(NASA-CR-120576) DESIGN, DEVELOPMENT,
FABRICATION AND TESTING OF HIGH TEMPERATURE
FLAT CONDUCTOR CABLE (FCC) Final Report,
Jun. 1972 - Jul. 1974 (Martin Marietta
Corp.) 46 p HC $3.75
CSCL 09A G3/33
N75-14963
Unclas
07330

MARTIN MARIETTA

DESIGN, DEVELOPMENT, FABRICATION AND TESTING OF HIGH TEMPERATURE FLAT CONDUCTOR CABLE (FCC)

OR 13,246

Final Report

June 1972 through July 1974

Prepared for George C. Marshall Space Flight Center, Marshall Space Flight Center, Alabama 35812

Prepared by

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Date Prepared: July 31, 1974

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FOREWORD

This final report, prepared by Walter S. Rigling of the Materials Engineering Laboratories of Martin Marietta Aerospace, Orlando, Florida, describes work performed under Contract NAS8-29076 sponsored by the Research and Process Technology Division of NASA Marshall Space Flight Center, Alabama.

SUMMARY

This report presents the results of a successful development program for a 25-conductor flat conductor signal cable and a 3-conductor flat conductor power cable. The program began with a thorough characterization of candidate materials, followed by a prototype phase which included fabrication technique development testing and analysis of prototype cables. The program ended with the fabrication of 3000-foot production lengths of each cable followed by testing and anlaysis.

CONTENTS

I. TECHNICAL DISCUSSION

A. Introduction

The highest continuous temperature rating of flat conductor cable (FCC) available under MIL-C-55543 is 200°C. Flat cables employ conductors made of strip or flattened round copper conductors insulated with polyimide/fluorinated ethylene propylene or polytetrafluoroethylene films. The copper conductors are collated between the insulating films and the composite sealed providing electrical integrity and moisture resistance. Since the polyimide and tetrafluoroethylene films are not thermoplastic, some adhesive medium must be employed. Fluorinated ethylene propylene (FEP) acts as the adhesive to bond the polyimide film, but it is also the limiting factor for temperature resistance. Conductor thickness ranges from 0.003 to 0.010 inch, which requires a substantial amount of FEP material to completely encapsulate conductors and provide a composite bond. Since FEP is thermoplastic, it begins to soften and loses mechanical strength at temperatures above 200°C.

Any insulation system development is integrally dependent on the method of FCC fabrication. The initial approach consisted of individually insulating the conductors to withstand the electrical and mechanical environments at all temperatures; then it was intended that the conductors be woven into a flat configuration with a carrier which would maintain spacing and assist in mechanically strengthening the composite. In addition, the cured insulation system would not only be resistant to temperatures up to 350°C and abrasion and cut-through resistant, also could be stripped readily from the flat conductor. Ultimately, any system developed must be applicable to production manufacturing techniques.

B. Woven Cable Development

1. Material Characterization

After a thorough survey of existing material systems, 8 polyimide resin based materials were selected for initial screening. These materials in addition to exhibiting high temperature resistance were capable of being applied in tape or multiple pass liquid varnish form, thus maintaining concentricity in the required thin insulation wall. The resin systems considered are listed in Table I. All materials were first subjected to thermogravimetric analysis (TGA) and their weight loss versus temperature plotted. Figure 1 is the TGA plots of the potential materials. TGA was also conducted on insulation slugs taken from a 26 gauge round wire. This insulation composite consisting of a .1-mil FEP-fluorocarbon resin, 1-mil polyimide film, .1-mil FEP-fluorocarbon resin tape, single layer wrap with a 2/3 overlap, and a 0.001-inch aromatic polyimide ("Liquid H") resin coating was heat aged at 350°C for 25, 40 and 60 hours. The 25-hour specimen exhibited slight stiffening of the polyimide overcoat when subjected to extreme flexing. Stiffening and embrittlement of the insulation system increased as the temperature exposure time increased. An examination of the TGA plots showed that the polyimide film by itself was capable of resisting degradation beyond 500°C under short term conditions. This was the most heat resistant material tested and represents the best choice of an insulation material.

The thermogravimetric analysis (TGA) conducted at a heating rate of 3°C/minute showed an initiation of weight loss at 400°C with a sharp drop-off starting about 460°C. The TGA equipment was then modified to hold a constant temperature of 350°C and weight loss was measured versus exposure time. Figure 2 shows the results of that test. A total weight loss of 20% was obtained after 98 hours exposure. Since the stripped insulation slugs present more exposed insulation area to the environment, the weight loss obtained is worst case and not representative of actual usage conditions therefore it was agreed to conduct the tests on insulated wire samples in air and in a vacuum, at 300°C and 350°C for 200 hours. In addition, it was decided to remove insulated wire samples at selected intervals and conduct a bend test around a mandrel whose diameter is ten times the wire diameter with a subsequent immersion dielectric test at 1500 volts (rms). The total insulation weight loss incurred averaged 4.69 percent after 312 hours, however, insulation dielectric breakdown progressively degraded to a failure at 500 volts.

TABLE I

CANDIDATE INSULATION MATERIALS

Figure Number	Resin System	Condition
1	Rhodia Kerimid 501 Polyamide-imide film	Cured 24 hours @ 250°C
2	Rhodia Kerimid 500 Polyamide-imide Varnish	Cured 24 hours @ 250°C
3	DuPont "Liquid H" Polyimide	Cured 24 hours @ 250°C
4	DuPont KAPTON Polyimide Film	As received
5	Wire Insulation Composite	As received
6	Fluorinated Ethylene Propylene Film	As Received

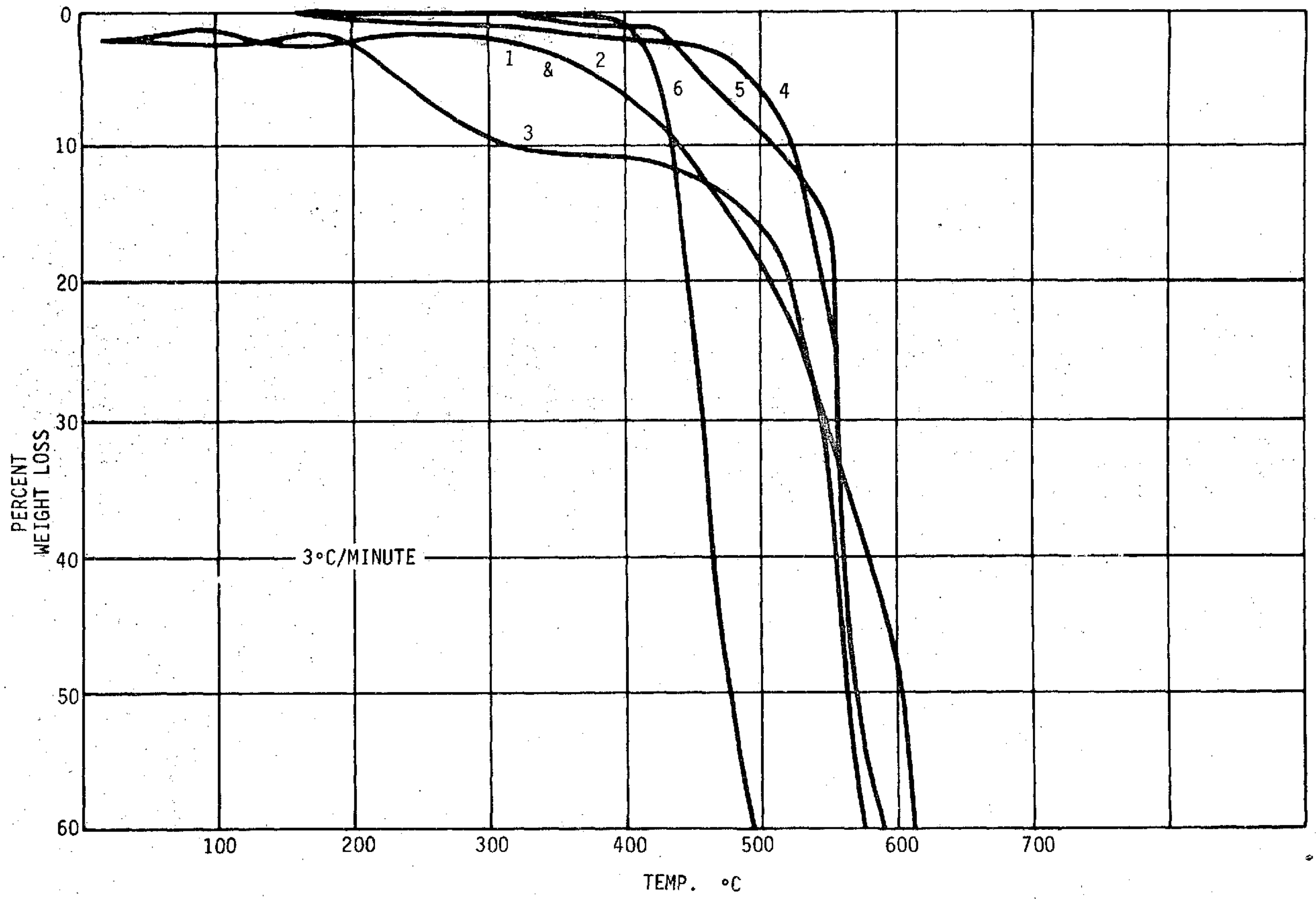

Figure 1. Thermogravimetric Analysis of Candidate Materials

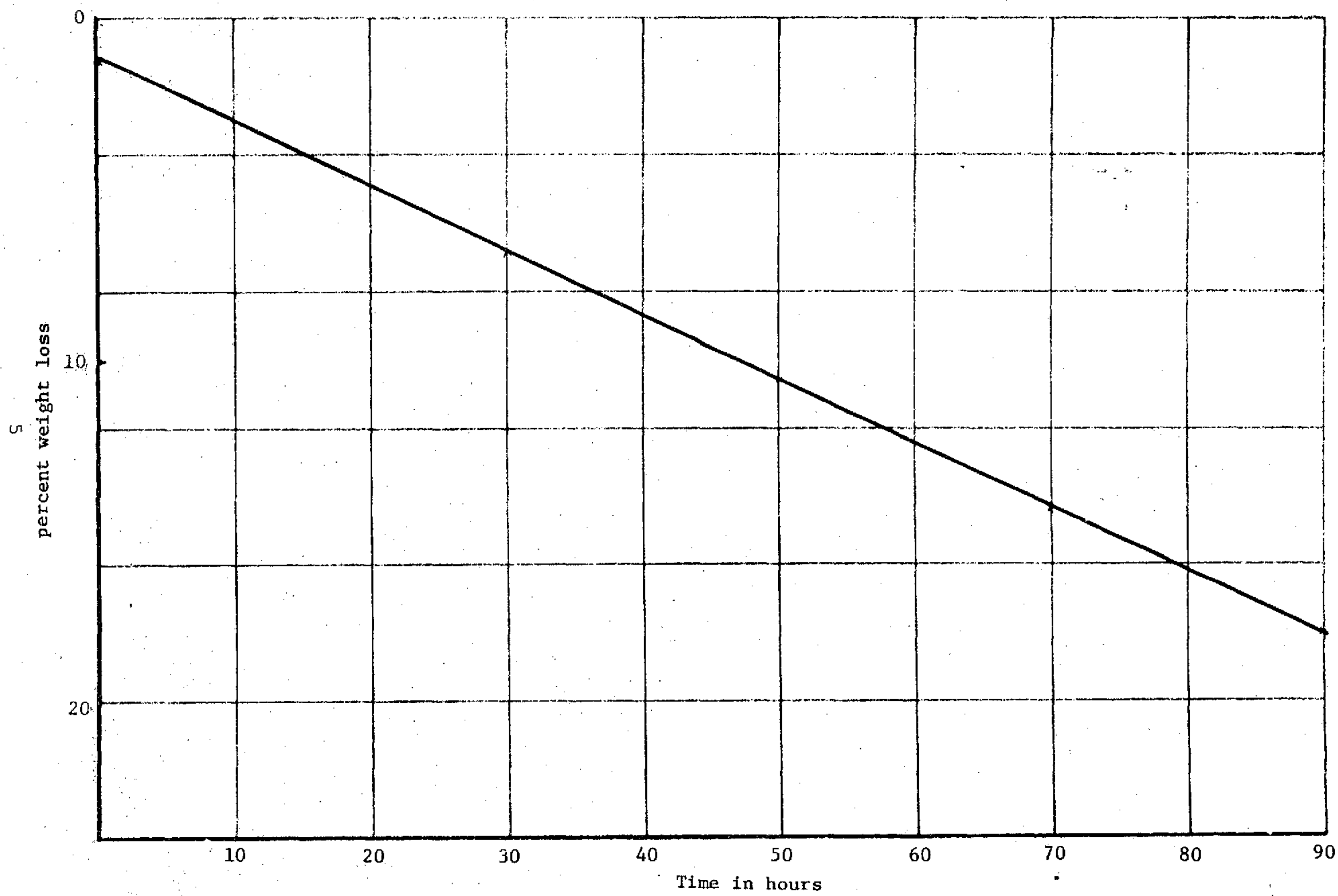

Figure 2. Weight Loss at 350°C

From the data it was concluded that the FEP (0.1 mil) and polyimide film construction was sufficiently heat resistant to meet program requirements, and that the "Liquid H" overcoat enhanced the heat resistance of the composite under functional conditions by reducing the debonding stresses on the FEP coating. The "Liquid H" however, embrittled after long term aging, and a polyamide-imide varnish supplied by Rhodia Corporation under the trade name Kerimid 500 was evaluated to determine its resistance to embrittlement under the same conditions.

The Kerimid 500 polyamide-imide varnish was applied to the round wire construction, composed of 0.1-mil FEP-Fluorocarbon resin coated on both sides of 1-mil polyimide film, tape wrapped with a 2/3 overlap and overcoated with 1 mil of liquid polyimide resin. The polyamide-imide material is more flexible than the "Liquid H", and it was hoped that the construction would be less brittle under aging at 350°C. Specimens were subjected to 350°C for 24, 40, and 60 hours and examined for embrittlement and cracking. The 24 hour specimens appeared to be less brittle with the amide-imide than the "Liquid H", but the 40-and 60-hour specimens showed little difference.

As a further measure of useful life, specimens taken during the above thermal exposures were subjected to dielectric withstanding and insulation resistance testing. From these data a profile of the useful life of the FEP bonded construction under the following conditions was obtained:

1 350°C in air - 100 hours

2 350°C in a vacuum - 150 hours (5×10^{-4} torr)

3 300°C in air - >120 hours

4 300°C in a vacuum - 230 hours (5×10^{-4} torr)

2. Design Specification

Based on the results of these analyses woven flat conductor cable design specification drafts were developed. These drafts were coordinated with potential subcontractors and MSFC technical monitors, and the version shown in Appendix A was finalized.

C. Roll Laminated Cable Development

1. Material Characterization

During the analysis phase of the woven cable development, it was learned that a polyamide-imide adhesive coated polyimide film had become available from Atlantic Laminates, Inc. The adhesive was a dry film version of the Kerimid 500 liquid system that was tested as a preinsulated wire overcoat and the polyimide film was the same DuPont Kapton also tested in the preinsulated wire development. Samples of 2-mil insulation film coated with 2 mils of adhesive were obtained and a short length of cable using 0.004 X 0.040 inch conductors was laminated. This cable was subjected to 300°C and 350°C aging tests in air and vacuum and showed a slightly greater loss in vacuum under comparable temperatures and times when compared with the tape wrapped version. The laminated construction remained flexible even after 288 hours at 350°C in air. As a result of the tests, the following aging profile was developed.

1 350°C in air - >190 hours

2 350°C in a vacuum - >250 hours (5×10^{-4} torr)

3 300°C in air - >140 hours (test discontinued)

Based on the success of these tests an attempt was made to order more coated film from Atlantic Laminates. They had discontinued the product, but a new source was found. Circuit Materials Corp. had developed an identical product and was making it available in continuous lengths so that if practical temperatures and dwell times could be developed the product would be adaptable to roll laminating.

Results of tests performed characterizing the temperature resistance of FEP/Kapton film and polyimide-amide adhesive coated Kapton film were reviewed at a meeting with the contractor and MSFC technical personnel.

General agreement was reached that if the polyamide-imide adhesive coated Kapton film could be adapted to the roll laminating process, it would present the better construction approach to a high temperature FCC than a tape wrapped pre-insulated and woven FCC. The advantages of a roll laminated cable are:

1 Better control of dimensional requirements

2 Easier processing

3 Easier termination

4 Lower cost.

2. Preprototype Development

It was agreed to pursue a feasibility study to determine the roll laminating capabilities of polyamide-imide adhesive coated Kapton film. Film material was ordered from Circuit Materials Corporation to be drop-shipped to the laminator, Parlex Corporation Methuen, Mass., where an experimental run was conducted.

The experimental roll lamination was conducted at Parlex with the contractor's task leader, a technical representative from MSFC and a representative from the adhesive supplier (Rhodia) present. A wide range of variables were investigated and included preheat of the adhesive coating of the film as controlled by the time against the rollers, the speed of tape traveling between the rollers, the pressure of the rollers on the tape, and the surface of the film that is laid against the rollers.

The condition of the bond of the adhesive to the polyimide film was poor prior to laminating. The coated film supplier stated that it was common but that when the two films are passed through the roll laminater the bond would improve.

While greater than 10 combinations of parameters were tried, the basic results were always the same. At temperatures below 290°C the appearance of the laminated films was good with very few voids discernable. As the temperature of the rollers was increased the voids became more numerous until at over 345°C the bonding layer was totally blistered. Attempts were made to drive off solvent in the adhesive prior to reaching the rollers, however little success was achieved. In addition, while the bond after laminating was somewhat greater than the initial bond supplied by Circuit Materials, the final result was not considered acceptable.

In an attempt to determine the effect of post cure on the bonded films, a specimen that had been roll laminated at 290°C was placed in an oven at 230°C. After approximately 1-1/2 hours no appreciable increase in bond strength was noted. The remainder of the bonded film was placed back in the oven for further post cure. After 4-1/2 hours exposure in the oven the specimen was again examined and the bond was found to be considerably improved.

Subsequent to this additional attempts were made using the same material with variations to the post cure and laminating conditions.

The first attempt was made using silicone rubber rollers at 190°C and 1.2 feet per minute laminating speed. Various roll pressures were tried in order to eliminate bubbles. However, at pressures sufficient to eliminate bubbles the alignment of conductors could not be held constant and the rubber roller approach was abandoned.

Using steel rollers at 1.2 feet per minute and holding the temperature at 175°C, the conductors continued to "swim" when sufficient roll pressure was applied to reduce voids. By decreasing the temperature to 163°C and maintaining the same pressure, swimming was reduced while voids were eliminated. At 150°C an increase in pressure was again required to eliminate voids and conductor swimming returned.

With no post cure the bond of the Kerimid to Kerimid was adequate while that of the Kerimid to Kapton was not. When post cured at 230°C for 4 hours the material composite shrank longitudinally and bubbles appeared in the Kerimid to Kapton interface. When post cured at 175°C for 4 hours shrinkage was reduced and neither voids nor bubbles appeared. Under the latter conditions the bond of Kerimid to Kapton was substantially increased.

Based on these findings 3-conductor and 25-conductor prototype cables were laminated. Both cables, while passing water immersion dielectric strength testing, exhibited marginal bonding of the adhesive layer to the insulating film and did not show a complete encapsulation of the conductors by the adhesive. Nonetheless, the cable was a distinct improvement over the original prototype attempt.

The results of these experiments clearly demonstrated the feasibility of roll laminating a flat conductor cable capable of meeting program technical requirements by using the polyamide-imide adhesive on the polyimide insulation film. There remained, however, two major problems. The first concerned the elimination of bubbles during lamination and after post cure and the second concerned the improvement of the Kerimid to Kapton bond.

Based on limited runs performed at MSFC which utilized adhesive coated film that had been dried for 15 minutes at 120°C, there was an indication that bubble free lamination may be achieved by using a film containing something less than the 23% solvent supplied in the film used for the initial runs.

In an effort to verify this theory three lots of Kapton film coated with Kerimid containing 28%, 20.4% and 9.9% solvent were shipped to Parlex. Unfortunately, attempts to produce a suitable cable with the low solvent material was unsuccessful since the flow of the Kerimid was drastically reduced. It was apparent that in order to obtain adequate tack and flow of the Kerimid at reasonable pressures and temperatures (175°C) greater than 20% solvent was required.

At the same time a parallel investigation was being conducted into means for improvement of the Kerimid to Kapton bond. While it was significant that the material to date had been processed with the adhesive on the glossy side of the Kapton film, the most important factor in developing an improved bond was the discovery that 3-mil film exhibited substantially better and more consistant bondability than the 2-mil film. Examination of the surfaces of 2-and 3-mil Kapton film using the scanning electron microscope (SEM) exposed no significant difference in surface roughness between the films. When questioned as to the reason for the difference in bondability between the films DuPont specialists were unable to explain it, however, they were aware of this fact. In addition, their experience shows that 5-mil Kapton has the greatest bondability and the 1 mil has the least. From this point, it was agreed that 3-mil Kapton would be used for all future cable and that a 2-to 3-mil thick layer of Kerimid adhesive would be used for the next prototype cables.

3. Design Specifications

While preliminary drafts of the roll laminated FCC design specification had been submitted to MSFC and to the laminator, sufficient data and experience had been obtained at this point to draft a finalized version of the specifications for use in the fabrication and inspection of prototype and production cables. This draft is presented in Appendix B.

4. Prototype Development

In the fabrication of the first prototype cables, several approaches using combinations of rubber rollers and steel rollers were tried. The most successful cable fabricated was a 25-conductor version using two steel rollers at 175°C and 2 feet per minute. This cable had good adhesion to all interfacing materials and the fill between conductors was excellent.

Although the fill and adhesion of the three conductor cable was considerably better than that previously supplied, the rubber roller did not sufficiently deform the Kapton film to ensure fill of the Kerimid adhesive against the edge of the wide conductor. A grooved steel roller was considered a necessity for future 3-conductor cables.

The validity of this decision was verified by the fabrication of the next 3-conductor prototype. The effect of the grooved rollers was apparent with fill along the edges of the conductors complete and the interlaminar bond excellent.

With both prototype cables successfully laminated it remained for a post cure cycle to be developed that would drive out the solvent without adversely affecting the interlaminar bond of the cable and without introducing bubbles in the adhesive layer.

The solvent content in the adhesive layer after lamination is still approximately 15%. This solvent, which is N-Methyl Pyrolidone, if allowed to remain will cause severe blistering when the cable is subjected to the 350°C test temperature. A great deal of effort was expended to develop a practical post cure cycle. It was found that a long term low temperature cure was necessary prior to implementing shorter term higher temperature steps. It was further determined that any attempt to accelerate release of the solvent by shortening the time at elevated temperature would cause blistering. The time-temperature relationship for the 25-conductor cable post cure cycle was finalized as follows:

1 120°C - 16 hours, 175°C - 4 hours, 200°C - 4 hours,

2 230°C - 4 hours, and 260°C - 24 hours.

The final consideration in the optimization of the cure cycle was the elimination of the severe darkening of the Kapton film as the result of the post cure. This problem was overcome by continuously purging the curing oven atmosphere with nitrogen. While there remained a certain degree of darkening the cured cable was completely translucent and not opaque as was the cable that was cured in air. The use of nitrogen also eliminated slight embrittlement of the film that was noted after the post cure in air.

It was expected that the post cure cycle developed for the 25-conductor cable would also be applicable to the 3-conductor cable. Unfortunately, the additional thickness of adhesive that results along the edge of the 0.010 inch thick conductor contains a proportionately greater amount of solvent which must be released slowly if bubbles are to be prevented. The 250°F starting temperature was too high for this cable and after much testing the following cycle was selected:

24 hours at 68°C, 8 hours each at 94, 108, 121, 135, 149, 178, 204, and 232°C, and 24 hours at 260°C.

Even after this extended cure small bubbles were observed in the adhesive layer adjacent to the conductor. Exhaustive testing was undertaken in an attempt to eliminate these bubbles, however, there is apparently no way to completely avoid the evolution of randomly dispersed 1 mm and smaller diameter bubbles. The bubbles occur on an average of less than one per centimeter; they do not interlock and have no effect on stripping, moisture pickup, or electrical properties. While they can be detected using unaided vision under ideal lighting conditions, actual observation must be done at greater than 7X.

Both the 25-conductor and 3-conductor prototype cables were subjected to the tests specified in the contract technical requirements 1-2-65-28028. The results of these tests are shown in Appendix C. As noted in the moisture resistance tests of the 25-conductor cable the presence of even small amounts of residual solvent can degrade the insulation resistance of the cable in a high humidity environment. The NMP is hygroscopic and apparently causes the adhesive to retain an abnormal amount of moisture. This can be overcome by adequate post curing.

5. Production Lot Fabrication and Test

With the successful fabrication and test of the prototype cables it remained for the 3000-foot production lots to be fabricated. Based on the thorough background and experience gained in the development of the previous cables no major problems arose in the fabrication of these production cables. Due to this being the first attempt at long lengths moderate difficulties were encountered while attempting lengths over 100 feet, however, the following percentages of various lengths were produced:

3 conductor - over 100 feet - 72%, over 50 feet - 14%, over 25 feet - 14%
25 conductor - over 100 feet - 50%, over 50 feet - 12%, over 25 feet - 38%

Testing of the production cables was successfully completed after post curing using the cycles previously developed. The results of the tests are noted in Appendix D.

6. Insulation Stripping Development

As part of the overall program, methods for stripping the insulation from conductors to be terminated in connectors were investigated. Two basic approaches were considered in an effort to provide the most practical method.

The first approach considered mechanical methods similar to those presently used on polyimide-fluorinated ethylene propylene and polyester polyethylene insulated cables. The equipment used included the NASA developed precision knife edge stripping tool, a commercial knife edge stripping tool, and an abrasive wheel stripping tool. The knife edge tools could be adjusted to remove the insulation and the adhesive away from the conductor a large percentage of the time; however, the adhesive bonded so well to the conductors that occasional skips in the stripping process occured making this methods inconsistant. In addition these strippers could not remove the adhesive which remained between conductors. The abrasive stripper could be adjusted to remove the insulation, but the mechanical strength of the adhesive was such that when the pressure was set sufficiently high to remove it, the conductor was damaged.

The second approach consisted of soaking the ends of the cable in various chemical strippers. The strippers that were most effective where caustic in nature and included potassium hydroxide, sodium hydroxide, and Decap (Dynalloy, Inc.). The solutions were tried at various temperatures up to 95°C. The most successful combination was potassium hydroxide heated to 95°C. The cable was prepared by first wrapping tetrafluoroethylene adhesive tape around the cable at the point where the stripping was to stop. The tape acted as a resist and provided a reasonably clean stripping line. The cable end was immersed in the solution for a period of approximately 15 minutes then removed. After this time, the composite insulation-adhesive was sufficiently dilated and softened so that it could be removed by brushing under water with an acid brush. The stripped end was then dipped in a dilute solution of acetic acid followed by flushing in running water. This method was used in the latter prototype testing and the production cable testing and provided consistant results.

II. CONCLUSIONS

The many material, design, fabrication, and analysis factors involved in the successful development of flat conductor cables capable of operation at temperatures of 350°C have been assessed in this program. While it was the original goal of the program to produce the cables using preinsulated flat conductors woven together using high temperature yarns, it is of major significance that through the innovative application of new adhesive materials and processing techniques it was ultimately possible to provide roll laminated cables similar to those presently used for lower temperature applications.

Following are several conclusions that have been reached as a result of this program:

1 The release of solvents at the edge of the conductors in the power cable causes bubbles to form because the insulation film which bridges the adhesive at this point cannot draw down to conform to the reduced adhesive film thickness. A thinner insulation film or the absence of a discrete film would eliminate this problem.

2 Grooved rollers are a necessity in the fabrication of cables utilizing conductors with thicknesses of 0.010 inch and greater.

3 Electrical characteristics are adversely affected by even low residual solvent levels in the finished cable.

4 The composite insulation adhesive system developed during this program will successfully meet electrical and mechanical test requirements at temperatures up to 350°C.

5 An inert gas atmosphere or a vacuum is required during post cure in order to prevent excessive darkening and embrittlement of the insulation film.

III. RECOMMENDATIONS

While production lengths of each cable have been successfully fabricated, there remain several areas that require investigation if greater producibility, reliability, and reduced cost are to be achieved. These include:

1 It was demonstrated that the subject cables could be made using 0.003 inch thick polyimide film, however, greater flexibility and a thinner crossection could be achieved if a 0.001 or 0.002 inch thick film were used. In order to achieve this improvement, methods must be developed to improve the bond of the adhesive to the thinner films.

2 Solvent contents of 25% or greater enable lamination at relatively low temperatures, however, the high post lamination solvent content requires time-consuming and costly post curing. Methods should be developed that will enable lamination at higher temperatures and lower solvent contents.

3 The polyimide film used as the primary insulation in the present cables presents interlaminar bonding problems and acts as a solvent barrier during lamination and post cure. It is recommended that studies into the feasibility of using only the polyamide-imide adhesive film for both adhesive and insulation be undertaken.

4 The batch curing of coils of laminated cables, while feasible, is slow and costly and requires large oven space for production quantities. It is recommended that a continuous inline post cure process be developed.

APPENDIX A

Woven Flat Conductor Cables - Design Specification

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REVISIONS

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Rev Status of Sheets

Con No. NAS8-29076
Drawn by R Taylor Dept. 5430 Date 2-8-72
Checker

Program Approval

Customer Approval

MARTIN MARIETTA CORPORATION
Orlando, Florida 32805

WIRE, ELECTRIC, POLYIMIDE INSULATED, FLAT COPPER CONDUCTOR

SIZE	CODE IDENT NO.	
A	04939	43020

Scale None Sheet 1 of 3

FIGURE I. - WIRE CONFIGURATION

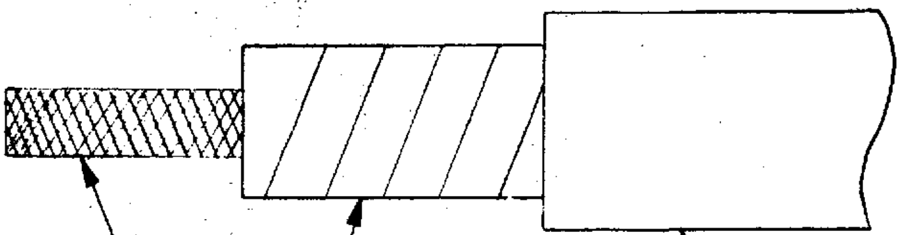

TABLE I. - CONSTRUCTION

DASH NUMBER	CONDUCTOR			FINISHED WIRE			INSULATION WRAP	
	CONDUCTOR THICKNESS MIN. (in)	CONDUCTOR THICKNESS MAX. (in)	CONDUCTOR WIDTH ±0.002 (in)	WIRE THICKNESS MAX. (in)	WIRE WIDTH MAX. (in)	MAX. RES. AT 20°C (OHMS/1000 FT.)	TAPE CODE	MIN. % OVER-LAP
-1	0.0035	0.004	0.040	0.016	0.054	60.9	.1-1-.1	66 2/3
-2	0.0096	0.010	0.560	0.022	0.574	2.0	.1-1-.1	66 2/3

SIZE	CODE IDENT NO.	
A		WIRE, ELECTRIC, POLYIMIDE INSULATED, FLAT COPPER CONDUCTOR
SCALE None	REV	SHEET 2 of 3

REQUIREMENTS

The complete requirements for wire described herein shall consist of this document and the issue in effect of Specification MIL-W-81381.

CONDUCTOR MATERIAL:	The conductor material shall be bare strip-conductor in accordance with the requirements of MIL-C-55543.
WIRE CONSTRUCTION:	Conductor dimensions, insulation material and dimensions, and wire construction shall be in accordance with Figure I and Table I.
LAMINATION SEALING:	No delamination at 350° ± 15°C - 25 hours.
INSULATION FLAWS (SPARK TEST):	2000 volts (rms).
DIELECTRIC TEST:	1500 volts (rms).

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Con No. NAS8-29076

Drawn by R. Taylor Dept. 5430 Date 72

Checker

Program Approval

Customer Approval

MARTIN MARIETTA CORPORATION
Orlando, Florida 32805

CABLE, ELECTRICAL, CONTROL, FLAT, FLEXIBLE, POLIMIDE INSULATED, BARE STRIP-COPPER CONDUCTOR, 600 VOLT, 350°C

SIZE	CODE IDENT NO.	
A	04939	43021

Scale None Sheet 1 of 4

FIGURE I - CABLE CONFIGURATION

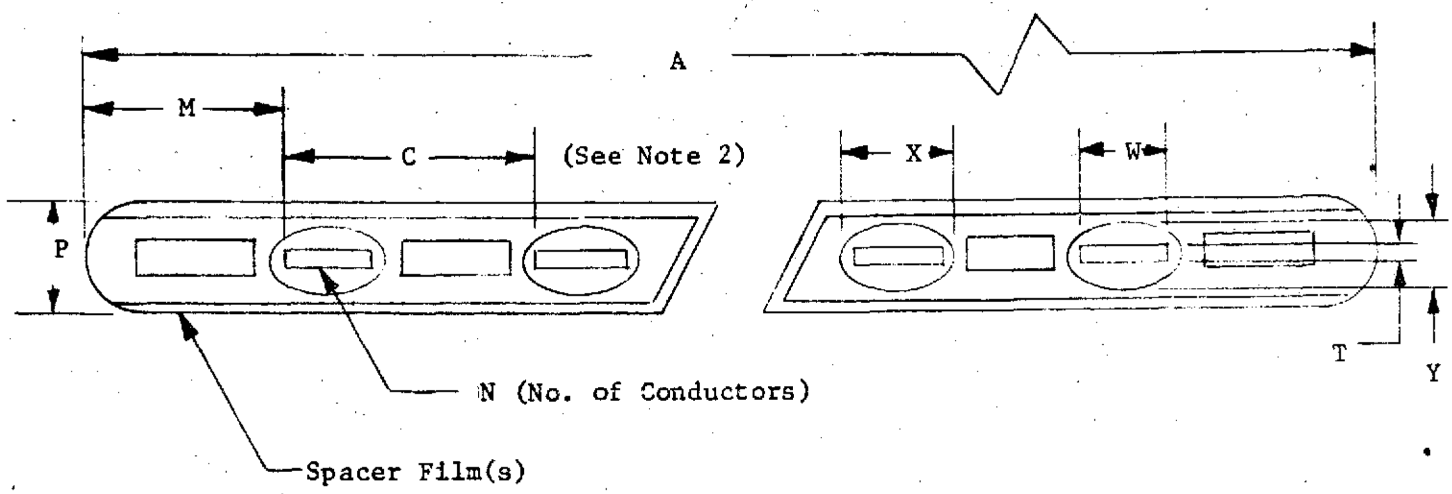

TABLE I

CONSTRUCTION DETAILS

"N" Number of Conductors	Cable Width "A" ±0.005	Cable Margin "M" ±0.005	Basic Spacing "C" ±0.005 (Note 2)	Cable Thickness "D" Max.	Conductor Cross Sec. "T" "W" +0.0000 -0.0005 ±0.002	Insulation Cross Sec. "X" "Y" Max.	Nearest AWG Wire Size (Note 3)	Maximum Conductor Resistance ohms/1000ft at 20°C
25	2.000	0.080	0.075	0.020	0.004x0.040	0.054x0.016	27	60.9

Notes: 1. All dimensions in inches. Equivalent metric dimensions can be obtained by multiplying the specified inch dimension by 2.540 to obtain centimeters.
2. "C" dimension, typical, noncumulative.
3. Based on conductor cross-section.

SIZE	CODE IDENT NO.	
A		CABLE, ELECTRICAL, CONTROL, FLAT, FLEXIBLE, POLIMIDE INSULATED, BARE STRIP-COPPER CONDUCTOR, 600 VOLT, 350°C
SCALE None	REV	SHEET 2 of 4

REQUIREMENTS

The complete requirements for procuring the cable described herein shall consist of this document and the latest issue of Specification MIL-C-55543.

TEMPERATURE RATING: 350°C (662°F) Max. conductor temperature

VOLTAGE RATING: 600 volts (rms)

PREINSULATED CONDUCTOR: Shall conform to Drawing 43020-1

CABLE CONSTRUCTION: Preinsulated conductors shall be woven into a flat configuration each conductor lieing in the same plane within 0.3 MILS and meeting the dimensional requirements of Table I.

WEAVE CONSTRUCTION: Twill weave

FILL FIBER: High temperature polyimide (NOMEX)

SPACER FILM(S): Polyimide film per MIL-P-46112, Type I

COMPLETED CABLE: A 6 foot long cable specimen shall meet the following requirements:

(1) The FCC when placed horizontally and unrestricted on a flat surface, shall conform to this surface longitudinally at all points to within 0.5 inches (max.).

(2) The FCC shall have no bowing or bending in the transverse direction, while unrestricted, greater than 0.060 inches per 2 inch width.

(3) While unrestrained, the FCC shall not have any excessive oil canning.

(4) With the FCC laying on a flat surface, apply a tensile load of 4 pounds to the specimen. The amplitude of any wave in the cable longitudinally shall not exceed 0.030 inches.

(5) With the FCC specimen pressed against a flat surface, the camber, or curve in the longitudinal axis of the cable, shall not exceed 0.060 inches per foot.

CONDUCTOR RESISTANCE: See Table I

INSULATION RESISTANCE: 500 Megohms-1000 feet (min.)

DIELECTRIC WITHSTANDING VOLTAGE: 1500 Volts (rms)

SIZE	CODE IDENT NO.	
A		CABLE, ELECTRICAL, CONTROL, FLAT, FLEXIBLE, POLIMIDE INSULATED, BARE STRIP-COPPER CONDUCTOR, 600 VOLT, 350°C
SCALE None	REV	SHEET 3 of 4

INSULATION FLAWS:	500 volts (rms)
THERMAL SHOCK:	-55° ± 5°C, 350° ±15°C, insulation shrinkage 1/8 inch (max.) Either end of specimen 1500 volts (rms) dielectric withstanding voltage.
FLAMMABILITY:	200 inches/min. (max), self-extinguishing within 10 seconds.
MOISTURE RESISTANCE:	Insulation resistance 50 megohms - 1000 fet. (min.)
FLEXING ENDURANCE:	-55° ± 5°C, 350° ± 15°C 800 cycles (min.)
MINIMUM LENGTH:	Cable shall be delivered in minimum lengths of 100 feet, unless otherwise specified.

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Program Approval	
Customer Approval	

MARTIN MARIETTA CORPORATION
Orlando, Florida 32805

CABLE, ELECTRICAL POWER, FLAT, POLYIMIDE INSULATED, BARE STRIP-COPPER CONDUCTOR, 600 VOLT, 350°C.

SIZE	CODE IDENT NO.	
A	04939	43022

Scale | Sheet 1 of 4

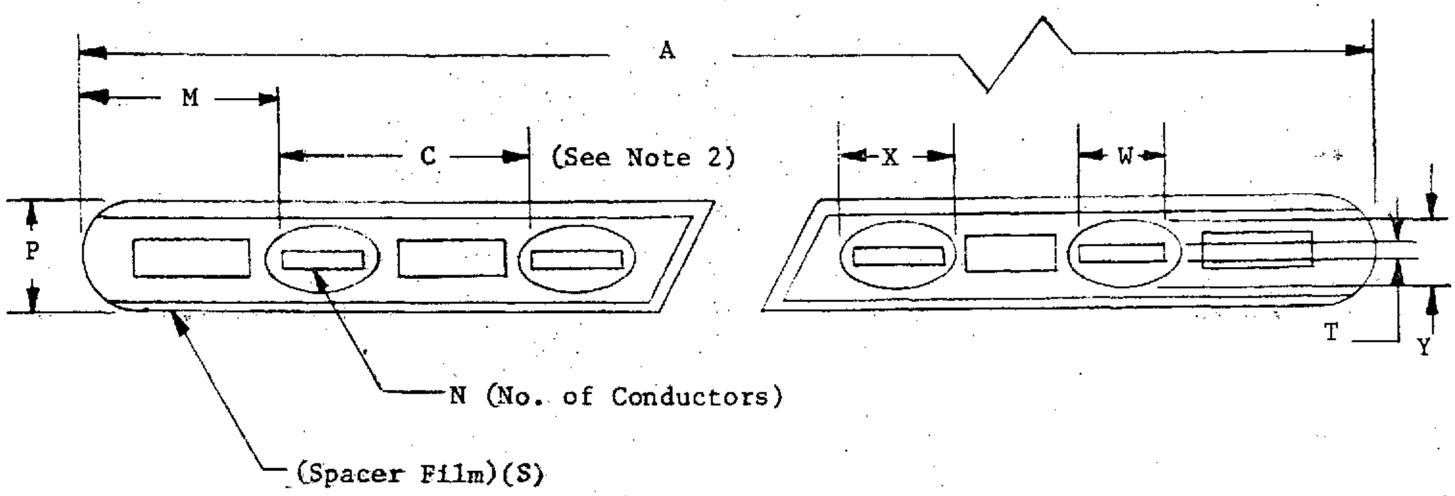

TABLE I

CONSTRUCTION DETAILS

"N" Number of Conductors	Cable Width "A" ±0.005	Cable Margin "M" ±0.005	Basic Spacing "C" ±0.005 (Note 2)	Cable Thickness "D" Max.	Conductor Cross Sec. "T" "W" +0.0000 -0.0006 ±0.002	Insulation Cross Sec. "X" "Y" Max.	Nearest AWG Wire Size (Note 3)	Maximum Conductor Resistance ohms / 1000 ft. at 20°C
3	2.000	0.075	0.075	0.026	0.010x0.560	0.574x0.022	12	2.0

Notes:
1. All dimensions in inches. Equivalent metric dimensions can be obtained by multiplying the specified inch dimension by 2.540 to obtain centimeters.
2. "C" dimension, typical, noncumulative.
3. Based on conductor cross-section.

SIZE	CODE IDENT NO.	
A		CABLE, ELECTRICAL POWER, FLAT, POLYIMIDE INSULATED, BARE STRIP-COPPER CONDUCTOR, 600 VOLT, 350°C
SCALE	REV	SHEET 2 of 4

REQUIREMENTS

. The complete requirements for procuring the cable described herein shall consist of this document and the latest issue of Specification MIL-C-55543.

TEMPERATURE RATING:	350°C (662°F) maximum conductor temperature
VOLTAGE RATING:	600 volts (rms)
PREINSULATED CONDUCTOR:	Shall conform to Drawing 43020-2
CABLE CONSTRUCTION:	Preinsulated conductors shall be woven into a flat configuration each conductor lieing in the same plane within 0.13 MILS and meeting the dimensional requirements of Table I
WEAVE CONSTRUCTION:	Twill weave
FILL FIBER:	High temperature polyimide (NOMEX)
SPACER FILM(S):	Polyimide film per MIL-P-46112, Type I
COMPLETED CABLE:	A 6 ft. long cable specimen shall meet the following requirements:

(1) The FCC when placed horizontally and unrestricted on a flat surface, shall conform to this surface longitudinally at all points to within 0.5 inches (max.)

(2) The FCC shall have no bowing or bending in the transverse direction, while unrestricted, greater than 0.060 inches per 2 inch width.

(3) While unrestrained, the FCC shall not have any excessive oil canning.

(4) With the FCC laying on a flat surface, apply a tensile load of 4 pounds to the specimen. The amplitude of any wave in the cable longitudinally shall not exceed 0.030 inches.

(5) With the FCC specimen pressed against a flat surface, the camber, or curve in the longitudinal axis of the cable, shall not exceed 0.060 inches per foot.

CONDUCTOR RESISTANCE: See Table I

SIZE	CODE IDENT NO.	
A		CABLE, ELECTRICAL POWER, FLAT, POLYIMIDE, INSULATED, BARE STRIP-COPPER CONDUCTOR, 600 VOLT, 350°C
SCALE	REV	SHEET 3 of 4

INSULATION RESISTANCE:	500 megohms - 1000 feet (min.)
DIELECTRIC WITHSTANDING VOLTAGE:	1500 volts (rms)
INSULATION FLAWS:	500 volts (rms)
THERMAL SHOCK:	-55° ± 5°C, 350° ±15°C, insulation shrinkage 1/8 inch (max.) either end of specimen 1500 volts (rms) dielectric withstanding voltage.
FLAMMABILITY:	2.00 inches/min. (max.), self-extinguishing within 10 seconds
MOISTURE RESISTANCE:	Insulation resistance 50 megohms-1000 ft. (min.)
FLEXING ENDURANCE:	-55° ± 5°C, 350° ± 15°C 800 cycles (min.)
MINIMUM LENGTH:	Cable shall be delivered in minimum lengths of 100 feet, unless otherwise specified.

APPENDIX B

Roll Laminated Flat Conductor Cables - Design Specification

Form Oct71 2013-A

REVISIONS

LTR	SH	DESCRIPTION	DATE	APPROVED
A	2	Table I, Conv. Cross Section, -2 From 0.040 X 0.040 to 0.004 X 0.040	3/19/74	W. Rigling

REV | SH | REV | SH | REV | SH | REV | SH | REV | SH | REV | SH

Rev Status of Sheets

Con No. NAS8-29076

Drawn by R. Perry Dept. Date

Checker W. Rigling 2-12-74

Program Approval W. S. Rigling

Customer Approval

MARTIN MARIETTA CORPORATION
Orlando, Florida 32805

CABLE, ELECTRICAL, FLAT, FLEXIBLE, POLYIMIDE/ POLYAMIDEIMIDE INSULATED, NICKEL COATED STRIP-COPPER CONDUCTOR, 600 VOLT, 350°C

SIZE	CODE IDENT NO.	
A	04939	47025
Scale	2-12-74 3/19/74	Sheet 1 of 3

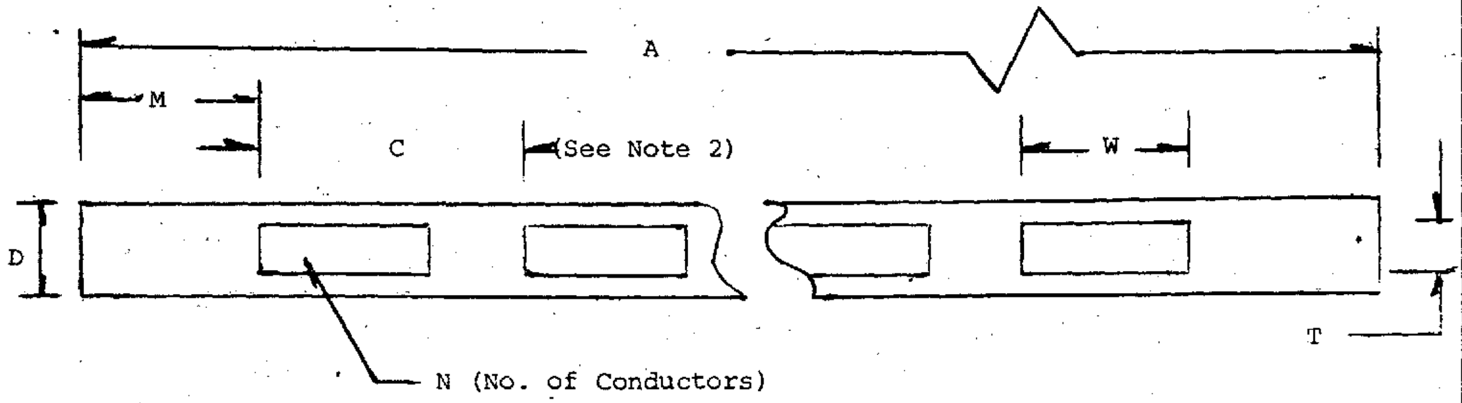

TABLE I

CONSTRUCTION DETAILS

Dash Number	"N" Number of Conductors	Cable Width "A" ±0.005	Cable Margin "M" ±0.005	Basic Spacing "C" ±0.005 (NOTE 2)	Cable Thickness "D" ±0.002	Conductor Cross Sec. "T" "W" ±0.0004 ±0.002	Nearest AWG Wire Size (NOTE 4)	Maximum Condctor Resistance ohms/1000ft at 20°C
-1	3	2.000	0.075	0.675	0.016	0.010 x 0.500	12	1.9
-2	25	2.000	0.080	0.075	0.010	0.004 x 0.040	27	60.9

NOTES:
1. All dimensions in inches. Equivalent metric dimensions can be obtained by multiplying the specified inch dimension by 2.540 to obtain centimeters.
2. "C" dimension, typical noncumulative.
3. Thickness of the insulation on each side of the conductors shall be uniform within 0.001 inch.
4. Based on conductor cross-section.

SIZE	CODE IDENT NO.	
A		47025
SCALE	REV 2-12-74 3-[illegible]	SHEET 2 of 3

REQUIREMENTS

MIL-C-55543 shall apply except as specified.

Temperature Rating: 350°C (660°F) maximum conductor temperature.
Voltage Rating: 600 Volts (rms)

INSULATION: Polyamideimide bonding film with polyimide film overlayer.

CONDUCTOR RESISTANCE: See Table I.

INSULATION RESISTANCE: 500 megohms-1000 ft. (min.)

DIELECTRIC WITHSTANDING VOLTAGE: 1500 Volts (DC).

INSULATION FLAWS: 1500 Volts (rms).

THERMAL SHOCK: -55 ± 5°C, 350° ± 5°C, insulation shrinkage 1/8 inch (max) (either end of specimen), 1500 volts (rms) dielectric withstanding voltage.

FLAMMABILITY: 2.00 inches/min (max), self-extinguishing within 10 seconds.

FLEXING ENDURANCE: 800 cycles @ -55 ± 5°C, 800 cycles @ 350 ± 5°C, 1 inch diameter mandrel.

MOISTURE RESISTANCE: Insulation resistance 50 megohms-1000 ft. (min).

CONDUCTOR ORIENTATION: All conductors must lie in the same plane to within 0.0003 inch.

CABLE LAY CHARACTERISTICS: A 6 foot long cable specimen shall be flat and straight to within the following specifications:

(1) The cable when placed horizontally and unrestricted on a flat surface, shall conform to this furface longitudinally at all points to within 0.5 inches (max).

(2) The cable, while unrestricted, shall have no bowing or bending in the transverse direction greater than 0.060 inches per 2 inch width.

(3) While unrestrained, the cable shall not have any excessible oil canning.

(4) With the cable laying on a flat surface, apply a tensile load of 4 pounds to the specimen. The amplitude of any wave in the cable longitudinally shall not exceed 0.030 inches.

(5) With the cable specimen pressed against a flat surface, the camber, or curve in the longitudional axis of the cable, shall not exceed 0.060 inches per foot.

LOT LENGTHS: Cable shall be delivered in minimum lengths of 100 feet, unless otherwise specified.

SIZE	CODE IDENT NO.	
A		47025
SCALE	REV 2-12-74	SHEET 3 of 3

APPENDIX C

Test Report - Prototype Cables

Test Report

25 Conductor and 3 Conductor Prototype Flat Confuctor Cables

INTRODUCTION

Thirty foot lengths of 25 conductor and 3 conductor, high temperature flat conductor cable conforming to Martin Marietta Corporation drawing Number 47025 were subjected to electrical and environmental tests selected from the technical requirements of NASA Scope of Work Request No. 1-2-65-28028.

TEST REQUIREMENTS AND RESULTS

The tests and requirements were in accordance with MIL-C-55543A unless otherwise noted.

1. The voltage rating of these cables is 600 volts (RMS).

2. Insulation Resistance - shall meet 500 megohms per 1000 feet, per par. 4.6.4.3 per MIL-C-55543A. See Table I.

3. Dielectric Withstanding Voltage - The FCC shall withstand 1500 volts (DC) between adjacent conductors, and all conductors to the external surface when submerged in water as described in paragraph 4.6.4.2 per MIL-C-55543A. Three 40 inch specimens from each cable were tested and passed the test. All Specimens passed.

4. Moisture Resistance - Insulation resistance of 50 megohms per 1000 feet minimum when tested in accordance with par. 4.6.10 per MIL-C-55543A. Three 40 inch specimens from each cable were tested. One 25 conductor specimen which had a normal postcure passed while the two specimens which had an accelerated postcure failed. See Table II.

5. Insulation Flaws - The cable shall not breakdown under a potential of 1500 volts (RMS) when tested in accordance with par. 4.6.4 per MIL-C-55543A. This test was performed by the cable supplier. The cables passed.

6. Thermal Shock - The cables shall be tested in accordance with par. 4.6.6 of MIL-C-55543A and shall meet the following requirements: -55° ± 5°C to 350° ± 150°C without shrinking greater than 1/8 inch, either end of cable, 1500 volts (RMS) dielectric withstanding voltage. Three specimens from each cable were tested. All passed.

7. Flammability - The FCC shall not exceed a 2 inch per minute burn rate and shall be self-extinguishing within 10 seconds in the air when run according to par. 4.6.7, per MIL-C-55543A. Three specimens from each cable were tested. All extinguished immediately after removal of the flame.

8. Flexure Endurance - The finished 25 conductor FCC shall have the ability to withstand bending around a 1 inch diameter mandrel 800 cycles at low temperature (-55 ± 5°C) and 800 cycles at a high temperature of 350 ± 15°C. Since MIL-C-55543 has no requirement for conductors as large as those in the 3 conductor cable 800 cycles was used only as a goal. The cable shall exhibit no degradation (cracking, discontinuity, delamination, etc.). Test shall be accomplished per par. 4.6.8 of MIL-C-55543A. Three specimens of each cable were tested at each temperature. All passed the test with no cracking, discontinuity, delamination or other evidence of degradation with the exception of one 3 conductor specimen which failed at 425 cycles.

CONCLUSIONS

1. The 25 conductor cables conforming to specification 47025 will meet the requirements of NASA Request No. 1-2-65-28028.

TABLE I

Insulation Resistance

Test Conductor Number	Conductor to Water (Megohms/1000 ft) Specimen #1	Specimen #2	Specimen #3	Test Conductor Pair	Conductor to Adjacent Conductor (Megohms/1000 ft) Specimen #1	Specimen #2	Specimen #3
1	5.0×10^9	4.0×10^9	1.0×10^9	1-2	1.0×10^9	3.5×10^{12}	$> 2.0 \times 10^{10}$
2	3.0×10^9	3.0×10^9	1.0×10^9	2-3	1.2×10^9	2.5×10^{12}	"
3	4.0×10^9	2.8×10^9	1.8×10^9	3-4	1.1×10^9	3.0×10^{12}	"
4	5.0×10^9	2.8×10^9	2.0×10^9	4-5	1.2×10^9	4.0×10^{12}	"
5	2.6×10^9	3.2×10^9	2.4×10^9	5-6	1.1×10^9	4.0×10^{12}	"
6	5.0×10^9	4.0×10^9	2.0×10^9	6-7	1.0×10^9	3.5×10^{12}	"
7	4.0×10^9	3.0×10^9	4.0×10^9	7-8	1.0×10^9	4.0×10^{12}	"
8	1.6×10^9	3.0×10^9	1.2×10^9	8-9	9.0×10^8	3.5×10^{12}	"
9	1.2×10^9	3.2×10^9	2.0×10^9	9-10	9.0×10^8	2.5×10^{12}	5.0×10^9
10	1.6×10^9	1.9×10^9	1.4×10^9	10-11	9.0×10^8	1.5×10^{12}	$> 2.0 \times 10^{10}$
11	3.0×10^9	4.0×10^9	4.0×10^8	11-12	1.0×10^9	4.5×10^{12}	"
12	2.0×10^9	3.4×10^9	2.6×10^9	12-13	1.2×10^9	2.5×10^{12}	"
13	1.0×10^9	3.0×10^9	2.0×10^9	13-14	1.4×10^9	3.5×10^{12}	"
14	3.0×10^9	3.2×10^9	5.4×10^8	14-15	1.0×10^9	4.0×10^{12}	"
15	3.0×10^9	4.0×10^9	6.0×10^8	15-16	1.0×10^9	5.0×10^{17}	"
16	3.0×10^9	1.2×10^9	4.4×10^8	16-17	1.3×10^9	4.0×10^{12}	"
17	1.6×10^9	4.0×10^9	1.4×10^9	17-18	1.4×10^9	2.5×10^{12}	"
18	4.0×10^9	5.0×10^9	3.0×10^9	18-19	1.4×10^9	2.5×10^{12}	"
19	4.4×10^9	6.0×10^8	6.4×10^8	19-20	3.0×10^9	2.5×10^{12}	"
20	4.6×10^9	4.0×10	4.0×10^8	20-21	3.0×10^9	4.0×10^{12}	"
21	5.0×10^9	3.2×10^9	2.0×10^9	21-22	3.0×10^9	2.0×10^{12}	"
22	3.0×10^9	3.0×10^9	1.2×10^9	22-23	2.0×10^9	2.5×10^{12}	"
23	5.0×10^9	2.0×10^9	3.2×10^9	23-24	2.0×10^9	3.0×10^{12}	"
24	4.0×10^9	3.0×10^9	1.0×10^9	24-25	3.0×10^9	2.5×10^{12}	"
25	5.0×10^9	8.0×10^8	1.2×10^9				

TABLE II MOISTURE RESISTANCE

Test Conductor Numbers	As Received (Megohms/1000 ft)			After Moisture Cycle (Megohms/1000 ft)			After 24 hours at Room Temp. (Megohms/1000 ft)		
	Specimen #1	Specimen #2	Specimen #3	Specimen #1	Specimen #2	Specimen #3	Specimen #1	Specimen #2	Specimen #3
1-2	3.0×10^{10}	3.0×10^{10}	6.6×10^{7}	9.0×10^{8}	Short	8.4×10^{4}	5.1×10^{7}	Short	7.5×10^{5}
2-3			1.95×10^{7}	1.5×10^{9}	9.0×10^{4}	3.0×10^{4}	4.8×10^{7}	2.25×10^{5}	-
3-4			1.5×10^{5}	1.5×10^{9}	2.4×10^{4}	7.2×10^{4}	6.9×10^{7}	7.5×10^{4}	1.35×10^{5}
4-5			1.65×10^{6}	1.65×10^{9}	4.5×10^{4}	4.2×10^{4}	7.2×10^{7}	5.6×10^{4}	8.1×10^{4}
5-6			2.7×10^{7}	1.65×10^{9}	4.5×10^{4}	4.5×10^{4}	7.5×10^{7}	2.4×10^{5}	8.4×10^{4}
6-7			$>3.0\times10^{10}$	1.3×10^{9}	1.2×10^{5}	9.0×10^{4}	6.6×10^{7}	4.5×10^{5}	8.1×10^{4}
7-8			$>3.0\times10^{10}$	6.6×10^{8}	3.9×10^{4}	1.14×10^{5}	6.0×10^{7}	6.9×10^{4}	1.2×10^{5}
8-9			$>3.0\times10^{10}$	1.3×10^{9}	2.1×10^{4}	3.9×10^{5}	6.3×10^{7}	1.8×10^{5}	5.4×10^{5}
9-10			$>3.0\times10^{10}$	2.1×10^{9}	1.8×10^{4}	4.8×10^{5}	6.9×10^{7}	4.2×10^{4}	6.9×10^{5}
10-11			$>3.0\times10^{10}$	1.8×10^{9}	1.4×10^{4}	1.8×10^{5}	6.6×10^{7}	3.9×10^{4}	2.46×10^{5}
11-12			$>3.0\times10^{10}$	1.8×10^{9}	1.7×10^{4}	8.4×10^{4}	6.0×10^{7}	3.9×10^{4}	1.95×10^{5}
12-13			$>3.0\times10^{10}$	1.5×10^{9}	2.4×10^{4}	8.7×10^{4}	8.4×10^{7}	8.1×10^{4}	2.1×10^{5}
13-14			$>3.0\times10^{10}$	1.8×10^{9}	2.4×10^{4}	2.58×10^{5}	7.2×10^{7}	7.2×10^{4}	6.0×10^{5}
14-15			6.0×10^{9}	1.5×10^{9}	3.6×10^{4}	2.55×10^{5}	1.35×10^{8}	8.1×10^{4}	1.32×10^{5}
15-16			7.5×10^{9}	1.8×10^{9}	2.9×10^{4}	1.44×10^{5}	1.08×10^{8}	1.05×10^{5}	2.4×10^{5}
16-17			3.0×10^{10}	1.8×10^{9}	6.3×10^{4}	1.74×10^{5}	1.38×10^{8}	1.02×10^{5}	2.49×10^{5}
17-18			3.0×10^{10}	1.65×10^{9}	6.3×10^{4}	1.59×10^{5}	1.41×10^{8}	1.8×10^{5}	2.7×10^{5}
18-19			2.4×10^{9}	1.8×10^{9}	5.1×10^{4}	5.4×10^{5}	1.08×10^{8}	1.74×10^{5}	1.05×10^{6}
19-20			7.5×10^{9}	1.9×10^{9}	1.14×10^{5}	2.22×10^{6}	1.11×10^{8}	1.71×10^{5}	6.3×10^{6}
20-21			7.5×10^{9}	1.5×10^{9}	1.8×10^{5}	2.64×10^{6}	1.02×10^{8}	2.4×10^{5}	5.4×10^{6}
21-22			7.5×10^{9}	1.3×10^{9}	3.0×10^{4}	5.1×10^{4}	5.4×10^{7}	1.14×10^{5}	6.0×10^{5}
22-23			$>3.0\times10^{10}$	7.5×10^{8}	5.4×10^{4}	5.4×10^{4}	7.5×10^{7}	1.8×10^{5}	6.9×10^{4}
23-24			$>3.0\times10^{10}$	1.5×10^{9}	1.65×10^{4}	1.02×10^{5}	7.8×10^{7}	2.1×10^{4}	1.2×10^{5}
24-25	$>3.0\times10^{10}$	3.0×10^{10}	1.5×10^{10}	1.95×10^{9}	1.68×10^{4}	1.02×10^{5}	8.1×10^{7}	3.6×10^{4}	2.1×10^{4}

TABLE III

Insulation Resistance - 3 Conductor Cable

Test Conductor Number	Conductor to Water (Megohms/1000 ft) Specimen #1	Specimen #2	Specimen #3	Test Conductor Pair	Conductor to Adjacent Conductor (Megohms/1000 ft) Specimen #1	Specimen #2	Specimen #3
1	3 x 10"	2.8×10^{9}	1.2×10^{9}	1-2	2.6 x 10"	1.5×10^{10}	6.5×10^{9}
2	2 x 10"	3.4×10^{9}	1.8×10^{9}	2-3	3.0 x 10"	1.3×10^{10}	9.0×10^{9}
3	2 x 10"	3.0×10^{9}	1.7×10^{9}				

TABLE IV

Moisture Resistance - 3 Conductor Cable

Test Conductor Numbers	As Received (Megohms/1000 ft)			After Moisture Cycle (Megohms/1000 ft)			After 24 hours at Room Temp. (Megohms/1000 ft)		
	Specimen #1	Specimen #2	Specimen #3	Specimen #1	Specimen #2	Specimen #3	Specimen #1	Specimen #2	Specimen #3
1-2	1×10^{11}	2×10^{12}	2×10^{12}	5×10^{10}	4×10^{11}	2.4×10^{11}	8.0×10^{11}	2×10^{12}	2×10^{12}
2-3	1.1×10^{11}	2×10^{12}	2×10^{12}	3.2×10^{10}	3.8×10^{11}	3.2×10^{10}	5.0×10^{11}	2×10^{12}	2×10^{12}

APPENDIX D

Test Report - Production Cables

Test Report

25 Conductor and 3 Conductor Flat Conductor Cables - Production Lot

INTRODUCTION

Thirty foot lengths of 25 conductor and 3 conductor, high temperature flat conductor cable conforming to Martin Marietta Corporation drawing number 47025 were subjected to electrical and environmental tests selected from the technical requirements of NASA Scope of Work Request No. 1-2-65-28028.

TEST REQUIREMENTS AND RESULTS

The tests and requirements were in accordance with MIL-C-55543A unless otherwise noted.

1. The voltage rating of these cables is 600 volts (RMS).

2. Insulation Resistance - shall meet 500 megohms per 1000 feet, per par. 4.6.4.3 per MIL-C-55543A. See Table I.

3. Dielectric Withstanding Voltage - The FCC sha-1 withstand 1500 volts (DC) between adjacent conductors, and all conductors to the external surface when submergen in water as described in paragraph 4.6.4.2 per MIL-C-55543A. Three 40 inch specimens from each cable were tested.

4. Moisture Resistance - Insulation resistance of 50 megohms per 1000 feet minimum when tested in accordance with par. 4.6.10 per MIL-C-55543A. Three 40 inch specimens from each cable were tested. See Table II.

5. Insulation Flaws - The cable shall not breakdown under a potential of 1500 volts (RMS) when tested in accordance with par. 4.6.4 per MIL-C-55543A. This test was performed by the cable supplier. The cables passed.

6. Thermal Shock - The cables shall be tested in accordance with par. 4.6.6 of MIL-C-55543A and shall meet the following requirements: -55° ± 5°C to 350° ± 150°C without shrinking greater than 1/8 inch, either end of cable, 1500 volts (RMS) dielectric withstanding voltage. Three specimens from each cable were tested.

7. Flammability - The FCC shall not exceed a 2 inch per minute burn rate and shall be self-extinguishing within 10 seconds in the air when run according to par. 4.6.7, per MIL-C-55543A. Three specimens from each cable were tested. All extinguished immediately after removal of the flame.

8. Flexure Endurance - The finished 25 conductor FCC shall have the ability to withstand bending around a 1 inch diameter mandrel 800 cycles at low temperature (-55 $\pm$ 5°C) and 800 cycles at a high temperature of 350 $\pm$ 15°C. Since MIL-C-55543 has no requirement for conductors as large as those in the 3 conductor cable 800 cycles was used only as a goal. The cable shall exhibit no degradation (cracking, discontinuity, delamination, etc.). Test shall be accomplished per par. 4.6.8 of MIL-C-55543A. Three specimens of each cable were tested at each temperature.

CONCLUSIONS

1. The 25 conductor and 3 conductor cables conforming to specification 47025 will meet the requirements of NASA Request No. 1-2-65-28028.

TABLE I

Insulation Resistance - 25 Conductor Cable

Test Conductor Number	Conductor to Water (Megohms/1000 ft) Specimen #1	Specimen #2	Specimen #3	Test Conductor Pair	Conductor to Adjacent Conductor (Megohms/1000 ft) Specimen #1	Specimen #2	Specimen #3
1	1.6×10^9	2.0×10^9	5.4×10^8	1-2	9.3×10^8	3.5×10^9	2.8×10^9
2	1.4×10^9	9.1×10^8	7.9×10^8	2-3	5.8×10^9	3.0×10^9	3.7×10^9
3	1.7×10^9	2.1×10^9	1.5×10^9	3-4	5.8×10^9	2.8×10^9	5.6×10^9
4	1.4×10^9	2.8×10^8	3.0×10^8	4-5	5.6×10^9	2.6×10^9	4.2×10^9
5	1.7×10^9	1.5×10^9	1.6×10^9	5-6	5.4×10^9	2.3×10^9	4.0×10^9
6	1.5×10^9	2.1×10^8	7.0×10^8	6-7	5.6×10^9	2.6×10^9	4.7×10^9
7	1.3×10^9	2.0×10^9	1.1×10^9	7-8	3.3×10^9	3.5×10^9	5.8×10^9
8	1.3×10^9	5.1×10^8	3.3×10^8	8-9	5.6×10^9	3.2×10^9	5.8×10^9
9	1.7×10^9	1.9×10^9	1.2×10^9	9-10	3.5×10^9	3.3×10^9	3.3×10^9
10	8.9×10^8	8.9×10^8	1.2×10^8	10-11	4.2×10^9	3.7×10^9	3.7×10^9
11	5.8×10^8	2.1×10^9	1.3×10^9	11-12	5.8×10^9	4.0×10^9	3.7×10^9
12	1.1×10^9	5.8×10^8	1.9×10^8	12-13	4.7×10^9	4.0×10^9	1.7×10^9
13	1.4×10^9	2.2×10^9	8.9×10^9	13-14	4.7×10^9	3.5×10^9	2.3×10^9
14	7.7×10^8	5.1×10^8	1.6×10^8	14-15	3.7×10^9	3.3×10^9	3.7×10^9
15	1.6×10^9	1.0×10^9	1.4×10^9	15-16	4.2×10^9	2.8×10^9	3.0×10^9
16	6.6×10^8	5.6×10^8	4.2×10^8	16-17	4.0×10^9	3.3×10^9	4.7×10^9
17	1.4×10^9	1.6×10^9	1.1×10^9	17-18	3.5×10^9	3.3×10^9	4.9×10^9
18	1.6×10^9	2.8×10^8	7.0×10^8	18-19	4.0×10^9	2.8×10^9	4.2×10^9
19	1.7×10^9	1.2×10^9	1.1×10^9	19-20	4.0×10^9	3.7×10^9	3.3×10^9
20	9.3×10^8	2.6×10^8	3.5×10^8	20-21	4.9×10^9	2.6×10^8	2.6×10^9
21	1.5×10^9	1.1×10^9	5.6×10^8	21-22	4.0×10^9	1.9×10^9	4.2×10^9
22	1.2×10^9	8.2×10^8	1.5×10^9	22-23	3.5×10^9	1.9×10^9	5.8×10^9
23	1.6×10^9	7.0×10^8	1.9×10^9	23-24	3.5×10^9	1.2×10^9	4.9×10^9
24	1.2×10^9	1.0×10^8	5.6×10^8	24-25	4.0×10^9	2.3×10^9	3.5×10^9
25	7.0×10^8	2.6×10^8	3.0×10^8	25-			

TABLE II

Moisture Resistance - 25 Conductor Cable

Test Conductor Numbers	As Received (Megohms/1000 ft)			After Mositure Cycle (Megohms/1000 ft)			After 24 hours at Room Temp. (Megohms/1000 ft)		
	Specimen #1	Specimen #2	Specimen #3	Specimen #1	Specimen #2	Specimen #3	Specimen #1	Specimen #2	Specimen #3
1-2	1.8 x 1C11	2.5×10^{12}	5.0×10^{12}	$>1.0 \times 10^{13}$	$>1.0 \times 10^{13}$	2.5×10^{12}	$>1.0 \times 10^{13}$	5.0×10^{12}	2.0×10^{12}
2-3	2.0×10^{12}	2.0×10^{12}	5.0×10^{12}	2.3×10^{12}	2.4×10^{12}	8.0×10^{11}	$>1.0 \times 10^{13}$	4.0×10^{12}	2.5×10^{12}
3-4	2.5×10^{12}	2.1×10^{12}	2.5×10^{12}	2.5×10^{12}	8.0×10^{11}	6.0×10^{10}	$>1.0 \times 10^{13}$	2.0×10^{12}	1.4×10^{12}
4-5	1.5×10^{12}	2.4×10^{12}	2.5×10^{12}	$>1.0 \times 10^{13}$	4.0×10^{12}	1.4×10^{10}	$>1.0 \times 10^{13}$	4.0×10^{12}	8.5×10^{10}
5-6	2.1×10^{12}	2.4×10^{12}	5.0×10^{12}	$>1.0 \times 10^{13}$	$>1.0 \times 10^{13}$	3.5×10^{11}	$>1.0 \times 10^{13}$	6.0×10^{12}	1.7×10^{12}
6-7	1.2×10^{12}	1.9×10^{12}	3.0×10^{12}	$>1.0 \times 10^{13}$	5.0×10^{12}	1.2×10^{12}	$>1.0 \times 10^{13}$	6.0×10^{12}	2.5×10^{12}
7-8	5.0×10^{12}	2.4×10^{12}	5.0×10^{12}	$>1.0 \times 10^{13}$	$>1.0 \times 10^{13}$	2.3×10^{12}	$>1.0 \times 10^{13}$	5.0×10^{12}	5.0×10^{12}
8-9	1.7×10^{12}	2.0×10^{12}	2.5×10^{12}	$>1.0 \times 10^{13}$	$>1.0 \times 10^{13}$	2.4×10^{12}	$>1.0 \times 10^{13}$	$>1.0 \times 10^{13}$	3.0×10^{12}
9-10	1.5×10^{12}	1.9×10^{12}	2.5×10^{12}	$>1.0 \times 10^{13}$	$>1.0 \times 10^{13}$	2.5×10^{12}	$>1.0 \times 10^{13}$	$>1.0 \times 10^{13}$	4.0×10^{12}
10-11	1.5×10^{12}	2.2×10^{12}	4.0×10^{12}	$>1.0 \times 10^{13}$	1.0×10^{13}	1.6×10^{12}	$>1.0 \times 10^{13}$	1.0×10^{13}	3.0×10^{12}
11-12	2.3×10^{12}	1.7×10^{12}	3.0×10^{12}	$>1.0 \times 10^{13}$	1.2 x 1-12	2.0×10^{12}	$>1.0 \times 10^{13}$	1.5×10^{12}	3.0×10^{12}
12-13	2.0×10^{12}	1.8×10^{12}	2.5×10^{12}	$>1.0 \times 10^{13}$	$>1.0 \times 10^{13}$	2.5×10^{12}	$>1.0 \times 10^{13}$	1.0×10^{13}	5.0×10^{12}
13-14	1.7×10^{12}	2.0×10^{12}	4.0×10^{12}	$>1.0 \times 10^{13}$	$>1.0 \times 10^{13}$	4.0×10^{12}	$>1.0 \times 10^{13}$	$>1.0 \times 10^{13}$	5.0×10^{12}
14-15	1.5×10^{12}	1.7×10^{12}	4.0×10^{12}	4.0×10^{12}	2.0×10^{12}	2.5×10^{12}	$>1.0 \times 10^{13}$	5.0×10^{12}	3.5×10^{12}
15-16	2.5×10^{12}	2.1×10^{12}	5.0×10^{12}	5.0×10^{12}	2.0×10^{12}	1.0×10^{12}	$>1.0 \times 10^{13}$	1.0×10^{13}	3.5×10^{12}
16-17	2.4×10^{12}	2.1×10^{12}	5.0×10^{12}	$>1.0 \times 10^{13}$	$>1.0 \times 10^{13}$	$>1.0 \times 10^{13}$	4.0×10^{12}	$>1.0 \times 10^{13}$	1.0×10^{13}
17-18	2.5×10^{12}	1.8×10^{12}	3.0×10^{12}	$>1.0 \times 10^{13}$	$>1.0 \times 10^{13}$	2.0×10^{12}	5.0×10^{12}	1.0×10^{13}	3.5×10^{12}
18-19	2.5×10^{12}	1.6×10^{12}	3.0×10^{12}	$>1.0 \times 10^{13}$	$>1.0 \times 10^{13}$	2.5×10^{12}	$>1.0 \times 10^{13}$	$>1.0 \times 10^{13}$	1.0×10^{13}
19-20	3.0×10^{12}	2.0×10^{12}	3.0×10^{12}	$>1.0 \times 10^{13}$	1.0×10^{13}	1.0×10^{13}	$>1.0 \times 10^{13}$	5.0×10^{12}	$>1.0 \times 10^{13}$
20-21	2.5×10^{12}	1.7×10^{12}	2.5×10^{12}	$>1.0 \times 10^{13}$	$>1.0 \times 10^{13}$	1.0×10^{13}	$>1.0 \times 10^{13}$	1.0×10^{13}	1.0×10^{13}
21-22	2.3×10^{12}	2.0×10^{12}	3.5×10^{12}	1.0×10^{13}	$>1.0 \times 10^{13}$	1.0×10^{13}	$>1.0 \times 10^{13}$	$>1.0 \times 10^{13}$	5.0×10^{12}
22-23	2.4×10^{12}	1.8×10^{12}	2.5×10^{12}	$>1.0 \times 10^{13}$	2.5×10^{12}	1.0×10^{13}	1.0×10^{13}	2.5×10^{12}	$>1.0 \times 10^{13}$
23-24	1.5×10^{12}	2.1×10^{12}	3.0×10^{12}	2.5×10^{12}	8.0×10^{11}	5.0×10^{12}	2.5×10^{12}	8.0×10^{10}	$>1.0 \times 10^{13}$
24-25	2.0×10^{12}	2.0×10^{12}	2.4×10^{12}	2.5×10^{12}	2.5×10^{11}	1.0×10^{13}	2.5×10^{12}	1.3×10^{11}	$>1.0 \times 10^{13}$

TABLE III

Insulation Resistance - 3 Conductor Cable

Test Conductor Number	Conductor to Water (Megohms/1000 ft) Specimen #1	Specimen #2	Specimen #3	Test Conductor Pair	Conductor to Adjacent Conductor (Megohms/1000 ft) Specimen #1	Specimen #2	Specimen #3
1	4.7×10^{3}	3.0×10^{8}	5.1×10^{8}	1-2	1.6×10^{9}	5.4×10^{8}	1.8×10^{9}
2	5.1×10^{8}	2.8×10^{8}	4.0×10^{8}	2-3	3.3×10^{9}	1.9×10^{9}	1.6×10^{9}
3	5.1×10^{8}	4.9×10^{8}	4.4×10^{8}				

TABLE IV

Moisture Resistance - 3 Conductor Cable

Test Conductor Number	As Received (Megohms/1000 ft)			After Moisture Cycle (Megohms/1000 ft)			After 24 hours at Room Temp. (Megohms/100 ft)		
	Specimen #1	Specimen #2	Specimen #3	Specimen #1	Specimen #2	Specimen #3	Specimen #1	Specimen #2	Specimen #3
1-2	2.5×10^{12}	2.5×10^{12}	2.5×10^{12}	2.0×10^{11}	2.2×10^{11}	1.5×10^{11}	4.0×10^{11}	1.3×10^{12}	2.0×10^{11}
2-3	2.5×10^{12}	4.0×10^{12}	2.5×10^{12}	1.4×10^{11}	1.6×10^{11}	1.9×10^{11}	3.5×10^{11}	6.5×10^{11}	4.0×10^{11}