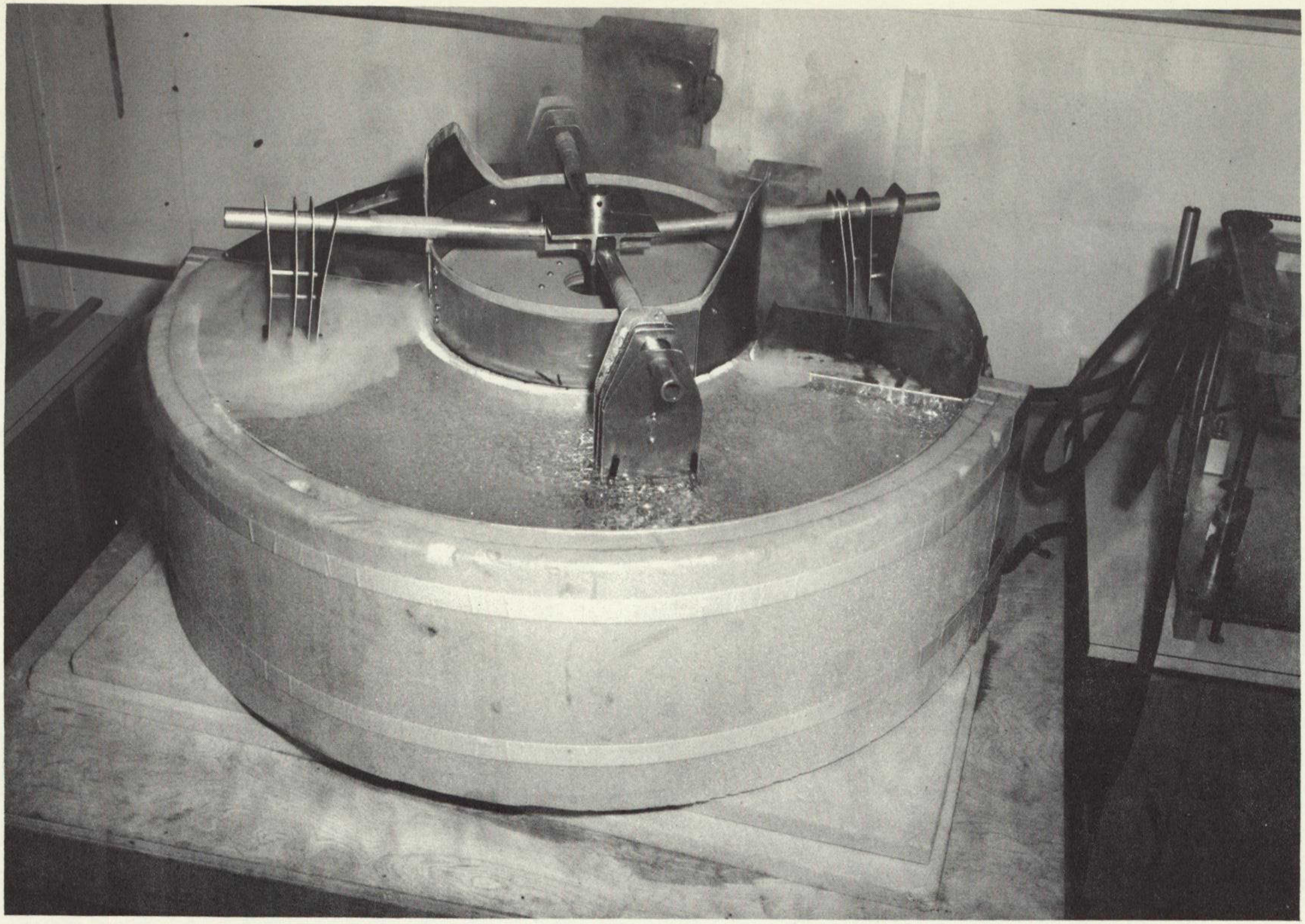


Figure 1. Rotary Test Machine

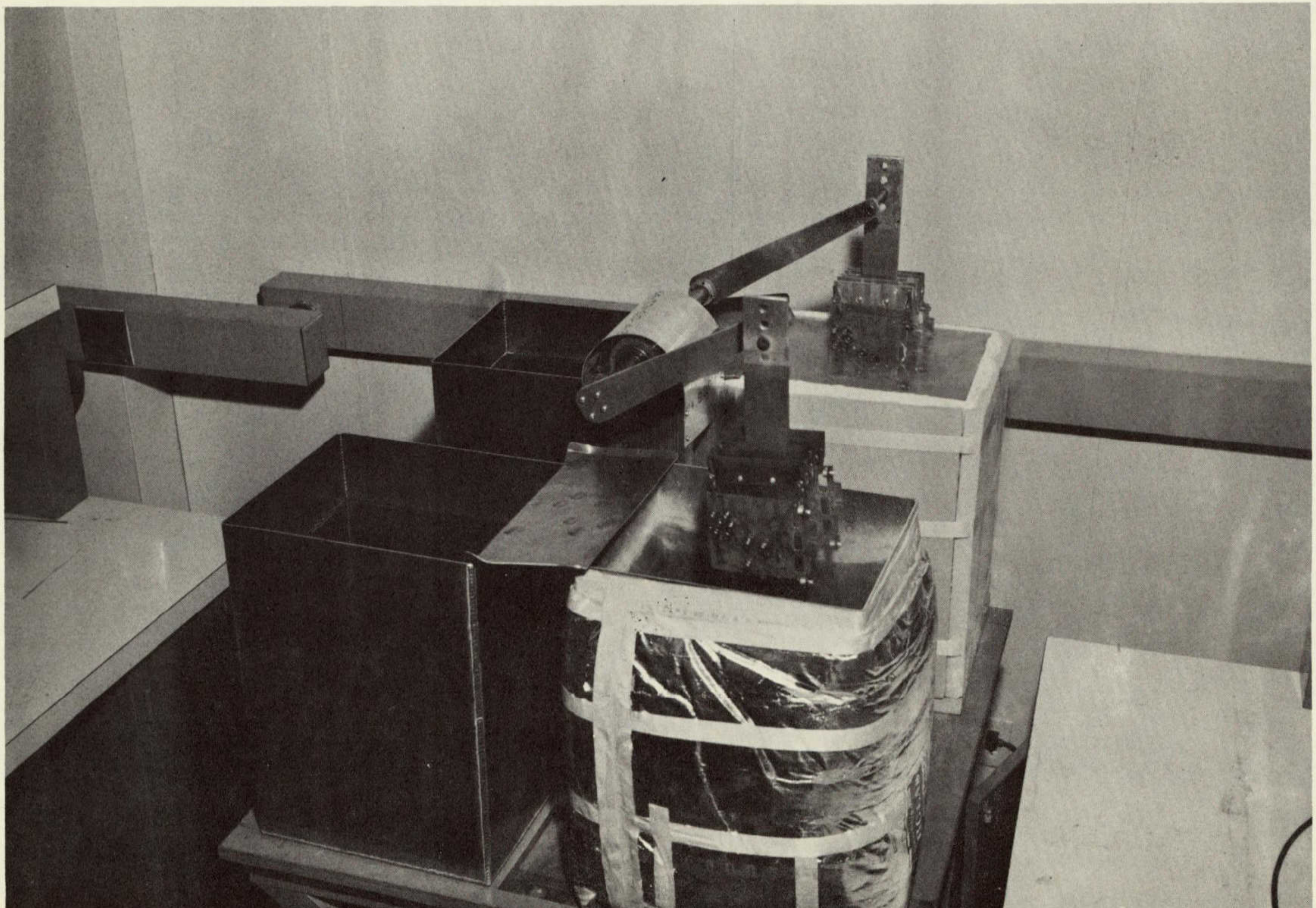


Figure 2. Two Arm Test Machine

of water at room temperature. The second arm moves between one tank of isopropyl alcohol cooled with dry ice and one tank of water at room temperature. The cycle is adjustable, but was set to dwell in each tank 45 seconds and transfer in 8 seconds.

II. TESTS

A. TEMPERATURE CORRELATION TESTS

1. Purpose.

Temperature correlation tests were conducted to prove the validity of the methods and test equipment described in Section I for the ATM printed circuit assemblies.

2. Test Specimens.

Six identical PC assemblies were constructed in the white room by a qualified solderer. Each assembly consisted of nine TO-5 transistors; each transistor had three gold plated kovar leads and were mounted on a 0.078 inch diallyl phthalate (DAP) transipad. The leads were formed over the 0.100 inch diameter copper pads between 0.050 and 0.100 inch and soldered with 60 percent tin 40 percent lead solder in accordance with NPC-200-4. The component side only was spray coated 0.008 inch thick with polyurethane PC-22 material. These assemblies were designated as temperature correlation boards and numbered one through six.

3. Test Procedure and Results

Boards one and two were thermally cycled on one of the arms through the tanks containing room temperature and boiling water. Boards three and four were thermally cycled on the other arm through tanks with water at room temperature and alcohol at -75°C. Boards five and six were placed on the rotating machine and cycled from -75°C to +100°C. The temperature correlation test results are tabulated in Tables II, III, IV, and V.

Figure 3 shows the data from the above temperature correlation tests along with the results for the earlier air cycling tests on similar PC assemblies.

Table V gives a quick review of the data in the low percentage of solder joint cracking area, which is of prime concern. At the 5 percent level, the rotary accelerated test giving a -75°C to a +100°C excursion not only requires 2 minutes instead of 1 hour per cycle, but is four times as severe. Thus, the new method requires less than 1 percent of the time to develop the same deterioration as did the earlier air cycling method. The values given in Table V are at the 10 percent level and were obtained from tests on the rotary accelerated testing machine. These values therefore must be multiplied to equate them with the air cycling values; the multiplying factors are greater for equating these values to the number of actual environmental cycles the equipment will withstand.

TABLE II

Accelerated Automated Solder Test Results for Specimens TC-1 and TC-2 - Temperature Correlation*

Inspected at Number of Cycles	TC-1 +25°C, +100°C Number of Cracks	TC-2 +25°C, +100°C Number of Cracks	Percent of Joints Cracked (Total 54)
20	0	0	0
40	1	0	1.85
60	3	0	5.5
80	5	0	9.3
100	7	1	14.9
120	8	1	16.8
140	9	4	24.0
160	9	7	28.6
180	10	11	39.0
200	15	12	50.0
220	15	15	55.8
270	15	15	55.8
320	15	15	55.8

*Two arm liquid dip machine.

Note: Each temperature correlation board had 27 solder joints.

TABLE III

Accelerated Automated Solder Test Results for Specimens TC-3 and TC-4 - Temperature Correlation*

Inspected at Number of Cycles	TC-3 +25°C to -75°C Number of Cracks (27 Joints)	TC-4 +25°C to -75°C Number of Cracks (27 Joints)	Percent of Joints Cracked (Total 54)
20	0	0	0
40	0	0	0
50	1	0	1.85
70	2	0	3.7
90	4	0	7.4
110	5	0	9.3
130	6	0	11.1
150	6	0	11.1
160	7	0	13.0
180	8	0	14.9
200	8	1	16.8
250	8	1	16.8

*Two arm liquid dip machine.

TABLE IV

Accelerated Automated Solder Test Results for Specimens TC-5 and TC-6 - Temperature Correlation*

Inspected at Number of Cycles	Temperature Correlation Boards		
	TC-5 Standard Number of Cracks	TC-6 Standard Number of Cracks	Percent Cracked (Total 54)
20	0	4	7.4
40	5	6	20.4
61	13	10	42.5
81	14	13	50.0
101	14	18	59.0
154	14	22	64.4
201	14	24	70.0
251	20	25	83.0
312	20	26	85.0
450	20	26	85.0
566	20	26	85.0
766	20	26	85.0
884	20	26	85.0
984	Discontinued	Discontinued	Discontinued

*Rotary test machine (-75°C to +100°C)

Note: Each temperature correlation board had 27 solder joints.

TABLE V

Temperature Correlation Data

Cycle Data	Percent of Cracks				
	5	10	15	20	
1) Air Cycle, 45 minutes to 1 hour, -55 to +125°C	60	69	88	110	Cycles
2) Water-Alcohol, 2 minutes, -75°C to +100°C	15	25	32	38	Cycles
3) Water-Water, 2 minutes, +25°C to +100°C	62	83	108	130	Cycles
4) Water-Alcohol, 2 minutes, +25°C to -75°C	75	125	181	-	Cycles

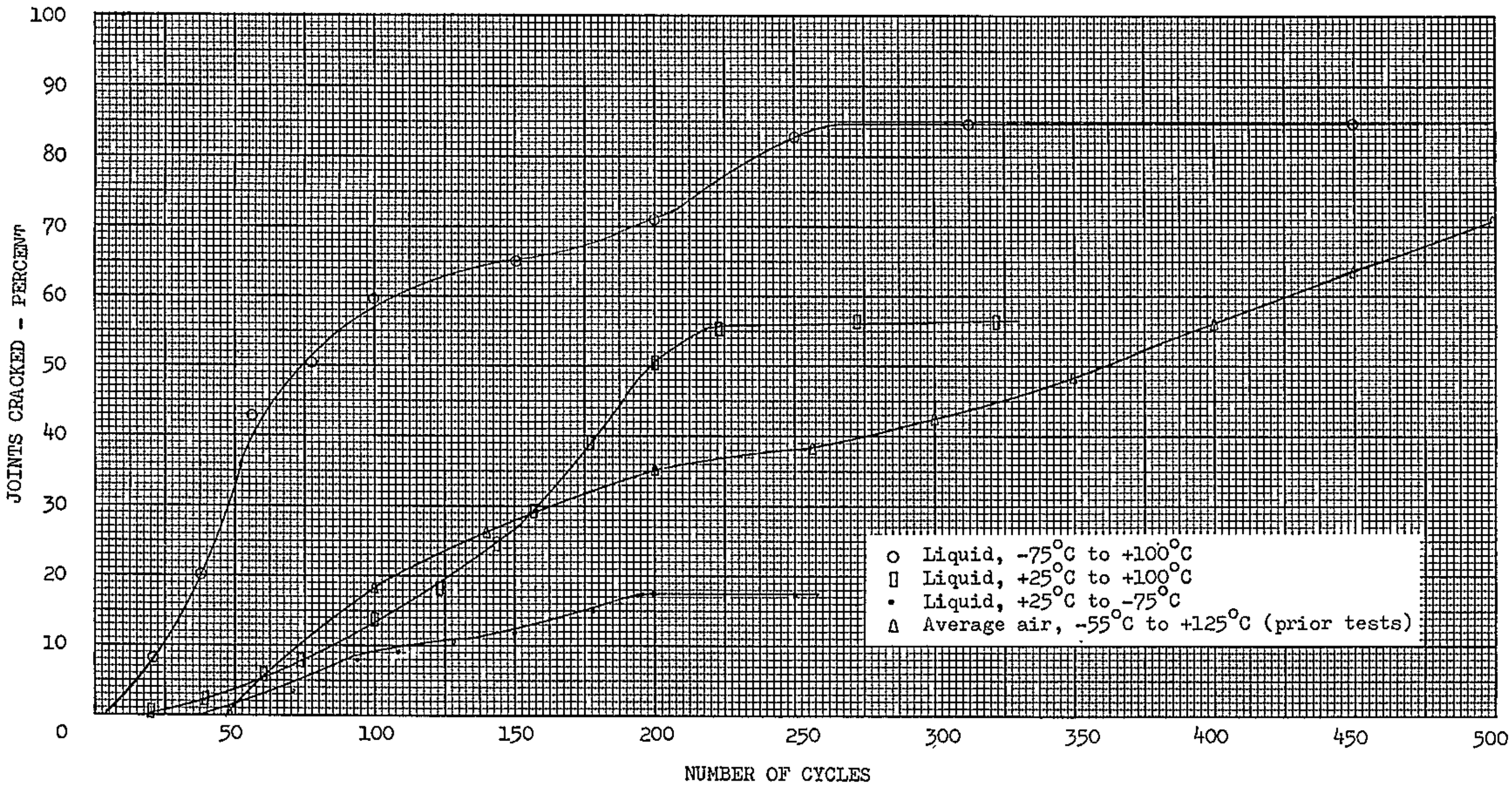


Figure 3. Temperature Correlation Curves for Standard Joints

B. GROUP 1 SOLDER JOINT DESIGN TESTS

1. Purpose

The solder joint design tests described in this section were conducted to evaluate the comparative advantages of a selected group of solder joint arrangements and materials.

2. Test Specimens

Twenty solder joint arrangements were constructed under white room conditions by qualified personnel. Normal NASA conditions and procedures identical with those used on the control signal processor were followed, including inspections, except where deviations are specifically stated. All completed PC assemblies were inspected and then spray coated with 0.006 to 0.008 inch of polyurethane PC-22 conformal coating on the component side only. However, the coating did not cure properly on the soft rubber spacers. All of these assemblies were inspected during construction and throughout the testing by a qualified inspector accustomed to NASA quality requirements and familiar with the solder cracking problem.

All the PC assembly boards were laminated woven fiberglass impregnated with epoxy resins. All PC boards, except for the relay assemblies (described on page 13), were nominally 1/16 inch thick and approximately 5 inches by 5 inches. The relay assemblies were on 3/32 inch thick boards of the same material.

The following solder joint arrangements were placed on the PC boards:

1 PC Board L100 (five designs)

- a Nine TO-5 transistors, each having three gold-plated kovar leads 0.016 to 0.019 inch in diameter were soldered into the PC board. A soft neoprene, 40 shore A hardness, 1/32 inch thick spacer was placed between the PC board and the transistor body. Each lead was formed over 0.1 to 0.15 inch and a copper tubelet slipped over the lead and bonded with 60/40 solder (60 percent tin and 40 percent lead).

- b Nine TO-5 transistors, each having three gold-plated nickel-iron leads 0.016 to 0.019 inch in diameter were soldered onto the PC board. The same type neoprene spacers and tubelets used for a, above, were used in this assembly. A 96 percent tin/4 percent silver solder was used.

- c Three kidney shaped silvered mica capacitors (DM 19 type) were installed upright on the PC board. Each lead was formed over and bonded with a heavy 60/40 solder.

d Fifteen one-tenth watt, hermetically sealed glass resistors were installed in accordance with NPC 200-4, except that a heavier than specified solder joint was prepared. Standard 60/40 solder was used.

e Twenty-seven 0.016 to 0.019 inch diameter nickel-iron leads were installed through the PC board. They extended out the component side approximately 1/8 inch and were formed over the circuit pad 0.1 to 0.15 inch. Each lead was soldered to the pad with a heavy fillet of 60/40 solder.

2 PC Board L101 (four designs)

a Nine TO-5 transistors, each having three gold-plated kovar leads, were installed with soft neoprene transipads. Each lead was brought through its hole and formed into a vertical loop approximately 1/16 inch in diameter with the end almost touching the lead where it came through the hole. The 60/40 solder was applied in a heavy fillet around the end of the lead and where it came through the hole, but the upper loop was left open. The lead and circuit pad were tinned using flux; however, the final soldering was done with solid 60/40 solder. This joint is defined as a "modified D loop."

b Nine TO-5 transistors, each having three gold-plated nickel-iron leads, were installed with soft neoprene transipads. Each lead was formed into a modified D loop, and the joints were made with 96 percent tin/4 percent silver solder.

c Fifteen one-tenth watt, hermetically sealed glass resistors were installed in accordance with NPC 200-4, except that a heavier than specified solder joint was prepared using 96 percent tin/ 4 percent silver solder.

d Twenty-seven gold-plated 0.016 to 0.019 inch diameter kovar leads were installed through the PC board. They extended out the component side approximately 1/8 inch and were formed over the circuit pad 0.1 to 0.15 inch. Each lead was soldered to the pad with a heavy fillet of 60/40 solder.

3 PC Board L102 (three designs)

a Nine TO-5 transistors, each having three gold-plated kovar leads, were installed with soft neoprene spacers. The leads were brought through the PC board and formed over 0.1 to 0.15 inch. However, the lead was formed over a small wire such that the end of the lead touched the pad with a slight pressure and the lead did not form tightly across the edge of the hole. After the lead and pad were tinned and wicked off, a heavy joint was made with solid core 60/40 solder without flux.

b Nine TO-5 transistors, each having three gold-plated kovar leads, were installed with soft neoprene spacers. The leads were formed over 0.1 to 0.15 inch. After tinning, a heavy joint of solid 60/40 solder was prepared.

c Twenty-seven 0.016 to 0.019 inch diameter, gold-plated kovar leads were installed through the PC board. They extended out the component side approximately 1/8 inch and were formed over 0.1 to 0.15 inch with tubelets installed over their ends. After tinning, a heavy joint of solid 60/40 solder was prepared.

4 PC Board L103 (three designs)

a Nine TO-5 transistors, each having three gold-plated nickel-iron leads, were installed with soft neoprene spacers. The leads were brought through the PC board and formed over 0.1 to 0.15 inch. After the lead and pad were tinned and wicked off, a heavy joint of 96 percent tin/4 percent silver was made.

b Nine TO-5 transistors, each having three gold-plated kovar leads, were installed with soft neoprene spacers. The leads were brought through the PC board 1/32 inch, squeezed flat, cut off, and soldered with a heavy fillet of 96 percent tin/4 percent silver solder.

c Three kidney-shaped silvered mica capacitors (DM 19 type) were installed upright on the PC board. Each lead was formed over a heavy fillet of 60/40 solder applied.

The relay boards were prepared in the following manner:

1 Relay Board RB 1. Five one-half size crystal case relays, each having eight 0.030 inch straight tinned nickel-iron pins, were installed. Each pin was soldered with heavy fillet of 60/40 solder in accordance with NPC 200-4.

2 Relay Board RB 2. Five one-half size crystal case relays, each having eight 0.030 inch straight tinned nickel-iron pins, were installed with 1/32 inch soft rubber spacers, 40 shore A hardness, between the relay and the board. Each pin was soldered with a heavy fillet of 60/40 solder in accordance with NPC 200-4.

3 Relay Board RB 3. Five one-half size crystal case relays, each having eight 0.030 inch straight tinned nickel-iron pins, were installed. A copper, flanged tubelet was slipped over each pin, crimped, and resistance welded with the flange next to the circuit pad. Each pin was then soldered to the flanged tubelet and the circuit pad with 60/40 solder.

Six types of ATM PC boards were also tested. They were prepared in the following manner:

1 Boards 1 and 2. Five TO-5 transistors having gold-plated kovar leads were installed over 1/8 inch high, white, footed, polypropylene spacers. Each lead was formed over and soldered in accordance with NPC 200-4, except that a heavier 60/40 solder joint was used. One flat crystal case relay with 10 straight, 0.030 inch diameter, tinned, nickel-iron pins was also installed on each board with a 1/32 inch thick soft silicone rubber spacer; the spacer had a 40 shore A hardness. Each pin was soldered in accordance with NPC 200-4 with a heavy fillet of 60/40 solder.

2 Boards 3 and 6. Five TO-5 transistors with gold-plated kovar leads were installed over 1/32 inch thick soft silicone rubber, 40 shore A hardness, spacers, Each lead was formed over and soldered in accordance with NPC 200-4 procedures, except that a heavier 60/40 solder joint was made. One flat crystal case relay with 10 straight, 0.030 inch diameter, tinned, nickel-iron pins was also installed on each board with a 1/32 inch thick soft silicone rubber spacer; the spacer had a 40 shore A hardness. Each pin was soldered to the board in accordance with NPC 200-4 with a heavy fillet of 60/40 solder.

3 Boards 4 and 5 (designated GM-1 and GM-2)

a Six TO-5 transistors with gold-plated kovar leads were installed on 0.078 inch tall, diallyl phthalate spacers. The leads were formed over and soldered in accordance with NPC 200-4.

b Six TO-5 transistors with gold-plated kovar leads were installed in an inverted position with the top of the case against the PC board and the leads formed over (parallel to the sides of the case) and through the holes in the PC board. Each lead was soldered in accordance with NPC 200-4.

c Six TO-5 transistors with gold-plated kovar leads were installed in an inverted position with the top of the case against the PC board and the leads formed over (parallel to the sides of the case) and through holes in the PC board. The leads were cut off 1/32 inch above the board and soldered to the circuit pad with 60/40 solder.

3. Group 1 Test Procedures and Results

a. Procedures

Each specimen was clipped by two alligator clips onto arms of of the rotary thermal cycling machine and run for 20 cycles; each cycle consisted of 45 seconds in each tank and 15 seconds of drain and transfer time. One tank contained boiling water and the other tank contained isopropyl alcohol cooled with chunks of dry ice.

The PC assemblies were removed and the solder joints inspected for cracks under magnifications up to 30 power after each 20 cycles for the first 100 cycles. The number of cycles between inspections was regulated by other conditions after a pattern was established. The inspection criterion was a visible crack in the solder. The severity of the cracking was noted and the location and type of cracking in unusual cases. A few typical solder joints were sectioned and microphotographed.

b. Results

The test results are presented in tabular form in Tables VI through IX and on Figure 3. Each table references the board number and has a brief description of the joint type that can be identified further in the description section.

The statistical results in Table VI indicates the soft pad under transistors with the tubelets and heavy solder will meet the ATM goal with only a few minor cracks. Other types of joints show significant improvements over the NPC-200-4 solder joint but do not appear to be as good as the tubelet fix. The tubelet on the kovar lead only illustrates the effectiveness of the tubelet fix as no cracks occurred during the entire test of 3936 cycles. Note the nickel-iron leads, especially with 96 percent tin, 4 percent silver, consistantly have increased resistance to cracking.

The results in Table VI clearly indicate the capacitor and resistor solder joints will not meet the ATM goal unless they are improved.

The statistical results in Table VII indicates the soft rubber pad reduces relay solder joint cracking by approximately one-half. The addition of the crimped, welded, soldered flanged tubelet significantly increases the resistance of relay solder joints to cracking.

The statistical results of Table VIII show the regular NPC-200-4 solder joints passing more than 1100 and 1700 accelerated thermal cycles without cracking. These GM boards have been specially processed for the inverted transistor mounting layouts but the material is from the same stock and the results should be similar to other regular type joints. These layouts are widely spaced and near where the board was held which means this row of transistors would be out of the solution first as the level falls during testing. The joints have heavier solder than most but not enough to explain their unusually good resistance to cracking. These results should be disregarded as many other more reliable data are available on this type of joint.

The statistical results illustrated in Table IX show the relays and transistors on ATM PC boards using heavy solder joints and either polypropylene spacers or soft rubber spacers will develop cracks in a few hundred thermal cycles and will crack far short of the ATM goal. Additional improvement of both relay and transistor lead solder joints are indicated as a necessity for the ATM program.

Selected typical joints were sectioned and photomicrographed to show the extent of cracking and cracking patterns in various types of solder joints.

Photomicrographs A, B, and C in Figure 4 are typical of solder joints with 60/40 solder and a nickel-iron lead after only 3936 thermal cycles from -100°F to +200°F. Note in "A" how the solder has developed a lumpy appearance. Photograph "B" is a view of a further cut; both "A" and "B" are at 42 power magnification. The view of "C" is at 425 power magnification at the point in "B" shown by the arrow. Note that there is a good bond between the solder and the lead.

Figure 5 contains photomicrographs of a relay pin with a crimped, welded, flanged tubelet sectioned at two areas to show the extent of the cracking recorded after 3936 thermal cycles on the accelerated test machine. The "A" cross-section at the point of exterior crack shown be the arrow is magnified 50 times; "B" is a 335 time magnification of the cracked area illustrated by the arrow in "A". Note the void between tubelet and lead indicated by the large dark area. The "D" area is that shown by the arrow in "C" magnified 425 times; it shows that the crack is superficial and does no real harm, although it is a typical type of cracking on the crimped, welded, flanged tubelet on relay pins.

Figure 6 shows photomicrographs of a relay pin with a crimped, welded, flanged tubelet sectioned lengthwise at two areas to illustrate the second typical type of cracking that occurs during 3936 thermal cycles on the accelerated testing machine. Note that the cracking is very localized and superficial. Photograph "A" shows only the tubelet; note the crack in the solder in the hole section of the PC board at 43 times magnification. Photograph "B" shows the central cross-section of the relay pin, tubelet, and solder. Note that the arrow at the end of the pin shows a crack that occurred where the pin was clipped off. Photograph "C" is a magnified (500 times) view of the bond between the relay pin and the solder showing that a good metallurgical bond existed. Photograph "D" is a 500 times magnification that shows the extent of the localized cracking where the relay pin was clipped off; this is a typical crack.

Figure 7 consists of photomicrographs of a transistor lead with a tubelet sectioned at several places. Photograph "A" shows a section between the hole and the end of the tubelet. Note the voids in the solder. Visual

TABLE VI

Accelerated Automated Solder Test Results for Specimens
L100 through L103 (Test Number 1B)*

	L100					L101				L102			L103			
Insp at No of Cycles	Trans-Ni-Fe Soft Pad 96/4 Tubelets (27) No. Cracks	Resistors Nickel (30) 60/40 No Cracks	Capacitor Cu-Clad (6) 60/40 No Cracks	Trans-Kovar Soft Pad 60/40 Tubelets (27) No Cracks	Lead Only Ni-Fe (27) 60/40 No Cracks	Trans-Ni-Fe Soft Pad 96/4 Mod D (27) No Cracks	Resistor Nickel (30) 96/4 No. Cracks	Trans-Kovar Soft Pad 96/4 Mod D (27) No. Cracks	Lead Only Kovar (27) 60/40 No Cracks	Trans-Kovar Soft Pad 60/40 Grad Form (27) No Cracks	Leads Only Kovar (27) Tubes 60/40 No Cracks	Trans-Kovar Soft Pad 60/40 Flat-Formed (27) No Cracks	Trans-Ni-Fe Soft Rub Pad 96/4 Flat-Formed (27) No Cracks	Capacitor Cu-Clad (6) 60/40 No. Cracks	Trans-Kovar Soft Rub Pad 96/4 Str Flat (27) No. Cracks	No. Cycle Insp
50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	50
400	0	2M	0	0	0	0	1M	0	0	1M	0	0	0	0	0	116
516	0	2M	0	0	0	0	1M	0	1M	1M	0	0	0	1M	0	216
669	0	2M	0	0	0	3HM	2M	0	2M	1M	0	0	0	1M	0	770
766	0	2M	0	0	0	3HM	2M	0	2M+5S	1M	0	2M	0	3M	0	888
884	0	4M	0	0	3M+1S	4HM	2M	0	2M+9S	1M	0	2M	0	3M	0	1088
984	0	5M	1M	0	3M+1S	4HM	2M+1S	0	2M+11S	1M	0	2M	0	4M	0	1244
1120	0	9M	1M	0	6M+1S	4HM	2M+2S	0	2M+12S	1M+3S	0	2M+2S	0	4M	0	1444
1238	0	11M	1M	0	12M+1S	4HM	3M+2S	0	8M+18S	13S	0	2M+9S	4M	6M	1M	1744
1438	0	15M	2M	0	13M+2S	4HM	3M+2S	0	10M+18S	24S	0	2M+23S	4M+1S	6M	1M+2S	1984
1594	0	18M	2M	0	16M+2S	5HM	3M+2S	0	10M+18S	25S	0	4M+23S	8M+1S	6M	6M+2S	2484
1794	0	19M	2M	1M	18M+2S	5HM	4M+2S	4HM	10M+18S	25S	0	4M+23S	12M+1S	6M	9M+7S	2984
2094	0	23M	3M	1M	20M+2S	5HM	6M+2S	4HM	10M+18S	25S	0	4M+23S				
2334	0	23M+1S	3M	1M	20M+2S	5HM	6M+2S	4HM	10M+18S	26S	0	4M+23S				
2834	0	23M+1S	3M	1M	20M+2S	12HM+1S	6M+2S	27HM	10M+18S	26S	0	4M+23S				
3334	0	23M+1S	3M	1M	20M+2S	12HM+2S	6M+2S	25HM+2S	10M+18S	26S	0	4M+23S				
3936	2M-1S	23M+1S	3M	3M	20M+2S	12HM+2S	6M+2S	25HM+2S	10M+18S	26S	0	4M+23S				

Severity of Cracking Code: M - Minor crack on less than 1/3 of joint, S - Serious crack on 1/3 to 2/3 of joint, C - Critical crack affecting over 2/3 of joint.

*Rotary test machine (-100°F to +200°F), test started 9/18/67

TABLE VII

Accelerated Automated Solder Test Results for Relay Board Specimens (Test Number 1A)*

Inspected at Number of Cycles	Relays on Boards		
	No. 1 Rubber Pads Number of Cracks	No. 2 Standard Number of Cracks	No. 3 Eyelets† Number of Cracks
20	0	0	0
40	0	0	0
61	0	0	0
81	0	0	0
101	0	0	0
154	0	0	0
201	0	0	0
251	0	0	0
312	0	0	0
450	0	8S	0
566	0	8S	0
766	0	8S+2M	0
884	0	8S+4M	0
984	2S	8S+6M	0
1120	11S	15S+6M	0
1238	25S	21S+6M	0
1438	34S+6M	28S+12M	0
2094	Discontinued	Discontinued	0
3334	-	-	4M
3936	-	-	4M

Severity of cracking code:

M - Minor crack on less than 1/3 of joint
S - Serious crack on 1/3 to 2/3 of joint
C - Critical cracking affecting over 2/3 of joint

* -75°C to +100°C
†Crimped, welded, flanged tubelet

Note: Each relay board had 34 solder joints

TABLE VIII

Accelerated Automated Solder Test Results for Specimens
GM-1 and GM-2 (ATM Boards 4 and 5)*

Inspected at Number of Cycles	GM-1 Board (No. 4)			GM-2 Board (No. 5)		
	Trans Reg Pad 18 Std Kovar No. Cracks	Trans Inverted 18 Form Std Kovar No. Cracks	Trans Inverted 18 Straight Kovar No. Cracks	Trans Reg Pad 18 Std Kovar No. Cracks	Trans Inverted 18 Form Std Kovar No. Cracks	Trans Inverted 18 Straight Kovar No. Cracks
20	0	0	0	0	0	0
50	0	0	0	0	0	0
100	0	0	0	0	0	0
200	0	0	0	0	0	0
300	0	0	3M	0	0	0
634	0	1M+1S	3M	0	0	0
1134	2M	5M+1S	3M	0	3M	0
1594	3M	6M+1S	12M+2S	0	4M	13S
1736	5M	10M+1S	14M+2S	2M	11M	13S
1794	6M	10M+1S	14M+2S	2M	11M	15S
2044	7M	11M+1S	3M+12S	2M	12M	15S
2244	9M	11M+1S	3M+12S	2M	12M	15S
2544	11M	11M+1S	3M+12S	2M	12M	15S
2784	13M	11M+1S	3M+12S	2M	12M	15S
3054	15M	13M+2S	3M+12S	2M	12M	15S
3556	18M	15M+3S	6M+12S	2M	13M	3M+15S

M - Minor crack S - Serious crack over one-third of periphery of lead

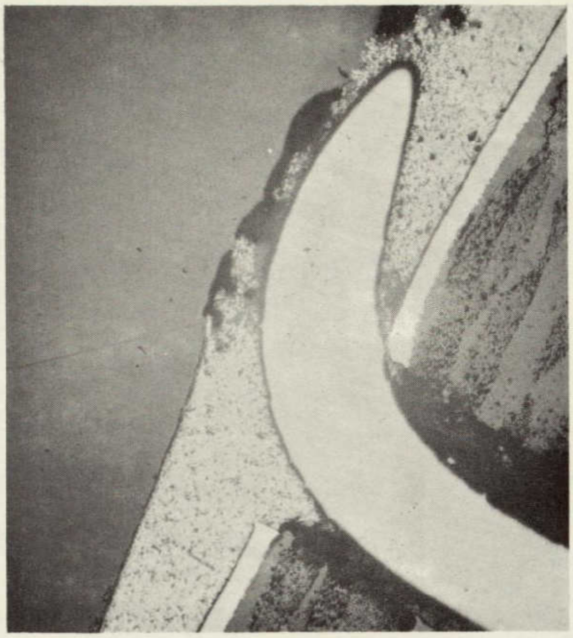
*Rotary test machine (-100°F to +200°F)

TABLE IX

Accelerated Automated Solder Test Results
for ATM Specimens 1, 2, 3, and 6*

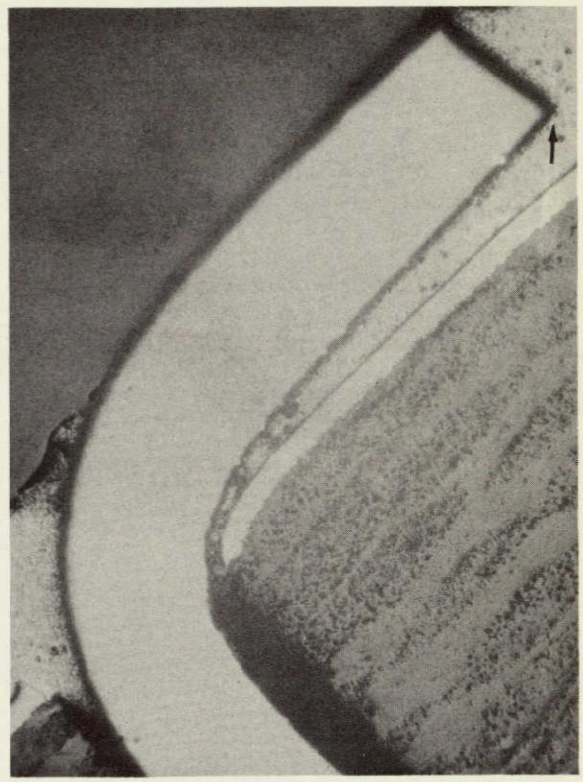
Inspected at Number of Cycles	ATM(No. 1) Board		ATM(No. 2) Board		ATM(No. 3) Board		ATM(No. 6) Board	
	Trans Polyp Pad 15k HS No. Cracks	Relay Rub. Pad 10 N-F HS No. Cracks	Trans Polyp Pad 15k HS No. Cracks	Relay Rub. Pad 10 N-F HS No. Cracks	Trans Rub. Pad 15k HS No. Cracks	Relay Rub. Pad 10 N-F HS No. Cracks	Trans Rub. Pad 15k HS No. Cracks	Relay Rub. Pad 10 N-F HS No. Cracks
20	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	0	0
100	0	0	0	0	0	0	0	0
200	0	0	0	0	0	0	0	0
300	0	0	3M	0	0	0	0	0
450	0	0	3M	0	0	0	0	0
701	8M+1S	2M+2S	15S	10S	0	0	0	0
800	9M+1S	2M+2S	15S	10S	1S	10S	3M+2S	0
1216	9M+2S	2M+2S	15S	10S	1M+1S	10S	3M+2S	6S+4LP†
1314	9M+3S	2M+7S	15S	10S	1M+2S	10S	3M+2S	6S+4†
1517	9M+3S	2M 7S	15S	10S	3M+2S	10S	3M+2S	6S+4†

M - Minor crack
S - Serious crack over one-third of periphery of lead
*Rotary test machine (-100°F to +200°F)
†LP - lifted pad on PC



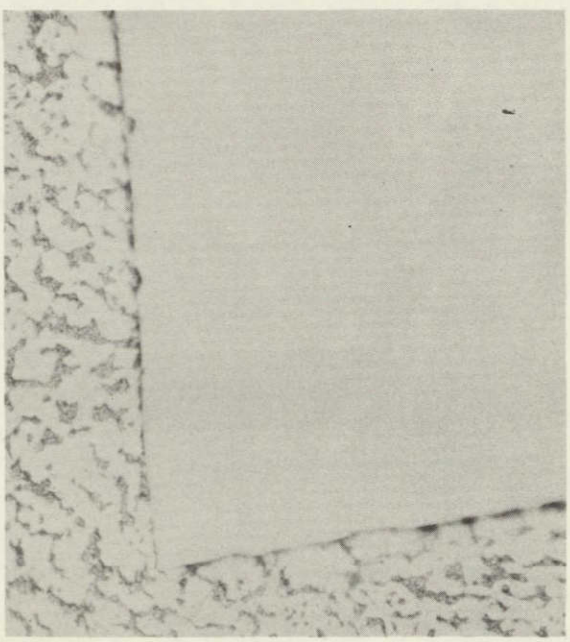
A

42X Magnification



B

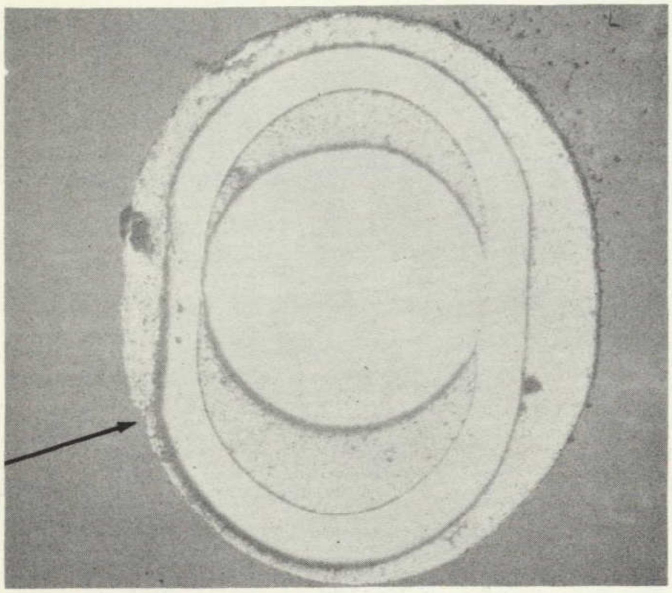
42X Magnification



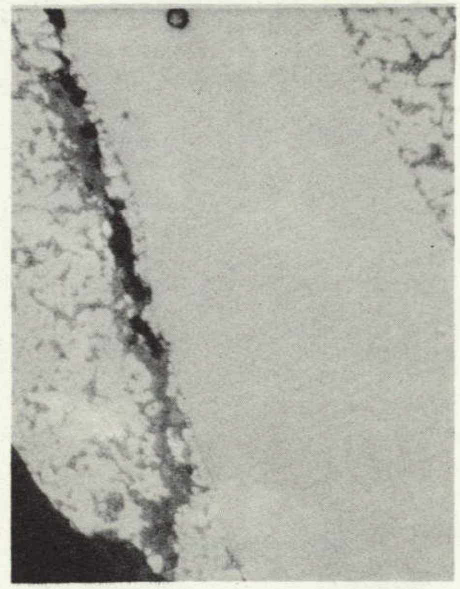
C

425X Magnification

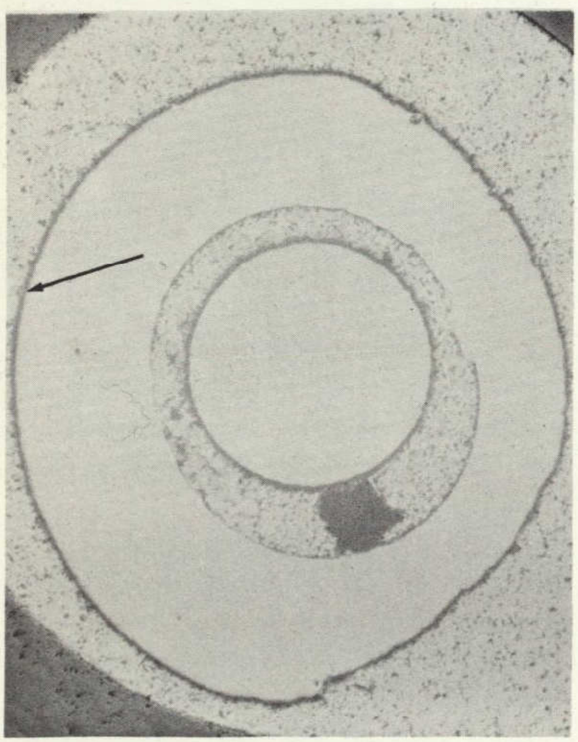
Figure 4. Typical Joint with 60/40 Solder and Nickel-Iron Lead after 3936 Cycles from -100°F to +200°F



A
50X Magnification



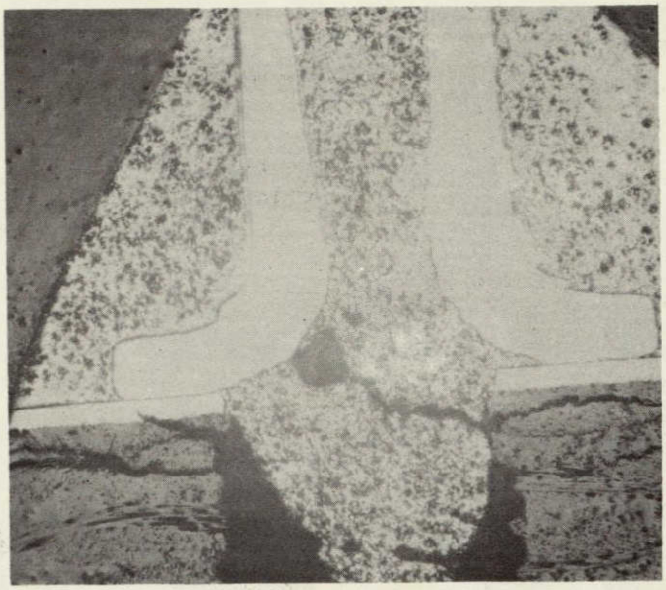
B
335X Magnification



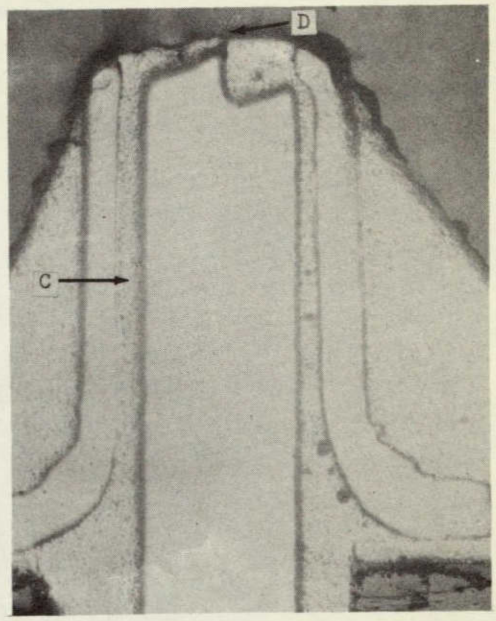
C
42X Magnification

D
425X Magnification

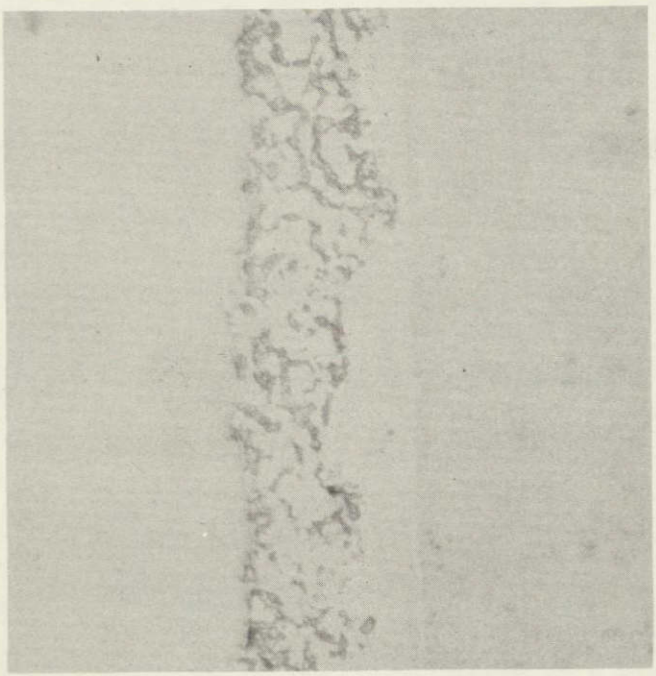
Figure 5. Cross-Section of Solder Joint with Relay Pin and Copper Tubelet after 3936 Cycles from -100°F to +200°F



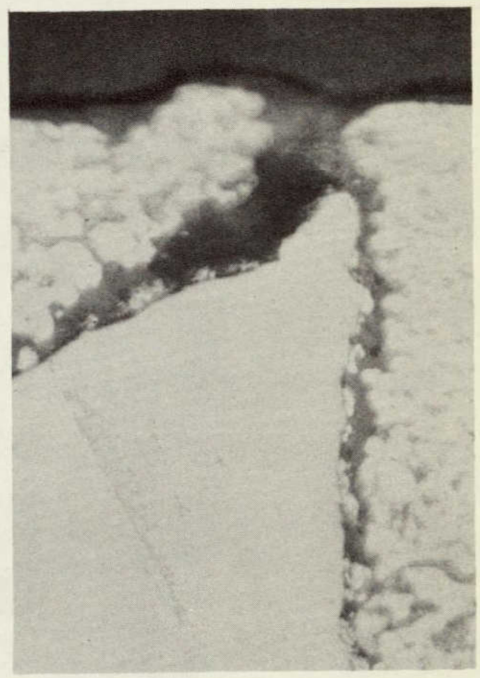
A
43X Magnification



B
38X Magnification

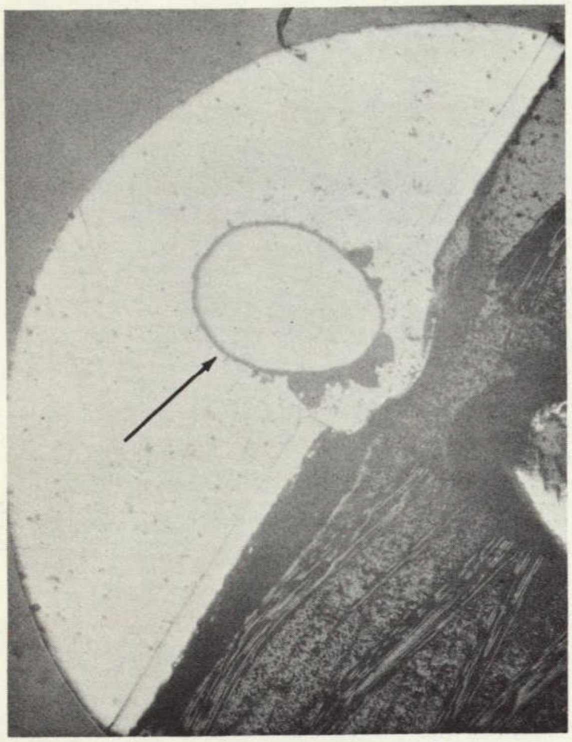


C
500X Magnification

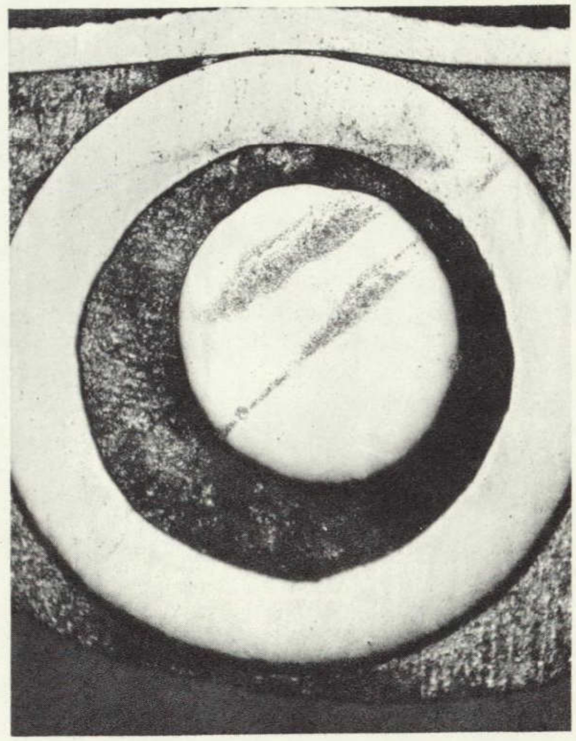


D
500X Magnification

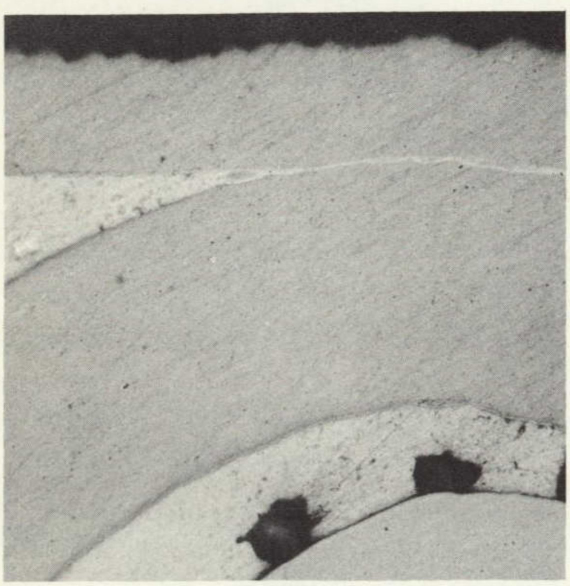
Figure 6. Lengthwise Section of Solder Joint with Relay Pin and Copper Tubelet after 3936 Cycles from -100°F to +200°F



A
42X Magnification



B
85X Magnification



C
212X Magnification

D
425X Magnification

Figure 7. Transistor Lead with Tubelet Sectioned to Show Bonding

examination at the arrow and other areas indicated a good bond between the solder, the lead, and the pad (42 times magnification after 3936 thermal cycles). Photograph "B" at 85 times magnification shows the cut across the tubelet and lead on one side. Photograph "C" is a view at 212 times magnification of the side containing some of the voids. Note the good bond between the solder at the pad and between the solder and both the tubelet and the lead. Photograph "D" is a view at 425 times magnification of a portion of the area in "C". This photograph again shows positively the good bond between the solder and both the lead and the tubelet.

C. GROUP 2 SOLDER JOINT DESIGN TESTS

1. Purpose

The solder joint arrangements described in this section were built and tested to evaluate the comparative advantages of the designs and to confirm the selected ATM arrangements will meet their expected environments.

2 Description of Construction of Test Specimens

Groups of similar contact arrangements were built onto approximately 5 by 5 inch printed circuit boards, several groups to each board. Normal NASA white room conditions and procedures identical with those used on the Control Signal Processor were followed, including inspections, except where deviations are specifically stated. All solders used were Kester Brand with No. 58 core, flux was No. 281 Kester. All completed PC assemblies were inspected and then spray coated with 0.006 to 0.008 inch of polyurethane, Hysol PC-22, conformal coating on the component side only. However, on the neoprene rubber pads, the coating did not completely cure. The coating did cure properly on the other types of spacers. All of these assemblies were inspected during construction and throughout the testing by a qualified inspector accustomed to NASA quality requirements and familiar with the solder cracking problem.

All of the PC assembly boards were laminated, woven fiberglas impregnated with epoxy resins. All PC boards, except for the relay assemblies, were nominally 1/16 inch thick. The relay assemblies were on 3/32 inch thick boards of the same material.

The following solder joint arrangements were placed on the following numbered PC boards:

1 On PC board L300 (two designs):

a Nine TO-5 transistors, each having three gold-plated kovar leads (all transistor leads were 0.016 to 0.019 inch in diameter) were soldered into split, loosely set, copper, funnel eyelets. A soft neoprene rubber, 40 shore A hardness, 1/32 inch thick spacer was placed between the PC board and the transistor. Each lead was formed over 0.1 to 0.15 inch through one of the four splits in the eyelet and a heavy fillet of 96 percent tin and 4 percent silver solder applied fastening the eyelet to the copper printed wiring circuit and the lead to both the eyelet and the copper pad.

b Fifteen one-tenth watt, hermetically sealed glass resistors, with gold-plated 0.025 inch diameter nickel leads were installed on the same board. Each lead was formed over and a copper tubelet slipped over it and soldered giving a heavy joint of the 96 percent tin and 4 percent silver solder.

2 On PC board L301 (three designs):

a Nine TO-5 transistors, each having three gold-plated nickel-iron leads, 0.016 - 0.019 inches in diameter, were installed on the PC board using soft neoprene rubber spacers between the board and transistor body. The leads were formed into 1/16 inch diameter vertical loops and soldered both where the lead comes through the PC board and at the end of the lead. However, the upper loop was left open, this type joint is referred to as an M-D or modified D loop. A heavy solder joint of 96/4 solder was produced.

b Three kidney shaped silvered mica capacitors (DM-19 type) with 0.032 inch diameter tinned copper clad (30 percent) steel leads were installed upright on the PC board. Each lead was formed over and a tubelet slipped over the end and a heavy solder joint made using 96/4 solder.

c Nine TO-5 transistors, each having three gold-plated kovar leads were installed on the same PC board using the 1/32 inch thick soft neoprene rubber spacers. The leads were cut off 1/10 inch above the PC board and the end was formed back on itself with the end against the PC board, giving a tight cane shape. A heavy solder joint was made using 96/4 solder.

3 On PC board L302 (five designs):

a Nine TO-5 transistors, each having three gold-plated kovar leads, were installed using 0.078 inch thick, diallyl phthalate (DAP) spacers. The leads were formed over 0.1 to 0.15 inch on the copper pad and a heavy solder joint was made using a solder composition of 97.5 percent lead, 1.5 percent silver and 1 percent tin.

b Nine TO-5 transistors, each having three gold-plated kovar leads, were installed using 0.078 inch thick DAP spacers. The leads were formed over 0.1 to 0.15 inch on the copper pad and a heavy solder joint was made using a solder composition of 96 percent tin and 4 percent silver.

c Fourteen one-tenth watt, hermetically sealed glass resistors, with gold-plated .025 inch diameter nickel leads were installed. Each lead was formed over 0.1 to 0.15 inch on the copper pad and a heavy solder joint was made using a solder composition of 97.5 percent lead, 1.5 percent silver and 1 percent tin.

d Three kidney shaped silvered mica capacitors (DM-19 type) with 0.032 inch diameter tinned copper clad (30 percent) steel leads were installed upright on the PC board. Each lead was formed over 0.1 to 0.15 inches and a heavy solder joint was made using a solder composition of 96 percent tin and 4 percent silver.

e Thirty kovar transistor lead clippings approximately 1/2 inch long were installed on the board. Each lead was placed through a hole and formed over 0.1 to 0.15 inch and held still while a heavy solder joint was made using a solder composition of 60 percent tin and 40 percent lead.

4 On PC board L303 (four designs):

a Nine TO-5 transistors, each having three gold-plated kovar leads, were installed using 0.078 inch thick DAP spacers. The leads were formed over 0.1 to 0.15 inch on the copper pad and a heavy solder joint was made using a solder composition of 60 percent lead, 37.5 percent tin and 2.5 percent antimony.

b Nine TO-5 transistors, each having three gold-plated kovar leads, were installed using 0.078 inch thick DAP spacers. The leads were formed over 0.1 to 0.15 inch on the copper pad and a heavy solder joint was made using a solder composition of 60 percent tin and 40 percent lead.

c Fifteen one-tenth watt, hermetically sealed, glass resistors, with gold-plated 0.025 inch diameter nickel leads were installed. Each lead was formed over 0.1 to 0.15 inches on the copper pad and a heavy solder joint was made using a solder composition of 60 percent lead, 37.5 percent tin and 2.5 percent antimony.

d Three kidney shaped silvered mica capacitors (DM-19 type) with 0.032 inch diameter tinned copper clad (30 percent) steel leads were installed upright on the PC board. Each lead was formed over 0.1 to 0.15 inches and a heavy solder joint was made using a solder composition of 96 percent tin and 4 percent silver.

5 On PC board L304 (five designs):

a Nine TO-5 transistors, each having three gold-plated kovar leads, were installed using 0.078 inch thick DAP spacers. The leads were formed over 0.1 to 0.15 inches on the copper pad and a heavy solder joint was made using a solder composition of 95 percent tin and 5 percent antimony.

b Nine TO-5 transistors, each having three gold-plated kovar leads, were installed using 0.078 inch thick DAP spacers. The leads were formed over and a copper tubelet, 0.093 inch long, was slipped over the end of the lead and soldered using 60 percent tin, 40 percent lead solder. The leads extended approximately 1/64 to 1/32 inch out of the tubelets and a heavy fillet of solder was placed on the heel of each joint.

c Fifteen one-tenth watt, hermetically sealed, glass resistors, with gold-plated 0.025 inch diameter nickel leads were installed. Each lead was formed over 0.1 to 0.15 inch on the copper pad and a heavy solder joint was made using a solder composition of 95 percent tin and 5 percent antimony.

d Three kidney shaped silvered mica capacitors (DM-19 type) with 0.032 inch diameter tinned copper clad (30 percent) steel leads were installed upright on the PC board. Each lead was formed over 0.1 to 0.15 inch and a heavy solder joint was made using a solder composition of 96 percent tin and 4 percent silver.

e Thirty gold-plated dumet leads (oxygen free, 18 - 26 percent copper) .020 inch in diameter and approximately 1/2 inch long were installed on the board. Each lead was placed through a hole and formed over 0.1 to 0.15 inch on the copper pad and held still while a heavy solder joint was made using a solder composition of 60 percent tin and 40 percent lead.

6 On PC board L305 (five designs):

a Nine TO-5 transistors, each having three gold-plated kovar leads, were installed using 0.078 inch thick DAP spacers. The leads were formed over 0.1 to 0.15 inches on the copper pad and a heavy solder joint was made using a solder composition of 41.4 percent lead, 55 percent tin and 3.6 percent antimony.

b Nine TO-5 transistors, each having three gold-plated kovar leads, were installed using 0.078 inch thick DAP spacers. An elongated "D" loop was made by bringing the leads up through the hole approximately 0.040 inch and forming it parallel to the board for approximately 0.15 inch, then forming the end down and under so the end was against the board and beneath the elongated portion almost to the hole. The portion against the board was soldered using a solder composition of 41.4 percent lead, 55 percent tin, and 3.6 percent antimony. This joint is referred to as a D-F or D flattened loop.

c Fifteen one-tenth watt, hermetically sealed, glass resistors, with gold-plated 0.025 inch diameter nickel leads were installed. Each lead was formed over 0.1 to 0.15 inch on the copper pad and a heavy solder joint was made using a solder composition of 41.4 percent lead, 55 percent tin, and 3.6 percent antimony.

d Three kidney-shaped silvered mica capacitors (DM-19 type) with 0.032 inch diameter tinned copper clad (30 percent) steel leads were installed upright on the board. Each lead was formed over 0.1 to 0.15 inch and a heavy solder joint was made using a solder composition of 96 percent tin and 4 percent silver.

e Thirty copper leads 0.020 inch in diameter and approximately 1/2 inch long were installed on the PC board. Each lead was placed through a hole and formed over 0.1 to 0.15 inch on the copper pad and held firmly while a heavy solder joint was made using a solder composition of 60 percent tin and 40 percent lead.

7 On PC boards L307 and L308 (one design):

a Nine TO-5 transistors (on each board), each having three gold plated kovar leads, were installed using 0.078 inch thick DAP spacers. The leads were formed over 0.1 to 0.15 inches on the copper pad and a heavy solder joint was made using a solder composition of 60 percent tin and 40 percent lead. Both of these PC assemblies were coated on both sides of the boards with an epoxy material, Hysol PC-16, a conformal coating used on the Pershing Program PC boards.

8 On PC boards L310 and L311 (three designs on each):

a On each board six TO-5 transistors, each having three gold plated kovar leads, were installed using 0.078 inch thick DAP spacers. The leads were formed over and copper tubelets, 3/32 inch long, were slipped over the ends and a heavy solder joint was made using a 60 percent tin and 40 percent lead solder composition.

b On each board six TO-5 transistors, eaching having three gold plated kovar leads, were installed in an inverted position with the top of each transistor against the PC board and the leads formed over and down parallel to the case and through holes in the board. Each lead was formed over on the copper pad and a 3/32 inch long copper tubelet slipped over the end and both soldered to the copper pad using a 60 percent tin and 40 percent lead solder composition.

c On each board six TO-5 transistors, each having three gold plated kovar leads, were installed in an inverted position. The top of each transistor case was against the PC board with the leads formed over and parallel to the case down through holes in the board. Each lead was formed over 0.1 to 0.15 inches on the copper pad and a heavy solder joint using a 60 percent tin and 40 percent lead solder was produced.

9 On PC board L312 (one design):

a Four half-size crystal case relays, each having eight 0.030 inch diameter straight tinned nickel-iron-chromium leads, were installed on the PC board with a 1/32 inch thick soft neoprene rubber, 40 Shore A hardness, spacer between the board and the relay case. A 1/16 inch long, flanged, copper tubelet was placed on each lead, crimped, and resistance welded with the flange next to the circuit pad. Each pin was then soldered to the flanged tubelet and the circuit pad with 60 percent tin and 40 percent lead solder.

10 On PC board L313 (one design):

Four half-size crystal case relays, each having eight 0.030 inch diameter straight tinned nickel-iron-chromium leads, were installed on the PC board with a 1/32 inch thick soft neoprene rubber, 40 Shore A hardness, spacer between the board and the relay case. A 1/16 inch long, flanged copper tubelet was placed on each lead with the flange against the copper circuit pad. Each pin was then soldered to the flanged tubelet and the circuit pad with 60 percent tin and 40 percent lead solder.

11 On PC boards L314, L315, L316, L317 and L318:

Each of these five PC boards had nine TO-5 transistors, each having three gold plated kovar leads, installed using various types of spacers. The leads were formed over and a copper tubelet, 0.093 inch long, was slipped over the end of each lead and soldered using 60 percent tin and 40 percent lead solder. The following boards were built with the following types of spacers between the PC board and the transistors bodies:

a L314 - 1/16 inch thick polyurethane foam spacer.

b L315 - 0.078 inch thick diallyl phthalate spacer.

c L316 - 1/16 inch thick polyurethane rubber, 22 Shore A hardness spacer.

d L317 - 1/16 inch thick polyurethane rubber, 32 Shore A hardness spacer.

e L318 - 1/16 inch thick polyurethane rubber, 45 Shore A hardness spacer.

12 Special Aluminum PC board with oxided surfaces and copper circuit runs (five designs):

a Two TO-5 transistors, each having six gold plated kovar leads, were installed without any spacers. The leads were brought through holes and formed over and onto separate round copper pads where they were held firmly and soldered forming a heavy 60 percent tin, 40 percent lead solder joint.

b Two TO-5 transistors, each having six gold plated kovar leads, were installed using 1/8 inch high, footed, polypropylene spacers. The leads were brought through holes and formed over and onto separate round copper pads where they were held firmly and soldered forming a heavy 60 percent tin, 40 percent lead solder joint.

c Three TO-5 transistors, each having three gold plated kovar leads, were installed using 1/16 inch thick beryllium oxide spacers. The leads were brought through the holes and formed over on regular copper pads and a heavy solder joint was made using a solder composition of 60 percent tin and 40 percent lead.

d Three TO-5 transistors, each having three gold plated kovar leads, were installed using 0.078 inch thick DAP spacers. The leads were brought through the holes and formed over onto regular copper pads and a heavy solder joint was made using a solder composition of 60 percent tin and 40 percent lead.

e Nineteen one-tenth watt, hermetically sealed, glass resistors, with gold plated 0.025 inch diameter nickel leads were installed. Each lead was formed over onto the copper pad and a heavy solder joint was made using a solder composition of 60 percent tin and 40 percent lead.

3. Group 2 Tests

a. Procedure:

Each PC board was clipped by two alligator clips onto arms of the modified rotary accelerated thermal cycling machine shown in Figure 8. This is the same machine described in Martin Test Report OR-9187 on ATM Group 1 Solder Tests except four additional arms with counterbalance springs were added to facilitate the larger group of test boards. Each group of PC boards were thermally cycled twenty cycles and then each joint inspected. This frequency was continued for at least one hundred cycles before extending the number of thermal cycles between inspections. A cycle consisted of 45 seconds in boiling water followed by 15 seconds drain and transfer time followed by 45 seconds in the isopropyl alcohol cooled with an excess of dry ice chunks, followed by a 15 second drain and transfer time before going into the hot water for another cycle. The rotary motion moved the PC boards edgewise through the solutions. The boiling water started as de-ionized water but became contaminated by the alcohol and actually maintained the isopropyl alcohol at very nearly minus 100° F. The isopropyl alcohol was 97 percent pure, commercial grade.

At each inspection, 100 percent of the joints were inspected by the same, trained inspector for cracks visible under thirty power magnification. A developing crack was not recorded until an actual opening occured. Each crack was rated as: 1) minor if cracked less than one third around the periphery of the lead; 2) Serious if between one third and two thirds; and 3) Critical if over two-thirds.

b. Group 2 Test Results

The results are presented in tabular form in Tables X through XV. Each table has a brief description of the joint and references the test board and arrangement so that its complete description can be located in the section on test specimen construction.

The first six columns of Table X gives the cracking statistics for six solder compositions, one of which is the standard 60 percent tin, 40 percent lead solder being used on ATM and most other programs at Martin Marietta. These particular solder compositions were recommended by con-

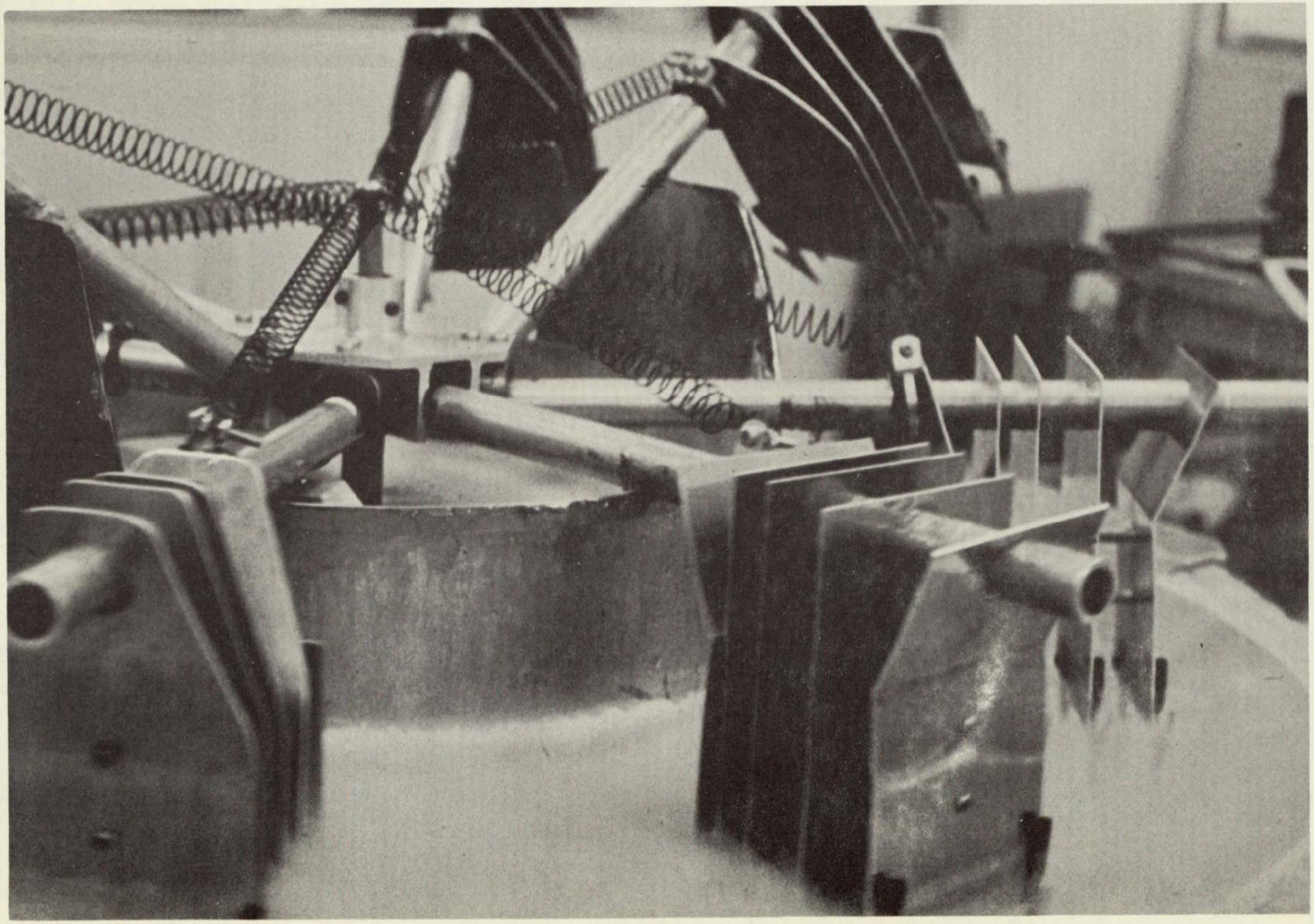


Figure 8. Modified Rotary Test Machine

TABLE X

Results of Thermal Cycling Transistor Solder Joints on PC Boards
Automated, Liquid, $-100^{\circ}F$ to $+185^{\circ}F$, 2 Minutes - Number of Visual Cracks
All Kovar Leads and Diallyl Phthalate Spacers

Reference Coating Joints Solder No. Joints	L302 (a) PC-22 Formed 0.1-0.15 97.5 Pb, 1.5 Ag, 1 Sn 27	L302 (b) PC-22 Formed 0.1-0.15 96 Sn, 4 Ag 27	L303 (a) PC-22 Formed 0.1-0.15 60 Pb, 37.5 Sn, 2.5 Sb 27	L303 (b) PC-22 Formed 0.1-0.15 60 Sn, 40 Pb 27	L304 (a) PC-22 Formed 0.1-0.15 95 Sn, 5 Sb 27	L305 (a) PC-22 Formed 0.1-0.15 41.4 Pb, 55 Sn, 3.6 Sb 27	L307 + L308 PC-16 Formed 0.1-0.15 60 Sn, 40 Pb 54
Insp cycles							
20	0	0	0	0	0	0	2M
40	0	0	0	2M	0	0	4M + 4S
60	0	0	1M	4M	2M	0	6M + 5S
80	1M	1M	1M	5M	2M	0	6M + 5S
100	1M	1M	1M	6M	4M	1M	9M + 5S
120	2M	2M	1M	6M	4M	3M	10M + 5S
140	2M	3M	1M	6M	4M	3M	10M + 5S
200	2M	3M	3M	10M	5M	6M	14M + 5S
250	2M	6M	9M	12M	7M	6M	19M + 8S
300	2M	7M	9M	12M	7M	6M	19M + 8S
400	2M	8M	10M	14M	8M	11M	19M + 8S
490	3M	8M	11M	15M	8M	12M	Discontinued
659	5M	8M	11M	15M	8M	14M	
782	6M	8M	14M	17M	11M	14M	
982	7M	8M	15M	18M	11M	17M	
1,193	8M	10M	17M	21M	13M	20M	
1,400	8M	11M	17M	21M	14M	20M	
1,600	8M	11M	17M	21M	14M	20M	
1,900	8M	16M	23M	21M	14M	22M	
2,120	10M	16M	24M	22M	14M	22M	
2,420	10M	16M	24M	22M	16M	22M	
2,720	10M	16M	24M	22M	17M	22M	
3,038	14M	17M	24M	25M	17M	22M	
3,426	14M	17M	24M	25M	17M	*	
3,576	14M	17M	24M	25M	17M	26M	
4,131	13M + 1S	15M + 2S	24M	25M	17M	26M	
4,322	*	*	24M	25M	17M	1M + 25S	
4,517	13M + 1S	20M + 2S	25M	27M	18M	*	
4,708	13M + 1S	20M + 2S	25M	27M	18M	*	

*Not inspected

TABLE XI

Results of Thermal Cycling Transistor Solder Joints on PC Boards
Automated, Liquid, -100°F to +185°F, 2 Minutes - Number of Visual Cracks
All Kovar Leads with Tubelets and 60% Tin, 40% Lead Solder

Reference Spacers No. Joints	L304(b), L310(a), L311(a), L315 0.078 Inch Thick DAP 75 Total		L314 Poly U. Foam 27		L316 Poly U. Rub. 22A 18		L317 Poly U. Rub. 32A 18		L318 Poly U. Rub. 45A 18	
Insp Cycles	Cracks	%	Cracks	%	Cracks	%	Cracks	%	Cracks	%
100	0	0	0	0	0	0	0	0	0	0
200	2M	2.7	↕	↕	↕	↕	↕	↕	↕	↕
250	4M	5.4								
400	7M	9.3								
490	11M	14.7								
659	11M	14.7								
782	14M	18.6								
831	16M	21.4								
982	17M	22.7								
1,051	17M	22.7								
1,193	24M	32			0	0	0	0	0	0
1,351	24M	32			1M	5.5	1M	5.5	1M	5.5
1,400	33M	44			†	†	†	†	†	†
1,600	39M	52			†	†	†	†	†	†
1,651	44M	59			3M	16.6	1M	5.5	2M	11.1
1,900	44M	59			†	†	†	†	†	†
1,969	44M	59	0	0	4M	22.3	2M	11.1	2M	11.1
2,120	47M	62	3M	10	†	†	†	†	†	†
2,357	47M	62	†	†	4M	22.3	2M	11.1	2M	11.1
2,420	48M	64	3M	10	†	†	†	†	†	†
2,537	51M	68	†	†	5M	27.8	2M	11.1	3M	16.6
2,720	56M	75	18M	67	†	†	†	†	†	†
3,038	56M	75	18M	67	†	†	†	†	†	†
3,552	59M	79	†	†	9M	50	5M	27.8	5M	27.8
3,576	61M	81	18M	67	†	†	†	†	†	†
3,759	65M	87	†	†	9M	50	5M	27.8	5M	27.8
4,131	68M*	91	25M	92	Discontinued		Discontinued		Discontinued	
4,322	68M	91	†	†						
4,517	73M	97	25M	92						
4,708	73M	97	25M	92						

*18 joints removed from further testing (L315)
†Not inspected

TABLE XII

Results of Thermal Cycling New Transistor Solder Joint Designs on PC Boards
Automated, Liquid, -100^{o}F to $+185^{o}$F, 2 Minutes – Number of Visual Cracks

Reference Spacers Joint Solder No. & Mat	L300(a) 40A Rubber Split Fun Eye 96 Sn - 4 Ag 27 Kovar	L301(a) 40A Rubber Mod "D" Loop 96 Sn - 4 Ag 27 Ni - Iron	L301(c) 40A Rubber Cane Loop 96 Sn - 4 Ag 27 Kovar	L305(b) 0.078 DAP D-F Loop 41.4 Pb, 55 Sn, 3.6 Sb 27 Kovar	L310(b) Inverted Tub, L. Lead* 60 Tin - 40 Pb 18 Kovar	L311(b) Inverted Tub, S. Lead† 60 Sn - 40 Pb 18 Kovar	L310, 11(c) Inverted 0.1 - 0.15 Form 60 Sn - 40 Pb 36 Kovar
Insp Cycles							
40	0	0	0	0	0	0	0
100							
200							
300							
400							
490							
659							
782							
982							0
1,193							3M
1,400					0		25M
1,600					3M		30M
1,900				0	3M		30M
2,120				1M	11M		35M
2,420				1M	15M		35M
3,038			0	1M	15M		35M
3,426	0		1M	‡	‡		‡
3,576	3M		1M	3M	15M		35M
3,947	7M		‡	‡	‡		‡
4,131	7M		‡	17M	15M		35M
4,322	Discontinued		‡	17M	15M		35M
4,517			9M	Discontinued	‡		‡
4,708		0	9M		15M	0	35M

*L-Long
†S-Short
‡Not inspected

TABLE XIII

Results of Thermal Cycling Resistor Solder Joints on PC Boards
Automated, Liquid, -100°F to +185°F, 2 Minutes - Number of Visual Cracks

Reference Joint Solder No. Joints	L 300 (b) Tubelet 96 Sn - 4 Ag 30	L 302 (c) 0.1 - 0.15 Form 97.5 Pb - 1.5 Ag - 1 Sn 28	L 303 (c) 0.1 - 0.15 Form 60 Pb - 37.5 Sn - 2.5 Sb 30	L 304 (c) 0.1 - 0.15 Form 95 Sn - 5 Sb 30	L 305 (c) 0.1 - 0.15 Form 41.4 Pb - 55 Sn - 3.6 Sb 30
Insp Cycles					
60	0	0	0	0	0
100			0		
200			0		
250			1M		
300					
400					
490					
659					
782					0
982					1M
1193			1M		1M
1400			2M		1M
1600			2M		1M
1900			2M		2M
2120			3M		3M
2420			3M		3M
2720			3M		3M
3038			8M		3M
3576		0	8M		4M
4131	0	2M	8M		7M
4322	Discontinued	-	8M		7M
4517		3M	13M	0	Discontinued
4708		3M	13M	1M	

TABLE XIV

Results of Thermal Cycling Capacitors and Lead Solder Joints on PC Boards
Automated, Liquid, $-100^{\circ}F$ to $+185^{\circ}F$, 2 Minutes - Number of Visual Cracks

Reference Component Joint Solder No. JTS & Mat	L301(b) Capacitor Tubelets 96 Sn - 4 Ag 6 Cu-Clad Steel	L302,3,4,5(d) Capacitor 0.1 - 0.15 Form 96 Sn - 4 Ag 24 Cu-Clad Steel	L302(e) Lead Only 0.1 - 0.15 Form 60 Sn - 40 Pb 30 Kovar	L304(e) Lead Only 0.1 - 0.15 Form 60 Sn - 40 Pb 30 Dumet	L305(e) Lead Only 0.1 - 0.15 Form 60 Sn - 40 Pb 30 Copper
Insp Cycles					
20	0	0	0	0	0
60		0			
100		1M			
200		1M	0		
250		2M	1M		
300		2M	1M		
400		2M	2M		
490		2M	2M		
659		2M	2M		
782		2M	3M	0	
982		3M	5M	1M	
1,193		4M	11M	2M	
1,400		4M	15M	2M	
1,600		4M	15M	2M	
1,900		5M	17M	6M	
2,120		7M	24M	9M	
2,420		7M	24M	12M	
2,720		7M	24M	17M	
3,038		7M	26M	17M	
3,576		7M	26M	18M	
4,131		7M	30S	25S	
4,322		7M	-	25S	0
4,517		7M	30S	25S	Discontinued
4,708	0	7M	30S	25S	

TABLE XV

Group 2 Results of Thermal Cycling Relay Solder Joints and Special Aluminum PC Board
Automated, Liquid, -100°F to +185°F, 2 Minutes - Number of Visual Cracks
All Used 60% Tin -40% Lead Solder

Reference Spacers Joints Component No and Mat	L312 40A Rubber CWF Tubelet Relay 24 Ni-Iron	L313 40A Rubber F Tubelet Relay 24 Ni-Iron	Special Aluminum-Oxided PC Board				
			None Flat Flex Transistor 12 Kovar	1/8 Inch Polyp Flat Flex Transistor 12 Kovar	1/16 Be Ox Formed Transistor 9 Kovar	0.078 DAP Formed Transistor 9 Kovar	None Formed Resistor 38 Ni
Insp Cycles							
20	0	0	0	0	0	0	0
100							
490							
782							
982	0	0	0				
1193	1M	1M	4M	0		0	0
1400	3M	1M	12M	8M		1M	1M
1600	4M	1M	12M	8M	0	1M	1M
1900	5M	1M	12M	9M	4M	1M	5M
2120	5M	1M	12M	9M	4M	1M	5M
2420	5M	2M	12M	9M	4M	1M	5M
2720	24M	24M	12M	9M	4M	1M	5M
3038	24M	24M	12M	9M	5M	2M	5M
3576	24M	24M	12M	1M + 9S	4M + 2S	5M	15M
4131	24M	24M	12M	1M + 9S	4M + 2S	5M	15M
4517	24M	24M	12M	1M + 9S	4M + 2S	5M	15M
4708	24M	24M	12M	1M + 9S	4M + 2S	5M	15M
Discontinued							

sultants or by previous test reports as having some particular characteristic that should reduce the cracking phenomena. Although each of them showed improvements in some areas, there was no major improvement. The highest lead content solder in column one was by far the worst in general appearance since it turned a gray-black and seemed to corrode or erupt in spots, especially along the leads. Other lead bearing compositions did the same to lesser extents. Metallurgist consultants suggest some chemical or voltaic reactions took place during the test but feel it would require several isolation tests to pinpoint the major cause. It is not likely these reactions made any major difference in the results as they did not become apparent until late in the cycling results. The high tin composition solders maintained the best general appearance, the 96 percent tin, 4 percent silver was the best.

The last column in Table X should be compared on a relative basis with column 4 (L303b) since they are the same except for the number of joints and the conformal coating. The results prove there would be no advantage in going to an epoxy type conformal coating, at least not PC-16.

Table XI gives a comparison of several spacer materials on similar transistor assemblies. The figures in column 1 are the sum of similar test specimens using the Control Signal Processor standard rigid black diallyl phthalate transipad between the transistor body and the PC board. Column 2 used a 1/16 inch thick spacer of polyurethane foam material of approximately 40 shore A hardness. It is unlikely this material would be acceptable on the outgassing requirements for ATM. The last three columns used spacers of polyurethane rubber of the hardness shown. There is no significant difference in these three as the cracks are all relatively minor and insignificant. This table reaffirms the improvement in cracking resistance of solder joints when a resilient material is used between the transistor body and the PC board. Additional work would be necessary to determine the optimum material for this spacer.

Table XII show the statistical results of several new or different solder joint designs on transistor (TO-5 3 lead cases). It can readily be seen that all of these are substantial improvements over the ones shown in Table X. Those designs in columns 1, 2, 3 and 6 are substantial improvements over any in Table XI. However, they require greater changes in materials and/or procedures and are not required to meet the ATM goals. It is interesting to note the differences between columns 5 and 6 (Boards L310b and L311b). On solder joints on L310b the koval leads extend through the tubelets 0.020 to 0.035 inches and consequently cracked around this lead extension. On solder joints on L311b the leads barely came to the end of the tubelets and were obscured by the solder and did not crack. Unfortunately it is felt the leads should extend slightly for inspection purposes. The cracks appeared to be localized and minor, but their extent was not actually determined.

Table XIII shows the statistical results of thermal cycling several types of solder joints on nickel resistor leads. Earlier tests showed a standard NPC-200-4 resistor solder joint started cracking around 400 accelerated cycles. Substantial improvements were obtained by using tubelets and 96 percent tin, 4 percent silver solder, and by using either 95 percent tin, 5 percent antimony or 97.5 percent lead, 1.5 percent silver and 1 percent tin solder. However, the last solder composition is very difficult to apply and the joints turn a gray-black during thermal cycling. Due to an oversight, no solder joints were made on resistors using tubelets and 60 percent tin, 40 percent lead solder composition.

Table XIV shows the statistical results of thermal cycling two types of solder joints of capacitors with copper-clad (30 percent) steel leads on PC boards. Note cracking began at less than 100 cycles without tubelets and none of the six capacitor joints with tubelets and 96 percent tin, 4 percent silver solder cracked during the 4708 test cycles.

The last three columns in Table XIV show a comparison of the lead materials in solder joints. Note kovar lead joints started cracking at 250 accelerated cycles while dumet lead joints didn't start cracking until 982 cycles. The copper lead joints did not develop any cracks during their full 4322 cycle test. Note, these figures are on short pieces of leads which do not have components attached to create the external forces on the solder joint developed by expansion of materials between the component body and the solder joint.

The first two columns of Table XV show the statistical results of thermal cycling relay solder joints with flanged tubelets on them. Column one has crimped, welded flanged tubelets soldered onto the relay pins and circuit pad while the relays shown in column two has the flanged tubelets only soldered onto the pins and pads. The relay pins are cut off shorter on the relays in column two. The cracks recorded in both cases appear to be localized in the solder across the end of the lead and in the solder where it thins out near the outer end of the tubelet. Unfortunately, we were unable to section the relay solder joints to determine the exact extent of these cracks. From exterior visual examination there is no significant difference between the crimped, welded, soldered flanged tubelet and the soldered only flanged tubelet on relays. Both appear to maintain good solder joints even though minor cracks developed.

The results of relay tests on ATM Group 1 test indicated the crimped, welded, soldered flanged tubelet arrangement without the 1/32 inch thick neoprene rubber spacer between the relay and the PC board, withstood about 3334 cycles before developing cracks. However, these relay joints with the 1/32 inch thick neoprene rubber spacer began to develop cracks about 1200 cycles. This indicates the resilient spacer is not effective although it gave much improvement on standard relay pin joints on the Group 1 tests (Table VII). Additional testing should be done and sectioning of cracked joints performed to more accurately analyze the extent and causes of the cracks.

The last five columns of Table XV show the statistical results of thermal cycling a special oxide coated aluminum PC circuit board with various components attached. Resistors and transistors on this board withstood three to four times as many accelerated thermal cycles as on the standard epoxy-glass PC boards.

c. General Discussion of Results

During these tests some solder joint arrangements have been repeated and duplicate testing performed as a check on the construction and testing. Large differences have occurred. For example, in some transistors with tubelets, DAP spacers and 60/40 solder. On board L315 first cracking was noted at 831 cycle inspection while, on a similar arrangement on board L304, the first cracking was recorded at 200 cycles. A similar difference occurred on L310 (1193 cycles) and L311 (200 cycles). Examination indicates the amount of solder on the lead is directly related to the number of cycles it will withstand. Another important construction detail is the length the lead extends out of the tubelet. If the kovar lead extends out of the tubelet and is lightly covered with solder it will crack much sooner than if it is only flush with the end of the tubelet and covered heavily with solder. These cracks may not be serious but are in this data and must be considered the same as other cracks until enough have been sectioned and examined to evaluate the basic type crack. Most of the cracks appear to be minor; however, considerable sectioning and microscopic examination should be performed to fully evaluate them.

III. CONCLUSIONS

The following conclusions are derived from the accelerated test results:

1 Only minor improvements were obtained by the use of other soft solder compositions tested.

2 The addition of a copper tubelet over the end of the transistor lead substantially increases resistance to cracking. However, some minor cracks will develop during the 12,000 thermal cycle ATM goal although resilient pads and thin conformal coating are applied.

3 The resilient spacers between transistors and the PC board are beneficial. Their hardness is not critical as long as it is below 45 on the shore A hardness scale. Larger parts should have softer spacers.

4 Several types of transistor lead solder joints are capable of meeting the ATM goals, they include soft rubber spacer with a) split funnel eyelet joint with 96 percent tin, 4 percent silver solder, b) modified "D" loop joint with 96 percent tin, 4 percent silver solder, c) cane loop joint with 96 percent tin and 4 percent silver solder, and also the inverted transistor with a formed lead in a copper tubelet as long as the lead does not extend out the end of the tubelet, and as long as it has a heavy 60/40 solder joint.

5 Hermetically sealed 1/10 watt resistors with tubelets, 96 percent tin and 4 percent silver, and similar resistors with leads formed over 0.1 to 0.15 inches and a heavy solder joint made with 95 percent tin, 5 percent antimony are both capable of meeting the ATM goal.

6 Dipped, silvered mica capacitors (DM-19 type) with tubelets and a heavy solder joint of 96 percent tin, 4 percent silver are capable of meeting the ATM thermal cycle goal.

7 Solder joints on copper leads only will meet the ATM thermal cycle goal as long as they do not have external stresses applied to them.

8 There is no significant difference in the crack resistance of relay leads with crimped, welded, soldered and only soldered flanged tubelets. Both types can be expected to develop minor

cracks even though used with a resilient spacer between the relay and the PC board. A softer spacer under the relay should be more effective. The flanged tubelet is definitely beneficial in reducing relay solder joint cracking and in reducing the seriousness of cracks that may eventually occur.

9 The use of a rigid epoxy conformal coating (PC-16) instead of the seni-rigid polyurethane (PC-22) coating does not significantly improve resistance to cracking.

10 The special aluminum PC board with the oxide coating significantly reduces solder joint cracking from that experienced on epoxy-glass PC boards. From the limited data available, the aluminum PC board is three to thirty times better than the standard material for PC board use. Additional testing is needed if this material is to be seriously considered as a replacement.

IV. RECOMMENDATIONS

The following recommendations are presented for future considerations to improve the reliability of PC assemblies:

1 That efforts be expended to find a combination of a solder alloy and a generally acceptable lead material that will produce reliable long term solder connections to printed wiring boards.

2 That additional samples be made and tested in the areas of relays, resistors and capacitors to verify the specified ATM fixes are effective.

3 That production assemblies on ATM and other programs be thermally cycled over their respective temperature usage profiles for an appropriate number of cycles to determine the reliabilities of the entire assemblies, component operation as well as solder joint durability.

4 That standard solder joint assemblies be thermally cycled over the actual ATM temperature profile to give temperature correlation data with the accelerated testing already performed.

5 That selected solder joints that have been thermal cycled be sectioned and photomicrographed to better analyze the extent of cracking. That the cause of the reaction that appeared on some lead solder composition joints be determined and documented.

6 That the information developed by these tests be incorporated into a manual or specification to guide future PC assembly.

7 That an attempt be made to measure the electrical deterioration of solder joints that crack to determine beyond any doubt the full significance of the solder cracking phenomena. This should be checked at several power levels, temperatures, and during vibration excitation.

ACKNOWLEDGEMENTS

These tests were made possible by the combined efforts of many Martin Marietta employees. The major contributors were: 1) Ray Perez who supervised his production group of assemblers in the construction of all test specimens; 2) Bob Derickson, Martin Marietta Quality Inspector, who performed all of the inspections for both groups of tests; 3) Charles Diaz, Engineer, who assisted in the performance of the test and modification of the machine; and 4) John Cudd who designed and built both of the accelerated test machines described in the Group 1 report and used in these tests.

OR 9298

UNCLASSIFIED

Martin Marietta Corporation
FINAL TEST REPORT, GROUP 1 AND 2 TESTS, SOLDER STUDY CONDUCTED ON APOLLO TELESCOPE MOUNT GYRO PROCESSOR, D. F. Diel, March 1968
(Contract NAS8-11684)
58 pp UNCLASSIFIED REPORT

Described in this report is an environmental test study to improve solder joint techniques for the Apollo Telescope Mount (ATM). This report describes two new accelerated test machines and the results of a series of tests on various solder joint arrangements and materials.

1. Apollo Telescope Mount
2. Solder joint thermal cycling
3. PC assemblies
4. Two Arm Test Machine
5. Rotary Test Machine

I. Contract No. NAS8-11684
II. Diel, D. F.

OR 9298

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1. Apollo Telescope Mount
2. Solder joint thermal cycling
3. PC assemblies
4. Two Arm Test Machine
5. Rotary Test Machine

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