MCR-71-256

DESIGN, DEVELOPMENT, MANUFACTURE, TESTING, AND DELIVERY OF DEVICES FOR CONNECTION OF SOLAR CELL PANEL CIRCUITRY TO FLAT CONDUCTOR CABLE SOLAR CELL ARRAY HARNESS

Final Summary Report

October 1971

Contract NAS8-26114

Prepared for

National Aeronautics and Space Administration
George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

MARTIN MARIETTA DENVER DIVISION

DESIGN, DEVELOPMENT, MANUFACTURE, TESTING, AND DELIVERY OF DEVICES FOR CONNECTION OF SOLAR CELL PANEL CIRCUITRY TO FLAT CONDUCTOR CABLE SOLAR CELL ARRAY HARNESS

FINAL SUMMARY REPORT

CONTRACT #NAS8-26114

DRL 193 ITEM 2

Prepared By: P. A. Dillard

D. Waddington

Approved By: W. H. McCandliss
Deputy Program Manager

Approved By: W. B. Collins
Program Manager

FOREWORD

This report is submitted in accordance with Data Requirements List 193, Item No. 2, Contract NAS8-26114. This document summarizes the three-phase effort during which the Flat Conductor Cable (FCC) state of art was studied, connector concepts for FCC to solar panels were generated, and one chosen concept was designed, developed, manufactured, and tested according to contract requirements.

Other documents submitted during performance of this contract and referenced herein are listed below:

General Test Plan	MCR-71-70 Rev A, DRL 193, Item 6
Acceptance Test Procedure	MCR-71-202 Rev A, DRL 193, Item 7

ABSTRACT

Phase I

During Phase I, manufacturers and users of flat conductor cable, flat conductor cable connectors, and solar cell arrays were contacted to determine the technology status and problem areas which exist for the application of flat conductor cabling to solar cell arrays. The conclusions reached are as follows:

- No existing solar array has made use of flat conductor cabling which is attached to the solar cell interconnect system through a connector.

- Problems in the design of a connector for the effective use of flat conductor cable with solar cell panels are as follows:

  1) To reduce connector height to permit compact array panel storage with minimum interference with adjacent panels;

  2) To improve connector flexibility to permit its use on flexible folded and/or roll up arrays of either cadmium sulfide or silicon cells;

  3) To develop a suitable conductor attachment means from the solar cell panel interconnect system to the connector half which is mounted on the panel; such attachment should be suitable for both cadmium sulfide and silicon solar cells.

Phase II

The Phase II preliminary design activity report contained herein includes the following:

- Sketches, drawings, and photos of concepts showing technical detail which illustrate the proposed termination concepts and alternate approaches;

- Discussions of known and potential problem areas which may be encountered with the various proposed concepts;

- Comparative evaluation of the features and expected performance of proposed concepts against the criteria for this phase;

Identification and substantiation of one concept which will be developed, manufactured and tested during Phase III.

During Phase II, nine candidate connector configurations were originated, developed, and compared in sufficient depth that their performance could be measured. By comparing the concepts in nine performance categories and listing the outstanding considerations related to the development of the concepts, Martin Marietta obtained a performance score by adding all scores which were weighted according to the importance of each category.

By this method it was determined that Concept #1, Plastic Draw Latch, be designed, developed, manufactured and tested during Phase III of this contract.

Phase III

During Phase III, a 4-contact connector design with a plastic draw latch was developed and successfully tested. This new, plastic molded, self-latching connector is the result of design refinements on the plastic draw latch Concept #1 which was selected during Phase II. This report summarizes the detail design, connector manufacture, and prototype test results. Details of some of the developmental problems and proposed solutions are discussed. Eight prototypes were manufactured of which three were tested successfully per the General Test Plan and five were delivered to MSFC. The latter five connectors are to be subjected to the Acceptance Test Procedure by NASA-MSFC.

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SECTION 1.0 DESCRIPTION OF CONTRACTUAL WORK REQUIREMENTS

Section 1.1 Phase I Survey of Technology Status and Identification of Problem Areas

The Martin Marietta Corporation, Denver, shall sufficiently survey the fields of flat cable technology and solar cell (both silicon and cadmium sulfide C_dS) module technology to become knowledgeable of the problem areas and potential advantages and objectives of various existing design approaches for terminations and interconnection of cell circuitry and array harness wiring. Both long range objectives and interim usable designs shall be taken into account as these design approaches relate to improved power-to-weight ratios through the use of more exotic materials, lower contact impedance configurations, and higher voltage designs. Specific problems relating to materials and contact configurations versus operating voltage levels and allowable voltage drops shall be documented and requirements for solutions to the problems shall be identified. Any technology breakthroughs required for solution of any of the problems shall be specifically identified along with the time period in which the particular technology improvement might reasonably be expected to occur. Finally, the Phase I report shall reflect those problems existing within the present state of technology which can reasonably be expected to be resolved in the Phase II design approaches and shall identify the solar array technology to which each relates.

Section 1.2 Phase II Preliminary Design

Martin Marietta, Denver, will develop one or more concepts for termination and interconnection of flat cable conductors and solar cell modules. All potentially attractive concepts will be pursued until such time as definitive design screening can eliminate those with less promise. In deciding upon design approaches and in laying out design concepts, the following guidelines shall be followed:

- The design shall incorporate a direct termination of the flat conductors to the solar cell interconnect system, precluding the need for soldering, welding, or special wire-end termination hardware. Conductor leads may be soldered directly to the solar cell interconnect system provided that the connector half to which they are attached is mounted on the solar panel in question.

- The concepts shall not require the use of special tooling to either connect or disconnect the termination system. Prime attention should be given to devices which can be installed by hand. Devices which require screw drivers or other simple common hand tools may also be considered.

- The physical size of the termination system shall be minimized and the design shall approach a minimum weight-to-power ratio.

- A low connector profile height shall be adhered to. It shall be suitable for use with high density array packaging techniques such as stacking, fold-up, and roll-up.

- The concepts shall be designed to minimize contact resistance. Connector voltage rating and environmental sealing shall be compatible with the solar panel to which is is attached.

- The termination and interconnection concept shall preclude the need for either a secondary potting operation or additional clamps or supports to protect against excessive vibrations such as those experienced during launch.

<u>Section 1.3 Phase III Detail Design, Manufacture, Test, and Delivery</u>

During Phase III, Martin Marietta shall perform detailed design, fabrication, and testing of feasibility models of connectors proposed during Phase II and approved by MSFC. The design drawings and test plan documents shall be approved by MSFC prior to implementation of hardware. Any changes in designs after approval by MSFC shall be agreed to by MSFC before implementation of the change. The prototype hardware shall be developed as follows:

1) Perform detail design of selected method of flat cable to solar cell interconnection and circuit termination hardware.

2) Fabricate eight prototype models of the selected design for testing and submittal to MSFC as specified below.

3) Prepare and obtain MSFC approval for Acceptance Test Procedure and General Test Plan.

4) In addition to the three prototype models to be tested by the contractor, five prototype models of the concept shall be fabricated and shipped to MSFC.

   a) Upon completion of the Phase III design, fabrication, and test activity, Martin Marietta shall review all important aspects of the development effort in a presentation at MSFC.

In addition to the five prototype connectors, Martin Marietta shall deliver to MSFC one complete set each of reproducible drawings suitable for parts manufacture of all components, tooling, assemblies, and molds. In addition, all tooling and molds generated at Martin Marietta's plant in accomplishing this scope of work shall be delivered to MSFC upon completion of the effort.

b) This hardware is not quality sensitive.

SECTION 2.0 SUMMARY OF THE ACCOMPLISHMENTS AND ASSESSMENT AGAINST THE SCOPE OF WORK

Section 2.1 Accomplishments During Phase I

The Phase I effort proceeded by submitting array configuration questionnaires to eight companies and government organizations which are involved in spacecraft solar array manufacture and use. Flat conductor cable manufacturers and manufacturers of connector devices for flat conductor cable were also sent questionnaires. Later, eight of the array manufacturers and users were visited and the problems and features of their array concepts were discussed.

The questionnaire answers all indicated that no work has been specifically directed toward connecting flat conductor cabling to solar cell panels on existing array systems.

All of the flat conductor cable manufacturers indicated that they have the capability to manufacture cable to military specification MIL-C-55543.

Section 2.2 Phase II

During Phase II nine concepts were originated, developed, and compared. This report describes each concept and presents the following information:

- Illustrations of proposed termination concepts and alternate approaches;
- Discussion of known and potential problem areas which may be encountered with the various proposed concepts;
- Comparative evaluation of the features and expected performance of proposed concepts against the criteria noted above;
- Identification and substantiation of one concept which will be pursued in detailed design, fabrication, and test during Phase III.

Following the description of each concept in Section 3.0 there is a table which lists outstanding considerations which were used in evaluating that approach. It was not intended that all of the good and bad features be listed here; but rather that only the items be shown which were of primary importance in deciding whether that concept should be further developed during this contract.

Section 2.3 Phase III

The Phase III effort has resulted in a completely new self-latching 4-contact connector for FCC applications. Of the eight connectors manufactured and subjected to testing according to the General Test Plan, five were shipped to MSFC after undergoing the acceptance portion only.

All stated objectives of this effort have been met by Martin Marietta. There is, however, evidence that certain design improvements could be implemented which would lead toward making the subject connector a more desirable item of flight quality.

SECTION 3.0 DETAILED TECHNICAL INFORMATION

Section 3.1 Phase I

The Phase I effort was initiated by submitting array configuration questionnaires to eight companies and government organizations which are involved in spacecraft solar array manufacture and use. Flat conductor cable manufacturers and manufacturers of connector devices for flat conductor cable were also sent questionnaires. Later, eight of the array manufacturers and users were visited and the problems and features of their array concepts were discussed.

The answers to the questionnaire all indicate that no work has been specifically directed toward connecting flat conductor cabling to solar cell panels on existing array systems.

All of the flat conductor cable manufacturers indicated that they have the capability to manufacture cable to military specification MIL-C-55543.

A list of the companies contacted is shown in Table 3.1.1.

During visits to the makers and users of solar arrays, the expected problems related to adapting existing array designs for the use of flat conductor cabling and a connector to connect the flat conductor cabling to the solar cell panel were discussed. A summary of the resulting potential problems in adapting conductor cabling to existing array concepts is shown in Table 3.1.2.

None of the manufacturers of connector devices indicated capabilities to make connectors for flat conductor cabling per MIL-C-55544. Many of them have modified their standard connector line to adapt to FCC and then tested the connectors under conditions which correspond to MIL-C-55544. A summary of published performance data (from promotional brochures) on connectors from seven manufacturers and the MIL-C-55544 connector requirements are shown in Table 3.1.3.

General conclusions which resulted from the Phase I study effort are summarized as follows:

- No existing solar array has made use of flat conductor cabling which is attached to the solar cell interconnect system through a connector.
- Primary problems in the design of a connector for the effective use of flat conductor cable with solar cell panels are as follows:

TABLE 3.1.1

Companies and Agencies Contacted During Phase I

A. Solar Array Manufacturers and Users

COMSAT, Clarksburg, Maryland
NASA-Goddard, Greenbelt, Maryland
General Electric, Valley Forge, Pennsylvania
NASA-MSFC, Huntsville, Alabama
TRW Systems, Redondo Beach, California
Hughes, El Segundo, California
Lockheed, Sunnyvale, California
Boeing, Kent, Washington

B. Flat Conductor Cable (FCC) Manufacturers

W. L. Gore, Downey, California
Burndy, Denver, Colorado
Coleman, River Grove, Illinois
Philadelphia Insulated Wire, Moorestown, New Jersey

C. FCC Connector Manufacturers

ITT Cannon
Microdot
Ansley
Malco
AMP
Amphenol

TABLE 3.1.2

Potential Problems in Adapting FCC
To Existing Array Concepts

A. Folded Rigid Panels (ATM, OWS, Boeing)

1. Profile height (clear adjacent panels)
2. Inspectability
3. Test/replacement access
4. Comments
    a. Connector may be buried in panel
    b. Connector and structural attachment may be combined
    c. Connector flexibility not required
    d. Magnetic field not defined

B. Folded Flexible Panels (TRW, Lockheed)

1. Profile height (very thin - may be located outside of hinge lines)
2. Flexibility

C. Roll-Up Panels (GE, Hughes)

1. Profile height (very thin to prevent bulging of sheet)
2. Flexibility (extreme - to wrap around drum without distortion)

D. Inflatable (Martin)

1. Profile height (very thin)
2. Flexibility (extreme)

NOTE: Panel attachment and electrical connection functions may be combined in some applications

TABLE 3.1.3

Flat Conductor Cable Connector

Performance Data

COMPANY	VOLTAGE RATING	CURRENT RATING	CONTACT RESISTANCE	TEMPERATURE RANGE	VACUUM PERFORMANCE (OUT GASSING)	INSULATION RESISTANCE, CORONA, & EMI	CONTACT TO CONDUCTORS	CONNECTOR JOINING FORCE	ADAPTABILITY TO SOLAR ARRAY	VOLUME & PROFILE HEIGHT	INSULATION MATERIAL
CANNON	S.L.: 1000 VAC 70K FT: 300 VAC	3 AMP	12 MILLIVOLT @ 3 AMP	$-65^{\circ}F$ TO $+300^{\circ}F$		5000 MEGOHM 40 db MIN. ATTEN. DC TO 1000 MHz	WELD	IN 6oz/CONTACT OUT .5oz/CONT.		HEIGHT .215	DIALLYL PHTHALATE
MICRODOT	S.L.: 1000 VAC 70K FT: 300 VAC	3 AMP	4 MILLIOHM	$-65^{\circ}F$ TO $+300^{\circ}F$		5000 MEGOHM @ $25^{\circ}C$	WELD OR SOLDER	IN 6oz/CONTACT OUT .5oz/CONTACT		HEIGHT .208	DIALLYL PHTHALATE
ANSLEY	(CUSTOM)										
MALCŌ	300 VAC	3 AMP	2 MILLIOHM	$+95^{\circ}C$		1,000,000 MEGOHM	FORM WELD SOLDER				
AMP	S.L.: 1200 VAC 50K FT: 550 VAC	3 AMP	25 MILLIOHM (MAX)	$-65^{\circ}C$ TO $+125^{\circ}C$		>1000 MEGOHM	CRIMP PIERCE INSULATION	IN 5oz/CONTACT OUT .75oz/CONT.		HEIGHT .75	DIALLYL PHTHALATE
AMPHENOL	S.L.: 300 VAC	5 AMP	4 MILLIOHM	$-65^{\circ}C$ TO $+125^{\circ}C$		5000 MEGOHM MAG PERM <2.0 MU	MELT INSUL- WELD CONTACT				
MIL-C-55544		3-5 AMP	MIL-C-39029 12 MILLIOHM	$-65^{\circ}C$ TO $+125^{\circ}C$		>5000 MEGOHM >50 MEGOHM AFTER HIGH TEMP	CRIMP CABLE COND. PIERCE SOLDER WELD	IN: 1.5oz/CONT OUT: 1oz/CONTACT		HEIGHT .560	POLYPHENYLENE OXIDE

1) To reduce connector height to permit compact array panel storage with minimum interference with adjacent panels;

2) Improve connector flexibility to permit its use on flexible folded and/or roll up arrays of either cadmium sulfide or silicon cells;

3) To develop a suitable conductor attachment means from the solar cell panel interconnect system to the connector half which is mounted on the panel; such attachment should be suitable for both cadmium sulfide and silicon solar cells.

. The use of a connector on roll up type flexible arrays as a means of replacing solar cell panels is viewed as impractical by most manufacturers.*

Section 3.2 Phase II

Section 3.2.1 Design Principles

During Phase II, nine concepts were originated, developed, and compared. This report describes each concept and presents the following information:

. Illustrations of proposed termination concepts and alternate approaches;

. Discussion of known and potential problem areas which may be encountered with the various proposed concepts;

. Comparative evaluation of the features and expected performance of proposed concepts;

. Identification and substantiation of one concept which will be pursued in detailed design, fabrication, and test during Phase III.

Following the description of each concept there is a table which lists outstanding considerations which were used in ev luating that approach. It is not intended that all of the good and ad features

*The only known solution to this problem was presented by Fairchild-Hiller in Report #652-00101-FR: Fabrication Feasibility Study of a 30-Watt/Pound Roll Up Solar Array, JPL Contract #951969, 15 August 1968.

be listed here; but rather that only the items be shown which were of primary importance in deciding whether that concept should be further developed during this contract.

Preliminary Criteria

Initially the new concept identification effort was directed to generating new connector concepts and adapting existing latching and fastening hardware to serve the electrical function. It was intended that the panel attachment and electrical connection functions be performed by the same device. Later, attention was turned to adapting the more conventional connectors to the flat conductor cable-to-solar panel connection function alone, without the additional panel attachment requirement. Several concepts of both types were generated which appeared promising. Preliminary criteria were established and used during further design and to compare the various concepts. The preliminary criteria, which were agreed to by the customer, subject to changes as this effort progressed, are shown in Table 3.2.1.

TABLE 3.2.1

Preliminary Design Criteria

Voltage Rating:	120 Volts
Current Rating:	3 Amps
Redundancy	Two positive and/or two negative wires per connector
Profile Height:	Solid Substrate: 0.3 inch Flexible Substrate: 0.1 inch
Sealing Requirements:	Same as for solar panel cell interconnects
Versatility(1):	Specialized
Contact Drop:	25 millivolts at 3 amp
Cycle Life:	50
Insertion/Separation Force:	5 ounces minimum per contact
Temperature Range:	-170 to 125°C(2)

NOTES: (1) Specialized means that a connector concept will be designed for each application. The development of a universal connector which could be used interchangeably on honeycomb, roll-up, and flexible folded array panels appears to be impracticable.

(2) It is expected that the connector will be electrically functional throughout the temperature range; but that it will be disconnected and/or reconnected only when the temperature is such that the connector material will not be damaged by such handling.

CONCEPT #1

PLASTIC DRAW LATCH

This concept (see Figure 3.2.1) is based on a plastic molded draw latch which was developed by Southco, Inc., Lester, Pa., 19113. Made from polypropylene and modified by integrally casting flat conductor cabling into it, the device offers potential as both a panel latch and electrical connector.

This concept is made by bonding flat conductor leads to the latch and to the keeper with contacts exposed so they are clamped between the mating surfaces with conductors in intimate contact. Both opening and closing are positive snap actions which require no tools. The latch body is a one-piece polypropylene molding with integrally hinged sections. Because the latch body surrounds the keeper and catches from one side only, there is no possibility of crossing polarities in the electrical hookup. All conductors are lined up exactly each time the connector/latch is engaged.

Crude models of the connector/latch were constructed to determine operational feasibility of the concept. Further design effort is required to determine whether the concept will meet the preliminary criteria noted above. A discussion with the manufacturer to determine whether the device could be molded from other materials such as teflon brought a no-interest negative response. Further contact is warranted because of the potentialities for this concept as noted below.

Some of the properties of polypropylene need to be investigated prior to starting the design effort for this concept. Some notes on polypropylene follow:

- Ultraviolet radiation: Polypropylene is adversely affected by ultraviolet radiation. Stabilizers provide some protection, but carbon black is more effective in preventing ultraviolet damage.

- Temperature: Several grades of polypropylene which require UL Group I or II (self-extinguishing) ratings to 95^{o}C continuous exposure are available. The increase in stiffness at very low temperatures should be investigated to determine whether cracking will occur.

- Dielectric strength: Dielectric strength of polypropylene is high and increases with temperature.

- ATM acceptability: Polypropylene is listed as acceptable for use on ATM as per "ATM Material Control for Contamination Due to Outgassing," George C. Marshall Space Flight Center document number 50M02442.

No further information is included in that report except that the material source was noted to be Union Carbide. Information regarding the performance of polypropylene in vacuum at elevated temperatures with ultraviolet radiation has been requested from the Chicago Office of Union Carbide.

Some significant features of this concept are as follows:

- Easily operable with no tools at nominal temperatures.

- Maintains predictable preload between conductor contacts which is determined by the creep strength of the latch material. Choosing different materials to vary contact pressure appears to be feasible. The performance of this concept is, therefore, a function of basic material properties and is not dependent on levers, springs, etc.

- Reliably performs both panel latching and electrical connection.

- Components of the device are readily available commercially. They may be purchased at nominal cost and modified as required to perform the desired function to prove the concept before proceeding with a specialized design effort.

- Minimum size of the existing commercially produced latch is .25 high x .68 x 1.75. By modifying the manufactured parts, Martin Marietta, Denver, reduced the height to .180. Futher height reduction may be feasible by redesigning molds for this specific application.

- Although not part of this contract, commercial exploitation of this device appears to be practicable (see Figure 3.2.2).

Primary considerations of the plastic draw latch are summarized in Table 3.2.2.

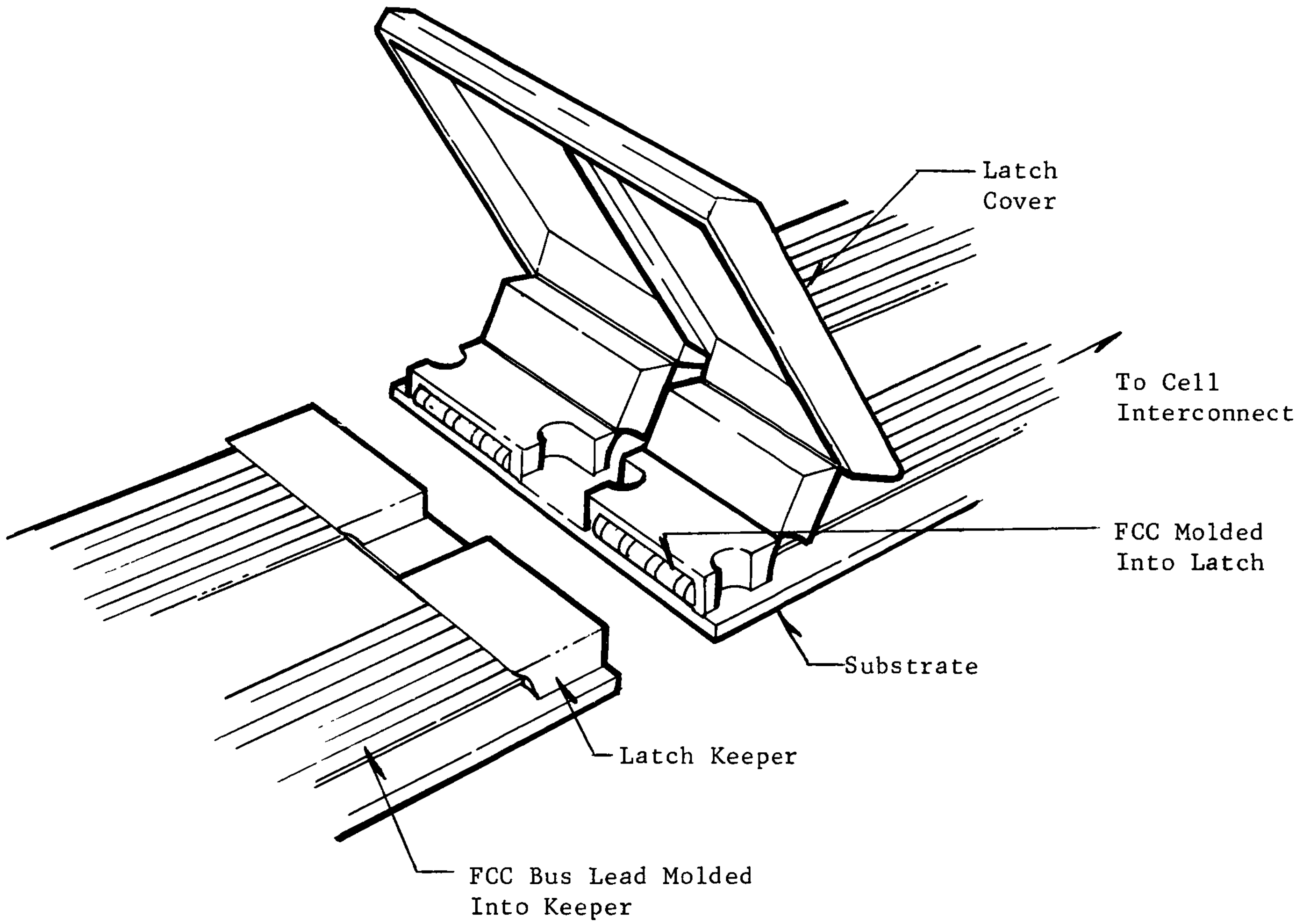


FIGURE 3.2.1: PLASTIC DRAW LATCH

TABLE 3.2.2

Primary Considerations for Concept #1

Plastic Draw-Latch

Desirable Points	Problem Areas
1. Both mechanical/structural and electrical functions in one device	1. Material embrittlement at low temperatures
2. Built-in strain relief	2. Material requires UV protection
3. Restrains motion in 3 directions	3. Requires cooperation of commercial company to produce aerospace quantities
4. Snap-action easy operation with no tools	4. High profile
5. No chance for polarity mix-up	
6. Positive constant pressure between contacts determined by bulk modulus of material	
7. Low cost	
8. Low development cost	
9. Commercial potential	

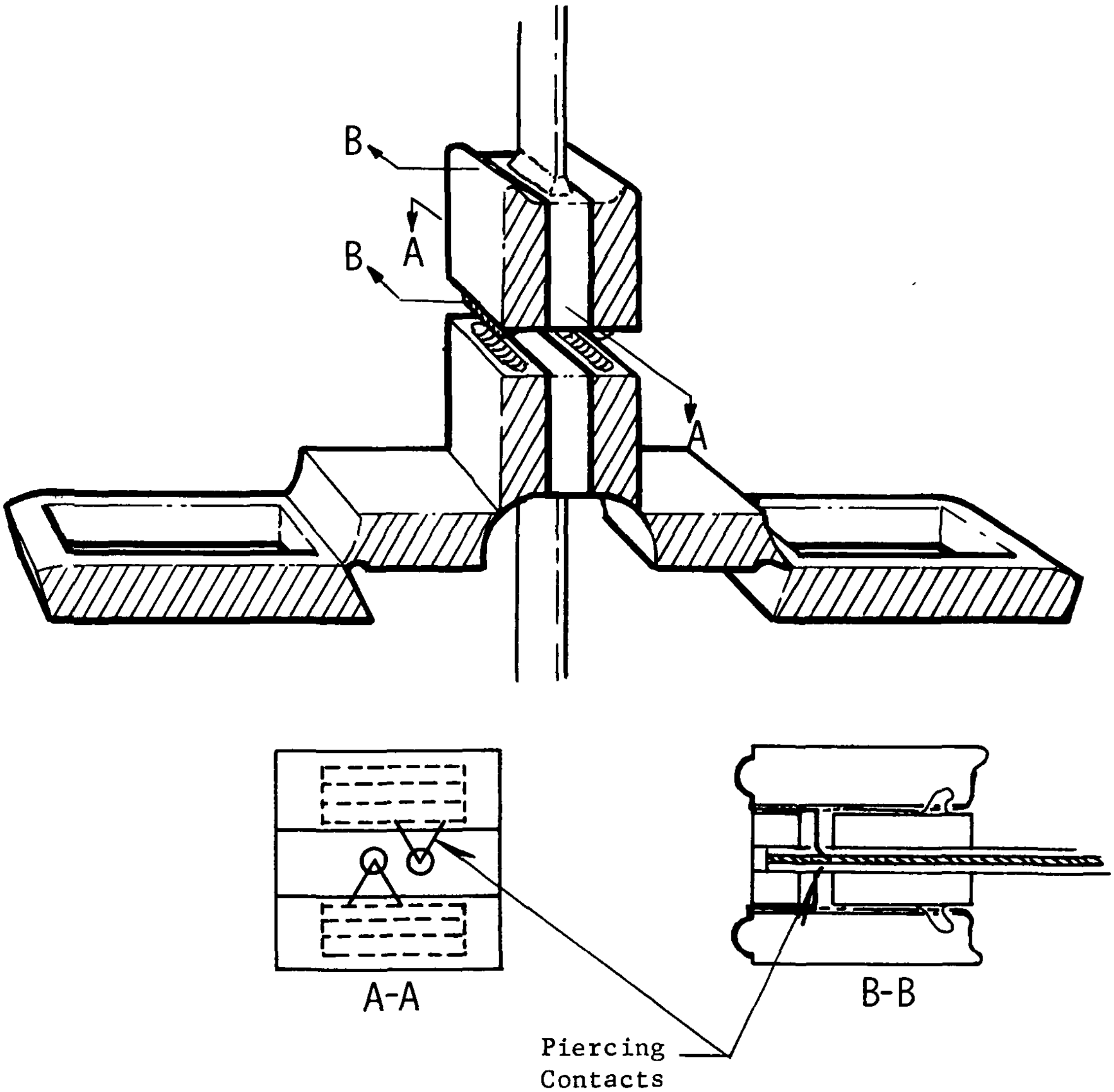


FIGURE 3.2.2: BACK-TO-BACK DRAW LATCHES WITH INSULATION-PIERCING CONTACTS (POTENTIAL COMMERCIAL APPLICATION)

CONCEPT #2

MIL-C-55544/7 MODIFIED

This concept uses connector per Military Specification MIL-C-55544/7 modified (Figure 3.2.3) for FCC to be molded into side instead of bottom of male half so that less space is required when female half is "buried" in the honeycomb panel. Implementation of this concept requires a small modification of the male part mold, and redesign of the receptacle for potting into the panel. All of the functions required in a connector have been well designed and proven in this design as it exists with the sole exception of low profile height. With the proposed modifications, the concept also would meet the height requirement when "buried" in a honeycomb solar panel to better utilize already available space. Primary considerations for this concept are summarized in Table 3.2.3.

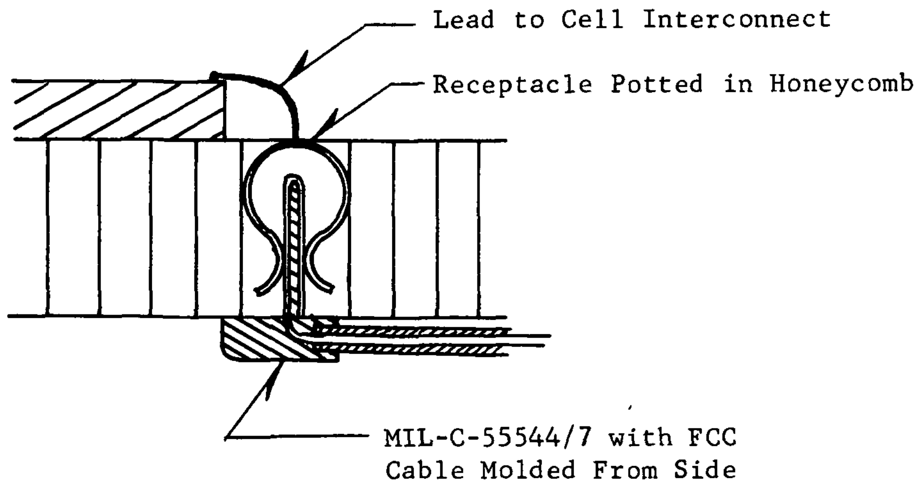


FIGURE 3.2.3: CONCEPT #2, MIL-C-55544/7 MODIFIED

TABLE 3.2.3

Primary Considerations for Concept #2

Desirable Points	Problem Areas
1. Proven connector concept and manufacturing method of plug part.	1. Requires mounting bracket or modification of substrate.
	2. High profile height
	3. Requires extensive modification of receptacle to permit burying (i.e., potting) into panel
	4. High development cost
	5. Requires development of potting method

CONCEPT #3

PIN AND SOCKET WITH MODIFIED CLAMP (FIGURE 3.2.4)

This concept was developed by modifying a pin and socket connector of a type which is made by several manufacturers to reduce profile height, to provide improved clamping means, and to provide environmental sealing.

On the model shown (this model was made from an AMP, Inc. connector; similar connectors are made by Cannon, Microdot, etc.), the profile height was reduced from 0.25 inch to 0.15 inch by removing the screw boss. Clamping pressure is provided by a wire spring clip which works like an automobile distributor cap retainer clamp. Alternately the clamp may be molded into the part as shown in Figure 3.2.5. Sealing was provided by potting holes, etc. with a silicon compound after the connector was assembled. Concept #3 primary considerations are summarized in Table 3.2.4.

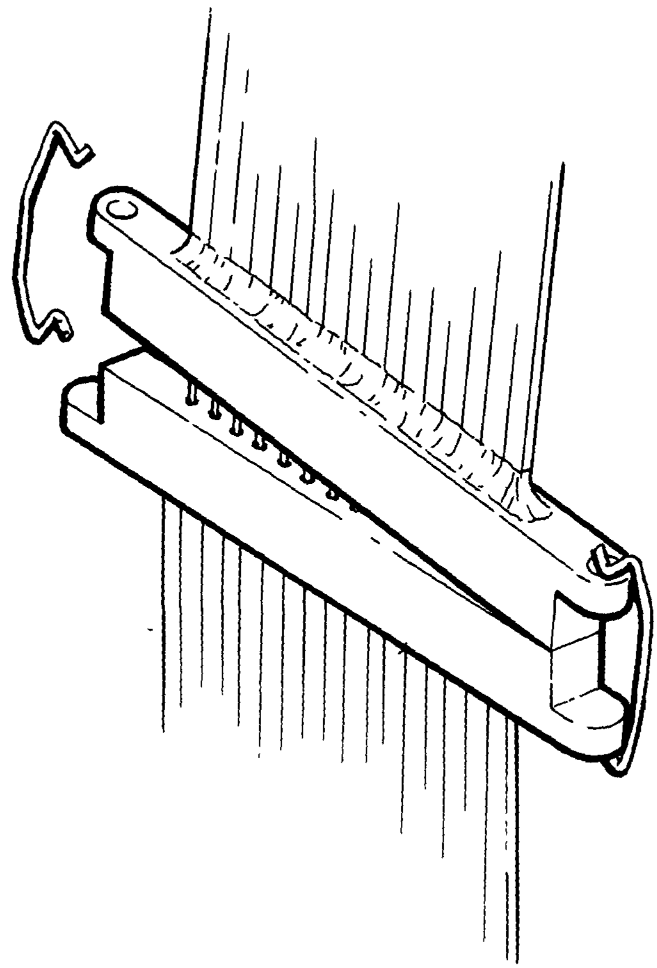


FIGURE 3.2.4: CONCEPT #3 PIN AND SOCKET

TABLE 3.2.4

Primary Considerations for Concept #3

Desirable Points	Problem Areas
1. Proven concepts	1. Inspection of pin-to-connector difficult
2. Low development cost	2. Wire spring clip requires tool for removal
	3. Molded clamp requires development
	4. High profile
	5. Very rigid

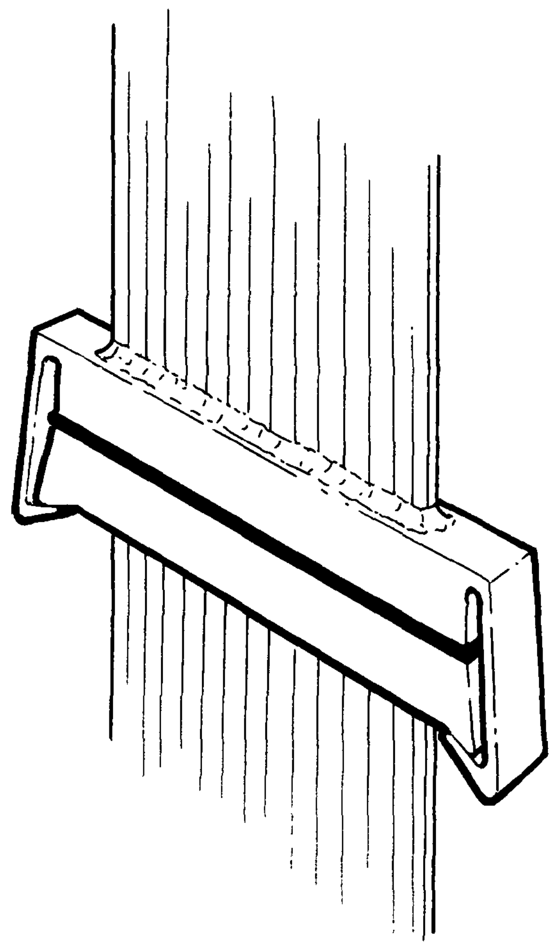


FIGURE 3.2.5: CONCEPT #3 WITH INTEGRALLY MOLDED CLAMPS

CONCEPT #4

SNAP-SLIDE

This is another concept which has been developed from a readily available fastening device (Figure 3.2.6). By adding a conducting spring and reducing the profile height, the snap-slide fastener by Dimco-Grey was made into a suitable connector (Figure 3.2.7).

Further development is required to develop a means of insulating this device. One concept uses non-metallic velcro-tape in which half of the closure is bonded to the flat conductor cable insulation on both sides of the connection and the other half of the closure is simply wrapped around, engaging the velcro on both sides of the connection. Height reduction of the fastener/connector from 0.28 inch to 0.15 inch has been accomplished by modifying components. See Table 3.2.5 for summary of primary considerations for this concept.

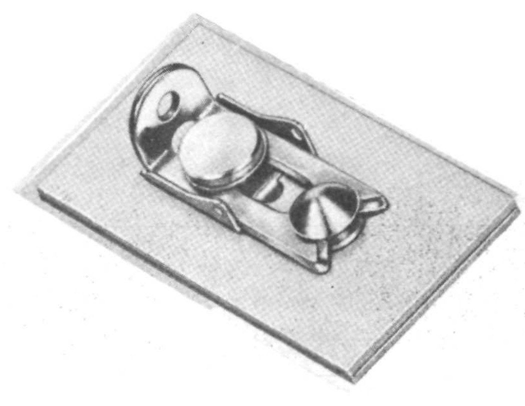


FIGURE 3.2.6: CONCEPT #4 SNAP-SLIDE FASTENER (UNMODIFIED)

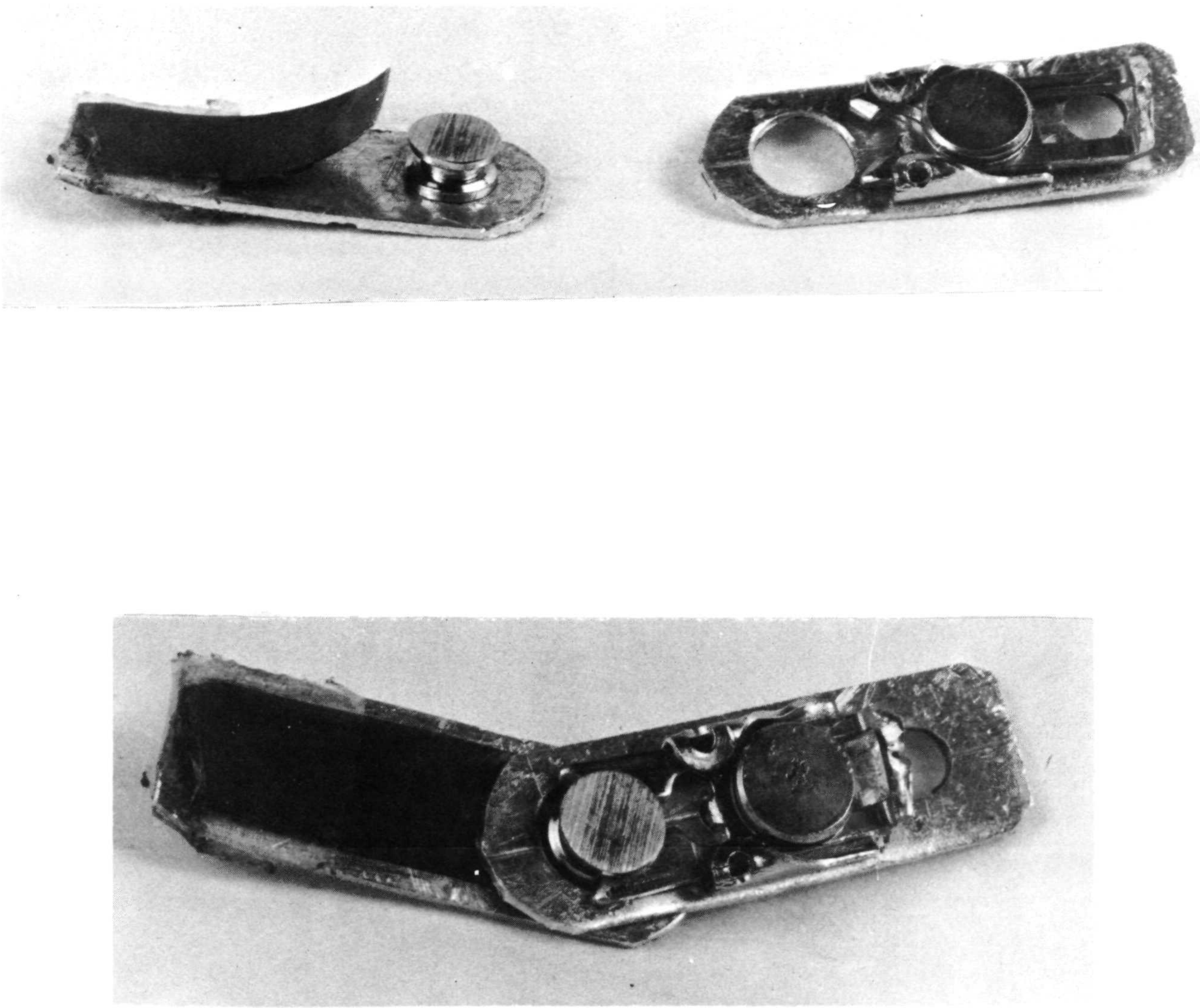


FIGURE 3.2.7: CONCEPT #4 SNAP-SLIDE

TABLE 3.2.5

Primary Considerations for Concept #4

Desirable Points	Problem Areas
1. Electrical and mechanical functions separate but still within same device	1. Requires insulation development
2. Only concept which permits in-plane flexing	2. High profile height
	3. Rigid out of plane

CONCEPT #5

BATTERY SNAP CONNECTOR

Battery snap connectors of the type used on 9-volt transistor radio batteries, as shown in Figure 3.2.8, have been considered. If a means of reducing the profile height is devised, this device may warrant further development. Present height is 0.31 inch. Improved methods of attaching the connector to FCC are also required. Primary considerations for this concept are summarized in Table 3.2.6.

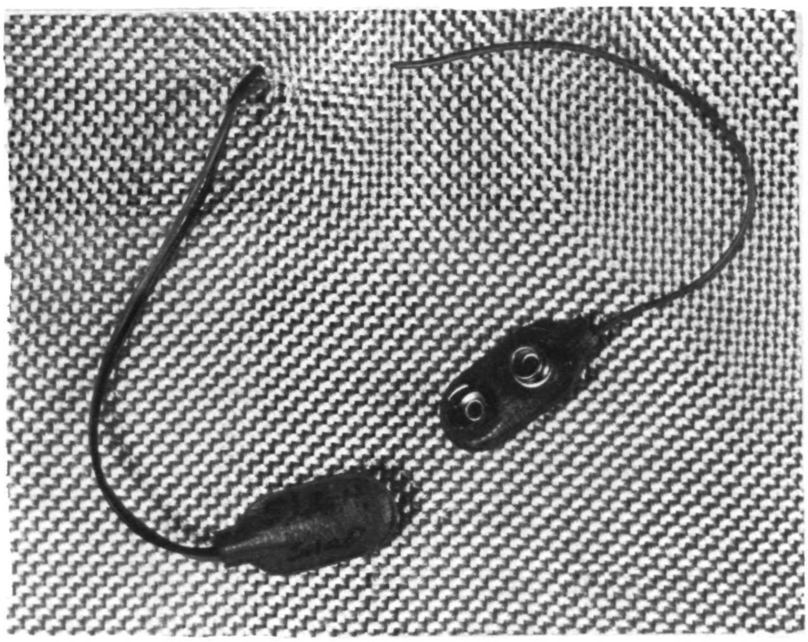


FIGURE 3.2.8: CONCEPT #5 BATTERY SNAP CONNECTOR

TABLE 3.2.6

Primary Considerations for Concept #5

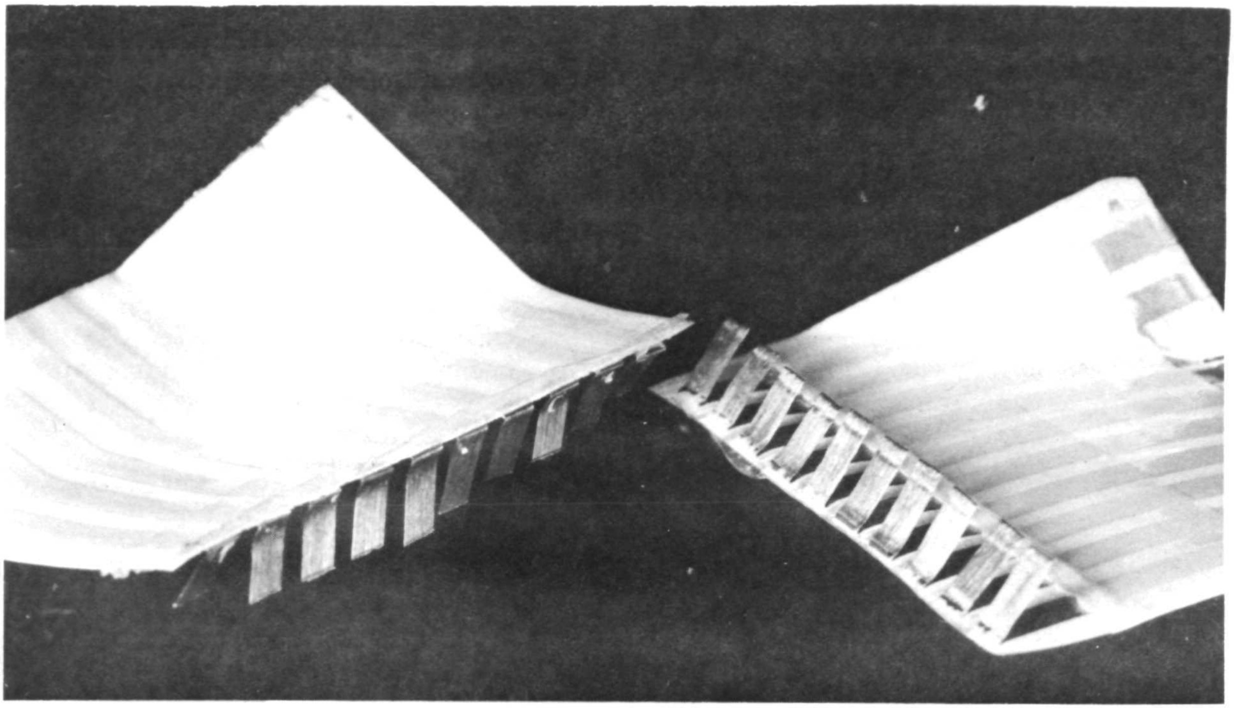
Desirable Points	Problem Areas
1. Simple	1. High profile height
2. Low cost	2. Requires development of attachment to conductors
	3. Requires strain relief

CONCEPT #6

BENT FLAT CONDUCTOR CABLE

This connector device (Figure 3.2.9) is made by stripping the mating ends of FCC and crimping the contacting conductors in a sheet metal seam. The connector would be sealed and held in position by tape across the joint on both sides. Potential problems with this concept may occur during thermal cycling. Bent conductors may not engage positively and inspection would be difficult.

This concept offers the lowest height of all the concepts (.026 inch). This fact alone makes this concept a strong candidate for further study. Primary considerations for Concept #6 are listed in Table 3.2.7.



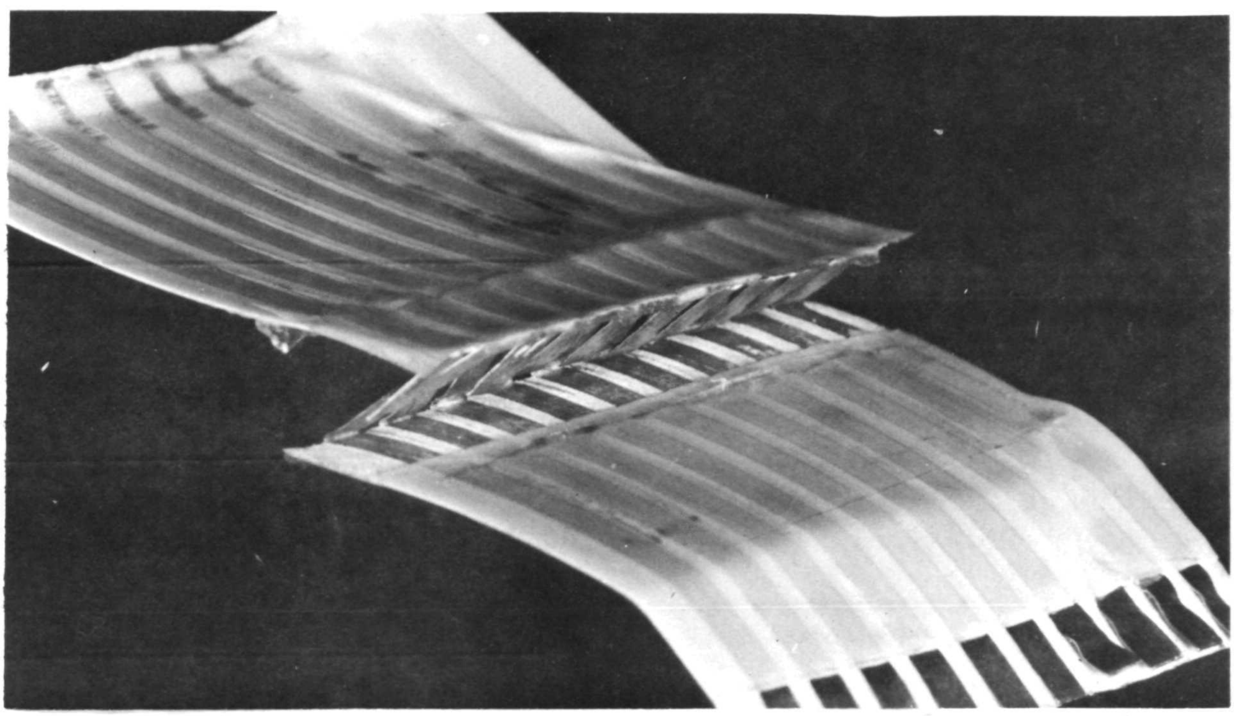


FIGURE 3.2.9: CONCEPT #6 BENT FLAT CONDUCTOR CABLE

TABLE 3.2.7

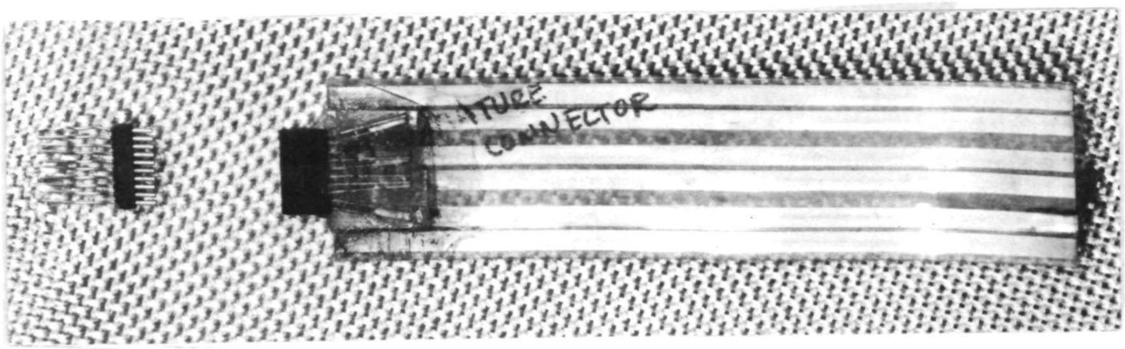
Primary Considerations for Concept #6

Desirable Points	Problem Areas
1. Least height of all concepts	1. Cycle life questionable
2. Least weight of all concepts	2. Needs clear insulation for inspection
3. Most flexible of all concepts	3. Pressure between contacts is uncertain

CONCEPT #7

MINIATURE CONNECTOR

Commercially available pin and socket connectors (Figure 3.2.10) with profile height of .075 are used in this concept. Leads are soldered so that several connector pins carry the current load of each flat conductor. After the connector leads are soldered or welded to the FCC, the connection is potted up to the connector body. Development of a suitable retention device for this concept would make it a very desirable candidate. Concept primary considerations are listed in Table 3.2.8.



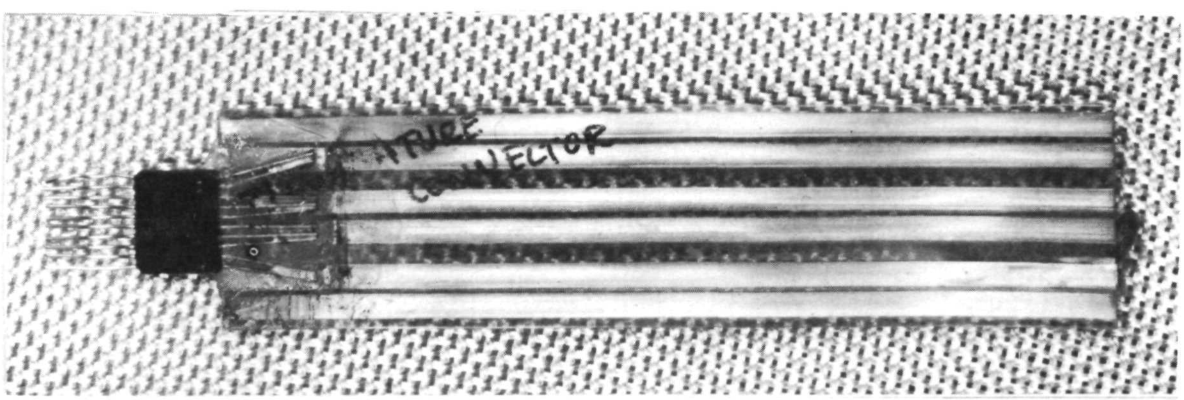


FIGURE 3.2.10: CONCEPT #7 MINIATURE CONNECTOR

TABLE 3.2.8

Primary Considerations for Concept #7

Desirable Points	Problem Areas
1. Thin body	1. Rigid
2. Readily available from several manufacturers	2. Requires mounting bracket and strain relief
3. Can solder or weld multiple pins to flat conductor for redundancy	3. Requires potting after attachment of pins to conductors
4. Very small mass	
5. Proven concept	

CONCEPT #8

CONDUCTIVE VELCRO

Early in this effort it appeared that conductive velcro (Figure 3.2.11) could be used to provide both electrical connection and structural attachment for solar panels. Even if conductivity were low, it was reasoned, larger areas of the material could be used with little weight penalty because of the dual functions it serves.

The manufacturer of velcro was contacted to determine whether the closure could be made from a good conductor material such as beryllium copper (BeCu). It was learned that the company had not tried BeCu and to have them try it would require a major funded development effort.

Investigation of already available velcro devices made from conductive material determined that this material is not suited to the FCC to solar panel connector application in its present form.

A simple resistance check on velcro Hi-garde® showed that increasing area does not reduce contact resistance sufficiently to permit use as a connector. Hi-Meg®, on the other hand, has a lower contact resistance but it is made from silver-impregnated nylon which is unreliable as a space material.

Further consideration of velcro for this purpose may be warranted when and if it is made from a space compatible conductive material. Table 3.2.9 shows primary considerations for this concept.

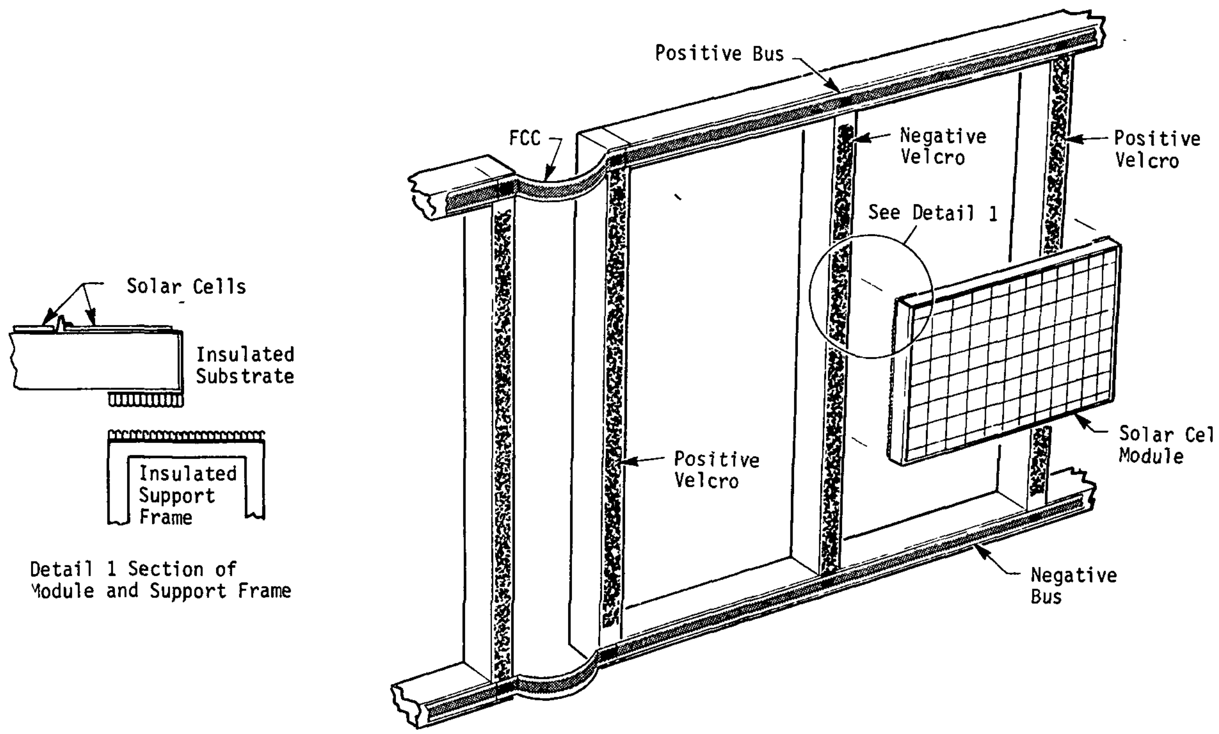


FIGURE 3.2.11: CONDUCTIVE VELCRO CONCEPT #8

TABLE 3.2.9

Primary Considerations for Concept #8

Desirable Points	Problem Areas
1. Combines electrical and mechanical fastening functions in easily operable device	1. Extremely high contact resistance
	2. Requires material development
	3. Contact pressure reduces during flexure

CONCEPT #9

INDEXING SPRING CLAMP

The clamping connector developed at MSFC offers many features which are desirable for a connector from FCC to solar panels. Its chief drawbacks are the high profile height when mounted on top of the panel and the loose parts during assembly and disassembly. Sufficient modifications to both the connector design and the solar panel to permit mounting the connector from the side instead of the top of the panel would make use of already available space on honeycomb panels.

On the proposed indexing spring clamp (see Figure 3.2.12), the connector is moved from the top of the panel to the edge. The configuration is based on the honeycomb edge design on the OWS panels. Application to other honeycomb panels may be made by suitable edge fitting design. Consideration has been given to the requirement of connecting the solar panel interconnecting bus on the front to the FCC main power bus on the back. The modification consists of adding an insulated connector bracket to the panel edge channel. A spring clamp forces the conductors into intimate contact. Indexing pins on the spring clamp ensure alignment of the conductors. The pressure from the clamp is transmitted through elastomeric pressure pads to press the bus conductors intimately against the conductors on the bracket. Connection to the cell module terminals would be by soldering them to the conductors on the bracket.

Concept #9 primary considerations are listed in Table 3.2.10.

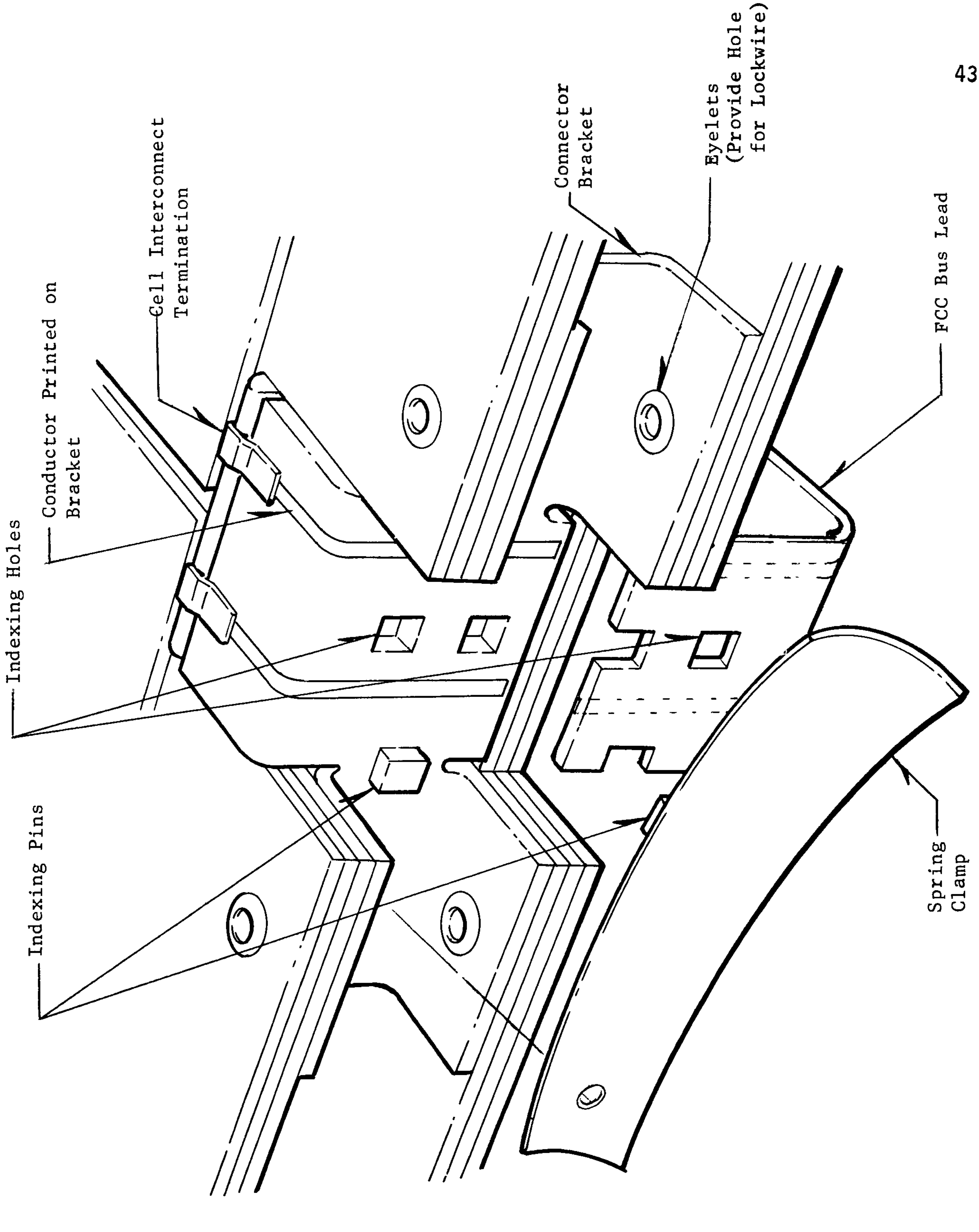


FIGURE 3.2.12: INDEXING SPRING CLAMP
CONCEPT #9

TABLE 3.2.10

Primary Considerations for Concept #9

Desirable Points	Problem Areas
1. Proven concept	1. Requires tool for operation
2. Predictable pressure between contacts	2. Requires development of clamping bracket
3. Built-in strain relief	3. Requires panel modification

The problem of attaching the connector to the solar cell interconnect system is similar for both silicon and cadmium sulfide cells. It is primarily related to the type of substrate used (whether rigid or flexible) and the array stowage method (whether roll-up, folded flexible, folded rigid, or stacked separate panels). As was earlier determined, one half of the connector may be mounted on the solar cell panel with conductor leads soldered or welded to the cell interconnect system.

Results of this Phase II effort indicate that on rigid panel arrays, the connector may be "buried" in the panel substrate thickness to reduce the overall height. For flexible arrays the height and flexibility of the connector must be such that the connector will not distort adjacent panels during stowage - causing cell and/or interconnect damage. Alternately, the connector may be located where it will not interfere with adjacent panels. An example of this method is Fairchild-Hiller's use of a miniature connector on their 30 watts/lb. roll-up solar array concept mentioned in comments on Phase I.

Specific applications for a connector for cadmium sulfide or silicon cells; rigid folded, rigid stacked, flexible folded, or roll-up solar cell panels must be designed in detail for each array system. The expected suitability for each of the candidate concepts to be adapted for use on either rigid or flexible panels is included in the concept evaluation under category <u>Flexibility Adaptability</u>. The importance of this category in the concept selection process is indicated by the assignment of a weighting factor of 2.

Section 3.2.2 Concept Evaluation and Phase III Concept Selection

Evaluation of the nine candidate concepts proceeded in two steps as follows:

- Primary considerations for each concept, the desirable points, and problem areas are listed with each point and area given a value of one. The development consideration score was obtained by subtracting problem areas from desirable points. This part of the evaluation is shown in Table 3.2.11.

- All concepts were compared by listing relative performance (giving scores from 9 to 1 in decreasing order) in ten categories as follows (see Tables 3.2.12 and 3.2.13):

  1) Height: Weighting factor = 3

TABLE 3.2.11

Development Consideration Scores for All Concepts

Concept		
#	Title	Score*
1	Plastic Draw Latch	+4
2	MIL-C-55544/7 Modified	-4
3	Pin & Socket Modified	-3
4	Snap-Slide	-1
5	Battery Snap	-1
6	Bent Flat Conductor	0
7	Miniature Connector	+2
8	Conductive Velcro	-2
9	Indexing Spring Clamp	0

*Development consideration score was obtained by subtracting the number of problem areas from the number of desirable points for each concept. This evaluation is assigned weighting factor of one in the performance score.

2) Strain relief: Compares ease of providing strain relief in connector body. Weighting factor = 1

3) Panel attachment: Rates feasibility of connector doubling as mechanical fastener for panel. Weighting factor = 1

4) Contact pressure: Compares amount and retention of contact pressures as it affects voltage drop. Weighting factor = 3

5) Development cost: Weighting factor = 1

6) Development potential: Compares anticipated growth of application potential for devices. Weighting factor = 1

7) Material properties: Temperature stability, arc strength, whether material has been developed for this application. Weighting factor = 2

8) Mounting provision: Ease of attaching connector body to substrate. Weighting factor = 1

9) Flexible adaptability: Base of adapting connector to be used for both flexible and rigid substrates. Weighting factor = 2

10) Commercial application potential: Includes existing potential when applicable. Weighting factor = 0.5

The score of the concept for each category is obtained by multiplying the relative number by the weighting factor. Categories 1) height, and 4) contact pressure were assigned the highest weighting factor (i.e., 3) because of their importance in fulfilling the requirements of this contract. Similarly, categories 7) material, and 9) flexible adaptability were assigned weighting factors of 2. All other categories received a weighting factor of 1 except commercial application potential.

The performance scores (see Table 3.2.14) on which Phase III concept selections are based were obtained as follows:

- Development consideration scores were listed for each concept
- Scores were multiplied by the respective weighting factor for each performance category
- Summing scores for each concept yielded the performance scores

TABLE 3.2.12

Relative Concept Performances in 9 Categories

(Scored from 9 to 1, Top to Bottom Respectively)

a) Height

Score	Concept	(Inches)
9	#6	0.03
8	#7	0.08
7	#8	0.12
6	#4	0.14
5	#3	0.15
4	#1	0.18
3	#5	0.25
2	#9	0.30
1	#2	0.56

Weighting Factor = 3

b) Strain Relief

Score	Concept
9	#1
8	#9
7	#2
6	#4
5	#3
4	#7
3	#8
2	#5
1	#6

Weighting Factor = 1

c) Panel Attachment

Score	Concept
9	#1
8	#4
7	#8
6	#2
5	#9
4	#7
3	#3
2	#5
1	#6

Weighting Factor = 1

d) Contact Pressure

Score	Concept
9	#9
8	#2
7	#1
6	#3
5	#5
4	#7
3	#4
2	#6
1	#8

Weighting Factor = 3

e) Development Cost

Score	Concept
9	#2
8	#3
7	#7
6	#1
5	#9
4	#5
3	#6
2	#4
1	#8

Weighting Factor = 1

f) Development Potential

Score	Concept
9	#1
8	#7
7	#9
6	#2
5	#4
4	#8
3	#3
2	#5
1	#6

Weighting Factor = 1

g) Material Properties

Score	Concept
9	#7
8	#9
7	#1
6	#2
5	#3
4	#4
3	#5
2	#6
1	#8

Weighting Factor = 2

h) Mounting Provision

Score	Concept
9	#1
8	#9
7	#4
6	#2
5	#8
4	#3
3	#7
2	#6
1	#5

Weighting Factor = 1

i) Flexible Adaptability

Score	Concept
9	#6
8	#7
7	#4
6	#8
5	#1
4	#3
3	#9
2	#5
1	#2

Weighting Factor = 2

TABLE 3.2.13

Relative Commercial Application Potential for Concepts

Score	Concept
9	#1
8	#5
7	#3
6	#2
5	#7
4	#4
3	#9
2	#8
1	#6

Weighting Factor: 0.5

TABLE 3.2.14

Performance Scores

Category	Weighting Factor	Concept #1 Plastic Draw Latch	#2 MIL-C-55544/7 Modified	#3 Pin & Socket Modified	#4 Snap-Slide	#5 Battery Snap	#6 Bent Flat Conductor	#7 Minia-ture Connector	#8 Conduc-tive Velcro	#9 Indexing Spring Clamp
FEATURE SCORE	1	4	-4	-3	-1	-1	0	2	-2	0
a) Height	3	12	3	15	18	9	27	24	21	6
b) Strain Relief	1	9	6	3	8	2	1	4	7	8
c) Panel Attachment	1	9	6	3	8	2	1	4	7	5
d) Contact Pressure	3	21	24	18	9	15	6	12	3	27
e) Development Cost	1	6	9	8	2	4	3	7	1	5
f) Development Potential	1	9	6	3	5	2	1	8	4	7
g) Material Properties	2	14	12	10	8	6	4	18	2	16
h) Mounting Provision	1	9	6	4	7	1	2	3	5	8
i) Flexible Adaptability	2	10	2	8	14	4	18	16	12	6
j) Commercial Application Potential	0.5	4.5	3	3.5	2	4	0.5	2.5	1	1.5
TOTAL PERFORMANCE SCORE		107.5	73	72.5	80	48	63.5	100.5	61	89.5

Section 3.2.3 Conclusions

Based on the evaluation results, it was recommended that the Phase III effort be directed to designing, developing and testing Concept #1, the Plastic Draw Catch. This recommendation was made because the performance score of 107.5 was higher than any other concept. The features of this concept in addition to its electrical functions made it the most desirable. The two most important additional features are built-in strain relief and mechanical/structural attachment.

Although the existing height of .180 inch is suitable for rigid substrates, further reduction would be required to adapt this concept to flexible panel arrays.

Section 3.3 Phase III

Phase II preliminary design studies showed the plastic draw latch (Figure 3.2.1) to be most desirable to pursue into detail design. The concept was to mold one set of contacts integrally with the latch cover; and the other set with the latch keeper. The connection would be made by compression between the contacts when the cover was latched.

To evaluate this concept, a test was run to determine voltage drop during thermal shock (see Appendix A) by recording voltage drop across the connector as it was moved from liquid nitrogen to hot oil. The results of this test showed erratic behavior as the connector heated up which increased on succeeding cycles. This was determined to be caused by differential thermal expansion and other material property changes during the rapid heating/cooling that was used. This led to consideration (and finally adoption) of a separate beryllium copper spring contact with its known behavior under extreme changing environments.

To provide back-up strength at high temperatures, the spring contacts were made double sided. The pinching forces they apply were designed to provide a minimum of 0.15 lb. per contact (see Appendix B). None of this load is supported by the plastic parts.

Section 3.3.1 Design Principles

Section 3.3.1.1 Design Description

Inherent in the design criteria (Table 3.3.1) are the two general objectives, 1) to reduce connector height to minimum, and 2) to make the connector easily operable without special tools.

TABLE 3.3.1

Design Criteria

- Interelectrode Resistance: (>10 megohm at 1000 volts)

  Less than 100 microamp at 1000 volts
- Current Rating: 3 amp
- Profile Height: <0.150 inch maximum
- Sealing: Same as cell interconnects
- Contact Drop: 30 millivolts at 3 amps
- Cycle Life: 50
- Contact Force: >0.15 lb. per pin
- Temperature Range: $-170^{o}C$ to $+125^{o}C$
- Number of Contacts: 4

The connector parts were assembled according to Drawing CON-10 (Figure 3.3.1). The connector parts and method of assembly are illustrated in the expanded view shown in Figure 3.3.2. It consists of the following parts:

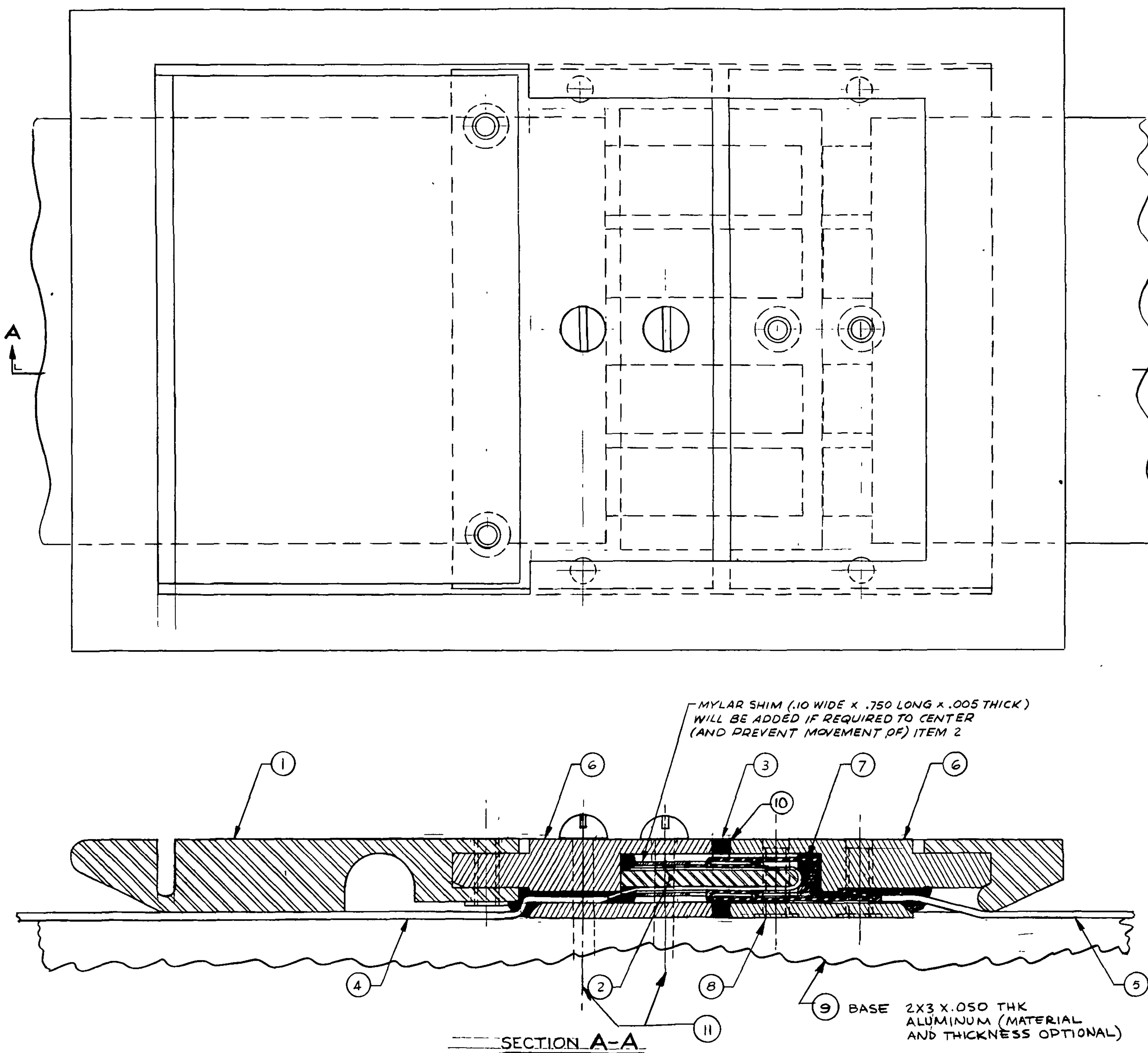
- 2 Receptacles
- 1 Pin Holder
- 2 FCC Leads
- 1 Body/Retainer
- 4 Spring Contacts

The description and function of these parts follow:

Receptacle (see Figure 3.3.3)

Two identical receptacles make up the connector body halves. They provide the case in which electrical contact is made. These parts provide locking and spacing for contacts, attachment and latching points for the body/retainer, provisions for inserting and potting the FCC leads, and sealing surfaces for compressing the seal when connector is latched.

REVISIONS				
SYM	ZONE	DESCRIPTION	DATE	APPROVED
A		WIDENED SLOT ADDED CHAMF MODIFIED ASSY INSTRUCTIONS.	28APR71	PaD.
B		ADDED ITEMS 9, 10 & 11 MODIFIED ASSY INSTRUCTIONS	30AUG71	PaD



ASSEMBLY INSTRUCTIONS

1) INSERT ITEM 5 (CON-14-2) LEAD THRU RECEPTACLE ITEM 6 (CON-15) AND SOLDER 4 ITEM 7 (CON-16) CONTACTS TO CONDUCTORS. PULL END OF LEAD, CAREFULLY GUIDING CONTACTS TO SEAT IN RECEPTACLE UNTIL SPRING ON CONTACT SNAPS INTO PLACE
2) INSERT ITEM 4 (CON-14-1) LEAD INTO ANOTHER RECEPTACLE ITEM 6 (CON-15) AND WRAP CONDUCTORS AROUND PINHOLDER ITEM 2 (CON-12). PULL END OF LEAD, CAREFULLY GUIDING PINHOLDER TO SEAT IN RECEPTACLE
3) USING SPARE PINHOLDER ITEM 2 (CON-12) STRETCH SEAL ITEM 3 (CON-13) AND POSITION OVER 1ST RECEPTACLE. BOND SEAL IN PLACE. REMOVE SPARE PINHOLDER
4) ASSEMBLE 2 RECEPTACLES FROM ABOVE WITH ONE BODY/RETAINER ITEM 1 (CON-11) AS SHOWN IN DRAWING
5) HOLDING ASSEMBLED CONNECTOR IN POSITION SHOWN IN DRAWING, DRILL .040 HOLES AND PRESS IN 4 EYELETS ITEM 8
6) WITH HOT IRON, CONTINUE PRESSING EYELETS INTO RECEPTACLES UNTIL FLUSH AS SHOWN.
7) INJECT POTTING INTO RECEPTACLES AROUND LEADS AND ADD FILLET AROUND BOTH FCC LEADS (ITEMS 4 & 5) WHERE THEY EXIT. CURE PER MANUFACTURERS INSTRUCTIONS
8) MOUNT CONNECTOR TO BASE WITH 00-90 SCREWS ITEM 11 AS SHOWN

ITEM	NO REQ'D	PART NO	DESCRIPTION	
11	2	00-90	SCREWS & NUTS	
—	—	STYCAST 2651	POTTING	EMERSON & CUMING
10	—	1506	ADHESIVE	LOCTITE
9	1	CON-10-9	BASE	
8	6	A2214	EYELET	STIMPSON
7	4	CON-16	SPRING CONTACT	
6	2	CON-15	RECEPTACLE	
5	1	CON-14-2	FCC LEAD	
4	1	CON-14-1	FCC LEAD	
3	1	CON-13	SEAL	
2	1	CON-12	PIN HOLDER	
1	1	CON-11	BODY/RETAINER	

FIGURE 3 3 1 FCC LATCHING CONNECTOR ASSEMBLY

SIZE	CODE IDENT NO	
D	04236	CON-10 REV B
SCALE 10/1		

9 April 71 VaK
27 Apr 71 VaK

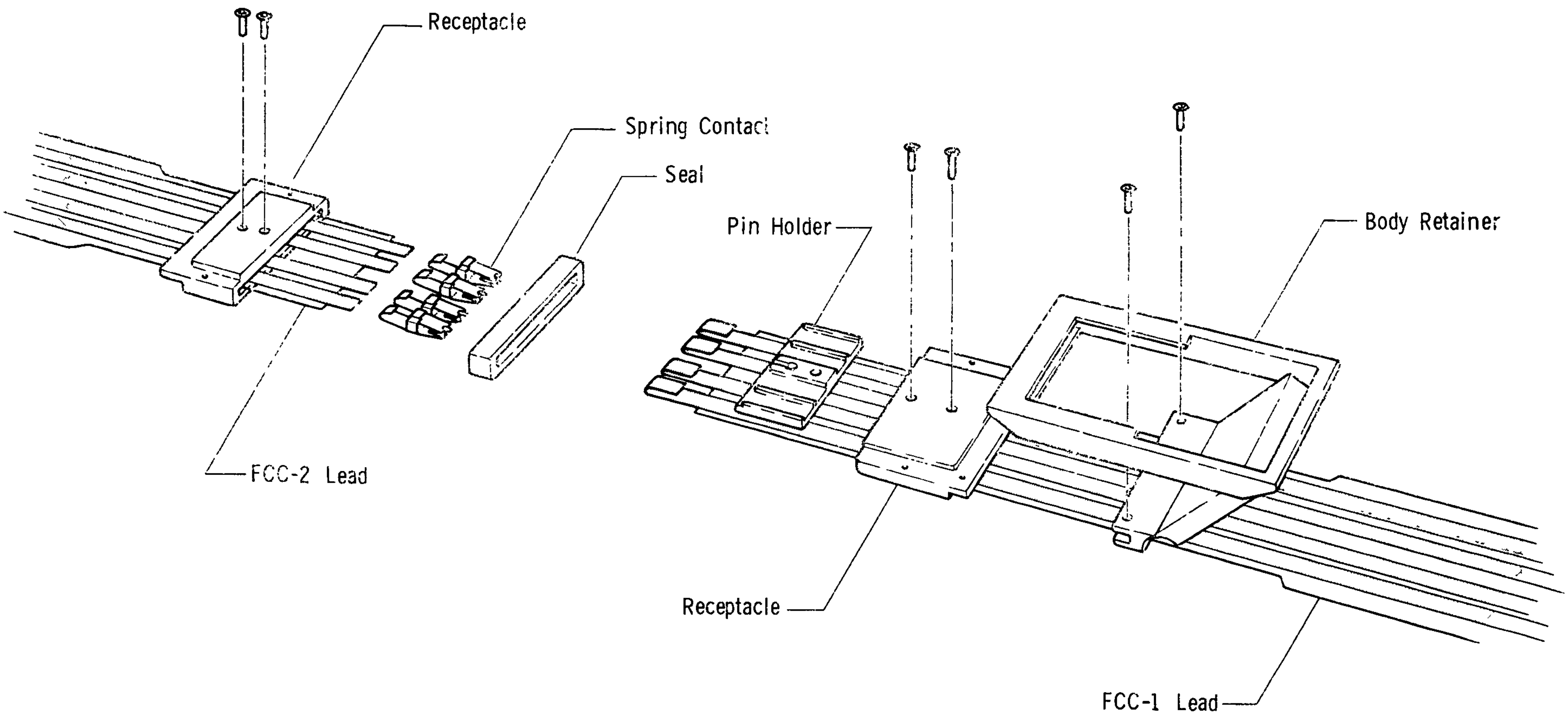


Figure 3.3.2 FCC Latching Assembly

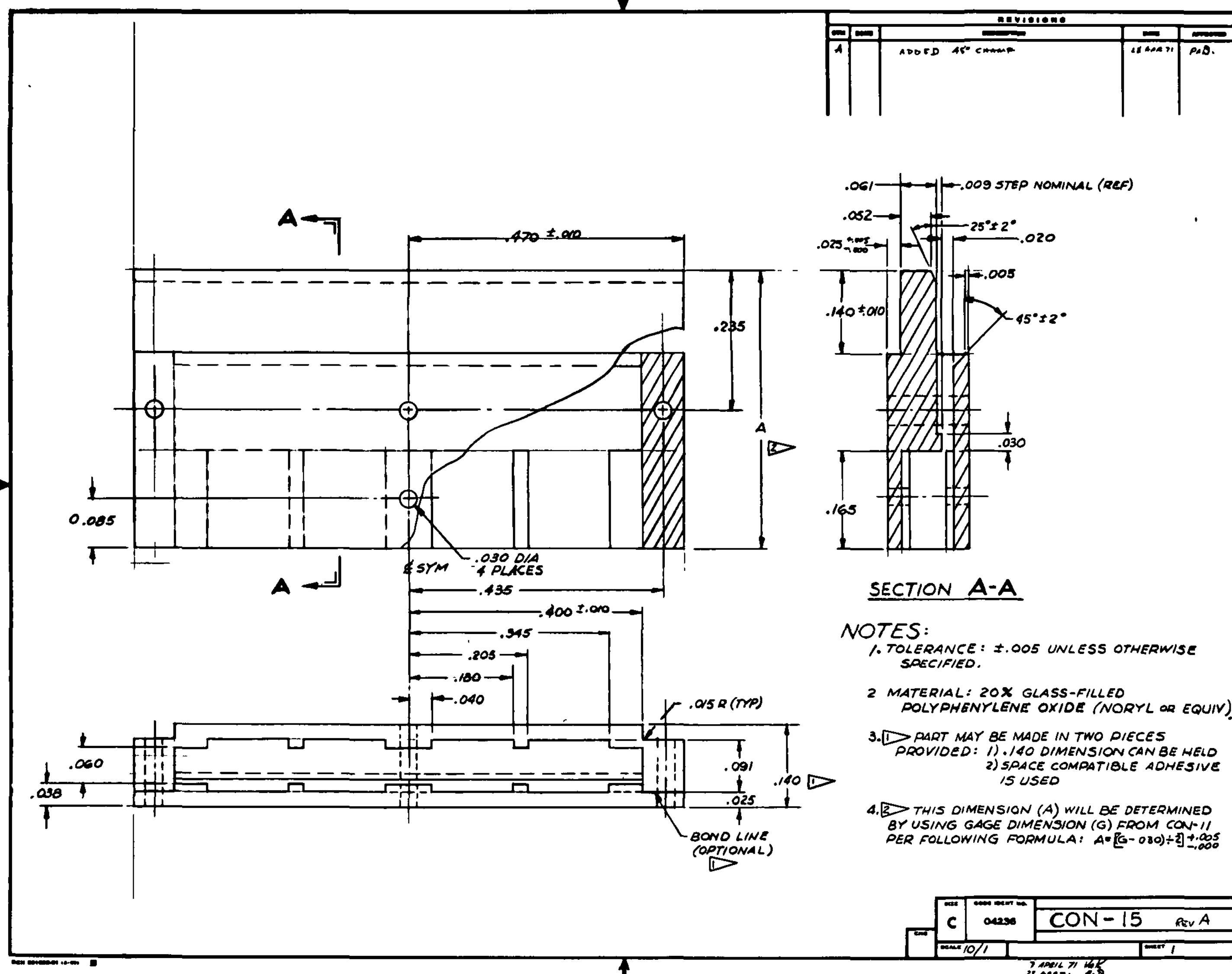


FIGURE 3.3.3 Receptacle

These parts were made by injection molding 20% short glass fiber - reinforced polyphenylene oxide. This material was chosen because of its good combination of mechanical and electrical properties throughout the temperature range as well as dimensional tolerance and stability. A photograph of the mold is shown in Figure 3.3.4.

Seal CON-13 (see Figure 3.3.5)

The seal is compression molded from RTV silicone rubber with durometer A60 and tear strength 30 lb./in. This part slips over the connection and is compressed between faces of the receptacles to provide both latching forces and sealing. Several attempts to obtain suitable parts using lower durometers and higher tear strengths were unfruitful. The present seal caused problems because air bubbles near the corners weakened the part enough to cause it to break when stretched for installation. Spare seals have been provided with the delivered connectors to replace those which may break after repeated cycling. This problem may be corrected in the future by changing to injection molding with flexible polyurethane. A photograph of the mold for producing the seal is shown in Figure 3.3.6.

The seal is stretched and bonded to the face of the female receptacle prior to connector mating. Upon repeated cycling the spring contacts tend to gouge the seal and pull it away - shearing the bond. A better means for supporting the seal should be developed.

Pin Holder (see Figure 3.3.7)

The pin holder (also injection molded in a mold shown in Figure 3.3.8 from 20% short-glass-fibre reinforced polyphenylene oxide) provides support and separation for the stripped and plated conductors in the male half of the connector. The conductors thus become the maie contacts.

FCC Lead CON-14 (see Figure 3.3.9)

The leads were fabricated by MSFC from standard FCC cable per drawing CON-17 (see Figure 3.3.10). The cable was stripped to provide for contacts, test points, and current leads. Conductors on the -1 part were plated where they wrap around the pin holder for better contact and less corrosion. Conductors on the -2 part were also plated but the gold was removed prior to soldering the spring contacts. Insulation on both sides of the cable was trimmed to permit insertion into receptacles.

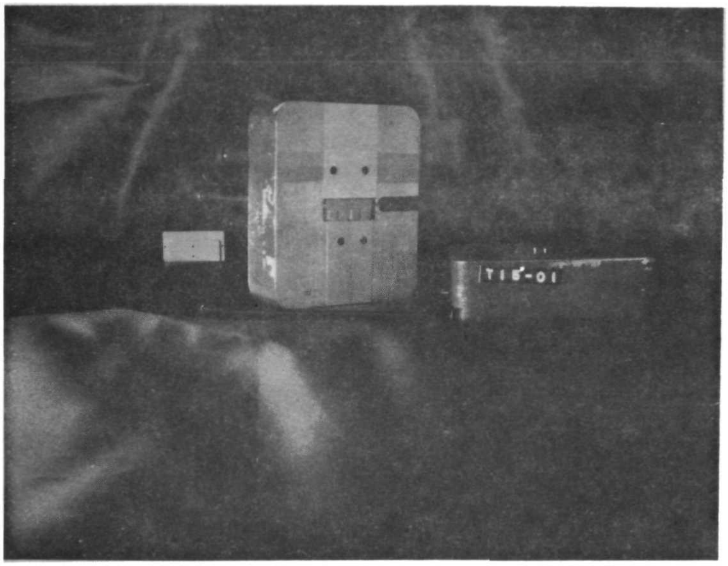
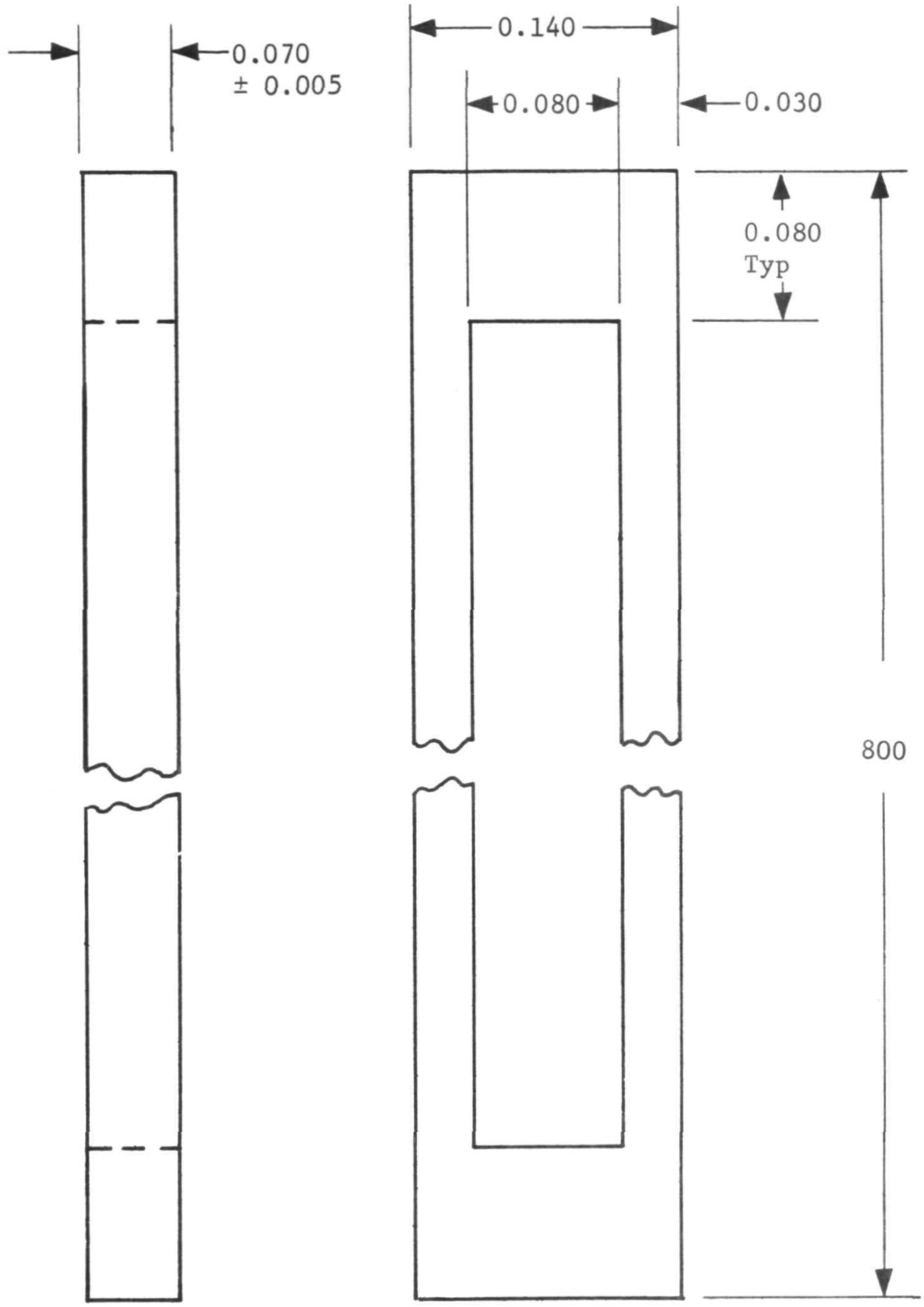


FIGURE 3.3.4

Receptacle Mold and Resultant Part



Note:

1. Tolerance - ±0.010 unless otherwise specified.
2. Material - Silicone rubber durometer A60, tear strength 30 lb/in.

FIGURE 3.3.5 Seal

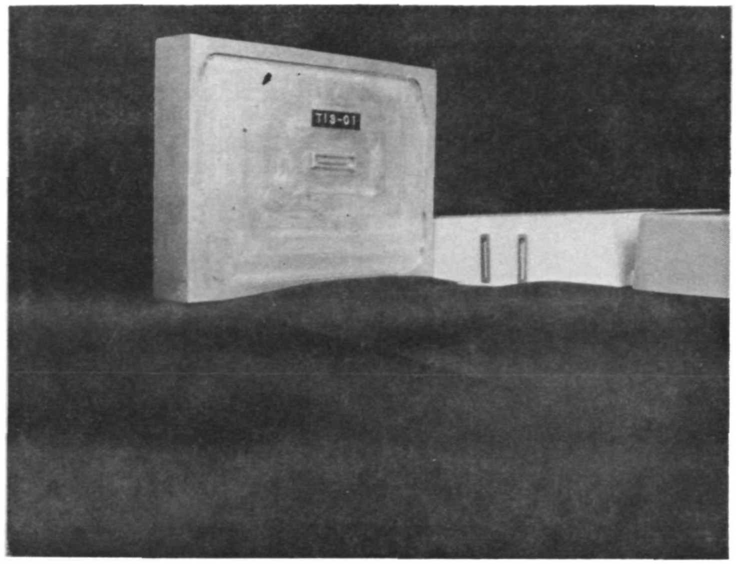


FIGURE 3.3.6

Compression Mold for Seal CON-13
and Two Resultant Parts

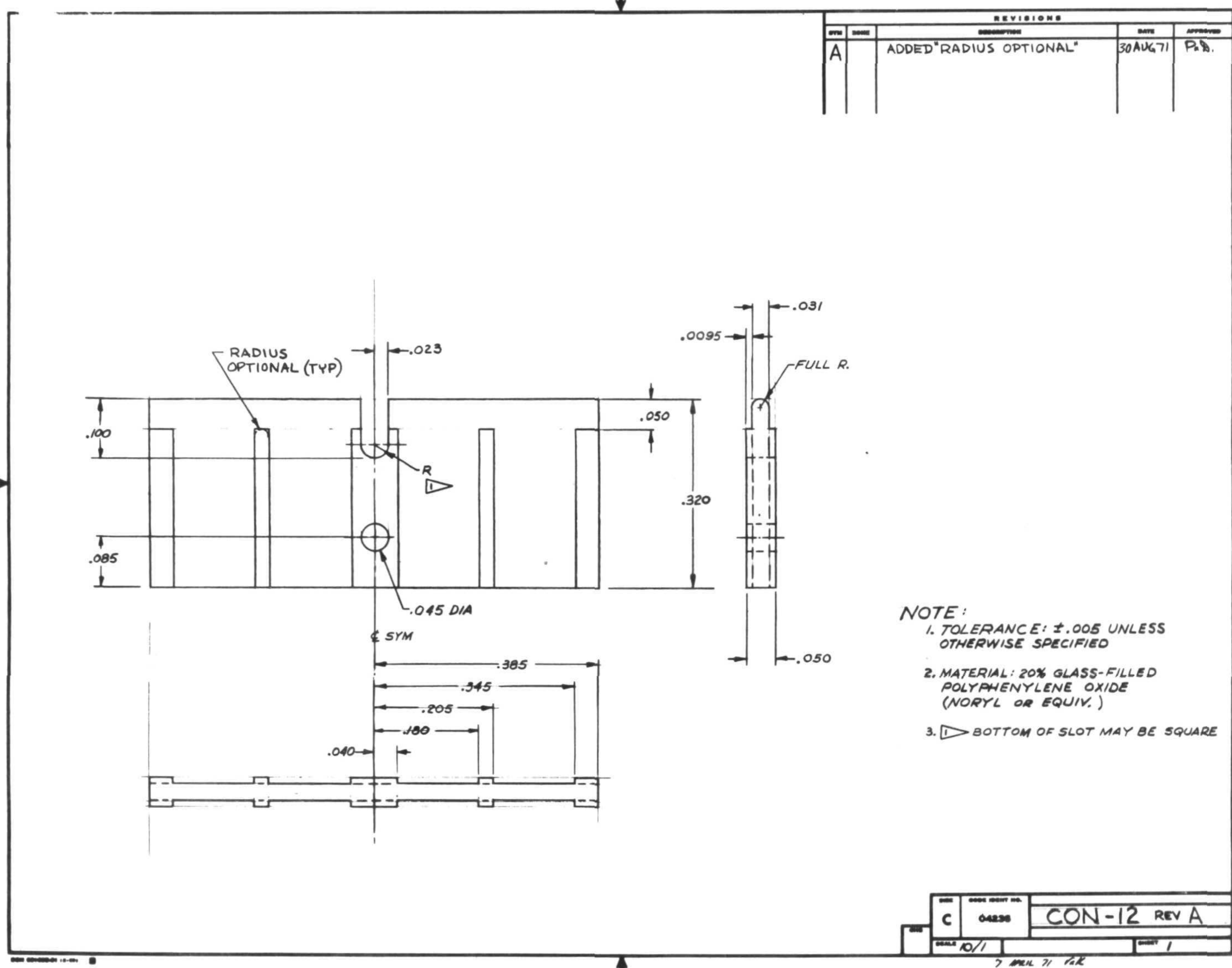


FIGURE 3.3.7 Pinholder

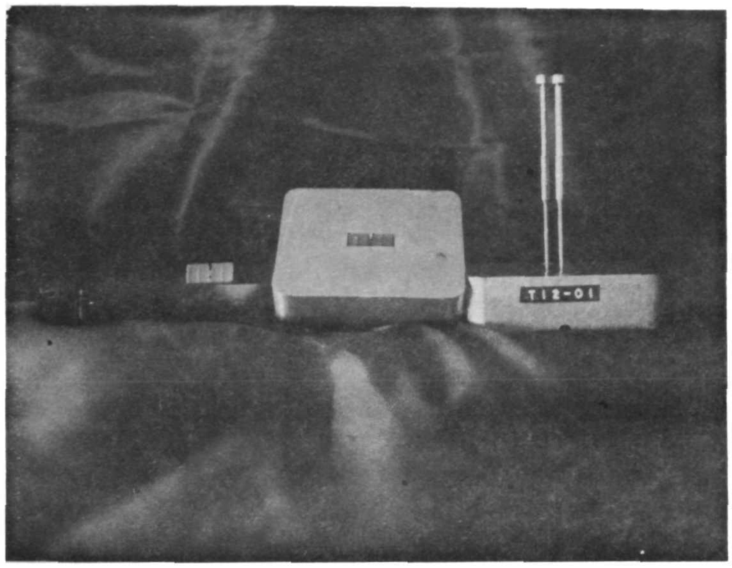


FIGURE 3.3.8

Pin Holder Mold and Resultant Part

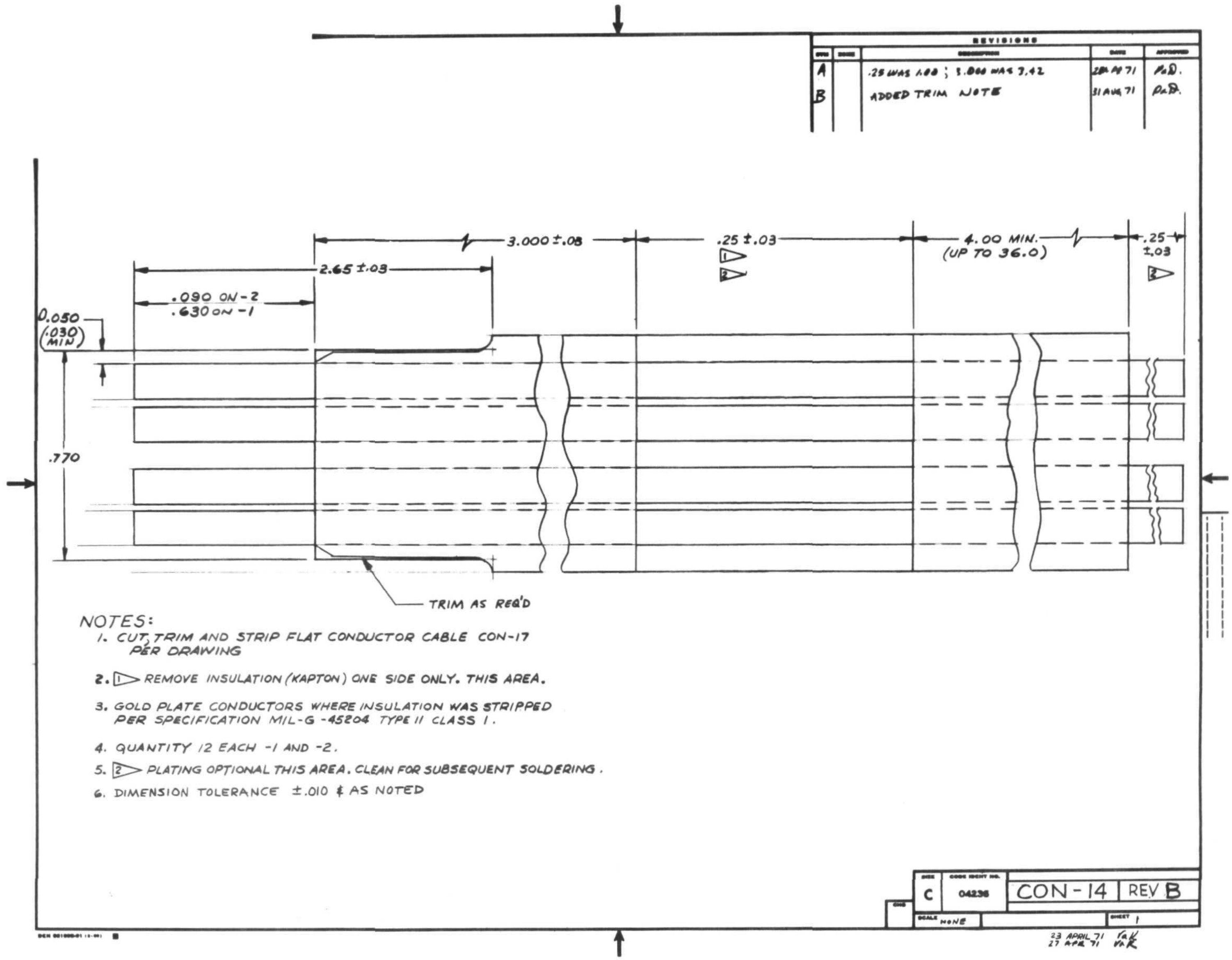
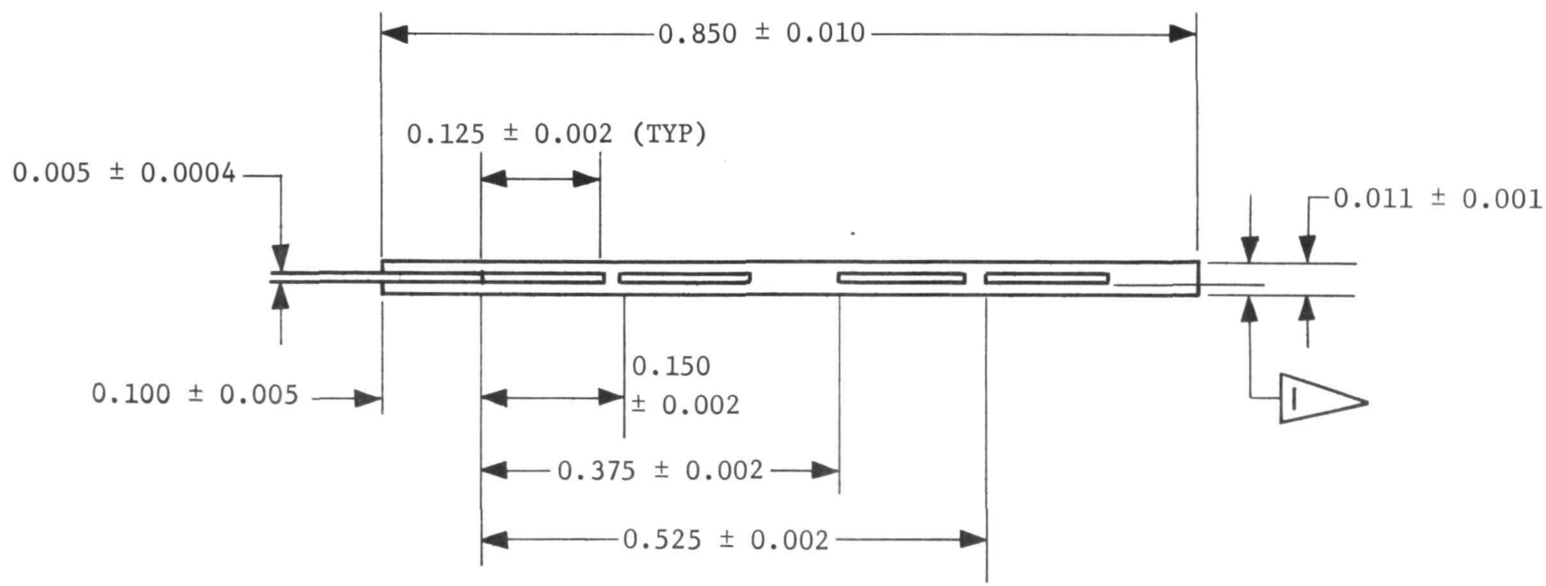


FIGURE 3.3.9 FCC Lead



Note:

1. Conductors - Strip-copper 0.005 x 0.125 nickel plated per specification MIL-C-55543; four conductors.
2. Insulation - Polyimide (kapton), 0.002 thick, bonded with fluorinated ethylene propylene (FEP).
3. Voltage rating - 300 V (rms); temperature rating - 200°C (392°F).
4. Insulation on each side of the conductor shall be uniform within 0.001.
5. All dimensions in inches.

FIGURE 3.3.10 Flat Conductor Cable

Spring Contacts (Figure 3.3.11)

The female part of the connector contains four spring contacts. These spring contacts are soldered directly to the FCC conductors and they are housed within the receptacle.

The spring contacts are formed from Beryllium Copper (BeCu) alloy 25, chosen because of its good conductivity and spring properties. The configuration was designed to provide positive contact forces under all operating conditions.

Several functions have been incorporated into the spring contact. The tab to which the lead conductor is soldered is also a spring which snaps into a retaining slot inside the receptacle which prevents the spring contact from pulling out when the connection is opened.

Electrical contact is made through two opposing pairs of spring loaded "skis" which ride over both sides of the mating contact - cutting into it during insertion. The compound leverage design of these "skis" causes them to exert nearly uniform force over their lines of contact.

Detailed analysis of contact loads and material stresses is in Appendix B. The minimum contact force of 0.2835 pounds is well above the design goal minimum of 0.15 pounds.

Initially it was thought that the tab which wraps over the top contact would have to be attached to that contact. Several methods including bonding, soldering and welding were tried. Bonding and soldering both caused a material build-up which would not permit the contacts to be slipped into the close-fitting receptacle. Spot-welding was used to attach the tabs although control of the process was very difficult and many parts were ruined.

Re-evaluation of the function of the spring contact and the restraint provided by the receptacle cavity showed that no fastening of the tab was required. This fact coupled with the difficulty of making good parts by spot-welding caused the decision to make one delivered connector (Serial #08) with tabs not fastened.

The blank from which the spring contact is formed is punched from .006 inch thick annealed BeCu strip (see composition and properties Table 3.3.2) on blanking die F16-01 (see Figure 3.3.12). It is progressively formed into the final part as follows:

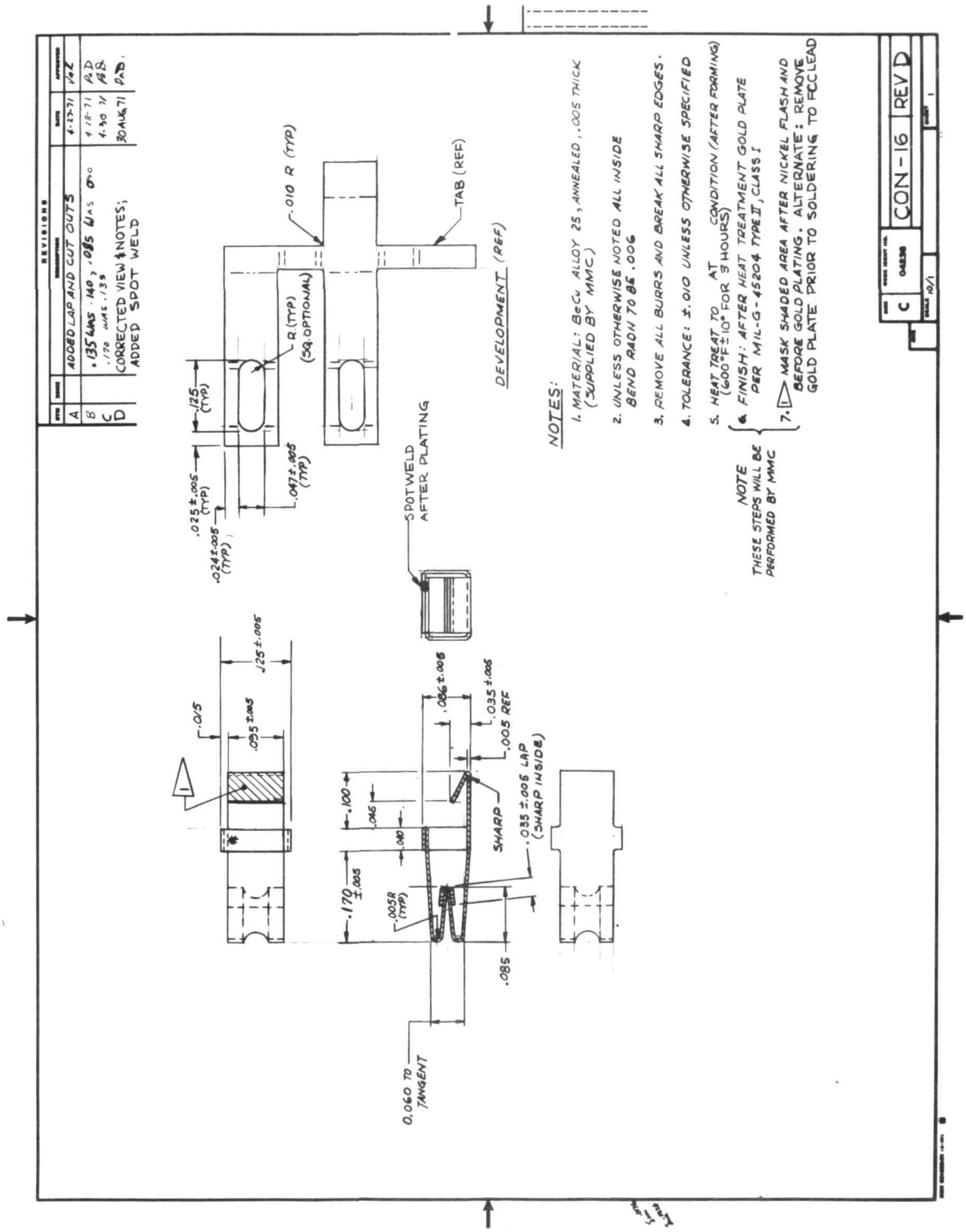


FIGURE 3.3.11 Spring Contact

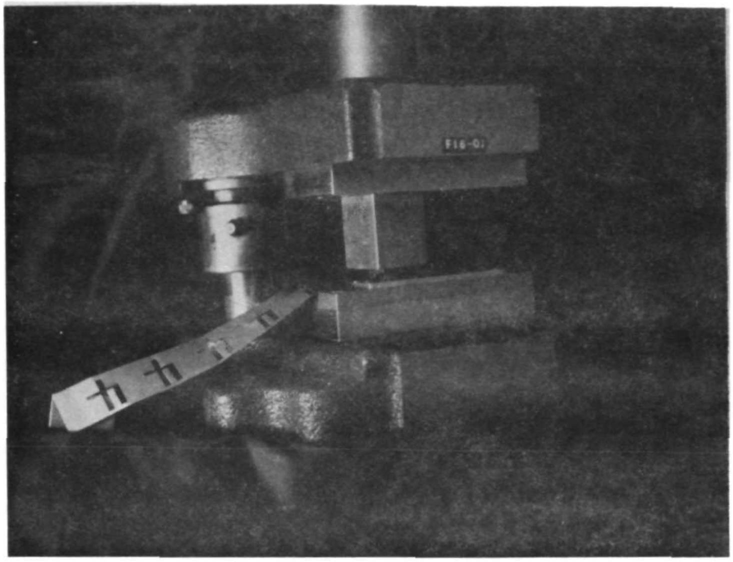


FIGURE 3.3.12

Contact Blanking Die Set

MATERIAL: Beryllium Copper Strip Alloy 25
Annealed Condition

SIZE: .006 Inch Thick

SPECIFICATION: QQC-533

Chemical Analysis (%)

C	MN	P	SN	SI	CR	NI	CU
			.02 .01	.09 .07	-.005 -.005	.02 .025	Bal. Bal.
MO	**FE**	**ZN**	**BE**	**CO**	**TI**	**AL**	**PB**
	.12 .12	-.02 -.02	1.82 1.86	.24 .25		.04 .05	.005 -.005

Physical Properties

Ultimate Tensile (f_{tu})

Original: 74,500 PSI
72,500

After Ht. Tr. for 3 Hrs. @ 600F.:

177,000 PSI to 183,000 PSI

TABLE 3.3.2

Composition and Properties of BeCu

a) The bend of the spacer for the "skis" is started on the tool F16-02 (see Figure 3.3.13) and pushed further over on tool F16-03 (see Figure 3.3.14) before it is finally doubled over and crimped by clamps.

b) The other end of the "skis" is formed on tools F16-04 (see Figure 3.3.15) and F16-03. Final adjustment is made by hand-held pliers.

c) To form the wrap the part is positioned over tool F16-06 (see Figure 3.3.16) and formed around tool F16-05 also shown in Figure 3.3.16. Spring angles are adjusted by hand after removing the part from the fixture.

d) The solder tab is formed by hand as a final operation before heat treat.

e) Parts are cleaned in a mild acid bath and plated - first with a nickel flash coat and then with 50 microinches of gold per MIL-G-45204 Type II, Class I.

Prior to soldering to conductors, the tabs are cleaned by tinning them with high heat solder and "wicking" both gold and solder away with braided wire.

Held in alignment by a metal strip, the contact spring tabs are soldered to the lead conductors, and (by pulling on the FCC lead) pulled into the receptacle until they snap into place. Several considerations indicate the need for further refinement of the spring contacts during future efforts on this connector design. Some of these are:

a) Presently the solder joint is directly in the load path during any pulling of the leads.

b) The solder joint is in the current path as well and offers a potential high resistance should it become unsoldered.

Body/Retainer (see Figure 3.3.17)

Perhaps the most unconventional feature of this connector design is the body/retainer which provides the sealing force as well as strain relief and latching through the overcentering hinge geometry.

The self-hinging property of polypropylene, from which the part is molded, enables the part to be made in one piece. The mold F11-01

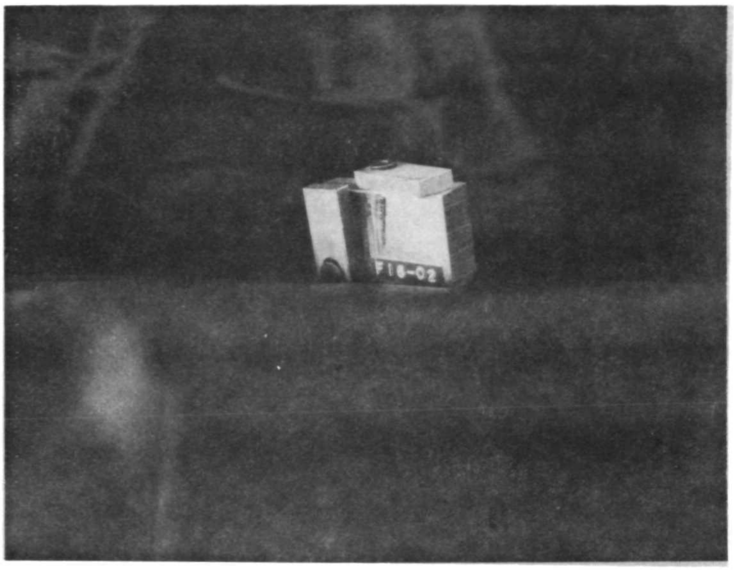


FIGURE 3.3.13

Doubler Forming Tool

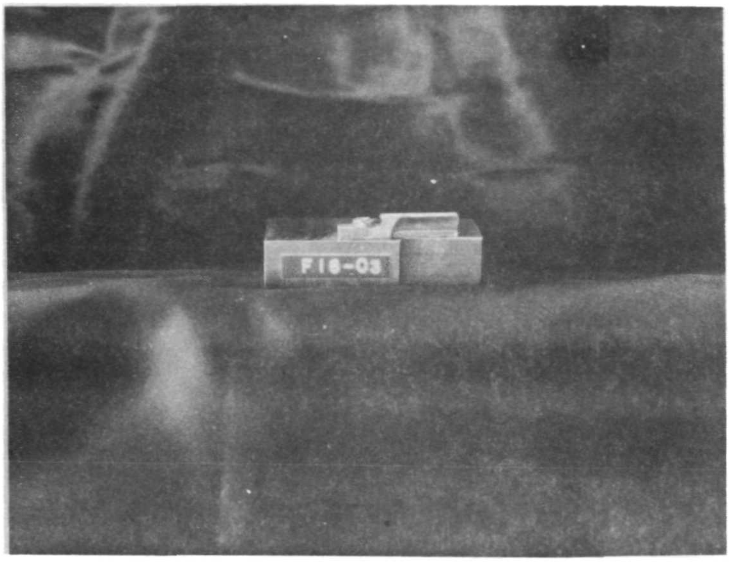


FIGURE 3.3.14

"Ski" Forming Tool

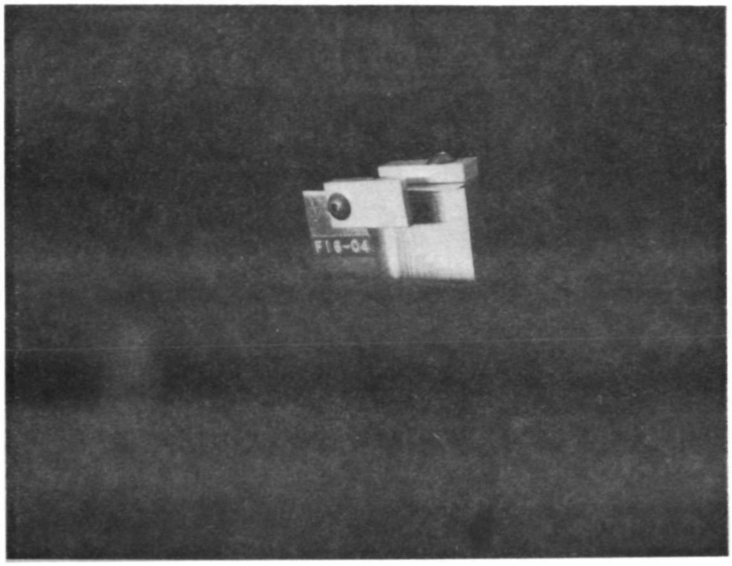


FIGURE 3.3.15

"Ski" Bending Tool

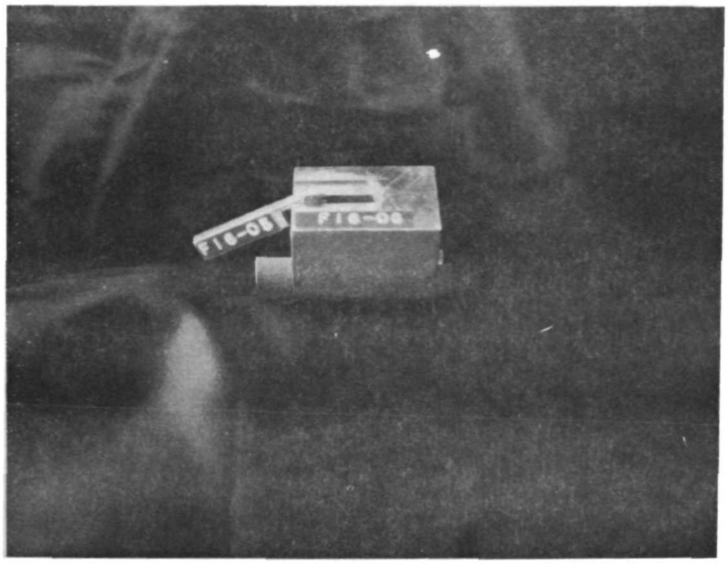


FIGURE 3.3.16

Tab Wrap Forming Tool

(see Figure 3.3.18) incorporates hand-operated inserts which permit forming the complex detail features of the part.

Flexural hinges are molded near opposite faces of the part. Part dimensions are such that latching forces exerted through the hinges form a couple which tends to keep the part latched.

A minor problem developed when the hinge on some of the parts bent in the thin area between the side of the 0.030 hinge slot and the beveled end section instead of between the bottom of the hinge slot and the flat bottom of the retainer assembly. See Figure 3.3.17. Although the spring action was adequate to retain the connector in a mated condition, the retaining force was less than if the hinge were at the bottom. This problem can be prevented on a future design by increasing the material thickness to ensure hinging at the design location.

On these prototype connectors there exists the potential for accidental release of the latch if the body/retainer were snagged and overcentered. Although this would reduce pressure around the seal, disconnection would not occur unless the leads were pulled or the connector were exposed to severe vibration. To reduce this potential, shear tabs could be incorporated into the body/retainer which would engage notches in the receptacles and snap into place when closed. A side benefit from this change would be improved strain relief for the connection.

Also incorporated into the body/retainer are the clevis which mounts permanently with rivets to one receptacle and the lip which engages the other receptacle during latching.

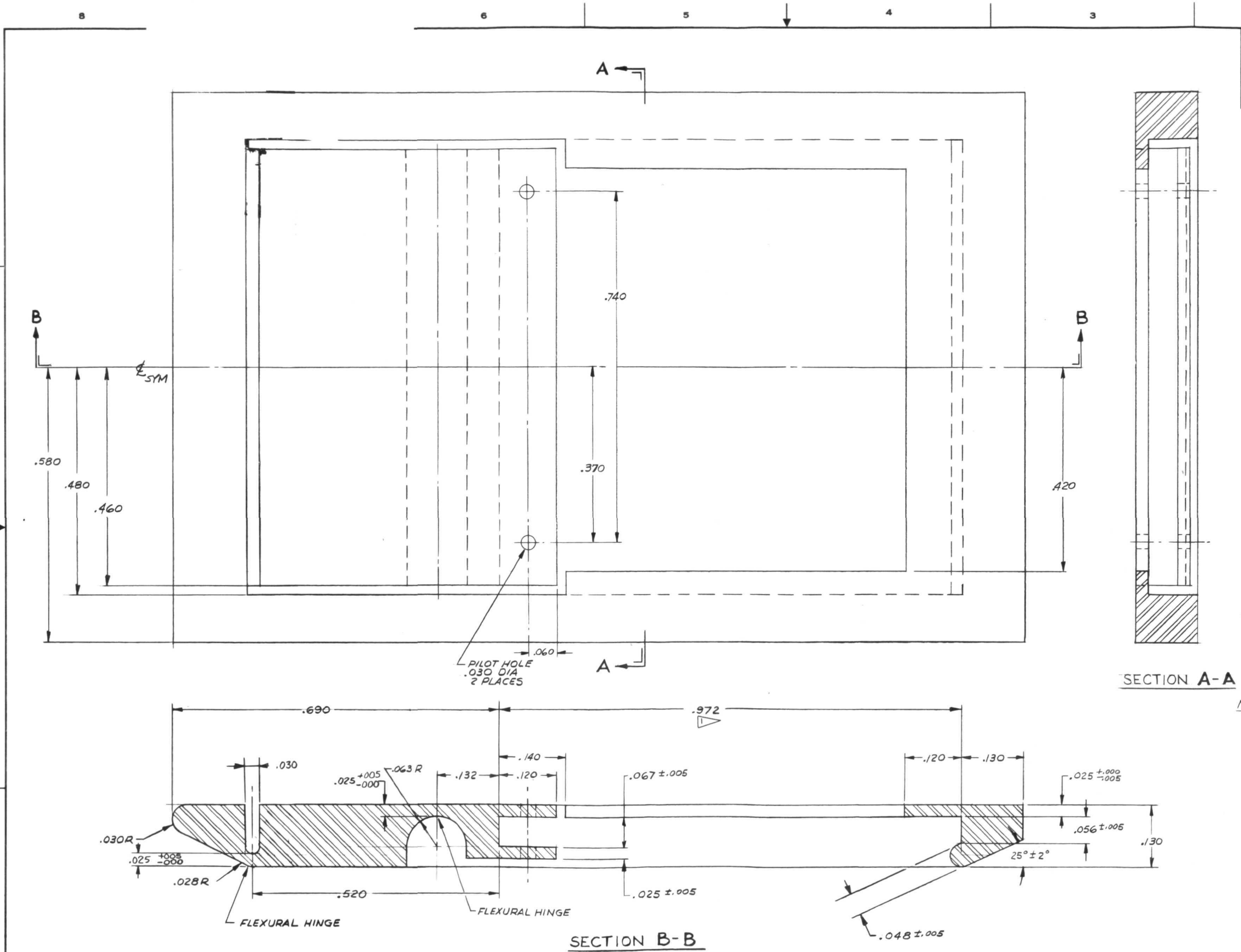
A question on behavior of the polypropylene during temperature cycling above 110°C existed until the tests were run. It appears that polypropylene, although weakened above 110°C, regains its properties when the temperature again returns to normal.

Connector Operation

When installed the male half of the connector, with the latching body/retainer attached, is mounted to the solar panel substrate (shown as an aluminum plate in Figures 3.3.19 through 3.3.22). The mating half is attached to the end of the FCC power harness lead. The connection is made by aligning the conductors and inserting them. Sealing and latching are accomplished simultaneously by

REVISIONS

SYM	ZONE	DESCRIPTION	DATE	APPROVED
A		.030 SLOT WAS .003	28APR71	P.D.
B		.025 +.005 -.000 WAS .025 ±.000 .010	30APR71	P.D.



NOTES:

1. TOLERANCE: ±.010 UNLESS OTHERWISE SPECIFIED.
2. FLEX PART UPON REMOVAL FROM MOLD AND HOLD IN POSITION SHOWN WHILE COOLING/CURING.
3. MATERIAL: GENERAL PURPOSE POLYPROPYLENE, BLACK COLOR.
4. [1] HOLD TOLERANCE ON THIS DIMENSION AS CLOSE AS PRACTICABLE. MEASURE ALL PARTS. MEAN OF MEASURED DIMENSIONS WILL BE GAGE DIMENSION (G) FOR PART No. CON-15 DIMENSION REPEATABILITY SHOULD BE G ±.005

FIGURE 3.3.17 BODY/RETAINER

SIZE	CODE IDENT NO.		
D	04236	CON-11	REV B
SCALE 10/1		SHEET 1	

9 April 71 P.R.
28 APR 71 P.D.

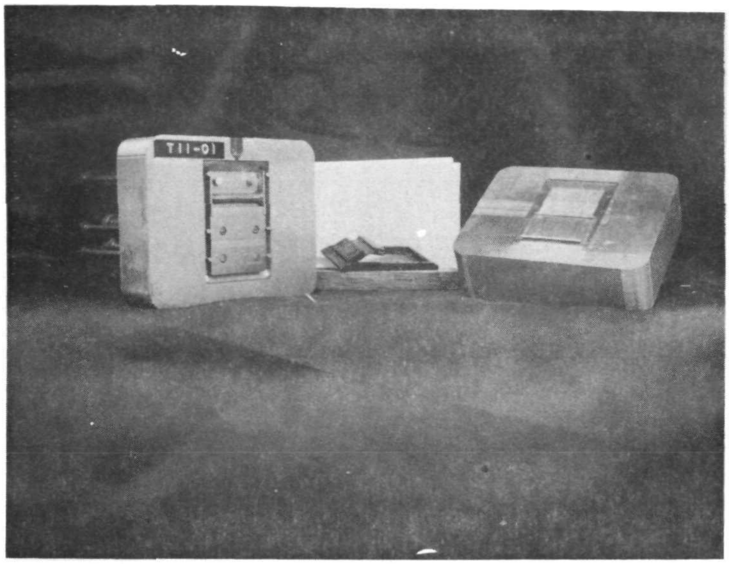


FIGURE 3.3.18

Body/Retainer Mold and Resultant Part

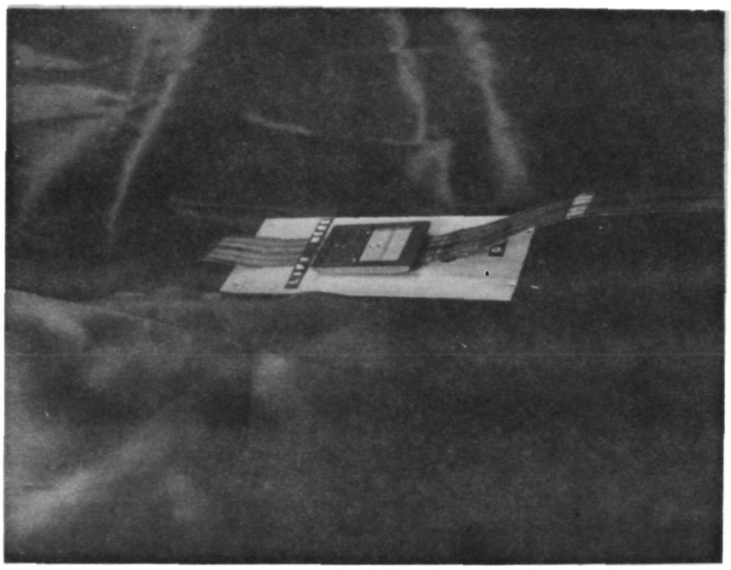


FIGURE 3.3.19

Connector Fully Latched

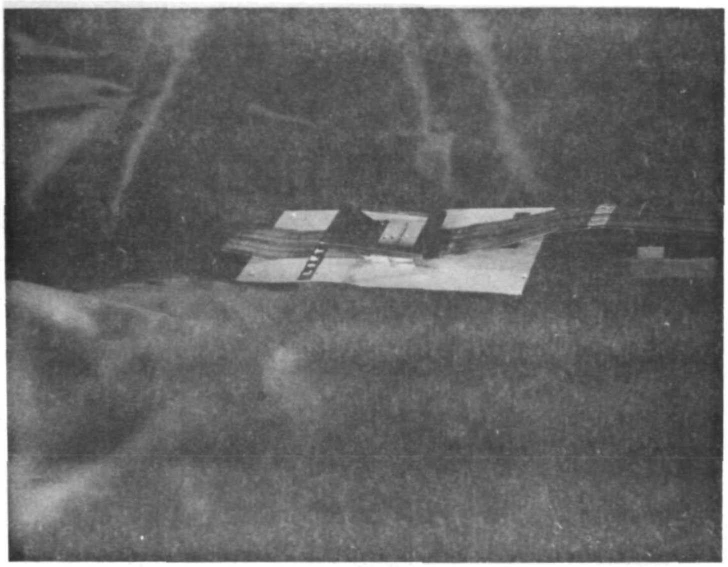


FIGURE 3.3.20

Unlatched with Connection Still Made

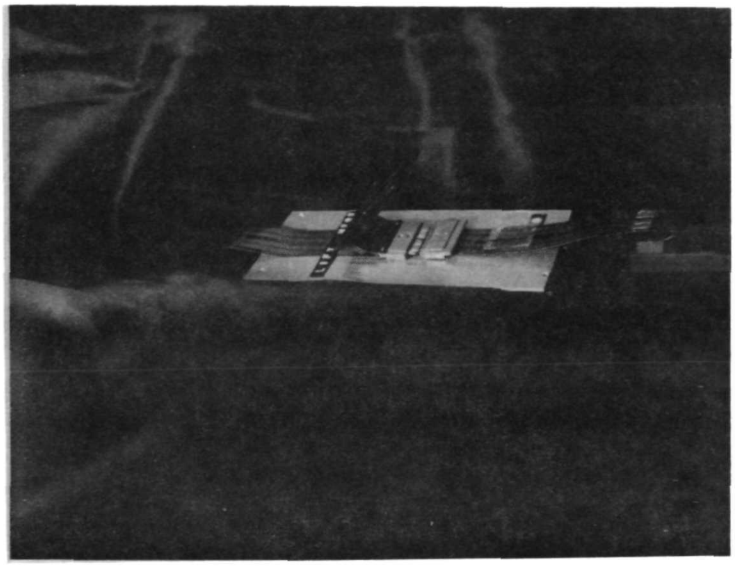


FIGURE 3.3.21

Conductors Aligned

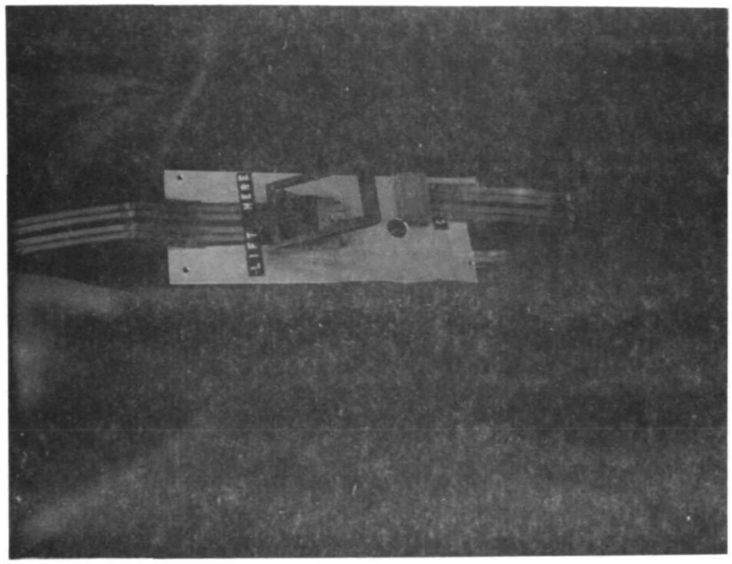


FIGURE 3.3.22

Connector Separated

placing the bail of the body/retainer over the ledge of the female receptacle and pressing toward the substrate. The two receptacles and seal have been sized to provide a tight fit which both compresses the seal and provides retention forces which cause the over-centered hinges to remain in the latched position.

Upon assembly of the prototype, Martin Marietta recognized the potential of operator error causing inadvertent crossing of conductors during connection if the female half approaches askew. A more remote but possible error could occur if the operator brought the female half in upside down. Although the connector will not latch in this position, the conductors may be made to contact.

To correct these situations, Martin Marietta recommends that pins be installed which will both align conductors before contact and prevent assembly when one half is upside down.

When the connector is disassembled, the operator may note that the seal retracts at the mating surface. This, upon repeated mating and separation, may cause separation of the seal along the bonded face. If the above suggested pins were used, they could also support the seal. This would eliminate the present requirement of bonding the seal to the receptacle face.

Section 3.3.2 Design Evaluation

A test program was established to determine the major performance parameters of the developed connector. A test plan to implement this program was prepared and submitted to NASA as document MCR-71-70. Comments and additions requested by NASA were incorporated and the revised plan was approved.

Section 3.3.2.1 Summary of Test Results

The objective of the testing was to verify that the design objectives of the flat conductor cable connector had been implemented in the assembled product, and that the connector assembly would meet the basic performance characteristics when used in an environment typical of space operations. Eight connector assemblies were fabricated and all eight were acceptable in terms of visual inspection. These eight connectors were then put into an electrical circuit and the contact voltage drop was measured. All were found to exhibit a contact voltage drop of less than 30 millivolts when corrected for normal test item length. These tests were defined as the Acceptance Test (within the General Test Plan, MCR-71-70, Rev A) for the fabricated articles to be performed at Martin Marietta. The Acceptance Test was then followed by subsequent Evaluation Tests of three of the connectors. Each of the three were subjected to measurement of the inter-electrode resistance. This measurement was made with approximately a foot of test lead on either side of the connector. Inter-electrode resistances were found to be of the order of 50,000 times the defined maximum of 10 megohms. One of the three connectors was then subjected to 240 hours of thermal cycling at high humidity and again tested for inter-electrode resistance. Moisture was found to have leaked inside and the high voltage apparently created an arc track and consequent short.

The remaining two connectors were temperature cycled from +125°C to -170°C for 15 cycles and contact resistance determined at the high and low temperatures of each cycle. At no time was the contact resistance found to exceed 5 milliohms.

The same two connectors were then vibrated on a shake table through a frequency range of 10 to 2000 Hertz at 15 g maximum. A detector adjusted to detect an open circuit of one microsecond or longer duration gave no indication of failure during vibration on each of the mutually perpendicular axes. Finally, each of the connectors was subjected to a pull test on the flat conductor cables. This test was run to determine whether this design could be used in other than solar array applications. A criteria for this test had arbitrarily been selected as identical to that used for the strength of a flat conductor cable which required support of 25 lbs. per inch of conductor width or 16.25 lbs. It was found that the connectors became unmated at a load of about 9.5 lbs.

Section 3.3.2.2 Description of Tests

Section 3.3.2.2.1 Acceptance Tests

Visual Inspection

The objective of performing visual inspection was to verify that the fabricated connectors met the design requirements in terms of the following parameters:

1) Configuration

2) Critical Dimensions

3) Finish

4) Adequate potting

5) Clean contact surfaces

The procedure used in performing the visual inspection was one of comparison of each of the parameters with the requirements called out on the production drawings. This comparison was made by an experienced quality control engineer. The only discrepancies noted were that some of the seals were not completely adhering to the connector bodies. This problem has been previously discussed.

Contact Resistance

The purpose of this test was to verify that the connector was, in fact, providing a stable electrical connection between each of the two flat conductors which were connected by the mated connector.

Contact resistance was measured for each connector by the voltmeter-ammeter method of MIL-STD-202, Method 307. A current of 3 ampere was conducted through each conductor mating pair in series. Voltage measurements were made by means of a digital voltmeter connected to the FCC at 6.45 ±0.05 inch spacing including the connector, as defined in MIL-C-55544. Figure 3.3.23 herein shows a schematic of the test setup, and Figure 3.3.24 is a photograph of the test. The measurement was made at ambient conditions in the laboratory (20 ±5°C). The criteria for acceptance was a voltage drop across each mating pair of less than 30 millivolts for a current of 3 ±1% amperes.

Upon performing the resistance test, it was found that the data were close to the acceptance criteria value. A measurement was, therefore, made of the voltage drop in a length of flat conductor cable without any connectors. The separation between voltage measurement points on this specimen was 5.7 inches (specification 6.0 ±0.5 inches).

Voltage drop readings were:

Pin 1	21.44
2	18.46
3	21.21
4	21.58

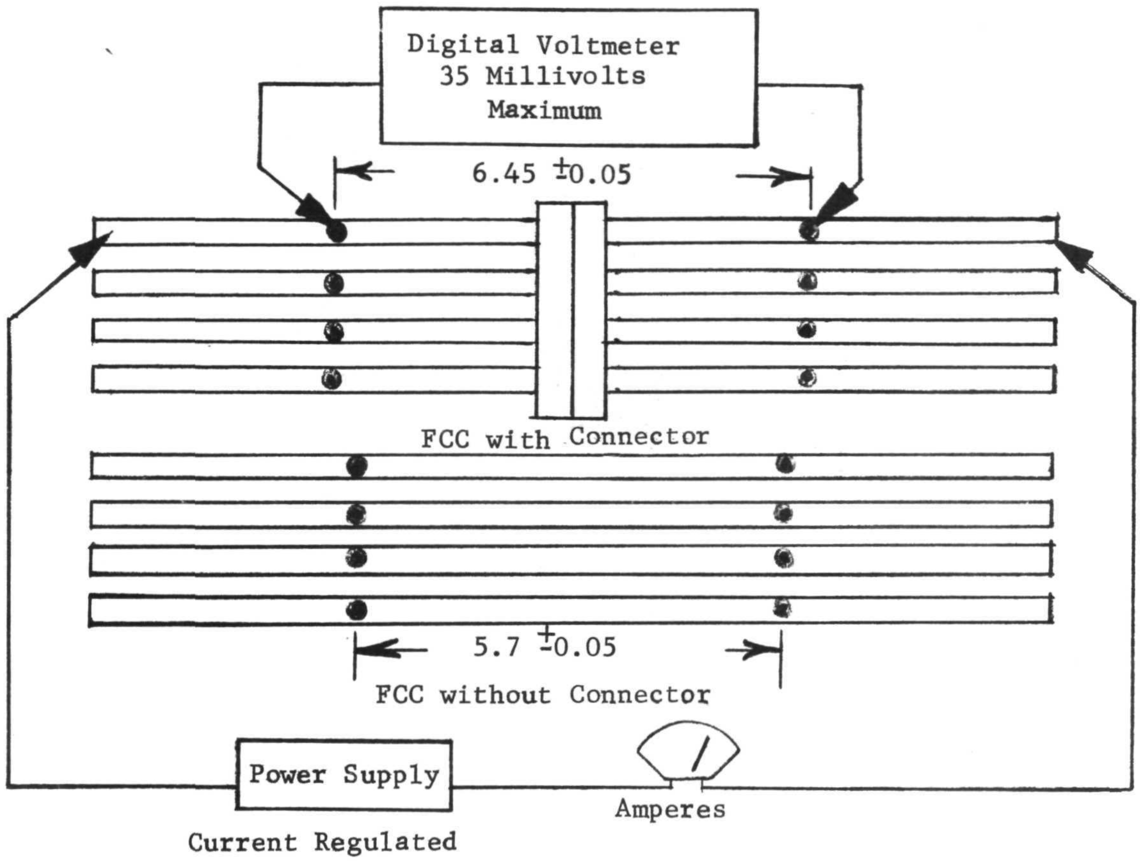


FIGURE 3.3.23

Schematic of Acceptance Contact Resistance Test

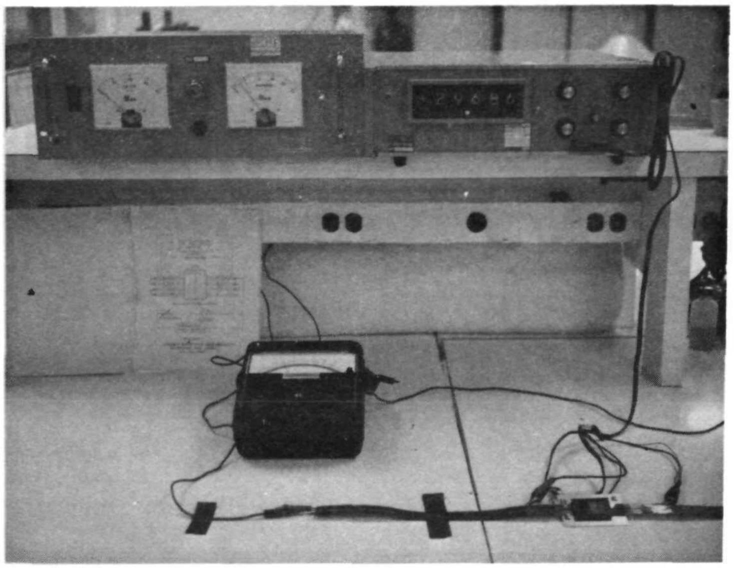


FIGURE 3.3.24

Acceptance Resistance Test Setup

The average of these is 20.67 millivolts. This is equivalent to 3.62 millivolts per inch. Since the test specimens were all 6.5 inches long (the maximum permitted by the test specification), it appears reasonable to assume that if the test had been performed at 5.5 inches (the minimum permitted by the test specification), the voltage drop would have been 3.62 millivolts lower. It is assumed that the 30 millivolts drop specified for acceptance was based upon a 6.0 inch test length. If all of the test data taken are reduced by 1.81 millivolts, the equivalent of one half inch of flat conductor cable, all data points are within the 30 millivolt criteria. Both the actual data recorded and the voltage drop computed for a 6 inch length are shown in Table 3.3.3.

3.3.2.2.2 Evaluation tests

To determine the performance of the connectors in some environments, typical of space applications, tests were performed on three of the connectors as follows:

Inter-electrode resistance at ambient temperature and humidity	Parts 01, 02, and 03
Inter-electrode resistance after 240 hours humidity cycling	Part 03
Contact resistance during thermal cycling	Parts 01 and 02
Contact resistance during vibration	Parts 01 and 02
Cable attachment pull test	Parts 01 and 02

Inter-electrode Resistance

The purpose of this test was to determine that there was no connection or appreciable leakage between adjacent conductors in the connector.

The resistance between adjacent conductors was measured at ambient laboratory conditions (temperature 20 $\pm 5^{o}C$) local atmospheric presure, humidity 20% - 50% in accordance with Method 302, Test Condition C of MIL-STD-202A. Three tests of two minutes each, one

TABLE 3.3.3

Voltage Drop Data During Acceptance
Contact Resistance Test

Part No.	Pin No.	Measured MV Drop 6.5" Length	Computed MV Drop 6" Length	Part No.	Pin No.	Measured MV Drop 6.5" Length	Computed MV Drop 6" Length
01	1	29.8	27.99	05	1	30.17	28.36
	2	28.5	26.69		2	28.91	27.10
	3	27.5	25.69		3	29.19	27.38
	4	29.8	27.99		4	31.14	29.33
02	1	29.9	28.09	06	1	30.44	28.63
	2	28.1	26.29		2	28.03	26.22
	3	30.2	28.39		3	28.36	26.55
	4	29.2	27.39		4	29.63	27.82
03	1	30.7	28.89	07	1	30.42	28.61
	2	29.8	27.99		2	28.01	26.20
	3	28.5	26.69		3	29.91	28.10
	4	30.4	28.59		4	30.76	28.95
04	1	30.01	28.20	08	1	29.83	28.02
	2	29.0	27.19		2	29.11	27.30
	3	28.14	26.33		3	29.21	27.40
	4	28.69	26.88		4	31.23	29.42

test between each pair of adjacent pins of a mated connector, were performed. A current of less than 100 micro-amperes was the criteria for acceptance when a voltage of 1000 volts $\pm$10% was impressed between the conductors. Figure 3.3.25 shows the test setup. It was found that the required equipment was incorporated in a Freed Transformer Corporation Model 1620 megohm meter, EQ 503126 in calibration until 22 November 1971. This meter was, therefore, used to perform the test. It reads directly in megohms. The criteria for acceptance then became

$$R = \frac{E}{I} = \frac{1000 \text{ volts}}{100\ 10^{-6} \text{ amperes}} = 10^7 \text{ ohms or } 0.01 \text{ gigohm}$$

Data recorded are shown in Table 3.3.4.

TABLE 3.3.4

Inter-electrode Resistance Data

Part No.	Pin No.'s	Resistance
01	1-2	800 gigohm
	2-3	600 gigohm
	3-4	600 gigohm
02	1-2	600 gigohm
	2-3	800 gigohm
	3-4	600 gigohm
03	1-2	70 gigohm
	2-3	200 gigohm
	3-4	500 gigohm

At ambient conditions, all three test items far exceeded the specified 0.01 gigohm inter-electrode resistance. It should be noted that the recorded data also included the leakage on the FCC leads which amounts to two feet of flat conductor cable.

Inter-electrode Resistance After Humidity Cycling

The purpose of this test was to demonstrate the capability of the connector to withstand moisture under conditions of high humidity and heat.

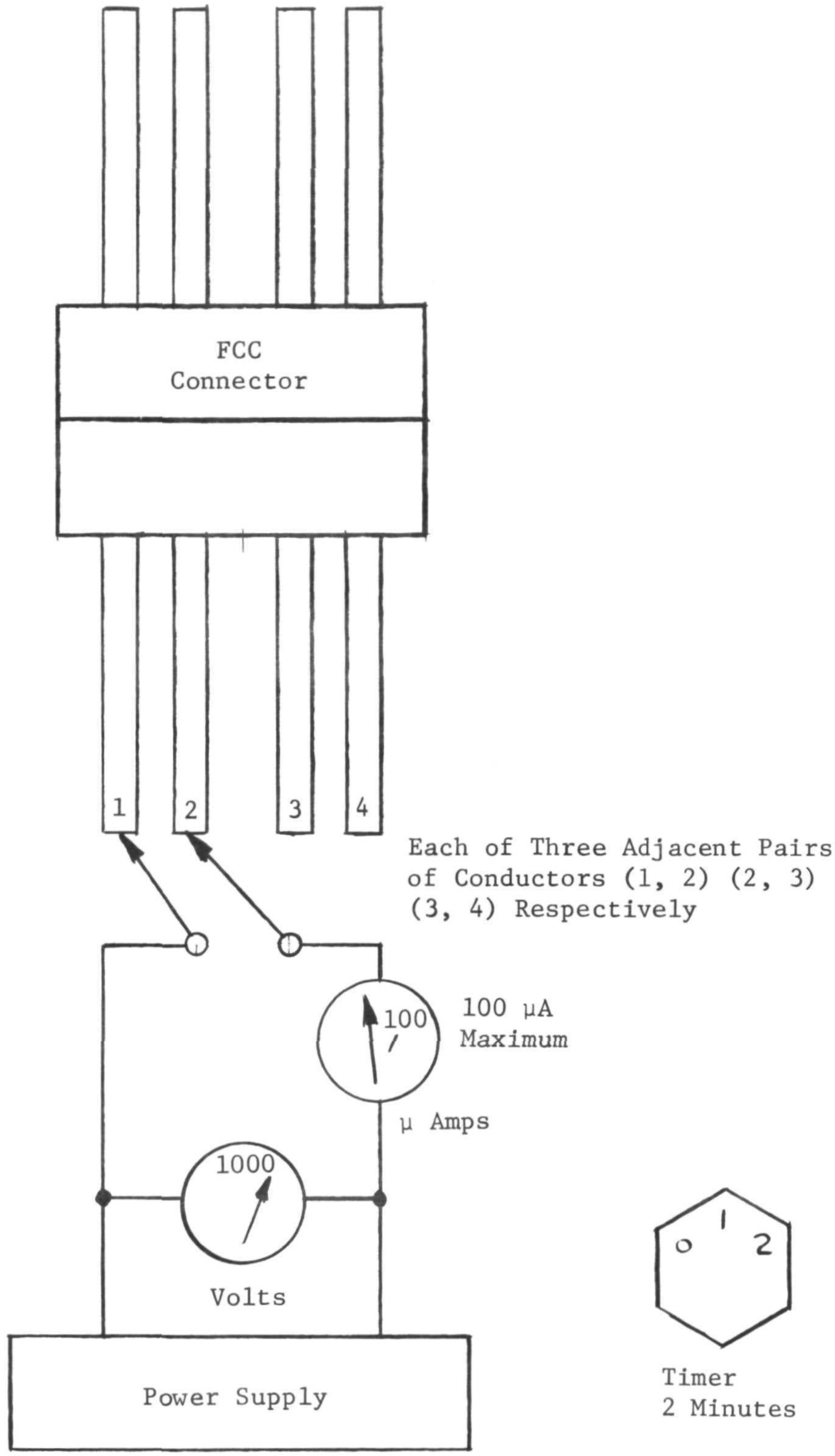


FIGURE 3.3.25 Interelectrode Resistance Test Schematic

A moisture resistance test was performed on connector No. 03 in accordance with MIL-STD-202, Method 106 as modified by MIL-C-55544. The sample was supported in the test chamber in a horizontal position. The temperature and humidity were then cycled in accordance with the specification, for 10 days. After the 10 days of humidity cycling, the inter-electrode resistance was again measured. The test was made while the sample was still in the chamber and at high humidity. The connector was then removed from the chamber and allowed to dry in laboratory ambient conditions for a period of 24 hours. The connector was not disassembled or de-mated during this period. After 24 hours, the inter-electrode resistance was again measured.

The chamber was EQ 526848, humidity chamber, Blue M. Next calibration is due 15 September 1971. A photo of the chamber and the sample in it are shown in Figure 3.3.26.

Data are recorded in Table 3.3.5.

TABLE 3.3.5

Inter-electrode Resistance After Humidity Exposure

Prior to Test	Pin 1 to Pin 2	70 gigohm
	Pin 2 to Pin 3	200 gigohm
	Pin 3 to Pin 4	500 gigohm
After 240-hours of Humidity Cycling	Pin 1 to Pin 2	Shorted at 500 Volts
	Pin 2 to Pin 3	15 megohm at 1000 Volts
	Pin 3 to Pin 4	Shorted at 750 Volts
After An Additional 24 Hours at Ambient	Pin 1 to Pin 2	Shorted -5K ohms with a Triplett
	Pin 2 to Pin 3	5 gigohms at 1000 Volts
	Pin 3 to Pin 4	Shorted -350 Volt 30 megohm with Triplett

A curve typical of each 24-hour cycle is shown in Figure 3.3.27.

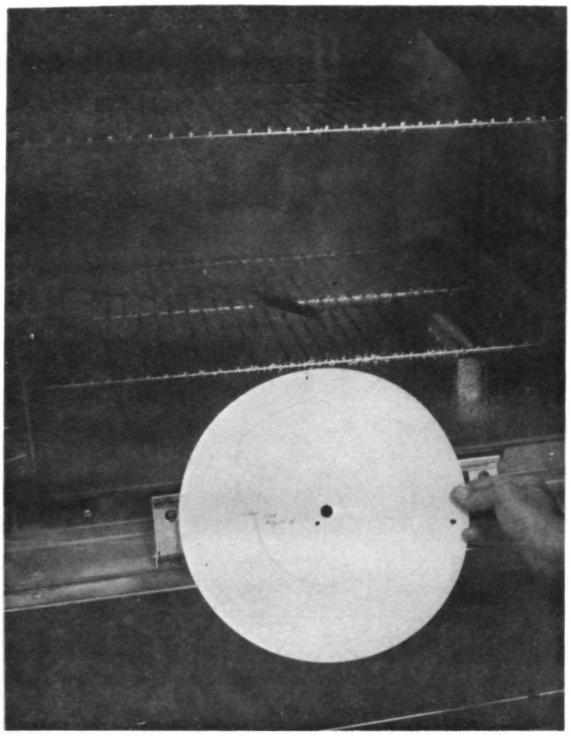


FIGURE 3.3.26

Moisture Resistance Test Apparatus
(Connector #03)

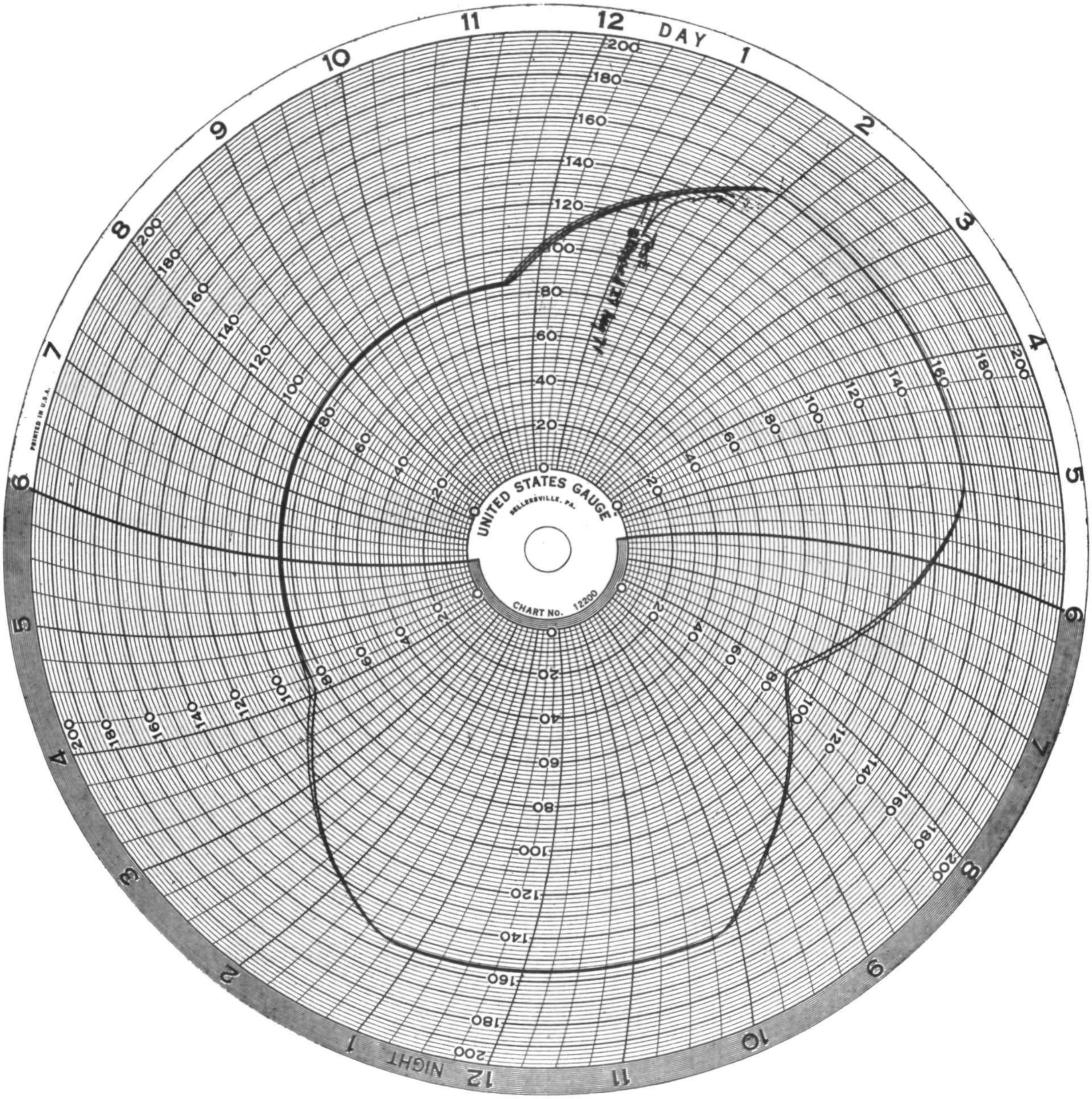


FIGURE 3.3.27

Wet and Dry Bulb Temperature Plot of One 24 Hour Cycle of Humidity Test

Contact Resistance During Thermal Cycling

The purpose of this test was to determine the effect of temperature and cyclic changes in temperature, such as experienced by an earth orbiting satellite, on the contact resistance of the flat cable connector.

Two connectors, part numbers 01 and 02, were supported on wire mesh racks in a temperature controlled chamber. Dry air was forcibly circulated through the chamber during the test.

Thermal cycling consisting of 15 cycles of cold and hot was then performed as follows:

High temperature was $125^{\circ}C \pm 5^{\circ}$

Low temperature was $-170^{\circ}C \pm 5^{\circ}$

Temperature transition from low to high or high to low was accomplished in a 15-20 minute period

Temperature remained stabilized (change of less than $2^{\circ}C$) at either the high or low extreme for at least 5 minutes before measurement of the contact resistance

Temperature indication was by a copper-constantan thermocouple mounted adjacent to the connector on the aluminum base plate

Contact resistance was measured during thermal cycling tests at the following times:

At initial ambient temperature

At cold temperature of each cycle after 5 minute soak

At hot temperature of each cycle after 5 minute soak

At ambient temperature after 15 cycles

Contact resistance was measured for each connector by the voltmeter-ammeter method of MIL-STD-202, Method 307. A current of 3 ampere was conducted through all four conductor mating pairs in series. Voltage measurements were made by means of auxiliary wires soldered to the FCC at 6.45 ± 0.05 inch spacing including the connector, as defined in MIL-C-55544. Figure 3.3.28 herein shows the test setup. The resistance of the flat conductor cable leads was found

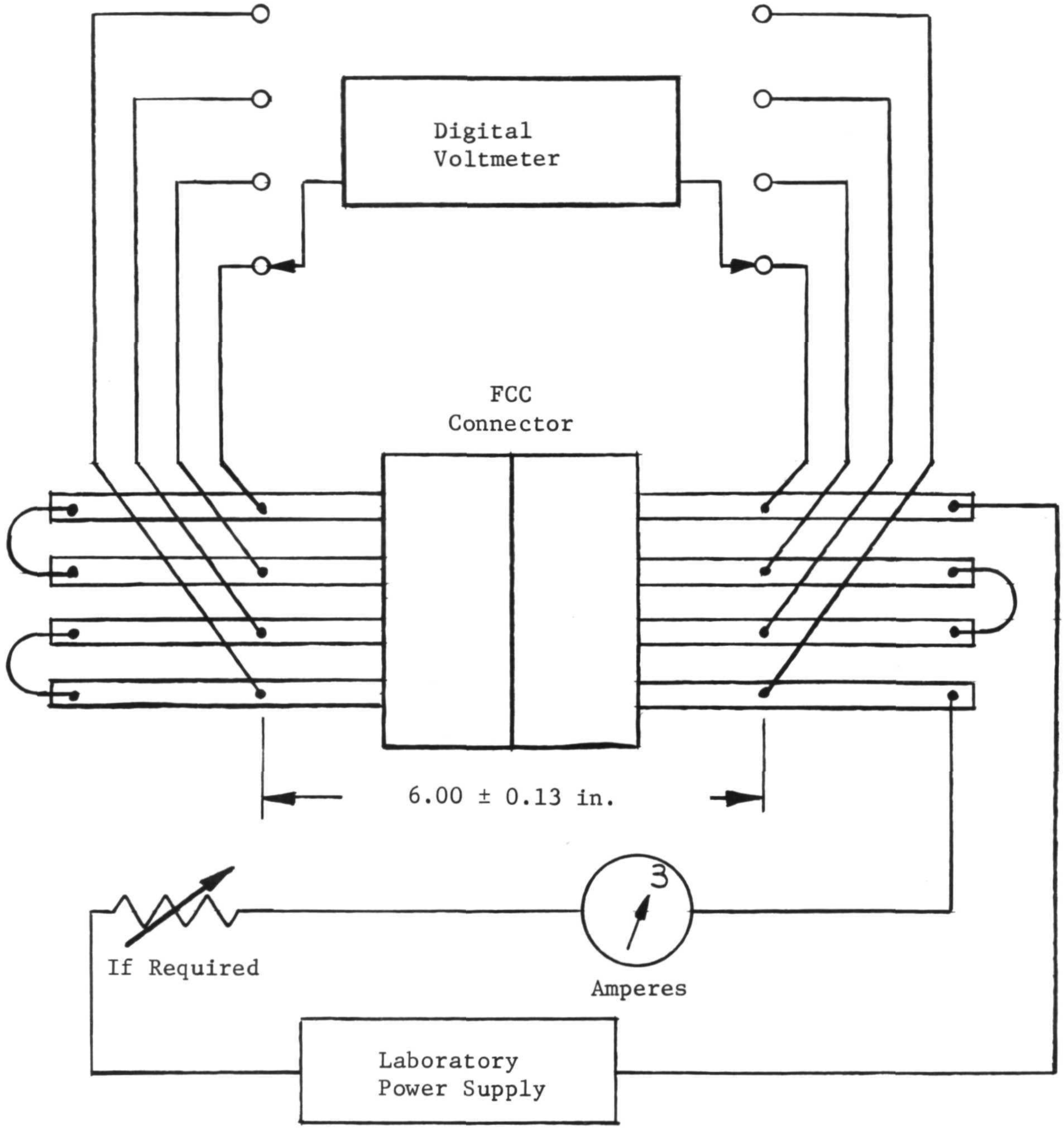


FIGURE 3.3.28 Contact Resistance Measurement during Thermal Cycling Test

to be a major portion of the voltage drop. In order to verify the connector performance, a piece of flat conductor cable without any connectors was put in the chamber and tested in the same manner as were the two connectors. The contact resistance contributed by the connector contacts was then found by subtracting the average voltage drop across the FCC from the voltage drop across the FCC and connector and dividing this difference by the 3 ampere current.

$$R = \frac{V_{connector} - V_{conductor}}{(I = 3 \text{ amperes})}$$

Figure 3.3.29 shows two photographs of the test setup for measuring contact voltage drop during thermal cycling.

Table 3.3.6 shows equipment used during this test.

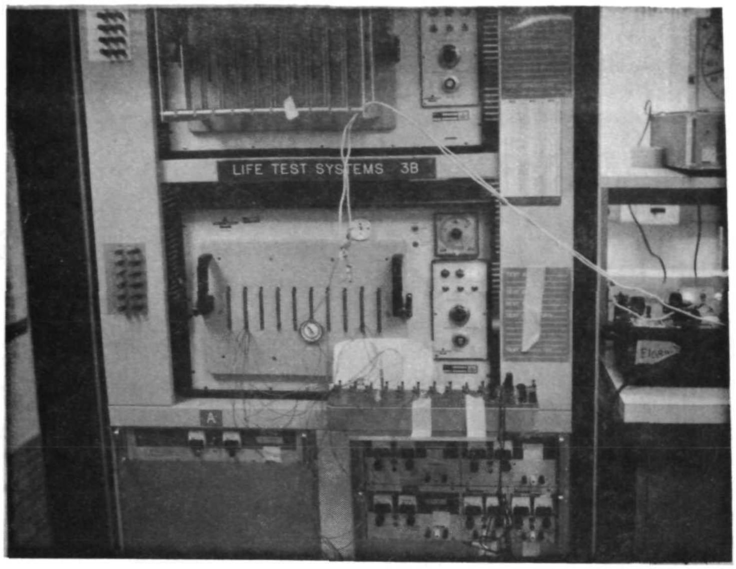
TABLE 3.3.6

Equipment Used in Contact Resistance Test During Thermal Cycling

Identification	Nomenclature	Manufacturer and Model	Next Calibration Due
EQ 527040	Oven	Delta MK 3900	12-22-71
EQ 005838	DVM	Dana 5600	10-15-71
ME 109925	Potentiometer	Browning	10-03-71
ME 104751	Ammeter	Weston 931	10-22-71
EQ 526805	Power Supply	Lambda LH 1184	10-08-71
EQ 133621	Timer	Gra-lab 167	N/A

Data recorded during the test are in Tables 3.3.7 through 3.3.13.

The average contact resistance of each connector remained well below 5 milliohm during the complete thermal cycle test. The resistance spread varied from 1.91 milliohms to 4.59 milliohms. It was of interest to note that in a number of cases, the resistance of one of the flat conductor cable conductors was noticeably lower than the other three. Figure 3.3.30 shows a distribution plot of the voltage drops recorded across the connectors and FCC for each of the thermal cycles. Deviations from the mean were much larger at -170^{o} than they were at $+125^{o}$. Some of this might be attributed to the inherent inaccuracy of measuring low temperature with a copper-constantan thermocouple. If the first low temperature reading



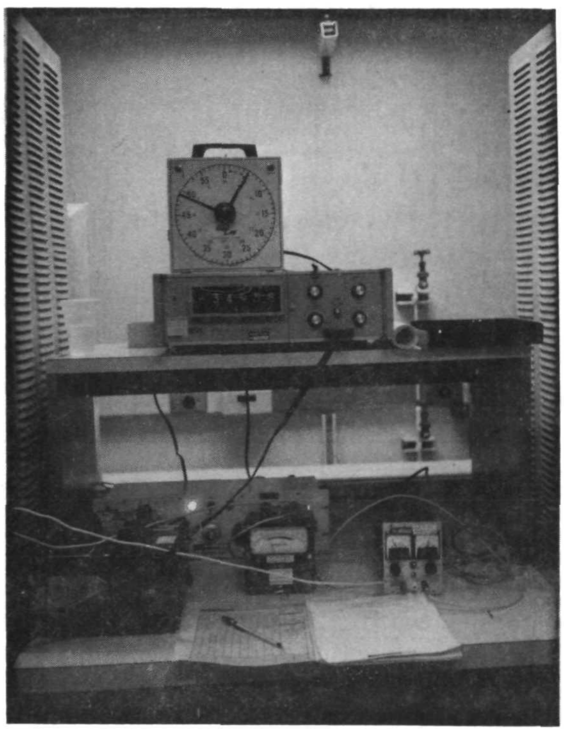


FIGURE 3.3.29

Test Apparatus Contact Voltage Drop During
Thermal Cycling (Connectors 01 and 02)

TABLE 3.3.7

Voltage Drop at Ambient Temperature
Before and After Thermal Cycling

Part No.	Pin No.	Voltage Drop	Voltage Difference*	Contact Resistance (Milliohms)
01	1	30.4	9.73	3.24
Before	2	29.89	9.22	3.07
Thermal	3	28.12	7.45	2.48
Cycling	4	29.26	9.19	3.06
02	1	30.92	10.25	3.41
Before	2	29.39	8.72	2.90
Thermal	3	30.95	10.28	3.42
Cycling	4	30.04	9.37	3.12
01	1	30.1	9.43	3.14
After	2	29.9	9.23	3.07
Thermal	3	28.2	7.53	2.51
Cycling	4	29.9	9.23	3.07
02	1	30.9	10.23	3.41
After	2	29.9	9.23	3.07
Thermal	3	31.0	10.33	3.44
Cycling	4	30.0	9.33	3.11

*The voltage drop average of four conductors without connector was determined to be 20.67 millivolts during acceptance testing. This value was subtracted from each measured voltage drop.

TABLE 3.3.8

Voltage Drops During Thermal Cycling
(Low Temperature $-170^{o} \pm 5^{o}C$, Voltage in Millivolts)

	Part 01				Part 02			
Cycle / Pin No. →	1	2	3	4	1	2	3	4
1	25.89	24.28	15.46	17.84	19.69	18.33	12.07	20.44
2	19.0	13.77	13.2	16.1	14.0	21.5	12.1	15.5
3	15.7	10.4	12.5	13.3	17.1	15.8	12.3	15.3
4	15.4	9.5	12.1	12.9	18.4	16.3	11.8	14.3
5	14.5	9.6	12.1	14.2	15.5	13.8	11.3	13.8
6	13.8	9.4	11.4	13.4	19.0	13.0	10.8	13.8
7	13.59	9.0	11.8	13.6	21.7	12.9	10.8	13.1
8	12.5	9.1	11.0	13.2	16.1	13.3	10.9	12.8
9	14.6	10.0	11.6	14.2	20.0	14.4	11.3	13.4
10	14.0	9.4	10.7	13.1	20.1	14.3	11.4	12.8
11	13.6	9.0	10.6	13.3	19.5	13.9	11.2	13.2
12	13.0	9.0	10.4	12.4	15.7	13.4	10.9	12.7
13	12.4	8.8	10.4	12.3	16.4	14.0	11.0	13.3
14	12.4	9.0	10.4	12.8	17.1	13.6	11.1	13.5
15	12.3	8.8	10.2	12.2	16.8	13.1	10.8	13.1
Sum	196.8	134.8	162.8	187.0	247.4	203.3	157.7	190.6
Average	14.05	9.62	11.62	13.35	17.67	14.52	11.26	13.61

Note: Cycle 1 data were deleted from the average as the deviation from the mean was too great to indicate validity.

TABLE 3.3.9

Low Temperature Voltage Across Four Conductor FCC
Without Connector (Voltage in Millivolts)

	Conductor No.			
Cycle	1	2	3	4
1	4.0	3.5	4.0	4.2
2	4.0	3.5	3.9	3.9
3	4.0	3.4	4.0	4.1
4	4.0	3.5	4.0	4.1

Average of all conductors = 3.88

TABLE 3.3.10

High Temperature Voltage Drops During Thermal Cycling
(High Temperature 125° ±5°C, Voltage in Millivolts)

	Part 01				Part 02			
Cycle	Pin No. → 1	2	3	4	1	2	3	4
1	40.8	41.0	38.0	41.1	42.2	39.3	41.6	40.4
2	40.2	39.5	37.6	40.7	41.6	39.1	41.7	40.1
3	39.8	38.9	37.4	40.6	39.1	41.7	41.7	40.1
4	39.3	38.5	37.1	40.2	42.0	39.5	42.1	40.6
5	40.1	39.1	37.7	40.8	42.0	39.6	42.2	40.7
6	39.5	38.5	36.9	40.1	41.5	39.2	41.7	40.2
7	39.1	38.3	36.8	39.7	41.0	38.7	41.3	39.7
8	39.2	38.2	36.7	39.5	40.9	38.6	41.2	39.7
9	39.1	38.1	36.6	39.7	41.0	38.5	41.3	39.8
10	38.9	38.0	36.5	39.4	40.8	38.5	41.1	39.6
11	39.7	38.1	37.4	40.2	41.2	39.1	41.5	40.0
12	39.4	38.4	37.1	39.7	40.9	38.6	41.2	39.7
13	39.9	38.3	36.9	39.7	41.0	38.6	41.3	39.8
14	39.3	38.2	36.9	39.6	41.0	38.6	41.3	39.8
15	39.7	38.7	37.4	40.1	41.4	38.9	41.6	40.1
Sum	594.0	579.8	557.0	601.1	618.7	586.5	622.8	600.3
Average	39.6	38.65	37.13	40.07	41.24	39.1	41.52	40.02

TABLE 3.3.11

High Temperature Voltage Across Four Conductor FCC
Without Connector (Voltage in Millivolts)

	Conductor No.			
Cycle	1	2	3	4
1	30.5	26.2	30.1	30.7
2	30.3	26.1	30.0	30.5
3	30.9	26.1	30.0	30.5
4	30.2	26.0	29.9	30.9

Average of all conductors = 29.30

TABLE 3.3.12

Low Temperature Resistance

Part No.	Pin No.	Average Voltage Drop	Voltage Difference*	Resistance (Milliohms)
01	1	14.05	10.17	3.39
	2	9.62	5.74	1.91
	3	11.62	7.74	2.58
	4	13.35	9.47	3.15
02	1	17.67	13.79	4.59
	2	14.52	10.64	3.54
	3	11.26	7.38	2.46
	4	13.61	9.73	3.24

*The low temperature voltage drop of 3.88 millivolts on the FCC was subtracted.

TABLE 3.3.13

High Temperature Resistance

Part No.	Pin No.	Average Voltage Drop	Voltage Difference*	Resistance (Milliohms)
01	1	39.6	10.3	3.43
	2	38.65	9.35	3.11
	3	37.13	7.83	2.61
	4	40.07	10.77	3.59
02	1	41.24	11.94	3.98
	2	39.1	9.80	3.26
	3	41.52	12.22	4.07
	4	40.02	10.72	3.57

*A high temperature voltage drop of 29.3 millivolts on the FCC was subtracted.

is neglected, the maximum deviation noted is of the order of 3 millivolts which is equivalent to one milliohm. The contact resistance distribution is shown plotted in Figure 3.3.31. It will be noted that pins 1 and 2 of connector 2 exhibit higher resistance at cold temperatures than at hot. The resistance was still lower than 5 milliohms, however. It is assumed although not verified that the contacts may have been inadequately cleaned to cause this unusual effect. This is based on the fact that the inorganic solder flux is difficult to remove after soldering the spring contacts to the FCC lead.

Contact Resistance During Vibration

The purpose of this test was to verify that vibration would not cause any of the contacts to open momentarily or the connector to become unmated.

Connectors, part numbers 01 and 02, were mounted on a shaker by screwing their mounting plates to a block of aluminum bolted to the armature of the shaker. The flat conductor cables leading to the connector were taped to the block about 2 inches from the connector. Two accelerometers were also screwed to the mounting block. One of these provided an output for a record, the other provided a feedback to control the amplitude of the shaker.

Contact resistance was monitored during vibration testing by use of a detector as described in MIL-STD-202, Method 310 for a normally closed circuit with a one microsecond time constant. This circuit impresses a voltage across the four contacts connected in series and will detect and indicate by means of a light if any of the contacts opens and remains open for a period of one microsecond. The connection is shown in Figure 3.3.32. Vibration was one complete sweep of 10 to 2000 Hz sine wave vibration and back to 10 Hz at an exponential rate of 1 octave per minute in accordance with Method 204B, Test Condition B of MIL-STD-202D. The amplitude was held at 0.06 inches peak to peak from 10 to about 70 cycles at which 15 g peak acceleration was reached. This 15 g peak acceleration was then maintained to 2000 Hz. The same pattern was repeated on the decreasing frequency portion of the cycle.

This test was accomplished on each of 3 mutually perpendicular axes.

Photographs of the test setup are shown in Figure 3.3.33.

Equipment utilized in performance of the vibration test is listed in Table 3.3.14.

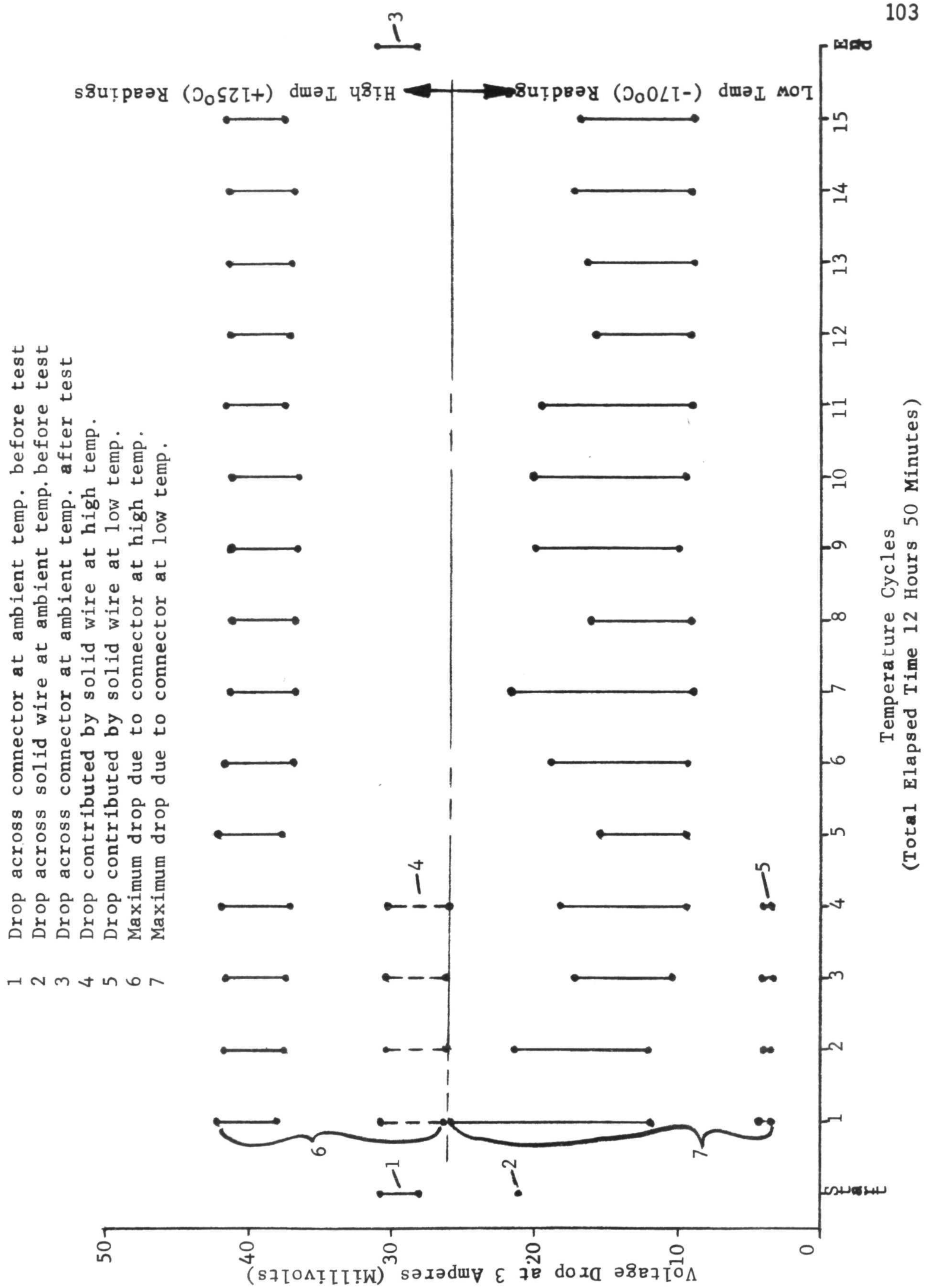


FIGURE 3.3.30

Range of Voltage Drops Through Connector Compared With Solid Wire During Temperature Cycles (Prototype Serial Numbers 01 and 02)

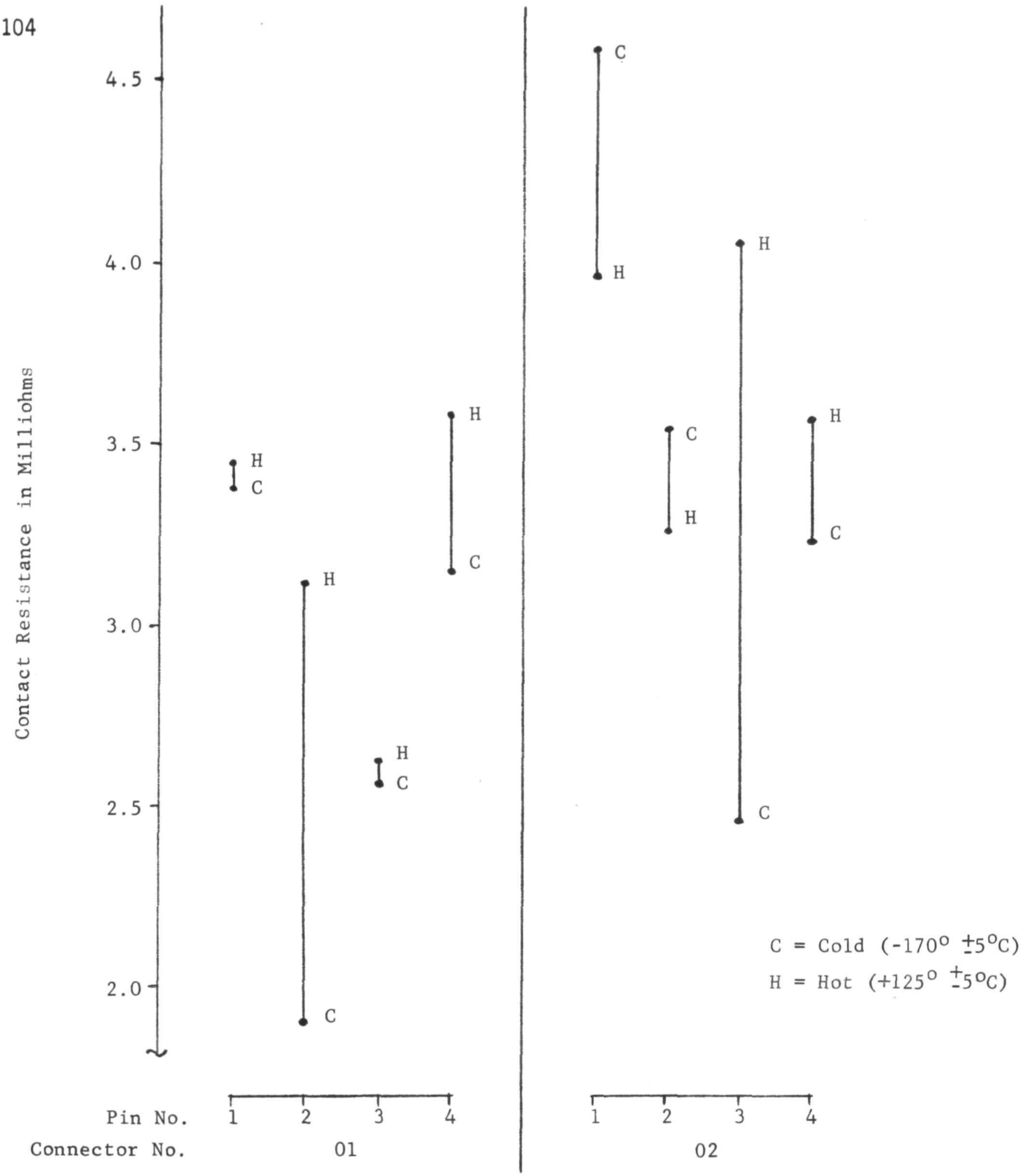


FIGURE 3.3.31

Distribution of Contact Resistance During Thermal Cycle Test

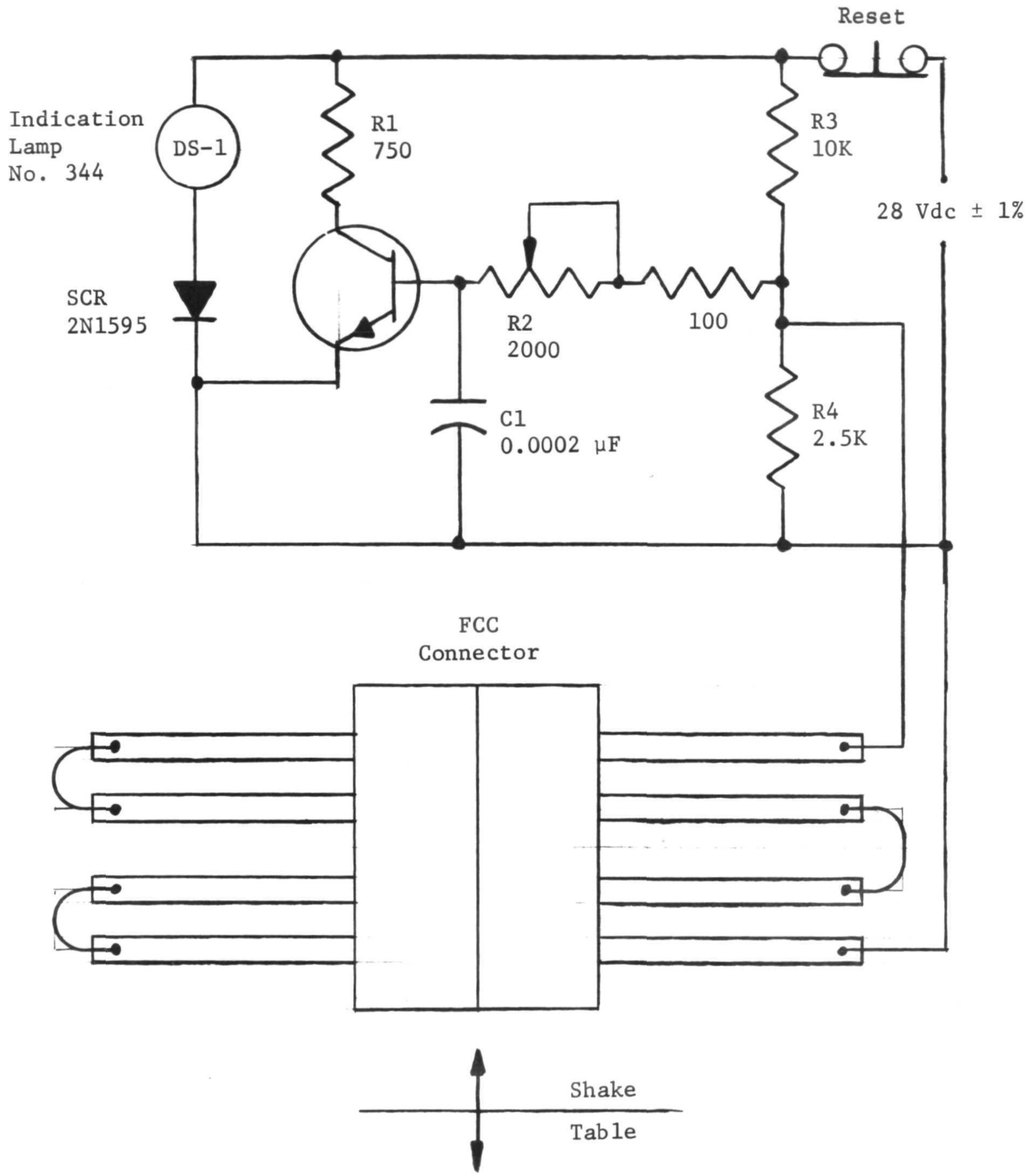
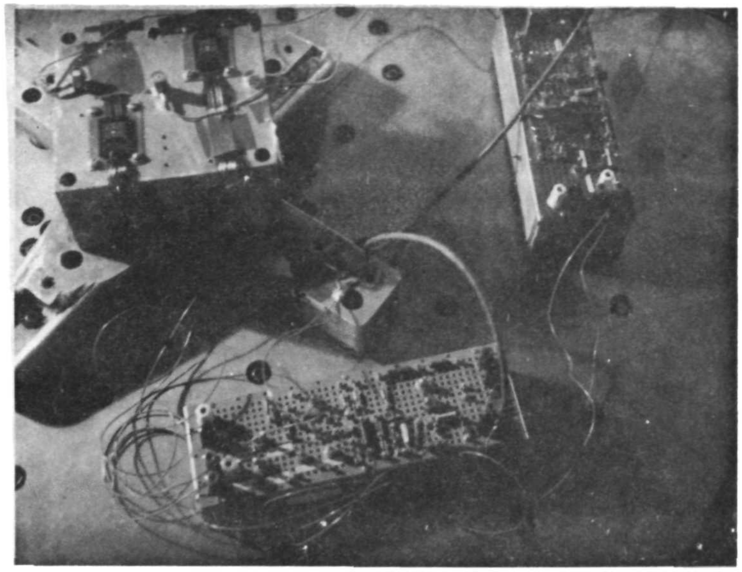


FIGURE 3.3.32 Contact Resistance Monitor - Vibration Test



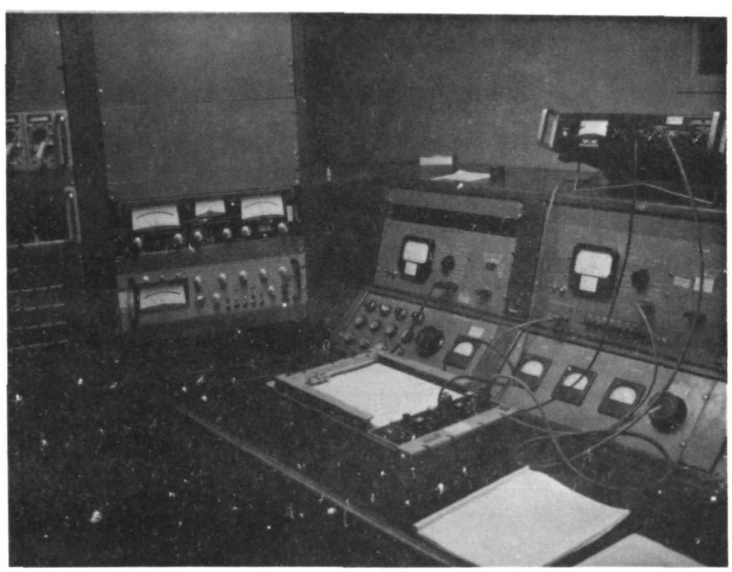


FIGURE 3.3.33

Vibration-Continuity Test Setup
(Connector #01 and 02)

TABLE 3.3.14

Vibration Test Equipment

Identification	Nomenclature	Manufacturer and Model	Next Cal. Due
AF 001146	Vibration System	Ling L-200	N/A
AF 006540	Sweep Oscillator	Spectral Dynamics N752-5	9-5-71
AF 003397	X-Y Plotter	Mosely 135	11-4-71
AF 006604	Long Converter	Mosely 7561A	11-9-71
EQ 525751	Charge Amplifier	Un. Holtz Dickey D-11	1-27-72
EQ 526968	Charge Amplifier	Un. Holtz Dickey D-11	10-14-71
VF98	Accelerometer	Endevco 2272	11-4-71
1811	Accelerometer	Endevco 2232	9-24-71
AF 003529	VTVM Contact Monitor	HP 400D	10-2-71
CM 002159	Transfer-Chatter Indicator	MMC Build	Local Cal. Scope & Gen.
No number	Transfer-Chatter Indicator	MMC Build	Local Cal. Scope & Gen.
AF 575223	Oscilloscope	Tektronix 531	
AF 30157	Pulse Generator	HP 212A	12-2-71

During vibration, no indication was received of an open circuit or chattering contact. The detectors were verified to be set and operating. Figure 3.3.34 shows the peak acceleration with respect to frequency. This plot was typical for all three axes.

Both connectors passed the vibration test with no deviations.

Pull Test

The purpose of this test was to demonstrate that the connector would not pull apart nor would the flat cable pull out of the connector when a pull of 25 lbs. per inch width of cable was applied without shock between the two conductors.

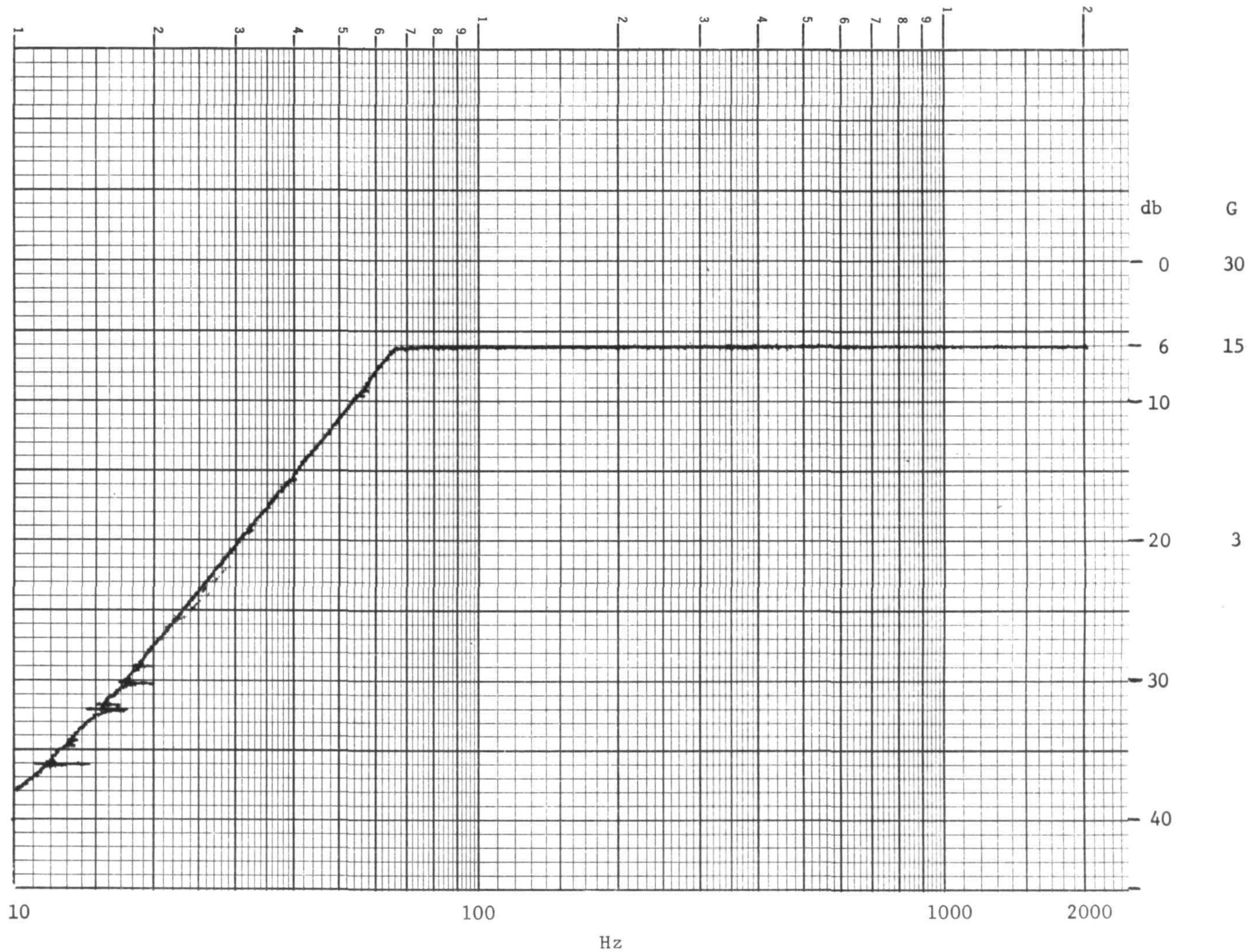


FIGURE 3.3.34 Vibration Curve

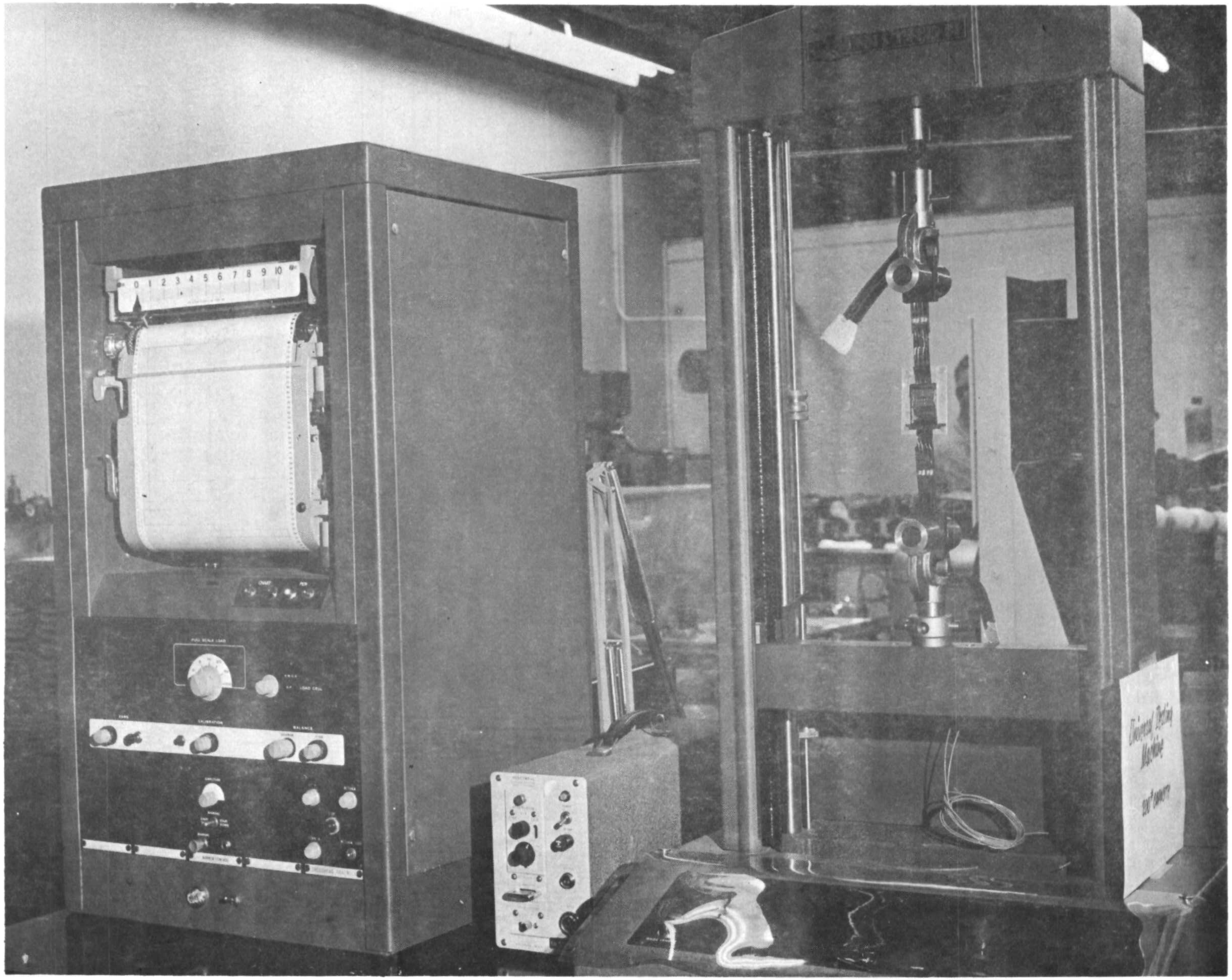


FIGURE 3.3.35 Pull Test Setup

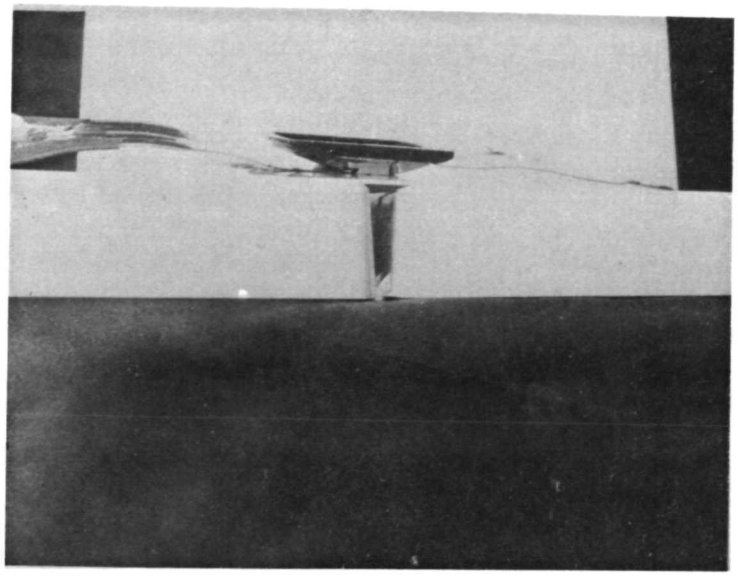


FIGURE 3.3.36

Connector at Separation During Pull Test
(Simulated)

Connectors and their associated flat conductor cables, part numbers 01 and 02, were individually installed on a tensile testing machine. The machine was previously calibrated by hanging precision weights on the machine. Photographs of the test setup are shown in Figure 3.3.35.

Equipment used for the test was EQ 530601, Universal Test Machine, Instron 200, which is calibrated each test.

During testing at 0.2 inches per minute rate, a recording was made of stress against strain for each connector. Connector 01 became de-mated at a load of 9.8 pounds and connector 02 became de-mated at 9.7 pounds. There was no indication of leads pulling out of the connectors.

Separation begins because the direct pull force on the leads causes eccentric loading on the connector which tends to unlatch the body/retainer. When the pull load is sufficient to overcome the load couple of the overcentering hinge (see Figure 3.3.36) the connector separates.

This condition may be eliminated by providing self-reacting supports for the cable leads on the body/retainer. Such provisions would make the body/retainer latch follow the pull on the leads, thus preventing release of the latch. Further recommendations for design improvements which would increase the load capacity are described in Section 3.3.3.

Section 3.3.3 Conclusions and Recommendations

The contract effort has resulted in a small, light weight connector designed for connection of flat conductor cable to a solar array. The connector design also provides a means of interconnecting two flat conductor cables. The connector requires no tools to mate or separate and has no loose or uncontained parts.

The connector has received limited testing as a result of this program, but has demonstrated satisfactory contact resistance during thermal cycling and during vibration. Inter-electrode resistance was above expectation at ambient conditions, but inadequate under severe humidity cycling. Neither high humidity nor condensation are normal environments associated with solar panels. Recommendations are included to improve this condition if future work is accomplished. Pull loading on the connected flat cables resulted in connector separation at something over half the load for which a flat conductor cable is designed. A connector should normally have the leads anchored so that there is no strain on the lead where it enters the connector; however, should greater load capability be required, improvements are suggested to provide this capability.

A test procedure and five assembled connectors are being delivered to NASA-MSFC for further evaluation.

Design Improvements - Recommendations

As with all new developmental design programs, design improvements have been discovered during this effort too late to be incorporated into the delivered devices. Although detail development work has not been performed, improvement approaches are indicated with reasonable confidence that they will be successful. Some of the suggested design improvements which should be pursued during follow-on effort are noted below:

1) Redesign spring contact to eliminate solder joint between spring contact and conductor. This would mean forming conductors to provide their own contacts and supporting them by spring clip retainer clamps.

2) Provide snap-action to hold body/retainer in latched position.

3) Provide shear tabs in body/retainer for greater pull resistance.

4) Provide holes in receptacle for guide pins which would align conductors before contact is made.

5) Use guide pins to support improved seal.

6) Injection mold seal from polyurethane of proper durometer to attain better material properties as well as improved manufacturing process.

7) Investigate integrally molding guide clamps with receptacle (similar to Figure 3.2.5) to provide connector latching so that body/retainer could be eliminated and connector size could be reduced.

NAS8-26114 CONNECTOR TEST

VOLTAGE DROP DURING THERMAL SHOCK

TEST CONDUCTED BY

P. Dillard, Engineer

R. Fuhrmann, Technician

APPROVED: W. McCandliss
Asst. Program Manager

APPROVED: W. Collins
Program Manager

PURPOSE

The Plastic Draw Latch connector concept was presented to the customer (MSFC) as the preferred concept to be pursued in Phase III. The primary concern by both MMC and MSFC was the performance of the latch material over the specified temperature range (-170°C to +125°C) as it affects contact pressure.

This test was run to determine whether discontinuities would occur during the thermal shock of repeated dipping from liquid nitrogen to hot fluid.

The intent was to determine whether polypropylene material properties would cause the connector to fail under severe thermal shock. Tests should be conducted later using anticipated spacecraft thermal excursion rates during eclipse.

SETUP (Figure 1)

1. Sample (Figure 2)

   The sample was made by clamping flat conductor cabling between the keeper and latch of a 200 series .07 latch by Southco, Inc. FCC used was # C-08-25-C-3-250-12-11-00-2-3. Separate leads for voltage and current were soldered to the flat conductors. A thermocouple was installed to measure temperature inside the connector cap.

2. Power Supply

   The power supply delivered 3 amp through the connector.

3. Recorder

   The recorder was connected to measure voltage drop across the connector with 6.5 inch total lead length vs. connector temperature (see Figure 2).

4. Heating Fluid

   Ultra-therm 250 was used as a hot bath for heating the connector. Bath temperature was maintained at 140°C ±10° during testing.

5. Cooling Fluid

   Liquid nitrogen was used as a cold bath for chilling the connector.

6. Sealant

   Silicon vacuum grease was applied to the bottom of the connector in an effort to exclude heating and/or cooling fluids from the contact region.

PROCEDURE

With 3 amps flowing through the connector, the voltage drop vs. connector temperature was plotted by the recorder.

RESULTS

Test results are shown in Graphs #1 and #2.

During #1 the temperature excursion of 333°C during heating from -196°C to +137°C occurred in 4 minutes 30 seconds. The cooling took 2 minutes. Voltage drop ranged from 2.6 mv at -170°C to 15.9 mv at +125°C.

During #2 the heating temperature excursion of 333°C occurred in only 2 minutes. Cooling took just 30 seconds. When part was moved over heating fluid to start the third cycle it exploded - apparently because of thermal stresses. Voltage drop ranged from 3.5 mv at -170°C to 17.0 mv at +125°C.

While no hysteresis was noted during #1; #2 showed pronounced hysteresis with maximum spread of 9 mv at -150°C.

EVALUATION

Using other tests at MMC, the author calculated voltage drop of conductor alone to be 2.34 mv at -170°C and 12.2 mv at +125°C. The results of this test indicate that the additional drop contributed by the connector in the line is from 1.26 mv to 4.8 mv. Similar tests on the connector used on ATM panels resulted in drops of 1.25 mv to 2.15 mv. The voltage drop across the proposed connector is well within the range of the ATM connector.

Two questions were raised by this test:

1. What caused the connector to explode at the start of cycle #3?

2. What caused the reduction in the time for heating and cooling?

The answer to question 1) may be that the thermal shock caused stresses within the material sufficient to precipitate failure. This may be further resolved by reducing heating rates to expected values during eclipse for future testing.

Question 2), however, may relate to a basic material property of polypropylene which should be studied further.

CONCLUSION

Because the voltage drop through this new connector is similar to that obtained from connectors approved for use on ATM, it is considered by MMC-Denver to warrant further design development of this concept. More study of polypropylene properties as affected by heating/cooling rates should be conducted as well.

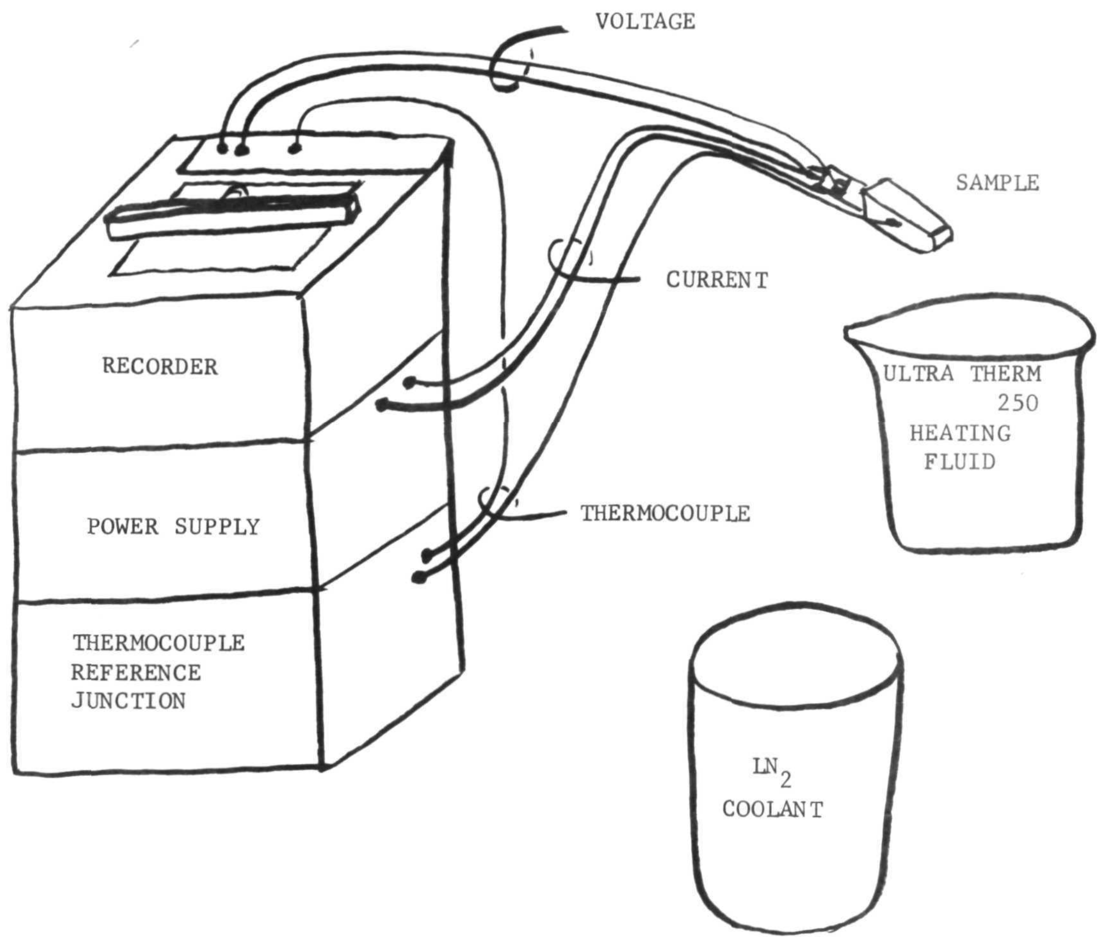


FIGURE 1 Setup

SIZE	CODE IDENT NO.	
A	04236	

CHG

SCALE | PAGE | SHEET

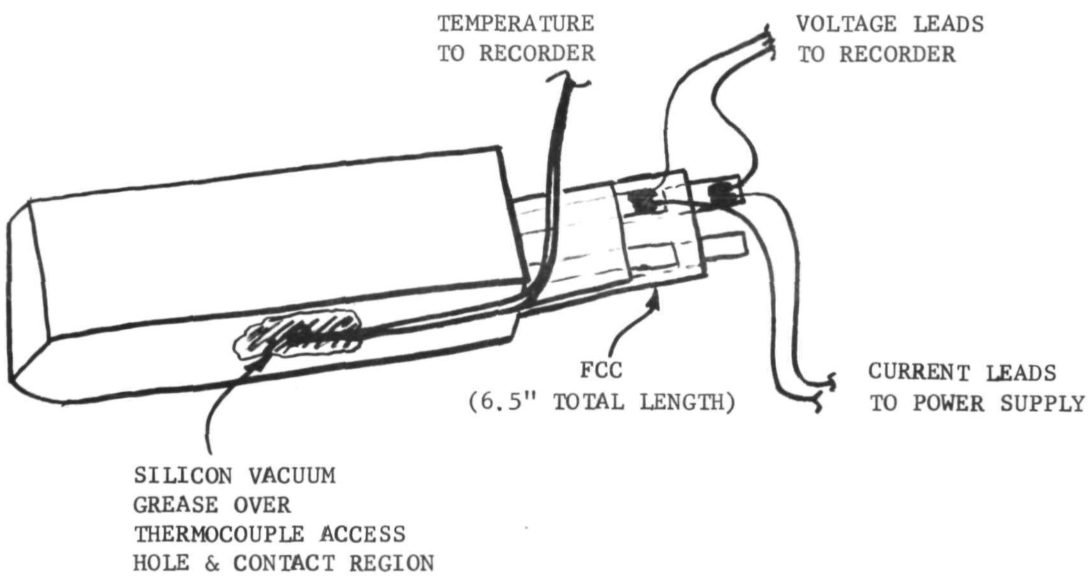
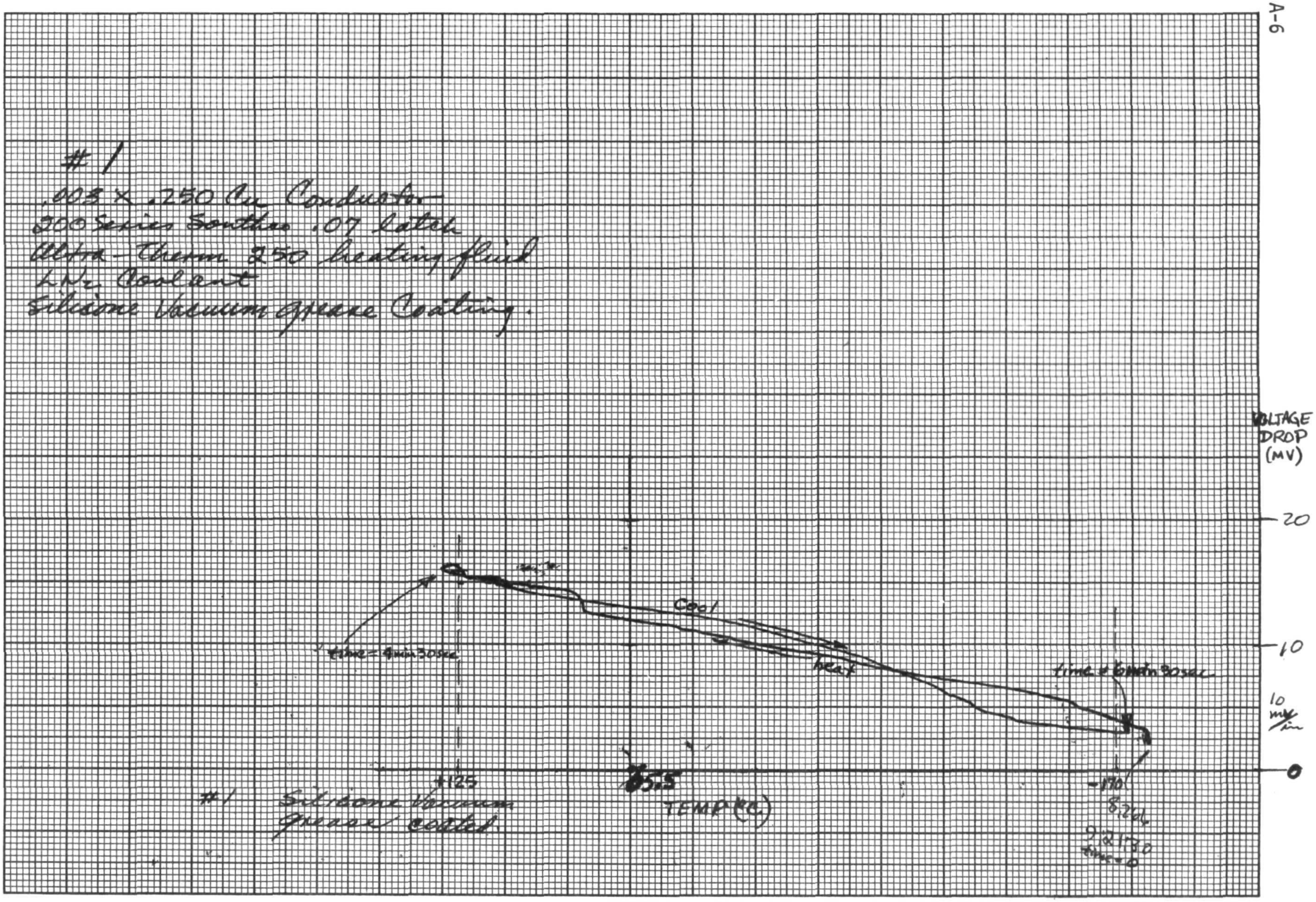
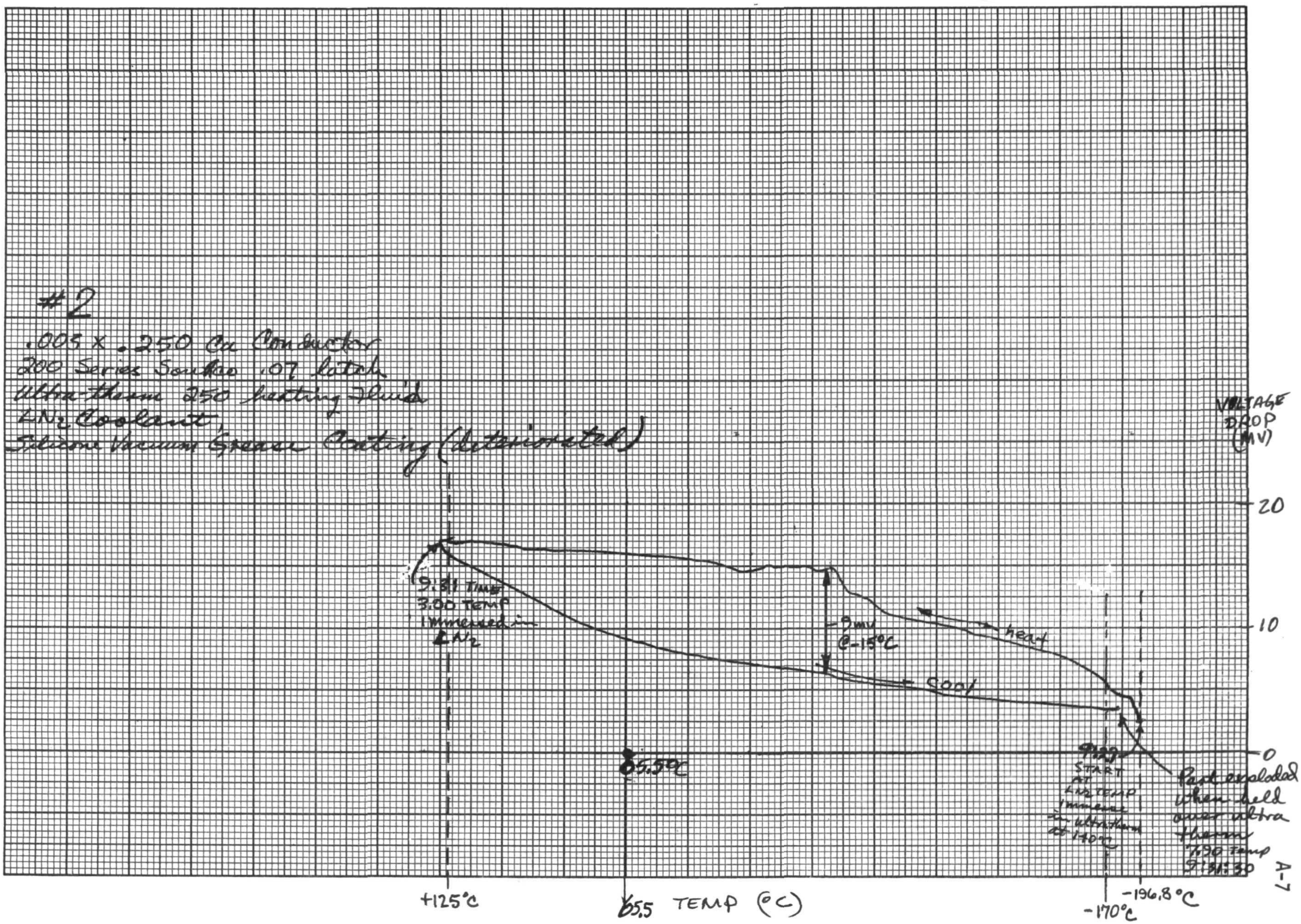


FIGURE 2 Test Sample

CHG	SIZE	CODE IDENT NO.	
	A	04236	
	SCALE	PAGE	SHEET


#1
.003 × .250 Cu Conductor
200 Series Southco .07 latch
Ultra-Therm 250 heating fluid
LN2 Coolant
Silicone Vacuum grease Coating.
VOLTAGE DROP (MV)
20
10
10 mv/in
0
time = 4min 30sec
Cool
heat
time = 6min 30sec
+125
35.5
TEMP (°C)
-170
#1 Silicone Vacuum grease coated.


#2
.005 x .250 Cu Conductor
200 Series Soutco .07 latch
Ultra-therm 250 heating fluid
LN2 Coolant
Silicone Vacuum Grease Coating (deteriorated)
VOLTAGE DROP (MV)
20
10
0
+125°C
65.5
TEMP (°C)
-170°C
-196.8°C
65.5°C
9.31 TIME
3.00 TEMP
Immersed in LN2
9mv @-15°C
heat
cool
START AT LN2 TEMP
Part exploded when held over ultra therm
9:31:30

APPENDIX B - ANALYSIS OF SPRING CONTACT CON-16

This analysis was made to determine whether the proposed spring contact will perform as designed. Extreme dimensions at both ends of manufacturing tolerances were used to determine minimum and maximum loads as well as whether material stresses were within allowable limits.

The minimum contact load was determined to be 0.2835 lb which is well above the required minimum of 0.15 lb. All stresses and deflections are well within allowable limits.

Material BeCu Alloy 25 $E = 19 * 10^6$ psi

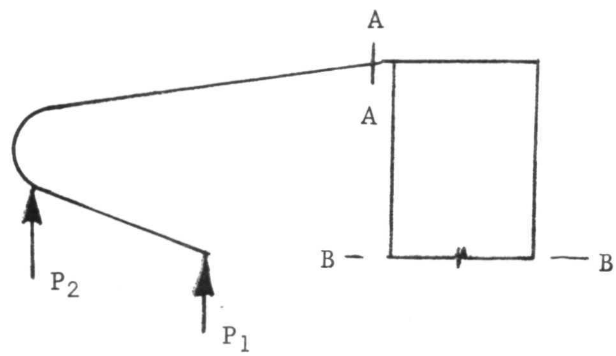
$F_{tu} = 200{,}000$ psi

$F_{cy} = 140{,}000$ psi

Items To Be Checked

1) Maximum stress at AA
2) Flange Crippling at BB
3) Contact Load

	P_1	P_2	$P_1 + P_2$	Defl
Minimum	0.2252	0.0583	0.2835	0.0176
Nominal	0.3883	0.1563	0.5446	0.205
Maximum	0.5784	0.1873	0.7657	0.0234



$$EI_0 = 1.388 \times 10^{-2}$$

$$EI_1 = 0.585 \times 10^{-2}$$

$$L_1 = 0.095 \text{ inch}$$

$$L_2 = 0.0854 \text{ inch}$$

For Minimum P_1 and P_2

$$b = 0.090 \text{ inch}$$

$$t = 0.0046 \text{ inch}$$

$$y_0 = \frac{(P_1 + P_2)(0.095)^3}{0.04164} + \frac{P_2(0.095)^2\ 0.0854}{0.02776}$$

$$y_0 = 0.020590\ P_1 + 0.048354\ P_2$$

$$\theta_0 = \frac{(P_1 + P_2)\ (0.095)^2}{0.02776} + \frac{0.095 \times 0.0854}{0.01388} P_2$$

$$\theta_0 = 0.325108\ P_1 = 0.909618\ P_2$$

$$y_1 = y_0 + 0.0854\ \theta_0 + \frac{(P_1 + P_2)(0.0854)^3}{0.04164} - \frac{P_1(0.0854)^3}{0.02776}$$

$$y_1 = 0.020590\ P_1 + 0.048354\ P_2 + 0.027764\ P_1 + 0.077681\ P_2$$

$$+ 0.014958\ P_2 - 0.007478\ P_1$$

$$y_1 = 0.040876\ P_1 + 0.140993\ P_2$$

$$\theta_1 = \theta_0 + \frac{(P_1 + P_2)(0.0854)^2}{0.02776} - \frac{P_1(0.0854)^2}{0.01388}$$

$$\theta_1 = 0.325108\ P_1 + 0.909618\ P_2 + 0.262722\ P_2 - 0.262722\ P_1$$

$$\theta_1 = 0.062386\ P_1 + 1.172340\ P_2$$

$$y_2 = y_1 + (P_1 + P_2)\ 0.000052 + 0.000686\ P_1$$

$$y_2 = 0.041614\ P_1 + 0.141045\ P_2$$

$$\theta_2 = -\theta_1 + 0.009109\ (P_1 + P_2) + \frac{\pi P_1\ (0.0073)\ 0.854}{1.17 \times 10^{-2}}$$

$$\theta_2 = -0.053277\ P_1 - 1.163231\ P_2 + 0.167396\ P_1$$

$$\theta_2 = 0.114119\ P_1 - 1.163231\ P_2$$

$$y_3 = y_2 + 0.854\ \theta_2 + \frac{P_1\ (0.0854)^3}{3\ (0.00585)}$$

$$Y_3 = 0.041614\ P_1 + 0.141045\ P_2 + 0.035489\ P_1 - 0.009746\ P_1$$

$$- 0.099340\ P_2$$

$$y_3 = 0.067357\ P_1 + 0.041705\ P_2$$

Assume

$$y_3 = y_2 = 0.0176 \text{ inch}$$

$$0.025743\ P_1 = 0.09934\ P_2$$

$$P_2 = \frac{25743}{99340} P_1 = 0.25914\ P_1$$

$$P_1 = \frac{0.0176}{0.067357 + \frac{25743}{99340} 0.041705} = \frac{0.0176}{0.078164} = 0.22517 \text{ lb}$$

$$P_2 = 0.05835 \text{ lb} \rightarrow P_1 + P_2 = 0.2835 \text{ lb}$$

$$y_2 = 0.00937 + 0.00823 = 0.0176 \text{ inch}$$

$$y_3 = 0.01517 + 0.00243 = 0.0176 \text{ inch}$$

For Maximum P_1 and P_2

$t = 0.0054$ $b_0 = 0.10$ inch $B_1 = 0.058$ inch

$L_1 = 0.075$ $E = 10.5 \times 10^6$ psi

$L_2 = 0.0646$ $R = 0.0077$ inch

$$I_0 = \frac{(0.0054)^3\ (0.1)}{12} = 1.3122 \times 10^{-9} \qquad EI_0 = 0.0137781$$

$$I_1 = \frac{(0.0054)^3\ (0.058)}{12} = 0.76108 \times 10^{-9} \qquad EI_1 = 0.0079913$$

$$y_0 = \frac{(P_1 + P_2)\ (0.075)^3}{0.0413343} + \frac{P_2 (0.075)^2\ 0.0646}{0.0275562}$$

$$y_0 = 0.0102064\ P_1 + 0.0233930\ P_2$$

$$\theta_0 = \frac{(P_1 + P_2)(0.075)^2}{0.0275562} + \frac{P_2 (0.075)\ 0.0646}{0.0137781}$$

$$\theta_0 = 0.204128\ P_1 + 0.555773\ P_2$$

$$y_1 = y_0 + 0.0646\ \theta_0 + \frac{(P_1 + P_2)(0.0646)^3}{0.0413343} - \frac{P_1(0.0646)^3}{0.0275562}$$

$$y_1 = 0.0102064\ P_1 + 0.023393\ P_2 + 0.013187\ P_1 + 0.035903\ P_2$$
$$+ 0.006522\ P_2 - 0.00478\ P_1$$

$$y_1 = 0.018606\ P_1 + 0.065818\ P_2$$

$$\theta_1 = \theta_0 + \frac{(P_2 - P_1)(0.0646)^2}{0.0275562}$$

$$\theta_1 = 0.204128\ P_1 + 0.555773\ P_2 + (P_2 - P_1)\ 0.151441$$

$$\theta_1 = 0.052687\ P_1 + 0.707214\ P_2$$

$$y_2 = y_1 + \frac{\pi(P_1 + P_2)(0.0077)^3}{0.0319652} + \frac{P_1(0.0077)^2\ 0.0646}{0.0079913}$$

$$y_2 = 0.018606\ P_1 + 0.065818\ P_2 + 0.000045\ P_2 + 0.000525\ P_1$$

$$y_2 = 0.019131\ P_1 + 0.065863\ P_2$$

$$\theta_2 = -\theta_1 + \frac{(P_1 + P_2)(0.0077)^2}{0.0079913} + \frac{\pi P_1(0.0077)\ 0.0646}{0.0159826}$$

$$\theta_2 = -0.052687\ P_1 - 0.707214\ P_2 + (P_1 + P_2)\ 0.007419 + 0.097775\ P_1$$

$$\theta_2 = 0.052507\ P_1 - 0.699795\ P_2$$

$$y_3 = y_2 + 0.0646\ \theta_2 + \frac{P_1(0.0646)^3}{0.0239739}$$

$$y_3 = 0.019131\ P_1 + 0.065863\ P_2 + 0.0033929\ P_1 - 0.045207\ P_2$$
$$+ 0.011245\ P_1$$

$$y_3 = 0.033768\ P_1 + 0.020656\ P_2$$

Assume

$$y_3 = y_2 = 0.0234$$

$\therefore$

$$0.014637\ P_1 = 0.045207\ P_2$$

$$P_2 = 0.323777\ P_1$$

$$0.0234 = 0.033768\ P_1 + 0.006688\ P_1$$

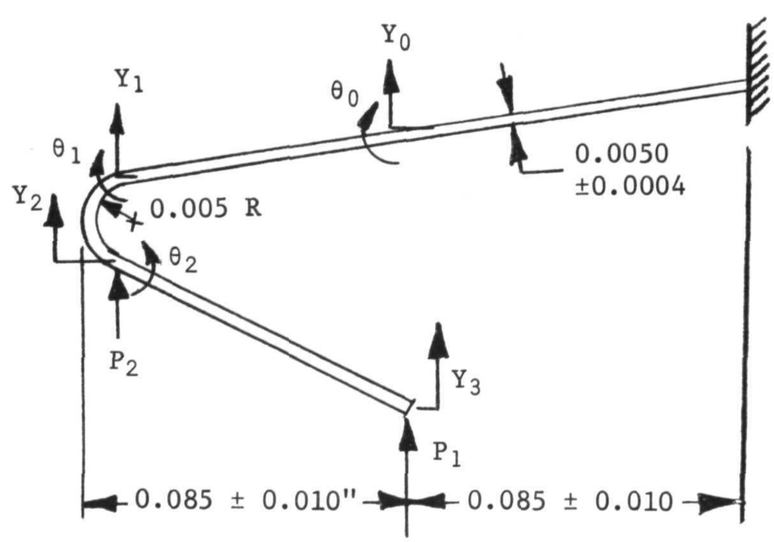
$$P_1 = \frac{0.0234}{0.040456} = 0.5784 \text{ lb}$$

$$P_1 + P_2 = 0.7657 \text{ lb}$$

$$P_2 = 0.1873 \text{ lb}$$

$$y_3 = 0.019531 + 0.003868 = 0.0234 \text{ inch}$$

$$y_2 = 0.011065 + 0.012336 = 0.0234 \text{ inch}$$



For Minimum P_1 and P_2

$P_1 = 0.22517$ lb

$P_2 = 0.05835$ lb

$M_{AA} = 0.095\ P_1 + 0.1804\ P_2$

$M_{AA} = 0.021391 + 0.010526 = 0.031917$ inch-lb

$$f_b = \frac{6(0.031917)}{(0.0046)^2\ 0.09} = 100{,}500 \text{ psi}$$

$M_{BB} = M_{AA} + 0.015\ (P_1 + P_2)$

$M_{BB} = 0.031917 + 0.004253 = 0.036170$ inch-lb

$$f_b = \frac{6(0.03617)}{0.092(0.3)^2} \sim \text{small}$$

For Maximum $P_1 + P_2$ ($P_1 = 0.5784$ lb; $P_2 = 0.1873$ lb)

$M_{AA} = 0.075\ P_1 + 0.1396\ P_1$

$M_{AA} = 0.0433 + 0.262 = 0.0695$ inch-lb

$$f_b = \frac{6(0.0695)}{(0.0054)^2\ 0.1} = 143{,}000 \text{ psi}$$

$M_{BB} = M_{AA} + 0.015\ (P_1 + P_2)$

$F_{tu} = 200{,}000$ psi

$M_{BB} = 0.0695 + 0.015\ (0.7657)$

$M_{BB} = 0.081$ inch-lb

For a Nominal Condition

$E = 19 \times 10^6$ $\quad t = 0.005$ $\quad b_0 = 0.095$

$L_1 = 0.085$ $\quad b_1 = 0.048$

$L_2 = 0.0775$

$I_0 = \frac{0.095}{12}(0.005)^3 = 0.989583 \times 10^{-9}$ $\quad EI_0 = 0.0188021$

$I_1 = \frac{0.048}{12}(0.005)^3 = 0.5 \times 10^{-9}$ $\quad EI_1 = 0.0095$

$$y_0 + \frac{(P_1 + P_2)(0.085)^3}{0.0564062} + \frac{P_2(0.085)^2\ 0.0775}{0.0376042} = 0.010888\ P_1 + 0.025778\ P_2$$

$$\theta_0 = \frac{(P_1 + P_2)(0.085)^2}{0.0376042} + \frac{P_2(0.085)(0.0775)}{0.0188021} = 0.192133\ P_1 + 0.542493\ P_2$$

$$y_1 = y_0 + 0.0775\ \theta_0 + \frac{P_2(0.0775)^3}{0.0564062} - \frac{P_1(0.0775)^3}{6(0.0188021)}$$

$$y_1 = 0.010888\ P_1 + 0.025778\ P_2 + 0.014890\ P_1 + 0.042043\ P_2$$
$$+ 0.008252\ P_2 - 0.004126\ P_1$$

$$y_1 = 0.021652\ P_1 + 0.076073\ P_2$$

$$\theta_1 = \theta_0 + \frac{P_2(0.0775)^2}{0.0376042} - \frac{(0.0775)^2\ P_1}{0.0376042} = 0.032410\ P_1 + 0.702216\ P_2$$

$$y_2 = y_1 + \frac{\pi(P_1 + P_2)(0.0075)^3}{0.038} + \frac{P_1(0.075)(0.0075)^2}{0.0095}$$

$$y_2 = 0.021652\ P_1 + 0.076073\ P_2 + 0.000035\ P_2 + 0.000494\ P_1$$

$$y_2 = 0.022146\ P_1 + 0.076108\ P_2$$

$$\theta_2 = -\theta_1 + \frac{(P_1 + P_2)(0.0075)^2}{0.0095} + \frac{\pi P_1(0.0775)\ 0.0075}{0.019}$$

$$\theta_2 = -0.032410\ P_1 - 0.702216\ P_2 + (P_1 + P_2)\ 0.005921 + 0.096108\ P_1$$

$$\theta_2 = 0.069619\ P_1 - 0.696295\ P_2$$

$$y_3 = y_2 + 0.0775\ \theta_2 + \frac{P_1(0.0775)^3}{3(0.0095)}$$

$$y_3 = 0.022146\ P_1 + 0.076108\ P_2 + 0.005395\ P_1 - 0.053963\ P_2 + 0.016333\ P_1$$

$$y_3 = 0.043874\ P_1 + 0.022145\ P_2$$

Assume $y_2 = y_3 = 0.176$ inch

$$y_2 = 0.022146\ P_1 + 0.076108\ P_2$$

$$y_3 = 0.043874\ P_1 + 0.022145\ P_2$$

$$0.021728\ P_1 = 0.053963\ P_2$$

$$P_2 = 0.40265\ P_1$$

$$0.0205 = (0.022146 + 0.030645)\ P_1 = 0.052791\ P_1$$

$$P_1 = 0.3883 \text{ lb}$$

$$P_1 + P_2 = 0.5446 \text{ lb}$$

$$P_2 = 0.1563 \text{ lb}$$

$$y_2 = 0.008599 + 0.011896 = 0.0205 \text{ inch}$$

$$y_3 = 0.017036 + 0.003461 = 0.0205 \text{ inch}$$