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FLAT CABLE ENGINEERING STUDIES FOR SATURN S-IVB VEHICLES

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SPACE SYSTEMS CENTER – HUNTINGTON BEACH, CALIFORNIA

– See: W. Willem Angele, MSFC

Why flat cable not gen'ly used before 1967 in S-IVB
(used on IU; Pegasus)

Gen'l advantages flat cable

- problems encountered

- use other than S-IVB

[Conducive to automatic tooling?]

[any known industrial uses now?]

Angele S&E ME-
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FLAT-CABLE ENGINEERING STUDIES FOR SATURN S-IVB VEHICLES

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ABSTRACT

This paper describes the engineering approaches, investigations, results and conclusions of two National Aeronautics and Space Administration (NASA) flat-cable contracts from the George C. Marshall Space Flight Center (MSFC) to the Douglas Aircraft Company, Inc., for feasibility studies on the S-IVB stage of the Saturn Vehicle. In addition, the objectives and approaches for a third contract, "Flat-Cable Engineering Study", are discussed. A sister Douglas Paper No. 4186, to be presented by Dr. P. L. Hill, covers in detail the manufacturing aspects of the Flat-Cable Development Program.

The Flat-Cable Development Program converted a 180 degree mockup of the Saturn S-IVB aft skirt from round-wire to flat-cable harnesses. Vehicle development, manufacturing and process procedures including fabrication and installation of over 100 flat-cable harnesses, and cost and weight comparisons were accomplished.

The Flat-Cable Application's Program studied the conversion of a proposed Block I S-IVB entire vehicle from round-wire to flat-cable harnesses. Flat-cable harness assemblies, installations, and modifications to electronic units were defined; laboratory tests were performed on electronic subsystems; and weight and cost comparisons were completed.

The Flat-Cable System Engineering Study is to advance the flat-cable technologies for application to current aerospace programs, with a minimum impact on engineering and qualification methodologies at reduced production costs.

INTRODUCTION

Many advances have been made during the past 10 years in the design and development of aerospace electrical components, packaging, and system performance. However, the interconnecting electrical harnesses have remained essentially the same. Improved conductor insulations and higher density connectors have been developed, but basically the design, fabrication, development, and installation of interconnecting wire harnesses have not changed. Figure 1 illustrates a typical conventional round-wire harness installation on the Saturn S-IVB vehicle.

For the past 6 years there has been one challenger, continuously developing and improving, which has as aspirations for the lion's share of future interconnecting aerospace electrical harnesses. Much pioneering development work was accomplished by and under contract to Mr. W. Angele of NASA/MSFC. See references a, b, c, and d. In addition, many other government agencies, aerospace contractors and hardware vendors have expended much talented effort on this promising newcomer. The Institute of Printed Circuits' Handbooks, see references e and f, present a synopsis of this effort.

Although limited application of flat-cable interconnecting harnesses has been made on various programs including: the Saturn Instrumentation Unit, the Pegasus, a unit of the General Dynamics Standard Missile, and others; the general use on aerospace systems has not been accepted. The purpose of the NASA/MSFC contracts with the Douglas Aircraft Company, Inc., has been to accomplish the systematic steps required for general acceptance and use of flat-cable interconnecting harnesses in the aerospace industry.

The development program proved the feasibility of replacing conventional round-wire harnesses with the flat-cable system in a major section mockup of an existing vehicle. Major cost and weight savings were realized, manufacturing procedures were established, and over 100 flat-cable harnesses were fabricated and installed. Figure 2 shows the final development and Figure 3 shows a detailed comparison between round and flat-cable equivalent installations.

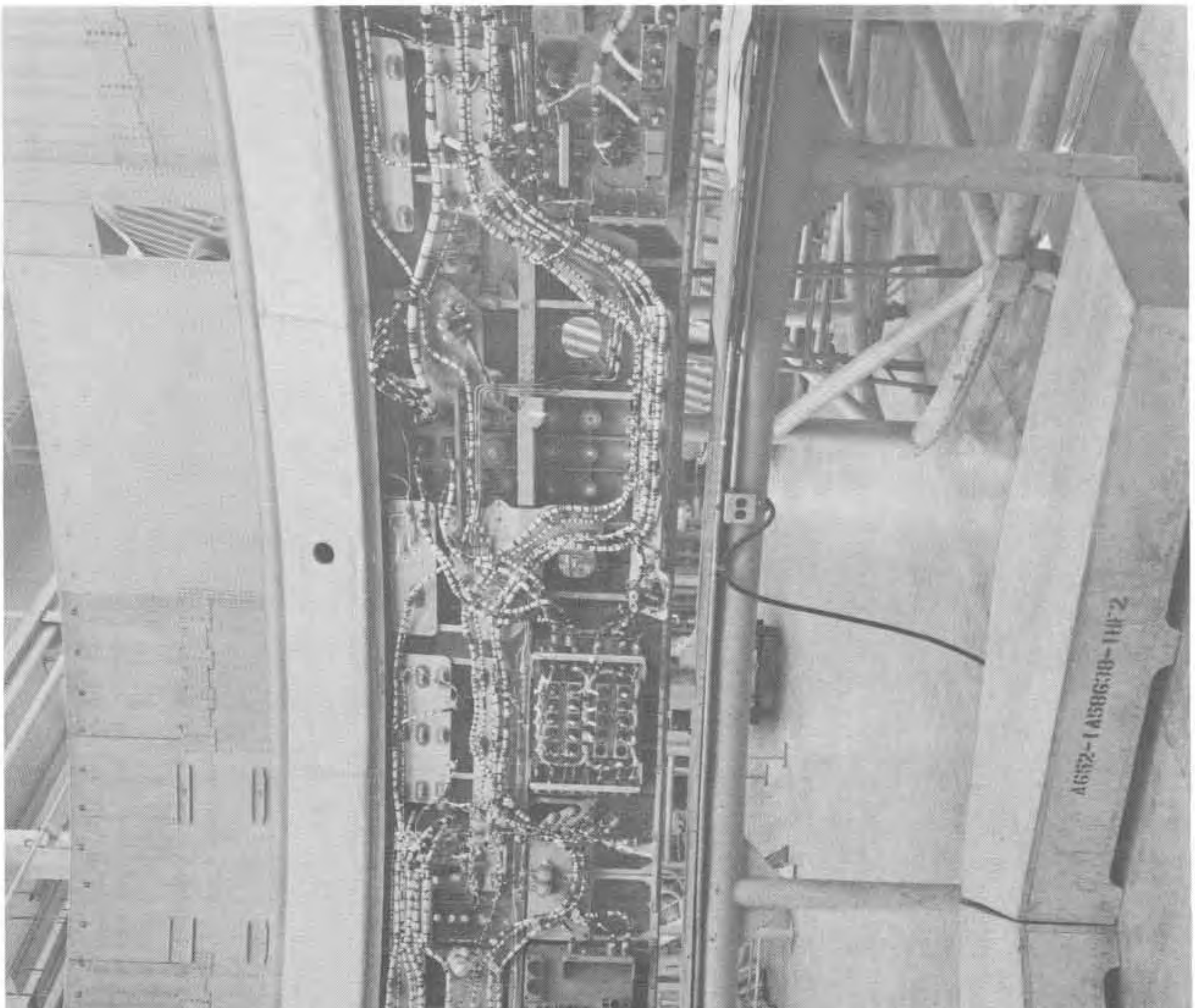

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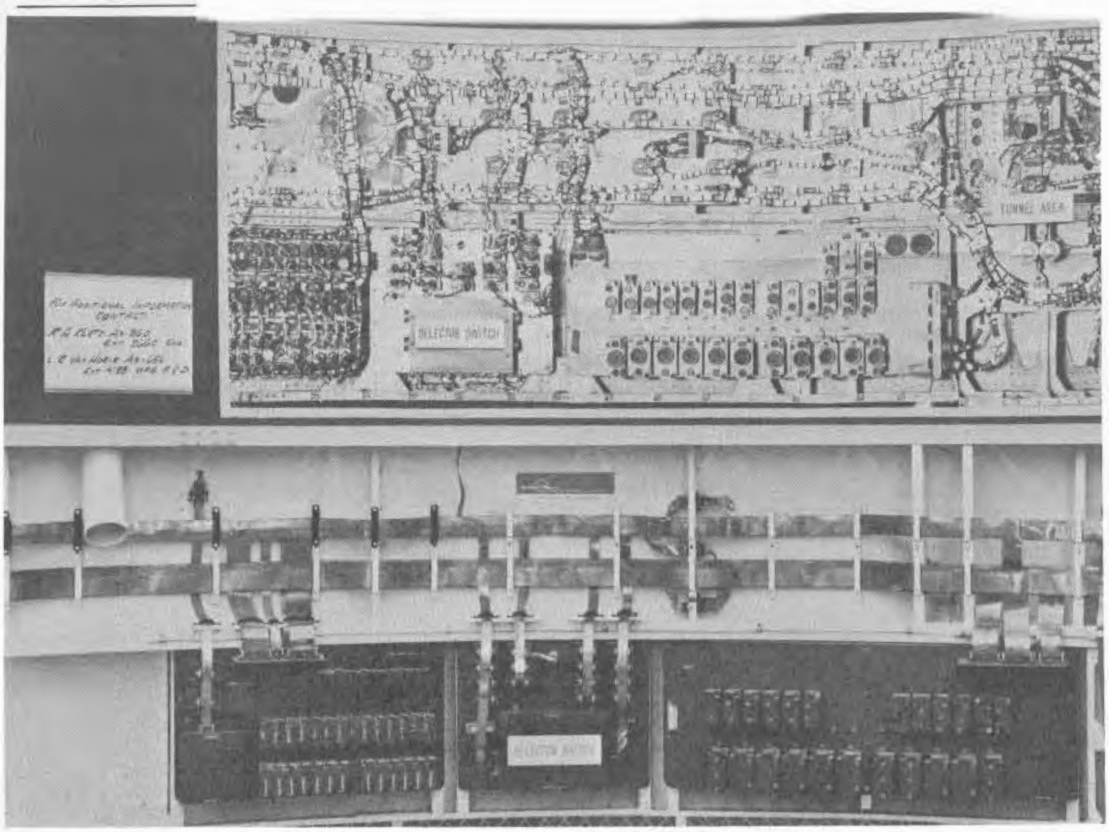
Figure 1. Typical Round-Wire Harness Installation – Saturn S–IVB Vehicle

DAC–20572

Figure 2. Final Flat-Cable Installation

note how much "cleaner"
in photos



SSC-016088 **Figure 3. Flat-Cable Vs Round-Wire Comparison of Equivalent Installations**

The Applications Program determined the effect of replacing the majority of the Saturn S-IVB round-wire harnesses with flat-cable harnesses. Substantial cost and weight savings were again indicated, with reliability improvement from the inherent characteristics of the flat-cable system. Laboratory comparative testing of typical systems proved the acceptability of flat cable for most requirements.

The Engineering Study now in progress will provide the remaining items and data required for general flat-cable application to future aerospace programs. These will include final specifications for cable and connectors, a production shielded termination system, and a flat-cable applications handbook.

GENERAL DISCUSSION

The primary objective of the effort described in this paper was to promote the development and future use of flat-cable interconnecting harnesses on aerospace programs; in other words, to replace the currently used round-wire systems with a lighter weight, lower cost, more reliable flat-cable system, which will also require simpler support structure and will occupy much less installation space. Figure 4 gives a pictorial presentation of the objective conversion.

In addition to the installation advantages of the flat-cable system, another major advantage is the ease and reliability with which the flat cables are terminated into their connectors. Figure 5 gives a pictorial comparison between the methods of harness assembly fabrications. The manual handling of individual conductors for identification, stripping, terminations, and contact insertion is replaced by automatic tooling which performs simultaneous and reliable functions on entire rows of conductors.

The results of the completed development and applications contracts, and the tasks to be accomplished on the engineering study now in progress, are described in detail in the following paragraphs.

FLAT-CABLE DEVELOPMENT PROGRAM

This program authorized by Change Order No. 579 to Contract NAS7-101 started in June 1965 and ended in May 1966. A 180 degree mockup section of the aft skirt of the Saturn S-IVB was converted from conventional round-wire to flat-cable interconnecting harnesses.

Selection of Mockup Section

The electrical/electronic installations in the aft skirt included signal-conditioning racks, sequence control, battery power supplies and distribution, umbilicals, flight disconnects, and tunnel feedthrough. The 180 degree section selected for development with flat-cable included the complete installation, or portions of each of these items, so that all problems associated with an actual development would be encountered.

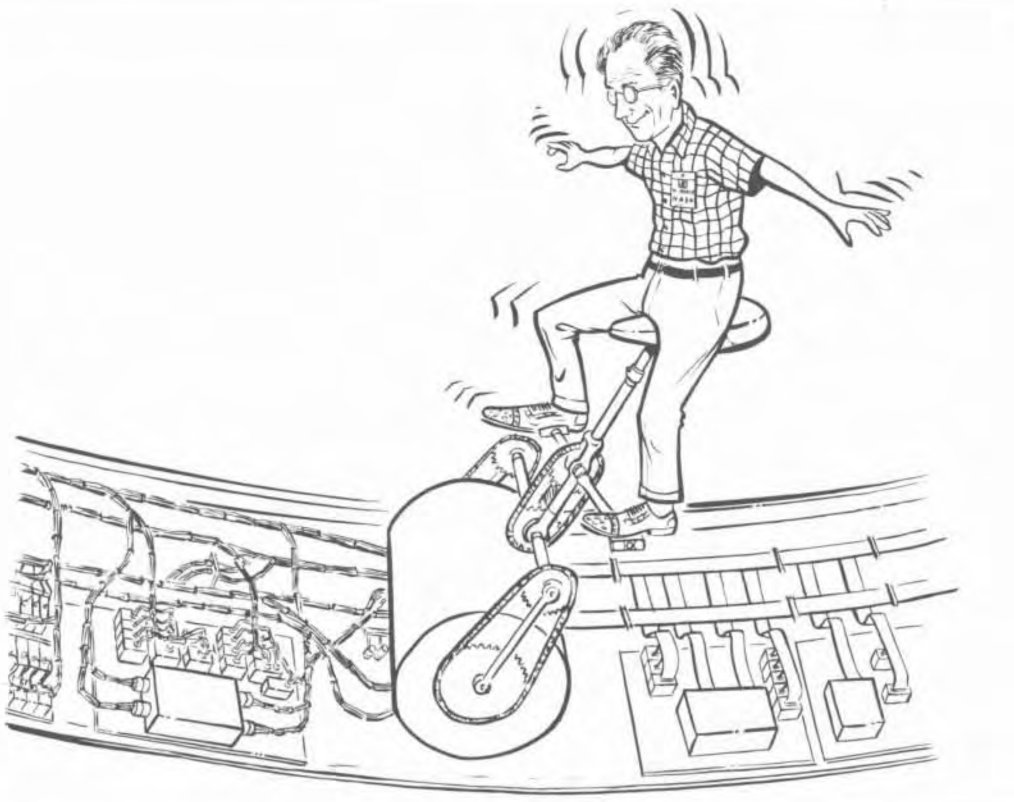


Figure 4. Pictorial Presentation of Conversion From Round-Wire to Flat-Cable Installations (1)

Figure 5. Pictorial Presentation of Comparison Between Methods for Round-Wire and Flat-Cable Harness Assembly (2)

Ground Rules for Circuit Conversion

The following ground rules were used for the flat-cable conversion:

1. Do not convert coaxial cables.
2. Do not convert power cables with wire sizes larger than 16 gage.
3. Delete 50 per cent of all shielded cable requirements. Of the remaining 50 per cent, convert one-half to flat cables shielded both sides; convert the remaining one-half to cables shielded one side.
4. Do not mix flat cable and round cable in the same connector.
5. The umbilical and flight disconnect connectors are to remain round, with those connectors containing wires of 16 gage or less to have flat cable.
6. Blackbox and electronic panels are not to be redesigned internally for flat cable. However, their connectors interfacing with the interconnecting flat-cable harnesses are to be converted.
7. All flat-cable connectors and flat cable are to be per MSFC-SPEC-219 and MSFC-SPEC-220. All mockup cables are to have H-film insulation and .075 centerline conductor spacing. The circuit analysis utilized .075 and .150 centerline spacing as required.

Method Used for Cable Network Layout Design

1. The existing cable network diagrams were revised to include only the 180 degree mockup area. These included both instrumentation and control circuitry.
2. Soft-wire tables were prepared to define all interconnecting conductor requirements in the mockup area. The conductivity, separation, and shielding requirements were included.
3. A scaled layout was prepared for all electronic modules and panels to include all receptacles mating with interconnecting harnesses.
4. Transparent overlays were prepared for each round-wire harness, and then combined for optimum flat-cable interconnecting harness assemblies and flat-cable receptacle sizes and quantities.
5. Flat-cable harness assemblies were defined to include all connectors and each flat cable width and length.
6. A cable network diagram was prepared to define all interconnecting harnesses in the mockup area.

Final Flat-Cable Harness Definition

After the final mockup development and prior to the fabrication of the actual flat-cable harnesses, simplified flat-cable harness drawings were prepared to define the 100 plus cable assemblies. Each cable width and type, as well as each connector size, was defined. The actual lengths, folds, and development were determined from the 10-mil mylar development cables. All harnesses were identified by part numbers and all plugs by item numbers. Since the electronic unit internal conversion was not included in this contract, no attempt was made to include pin assignments in the flat-cable harnesses.

Engineering Evaluation Tests

Certain engineering evaluation tests were performed on hardware developed on this program, to evaluate their worth for flight application. These tests included:

1. The permanent set in metal silicone-cushioned clamps under ambient and temperature cycling (-50°F to +200°F) conditions. A 35 per cent set which reduced to 12 per cent in 4 hours was experienced.
2. Slippage of flat-cable bundles in silicone cushioned metal and Velcro Lap clamps. See figure 6 for clamp picturization. Axial loads of less than 5 pounds for the cushioned clamp and in excess of 17 pounds for the lap clamp were applied without slip or failure.
3. Vibration tests on mockup sections of the flat-cable harnesses and support, including both cushioned and lap clamps. Both sinusoidal and random vibrations in excess of the Saturn requirements were applied to the three principal axes. These, plus major resonances resulting from inadequate fixture design, did not result in specimen failure. The vibration levels are shown on Table 1, and a typical vibration test setup is shown on Figure 7.
4. Electrical tests were performed on two flat-cable assemblies which included both flat-cable and round-wire connectors. The insulation resistance meager readings at 500 vdc averaged 4,500 megohms, with the lowest reading 1,500 megohms. The high-voltage leakage current was measured at 1600 vac, 60 cycles. The leakage current could not be detected on a zero to 10 ma meter.

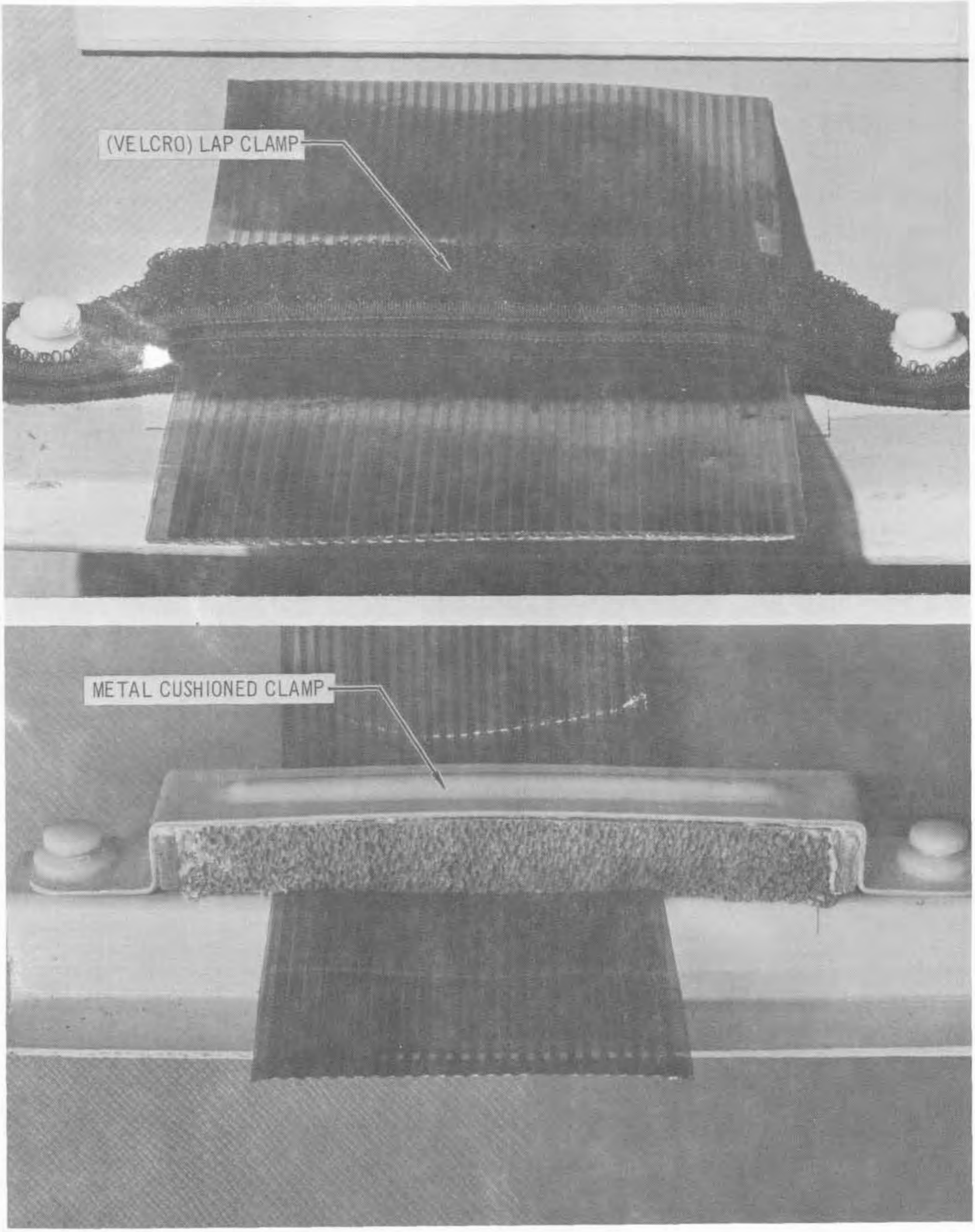


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Figure 6. Silicone Cushioned Metal Clamp and Velcro-Lap Clamp

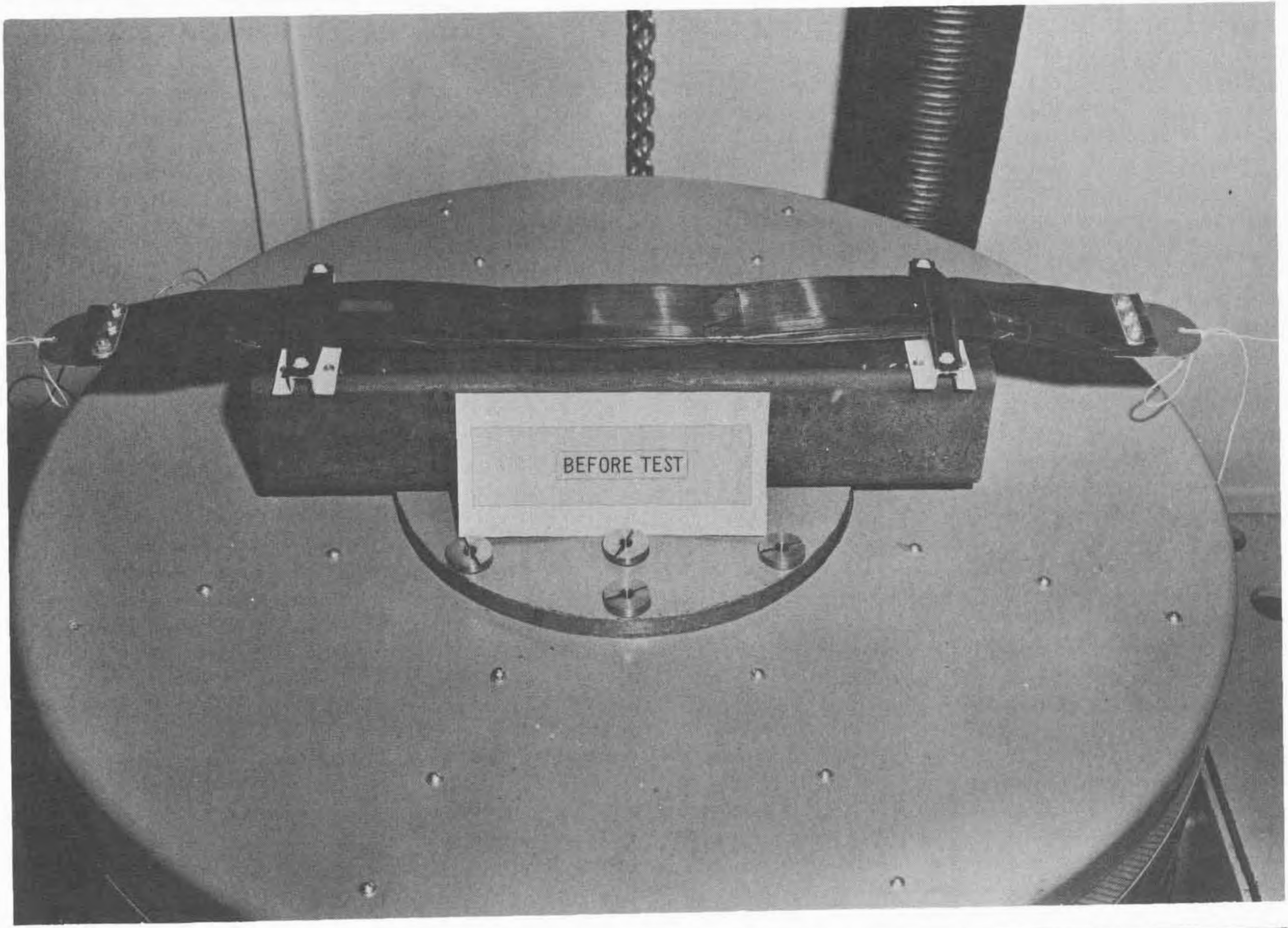

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Figure 7. Typical Vibration Test Setup

TABLE 1

VIBRATION TEST LEVELS AND DURATION

Sinusoidal Sweep Test *	
5 - 47	cps at .05 Inches D. A. Disp.
47 - 200	cps at 6.0 G's peak
200 - 295	cps at .0022 Inches D. A. Disp.
295 - 200	cps at 10 G's peak
Random Vibration Test **	
20 - 85	cps at .065 g^2/cps
85 - 280	cps at 6.3 dba/oct
280 - 1000	cps at .8 g^2/cps
1000 - 2000	cps at -12.0 db/oct

* Scan the given frequency range, logarithmically, at the rate of 1.0 octave/minute from the low frequency to the high frequency and back to the low frequency in each of axis specified above. The input vibration levels, 5 cps to 2000 cps (8 2/3 octaves), are as shown.

** Subject the specimen to the specified random excitation for twelve minutes in each axis specified. The excitation shall be applied as one input over the frequency interval from 20-2000 cps.

Summary

The results of the Development Program indicated the feasibility of converting conventional round-wire to flat-cable harnesses for a typical aerospace program. The resultant harnesses are more economical, weigh less, require simpler and lighter support systems, and are inherently more reliable. Additional effort recommended prior to incorporation on a flight vehicle included:

1. Preparation of final specifications for flat-cable and connectors, to include production shielding systems. Hardware would then be developed, qualified, and available for production use.
2. Include in initial design or redesign electronic units for flat-cable receptacles.
3. Definition of a Detailed Production Drawing Release for Flat-Cable Harnesses.
4. Establishment of a Complete Electrical Network Design System, including pin assignments for early program implementation.
5. Establishment of an Electromagnetic Interference Philosophy.
6. Investigation of Mechanized Design for definition and control of interconnecting harnesses to control cable and connector selection, pin assignments and separation requirements.

FLAT-CABLE APPLICATIONS PROGRAM

This program, authorized by Change Order No. 769 to Contract NAS7-101, ran from January 1966 to September 1966. It considered the conversion of an operational S-IVB vehicle to a proposed Block I vehicle utilizing MSFC H-film flat cable, molded plugs, and receptacles.

Definition of Block 1 Vehicle

The Block I vehicle was to consist of a baseline S-IVB stage which, with addition of suitable mission-oriented modification kits, would provide the necessary mission flexibility. The baseline configuration is defined as the vehicle which represents the "least common denominator" stage that would satisfy the vehicle/modification kit requirement matrix (Figure 8). In general, the major interconnecting harnesses are provided in the baseline vehicle for all kits; those electrical plugs not required are stowed; and distribution units are programmed as required for the desired vehicle configuration.

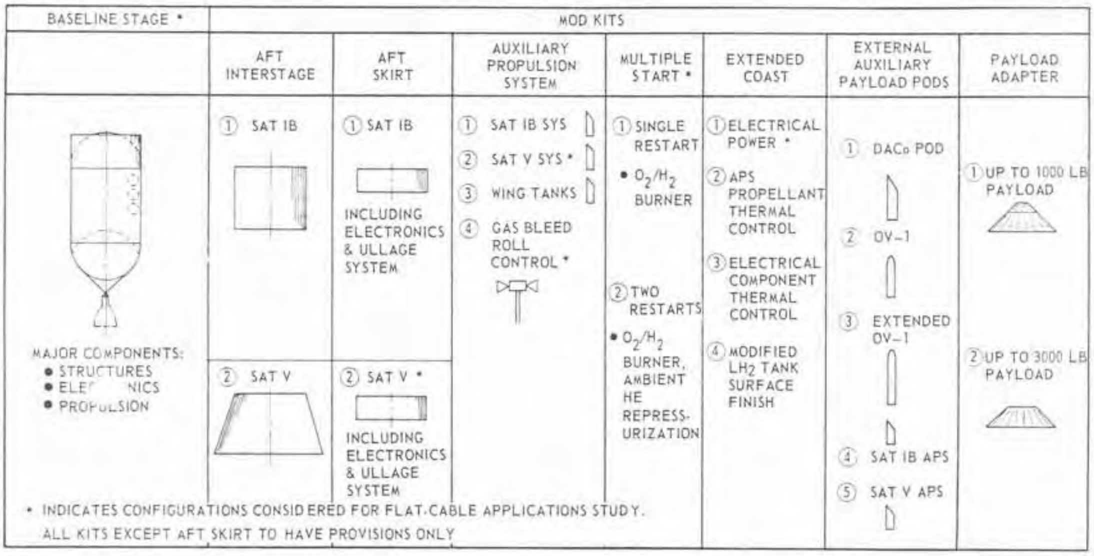

Figure 8. Block I Baseline Stage and Kit Concept

Ground Rules for Conversion

A prerequisite to performing the conversion from round- to flat-cable harnesses was the establishment of conversion ground rules which are listed as follows:

1. Do not convert coaxial cables.
2. Do not convert power cables with wire sizes larger than 16 gage.
3. All flat cable shall conform to MSFC-SPEC-220B; shall have H-film insulation, and shall be on .075 or .150 centerlines.
4. All flat-cable connectors shall conform to MSFC-SPEC-219A and shall include sizes 1 through 3 inches in 1/2 increments in the rectangular version, and 1/4 and 1/2 inch in the round version.
5. Certain existing electronic units, because of their small size and packaging concepts, will not be converted to flat cable connectors. These include transducers, pressure switches and potted modules.

6. The following S-IVB stage interface connectors will remain round:

    a. Forward and aft umbilicals

    b. Aft skirt/aft interstage flight disconnect

    c. J-2 engine interface

    d. APS interface

7. Circuit separation shall be provided by routing into three distinct classes:

Class 1	Class 2	Class 3
28-vdc power	Bi-level signals	5-vdc excitation
56-vdc power return	AC signals (greater than 1 volt)	5-vdc excitation return
28-vdc commands		5-vdc signals
28-vdc talkback		

8. Shielding shall be used for cables having voltages less than 1 volt direct current (these normally terminate in high-impedance circuits), and those having voltages varying more than 50 cps.

Investigation for Added Distributors:

The Development Program illustrated the harness simplification that could be realized by the addition of input-output connectors to electronic panels. The Block I distributors required for mission flexibility would provide further simplification. A comparison study was made early in the program to determine whether additional distributors would be used for the flat-cable system. At the mid-term review, it was decided to use the two additional distributors for simplification of interconnecting harnesses, pin assignments and connector selection; and to provide the maximum system flexibility for mission changes. Table 2 lists the distributor considerations for the various configurations and includes the number of distributors as well as the number of connectors required for each.

TABLE 2

DISTRIBUTOR/CONNECTOR REQUIREMENTS

Distributor	Round Wire Connectors	Flat Cable Connectors	
		Same Number Distributors	With Additional Distributors
Controls			
Forward			
28 V Pwr. Distr.	14	19	14
Controller	7	27	33
Aft			
28 V Pwr. Distr.	17	19	14
56 V Pwr. Distr.	12	10	10
Sequencer	5	15	6
Controller	13	28	20
Distributor No. 4			17
Instrumentation			
Forward			
Distributor No. 1	7	8	17
Distributor No. 2			30
Aft			
Distributor No. 3	13	14	27
TOTAL	88	140	188

Final Harness Definition

The final harness assemblies were defined as follows:

Cable network drawings were prepared showing all electronic units requiring interconnecting cables.

Soft wire information was added to the cable network drawings defining the number, conductivity, separation and shielding of the interconnections.

Scaled layout drawings were prepared showing all electronic units located in their respective installation locations. Using the cable network drawing data, and the ground rules established for conversion, the number, cable sizes and types, and connectors were selected for the flat-cable harnesses.

Cable definition sheets (see Figure 9) were prepared to define each harness assembly with information keyed to the following listing:

A. Existing round-wire cable and plug reference designation
B. Conductor quantity and conductivity requirements
C. Cable length in inches
D. Plug size in inches
E. Number, type, and width of cable
F. Ground lug
G. Cable harness gauge
H. Cable separation
I. Flat-cable transition into a round plug
J. Flat-cable reference designation (two digits for controls, three digits for instrumentation)
K. Mating electronic assembly

The flat-cable harnesses were then added to the scaled layout drawings (see Figure 10).

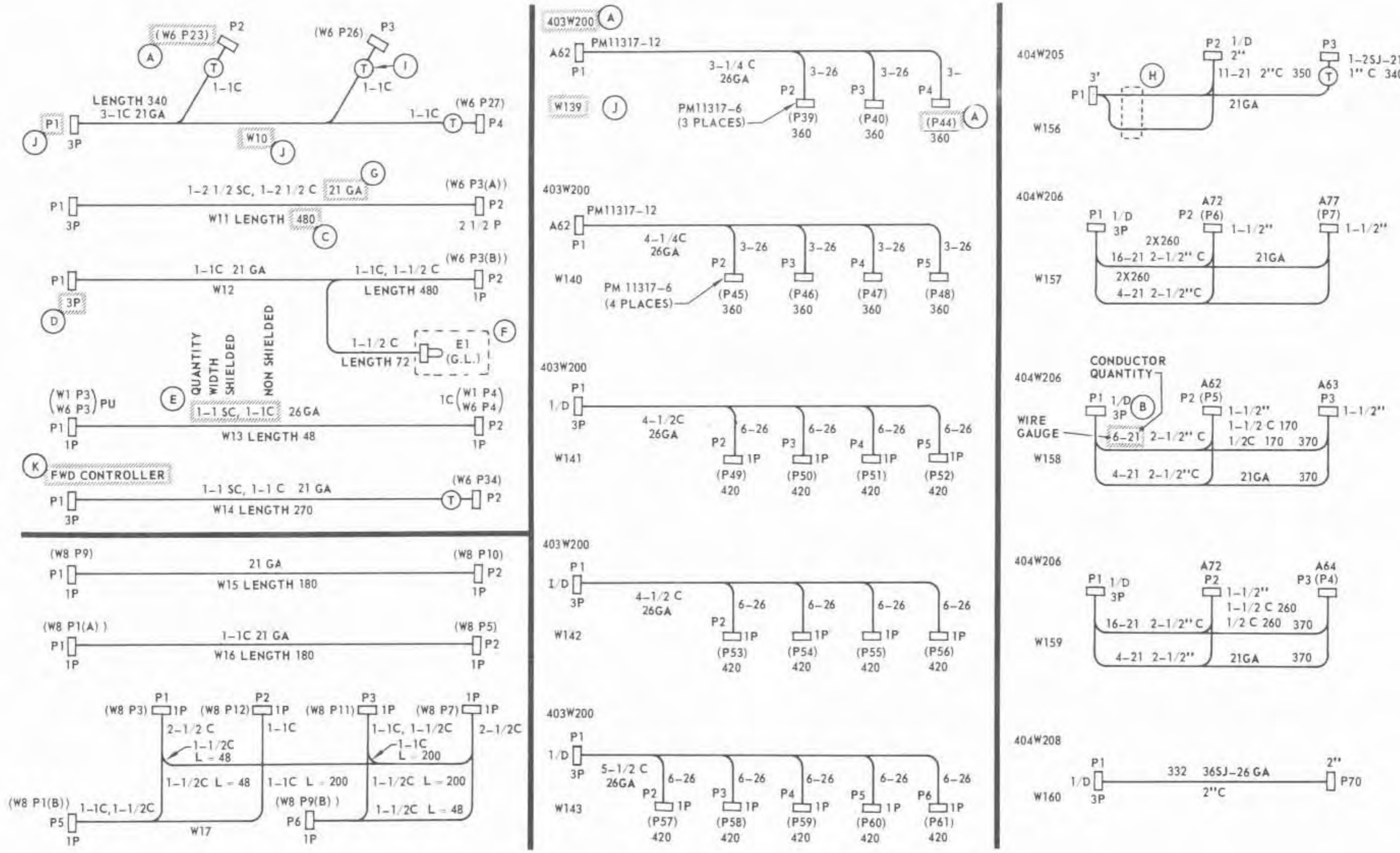

Figure 9. Typical Flat-Cable Definition Sheet

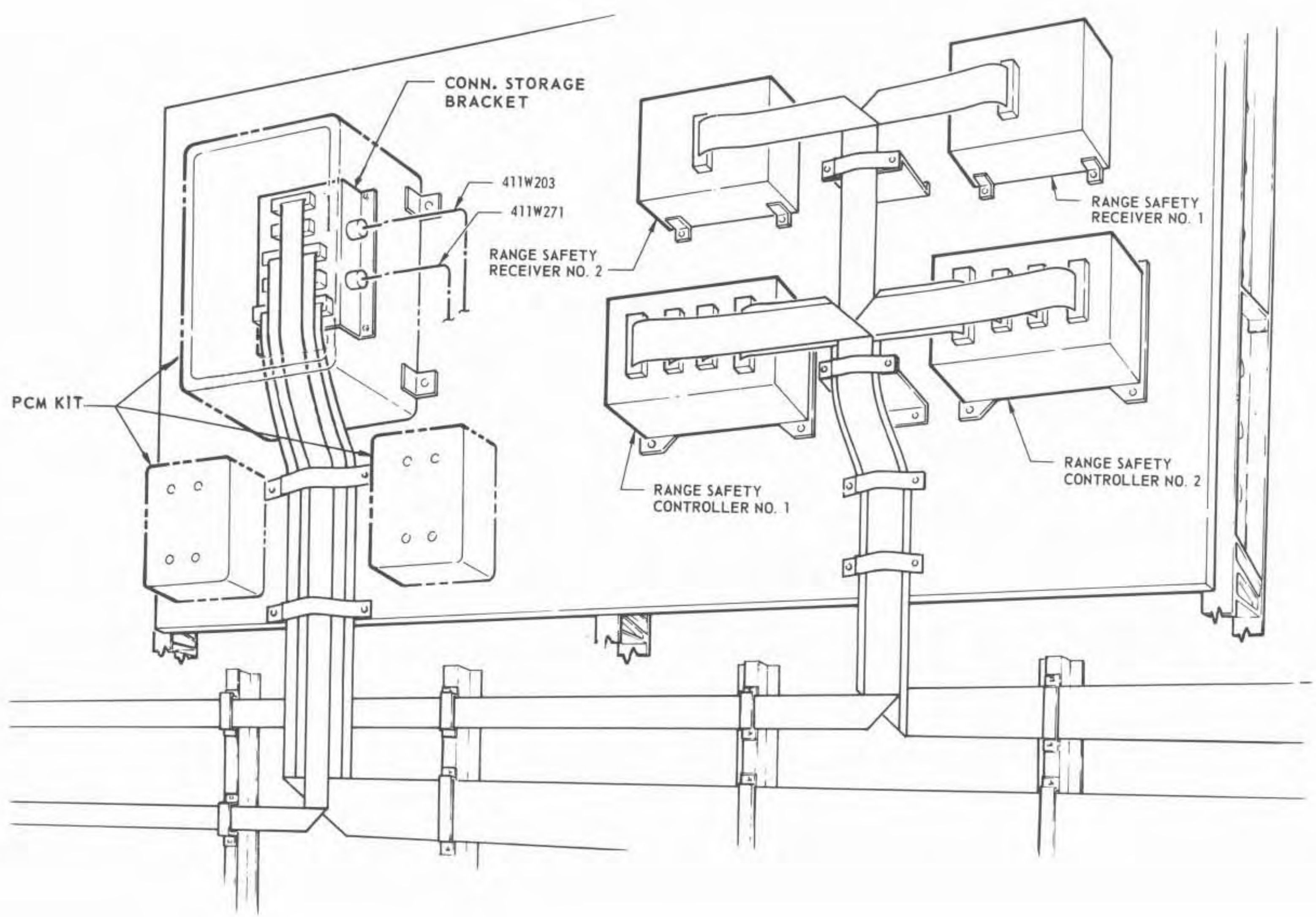

Figure 10. Typical Flat-Cable Installation

Modifications, New Design, and Qualification Testing of Electronic Units

All modified and new electronic units (see Table 3) were categorized into one of the following groups:

Group 1 - Pressurized assemblies requiring replacement of round connectors with flat-cable connectors.

Group 2 - Nonpressurized boxes requiring replacement of round connectors with flat-cable connectors.

Group 3 - Panel assemblies with flat-cable input/output added and/or existing round-wire connectors replaced with flat-cable connectors.

Group 4 - AMP Termi-Point distributors, either newly required or replacing existing panels having bus modules and round-wire input/output connectors.

The qualification tests required for each of these groups were established as shown in Table 4.

The qualification requirements are summarized as follows:

GROUP	NASA DESIGN CONTROLLED	GFP	DOUGLAS DESIGN CONTROLLED
1	1	2	2
2	6	2	0
3	0	0	8
4	0	0	6
TOTAL	7	4	16*

New Hardware Investigation

The new hardware included the design of a typical distributor unit and investigation of various flat-cable to round-wire transitions.

*NOTE: Only 6 units will require qualification testing. The remaining 10 will be qualified by similarity.

TABLE 3 - MAJOR ELECTRONIC UNITS TO BE MODIFIED OR DESIGNED

	GROUP 1	
PART NUMBER	TITLE	NOTES
50M35076	ATTITUDE CONTROL	(2)
50M10697	RANGE SAFETY RECEIVER	(1)
50M10698	DECODER, RANGE SAFETY	(1)
1A59358	P.U. ELECTRONICS ASSEMBLY	
1A66212	INVERTER CONVERTER	
	GROUP 2	
PART NUMBER	TITLE	NOTES
50M61118	REMOTE DIGITAL SUBMULTIPLEXER	(2)
50M60202	REMOTE ANALOG SUBMULTIPLEXER	(2)
50M60061	TIME DIVISION MUX DPIBO	(2)
50M67864	SWITCH SELECTOR	(1)
40M32016	RANGE SAFETY CONTROLLER	(1)
50M60067	PCM/DDAS	(2)
1A740553-503	CHANNEL DECODER	(2)
1A74051-501	CENTRAL CALIBRATION DECODER	(2)
	GROUP 3	
PART NUMBER	TITLE	
1B55688	SIGNAL CONDITIONING PANEL	
1B51354	FORWARD POWER DISTRIBUTOR, 28-VOLT	
1B39550	SEQUENCER	
1B51211	AFT POWER DISTRIBUTOR, 56-VOLT	
1B51354	AFT POWER DISTRIBUTOR, 28-VOLT	
	GROUP 4	
PART NUMBER	TITLE	
TBD	FORWARD INSTRUMENTATION	
TBD	AFT INSTRUMENTATION	
1B58189	AFT CONTROL DISTRIBUTOR BOX ASSEMBLY	
1B58187	FORWARD CONTROL DISTRIBUTOR BOX ASSEMBLY	
TBD	THRUST STRUCTURE DISTRIBUTOR BOX ASSEMBLY	

NOTES: (1) Government Furnished Equipment - NASA Responsible for Interface Redesign.
(2) MSFC Controlled Drawing - Douglas Will Revise Specification Control Drawings to Show Change of Connector Interface Only.

TABLE 4

QUALIFICATION TEST REQUIREMENTS

	Pressure Proof	Leakage	EMI	Humidity	Thermal Vac	Vibration (Sine and Random)	Acoustical Noise	Shock	Operational
Group I (1)	X	X	(2)						
Group II (1)			(2)	X	X				X
Group III (3)			(4)	X	X	X	X	X	X
Group IV (5)	X	X			X	X	X	X	X

(1) Tests shown must be performed on all units in this group.

(2) EMI tests required if connectors are relocated to revise the basic internal wiring harness.

(3) Only one each worst-case signal conditioning panel and one each power distribution assembly need be tested.

(4) EMI tests required on the signal conditioning panel only.

(5) Only one each of the 17- and 34-connector configurations need be tested.

Distribution Unit Design

A flat-cable connector distributor was designed with an AMP Termi-Point* wiring system which provided these advantages:

a. Minimum number of circuit breaks.
b. Minimum size and weight.
c. Wired automatically or manually.
d. Can be reworked on vehicle with connectors mated.

A pictorial presentation of the installation of such a distributor is shown in Figure 11. A mockup distribution unit using dummy flat-cable receptacles, Termi-Point posts, and interconnecting wiring applied with a hand gun is shown in Figures 12 and 13. A modified MSFC connector with Termi-Point posts would be required. It is believed that this design concept holds much promise for future flat cable application.

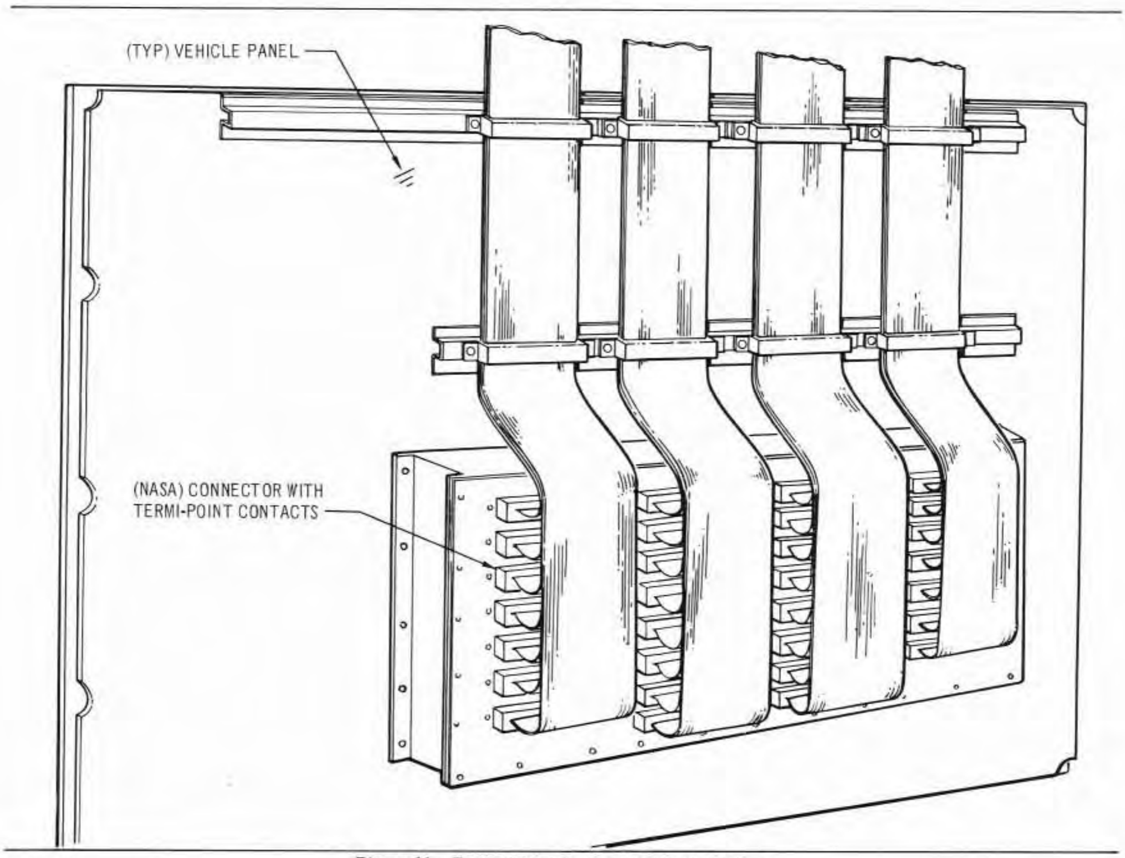

Figure 11. Typical Distribution Unit Installation

*Termi-Point is a trade name of AMP Incorporated, Harrisburg, Pennsylvania.

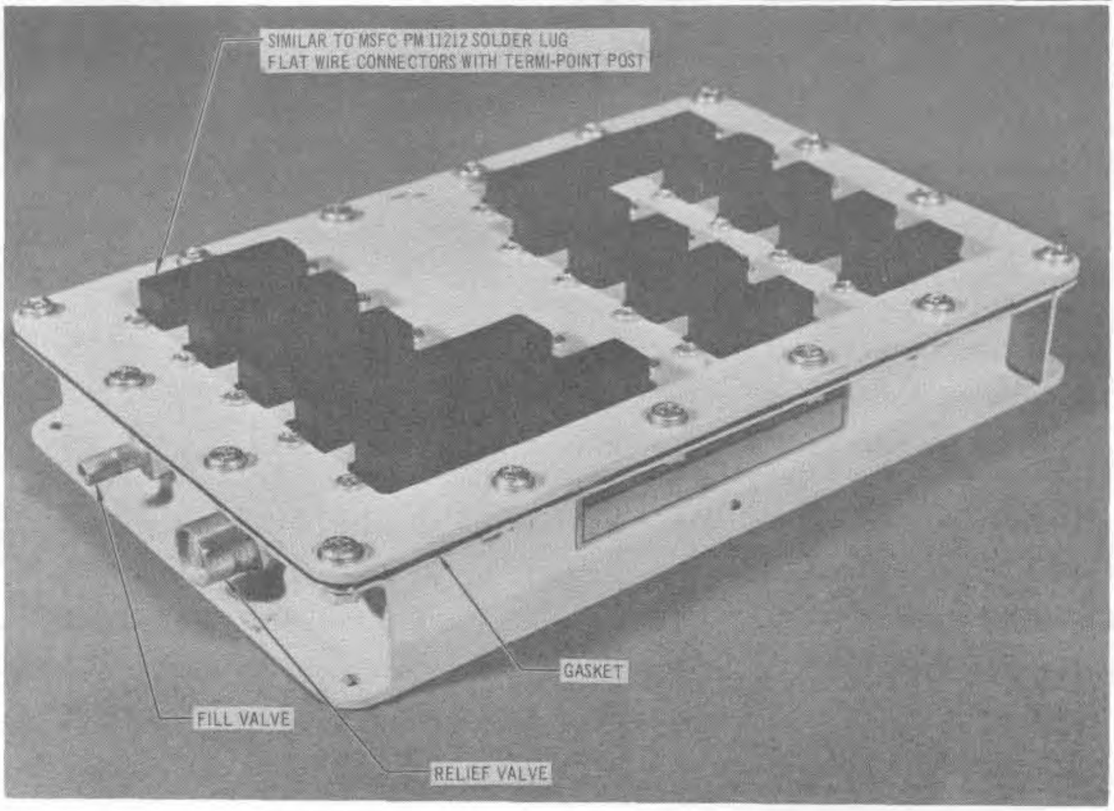

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Figure 12. Pressurized Flat-Cable Distribution Unit

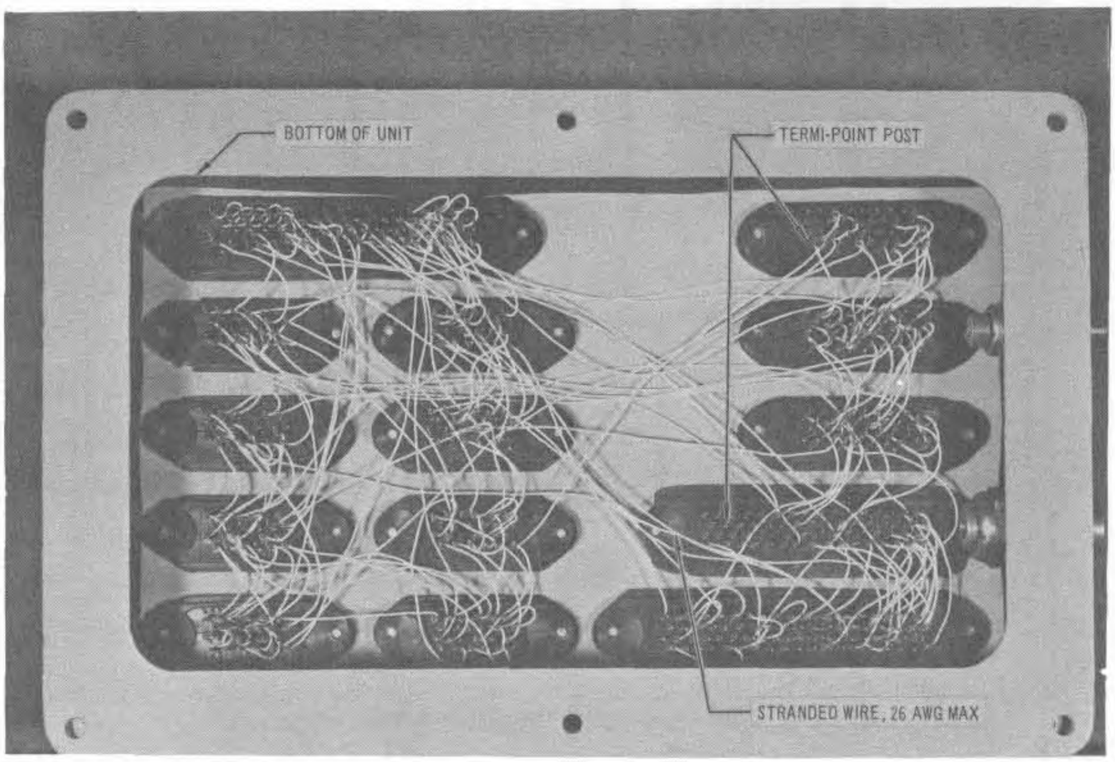

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Figure 13. Distribution Unit, Bottom (Cutaway) View

Flat-Cable to Round-Wire Transition

The retaining of numerous round-wire connectors necessitated the requirement for a flat-cable to round-wire transition. The objectives of this transition were:

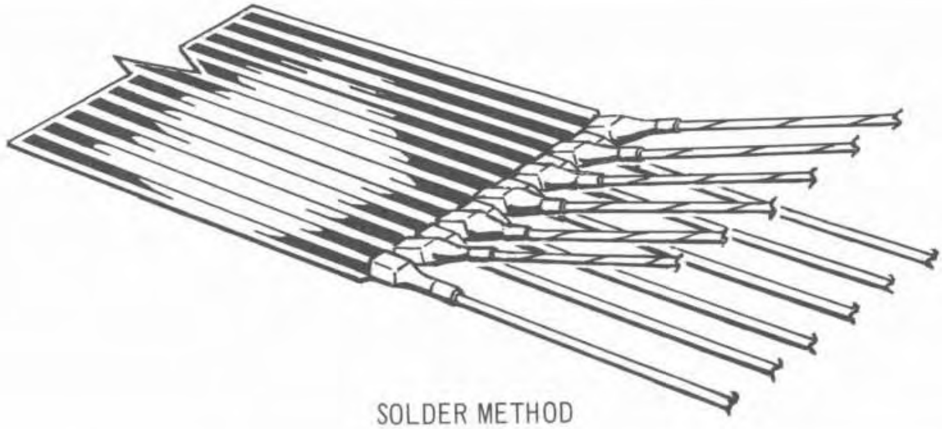
a. Minimum development and qualification.
b. Minimum weight, space, and installation requirements.
c. Minimum number of configurations.
d. Capability to accommodate different pin assignment requirements.
e. Maximum reliability.
f. Economical and manufacturable.

The methods of transition considered were welding, soldering, and crimping. See Table 5 for a summary of information on transitions considered. The solder sleeve is recommended for limited applications, and the acceptable crimp joint for higher production application. The miniature tungsten inert gas (TIG) welding seems to hold much promise for high production rate, high reliability, and low cost transitions for future application. See Figure 14 for illustrations of these transitions.

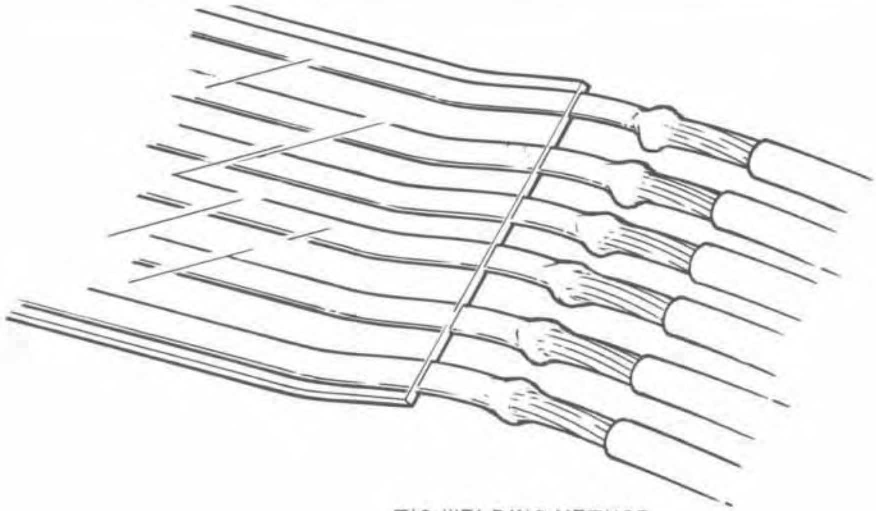
TABLE 5

SUMMARY CHART - FLAT-CABLE TO ROUND-WIRE TRANSITION

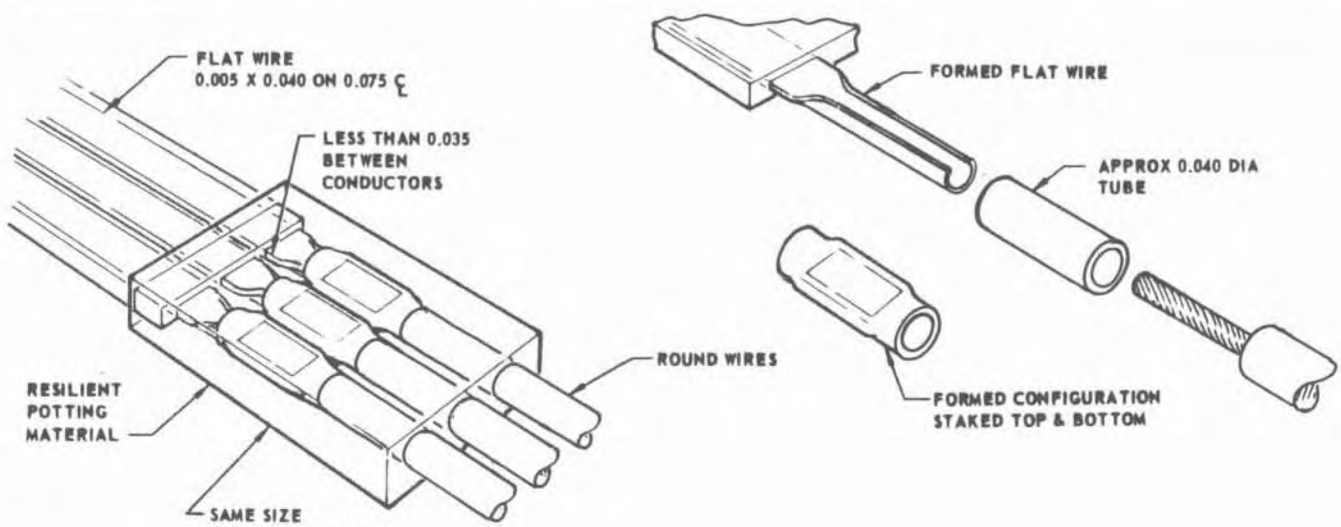
Type	Supplier Number	Round Wire Gage	Comments
Percussive Arc Weld	1	26	Not Acceptable
Percussive Arc Weld	2	24	Not Acceptable
Percussive Arc Weld	3	22	Not Acceptable
TIG Welding	4	22	Acceptable
Laser Welding	5	--	No Samples Prepared - Not Recommended
Solder Sleeves	6	26	Acceptable
Solder Sleeves	6	22	Acceptable
Crimp	7	22	Not Acceptable
Crimp	8	24	Acceptable



SOLDER METHOD



TIG WELDING METHOD



CRIMP METHOD

Figure 14. Flat-Cable to Round-Wire Recommended Transitions

Parametric Testing

The purpose of the laboratory analyses was to perform parametric tests on various S-IVB electronic subsystems interconnected with flat-cable harnesses. The comparison of converted subsystem's performance with that of the same subsystem using round-wire interconnecting cables indicates the effect that flat-cable conversion will have on the overall vehicle performance:

The following laboratory tests were conducted on the S-IVB Propellant Utilization subsystem and Telemetry subsystem:

a. Conducted interference
b. Radiated interference
c. Magnetic fields
d. Transient-conducted susceptibility
e. RF-conducted susceptibility
f. RF-radiated susceptibility
g. Magnetic susceptibility (cable induced)

The propellant utilization subsystem utilizes capacitance probes in the fuel and oxidizer tanks, plus electronics, and valve control to monitor, compare, and control the rate of fuel depletion. A block diagram is shown in Figure 15.

The telemetry system included simulated transducer outputs, signal conditioning, a NASA Model 270 Multiplexer, and a NASA Model 301 Pulse Code Modulation/ Digital Data Acquisition Assembly (Figure 16).

Figure 17 shows a birdseye view of a typical screen room test setup.

The results of the laboratory tests show that: the systems performed satisfactorily with the flat-cable harnesses; these harnesses are superior to round-wire harnesses for both radiated and conducted susceptibility; are equivalent for conducted and radiated interference; and are inferior for low-frequency, very-low-impedance circuits.

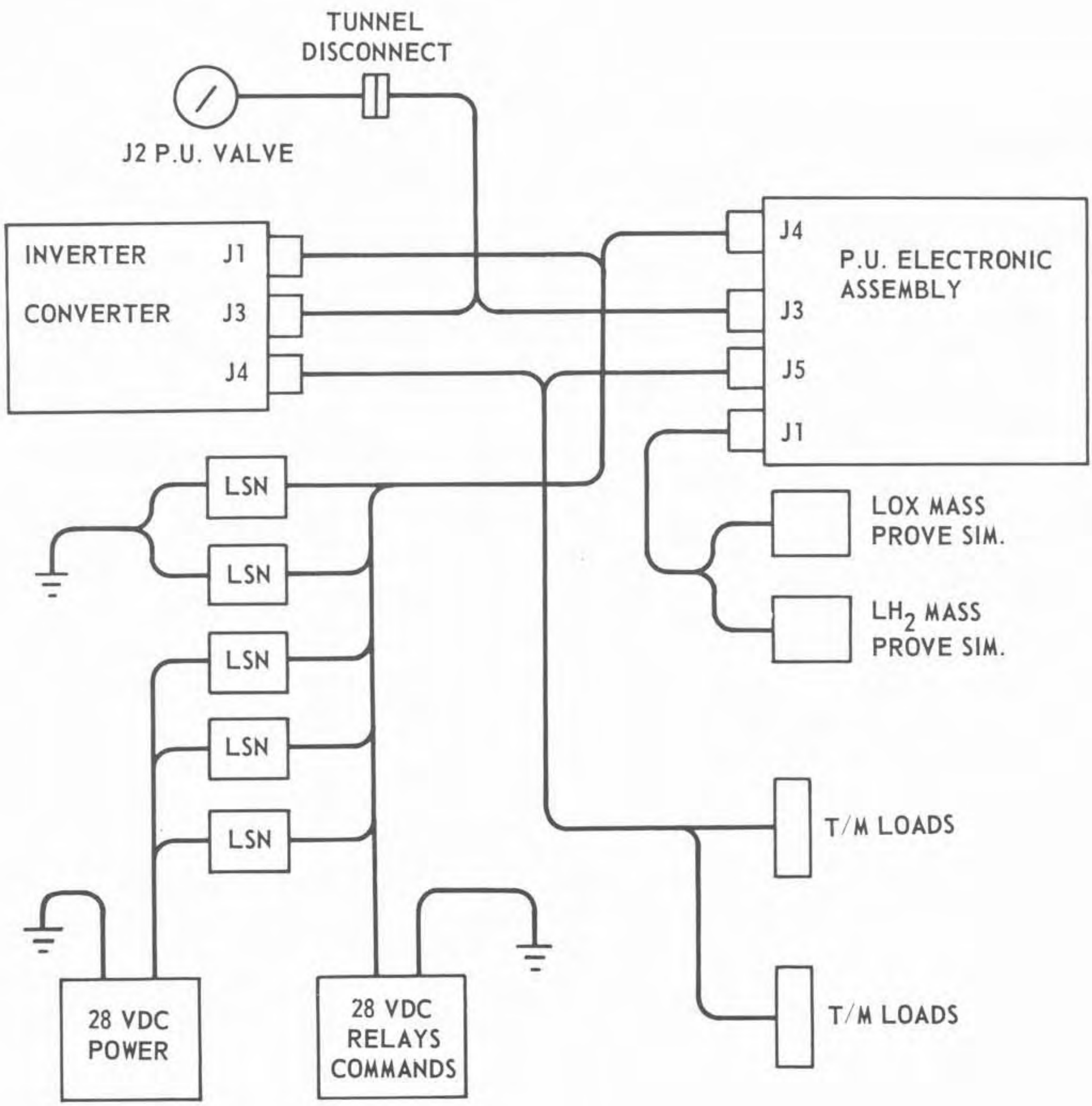


Figure 15. Block Diagram for PU System Test

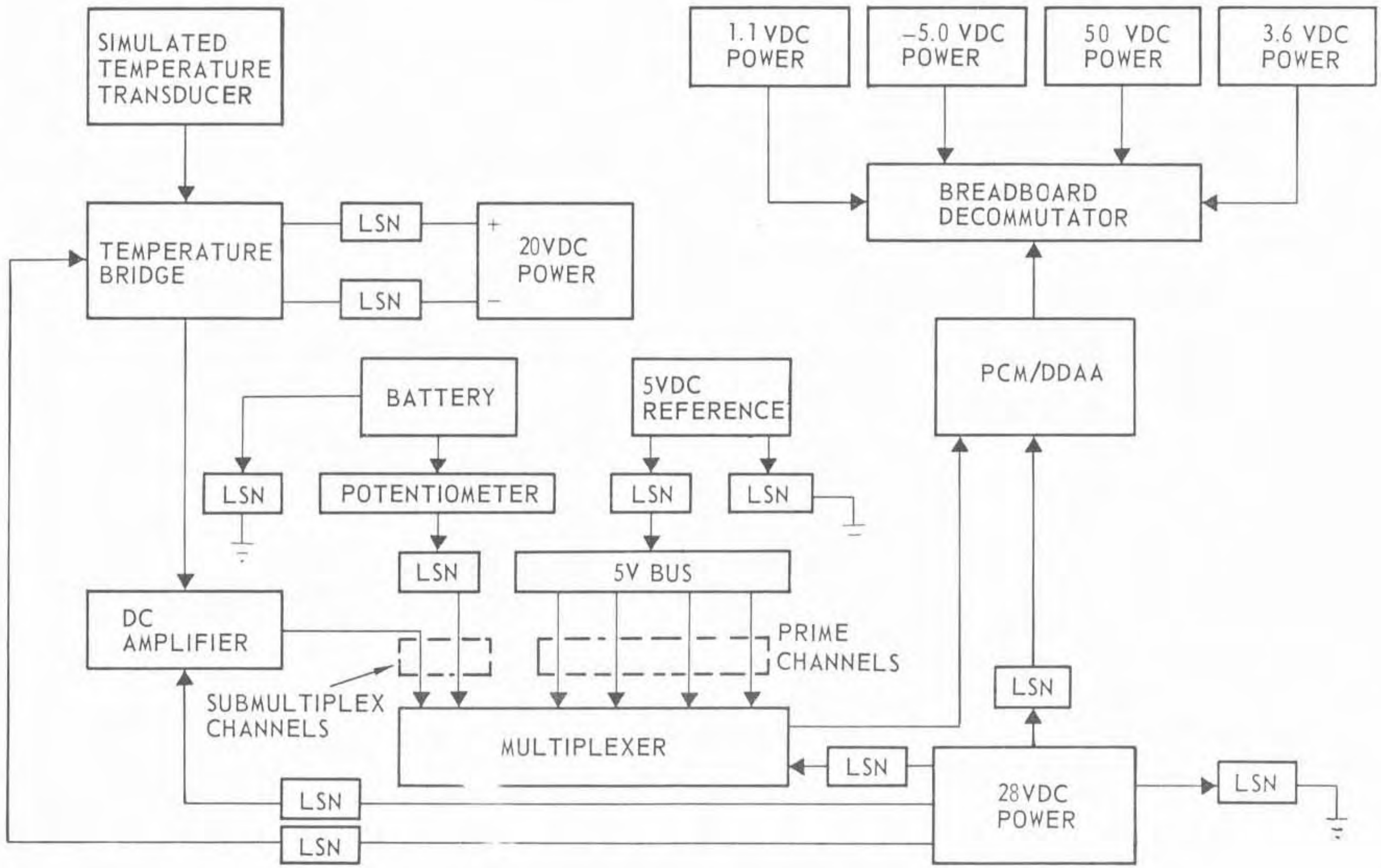


Figure 16 Block Diagram for T/M System Test

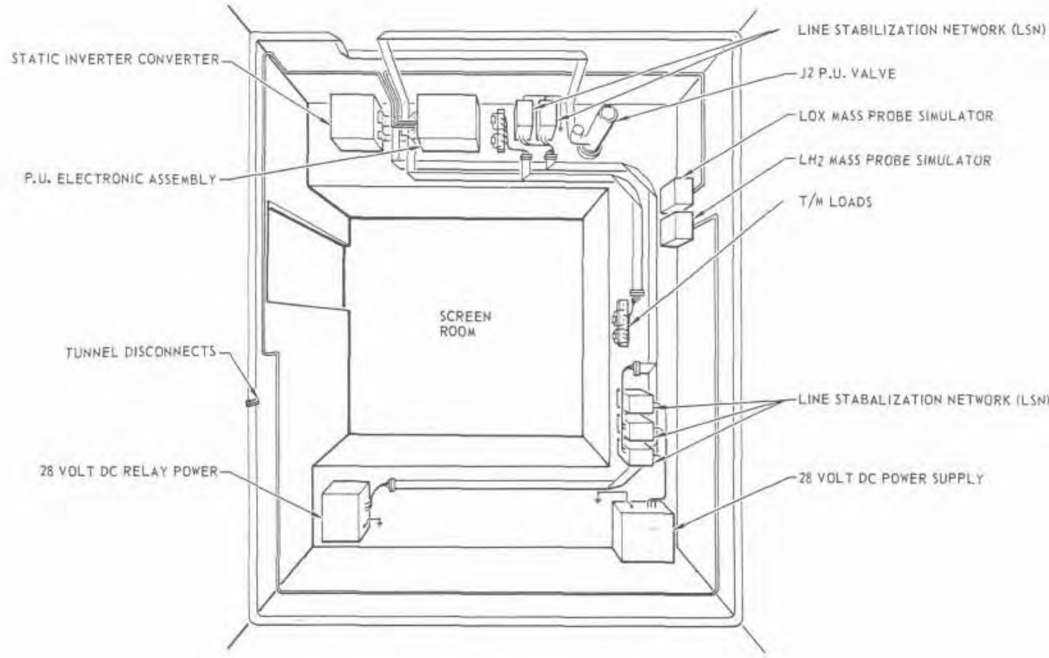


Figure 17. Test Setup, PU System

EMI Philosophy

An electromagnetic philosophy guide for circuit and system designers utilizing flat-cable includes these remarks.

There is no simple panacea for the elimination of either round wire or flat-cable electromagnetic incompatibilities. Each cable circuit must be analyzed individually. A few universal recommendations, which might be applied to specific cases with considerable discretion, are listed below:

a. Divide circuits into several groups on the basis of interference intensity and degree of susceptibility, while considering the following factors:

   1. Signal level
   2. Signal frequency
   3. Circuit impedance
   4. Minimum requested signal-to-noise ratio
   5. Circuit bandpass characteristics

b. Develop a fixed conductor assignment scheme for various types of signals placing the worst interferes at one edge; the susceptors at the other edge; and the moderate offenders in the middle as a buffer zone.

c. Stack cables with a fixed orientation so that compatible conductors are above each other.

d. Use shielded cables for susceptible circuits and alternating current signals.

e. Do not use single-shielded flat-cable where unshielded surfaces are adjacent due to stack layout or folded bends.

f. Placing flat cable against the ground plane provides partial shielding.

g. Where magnetic shielding properties are required, use flat cable with a complete circumferential shield. Significant magnetic fields will exist when signals contain considerable RF energy. This includes digital and video pulses.

h. Do not use flat cable to transmit radio frequencies.

i. Treat cable shields as an extension of the component case or installation structure.

Cost Comparison

The cost comparisons generated were for conversion of an operational S-IVB vehicle to a Block I vehicle. The costs for round-wire interconnecting harnesses were compared with those for flat-cable interconnecting harnesses. The costs considered included Douglas engineering, procurement, manufacturing, development, and qualification testing as follows:

RECURRING COSTS (27 Vehicles)	Increase	Decrease	% Change
Manufacturing			
Harnesses and Support		18,948 hrs.	40%
Engineering			
Sustaining	--	--	--
Material		$2,800	8%

NONRECURRING COSTS	Increase	Decrease	% Change
Manufacturing			
Development		2,000 hrs.	10%
Engineering			
Initial Design (Cable Network and Installation)	5,000 hrs.		15%
Qualification Testing	$320,000		New

The above figures give an indication of the cost percentage changes which could be expected for flat cable application to the Block I vehicle. For the 27 vehicles considered, a cost savings of approximately $1.3 million was predicted. However, design and qualification testing costs to government furnished and NASA design controlled equipment were not considered. These units are defined in Table 3.

If flat cable were applied to new design, not utilizing existing electronic units, substantial cost savings could be realized of approximately:

Cable Harness Development - 20%
Cable Harness Fabrication - 80%

Weight Comparison

The weight analysis was accomplished by comparing the weights of harnesses, supports, and box modifications for flat-cable application with those of the round wire configurations. The total vehicle weight savings is 470 pounds as shown in the following listing.

	Weight In Pounds		
	Additions	Deletions	Net
a. Basic Structure and Support			
Structural Design	9	67	-58
Installation Design	23	150	-127
b. Cable Harnesses			
Cables	306	600	-294
Attaching Hardware		29	-29
c. Black Box Conversion			
Group I	3	3	0
Group II	23	3	+20
Group III	34	16	+18
d. Total	398	868	-470

The weight savings breakdown for the converted flat-cable harnesses is:

a.	Actual operational vehicle round wire harnesses to be converted to flat cable.	486 lbs.
b.	Estimated Block I conversion round wire harnesses to be converted to flat cable.	114 lbs.
c.	Total round wire harnesses to be converted to flat cable (a. + b.).	600 lbs.
d.	Total flat-cable harnesses.	306 lbs
e.	Weight savings for flat-cable harnesses (c. - d.).	294 lbs.

The percentage weight saving for flat-cable harness

$$\frac{294}{600} \text{ X } 100 = 49 \text{ per cent}$$

This 49 per cent harness weight saving, realized through conversion as outlined per the study ground rules, could be increased to approximately 60 percent if 100 percent of flat-cable conductors and flat-cable connectors were used in a new design.

Summary

The flat-cable applications program indicated: a substantial cost saving for interconnecting harnesses; a dry stage weight saving of 470 pounds; the magnitude of redesign and qualification required by changes to electronic units; the new hardware items required; and the magnitude of increased engineering effort for redesigning existing round-wire to flat-cable systems. Required and/or beneficial tasks to be accomplished prior to application of flat-cable to a major program are:

1. Prepare a flat-cable applications handbook.
2. Develop production manufacturing methods for terminating shielded flat cable.
3. Complete specifications for cable and connectors, and perform required tests to establish qualified sources.
4. Develop computerized harness and black box methods to optimize design and simplify interconnecting harnesses.
5. Develop production methods for clamping harnesses.
6. Establish manufacturing, processing, and inspection techniques.
7. Develop and evaluate flat cable to round wire junctions.
8. Fabricate and evaluate flat cable distribution unit.

FLAT CABLE SYSTEMS ENGINEERING STUDY

General Description

The Flat-Cable Development and Applications Programs established definite advantages to be realized through the use of flat-cable interconnecting harnesses. They also defined those areas requiring further development prior to the general application to major programs. The purpose of this study is to pursue these areas to advance the state-of-the-art of flat-cable technologies for application in current aerospace programs, large or small, ground of flight, with a minimum impact on engineering and qualification methodologies at acceptable production costs. To accomplish this numerous tasks will be performed as explained below:

Task Description

Development of a practical, efficient, and reliable prototype shielded flat cable and termination method.

Establish specifications for production type flat cable system components which meet or exceed aerospace qualifications requirements.

Investigate mechanized design techniques to aid in design and production of a flat cable system by defining wire harness layout, cable assembly design, and checkout procedures; develop computerized techniques to simplify, speed and optimize these procedures.

Develop and document prototype flat cable clamps and installation techniques suitable for flight applications. Included shall be an improved method for installation and removal of individual cables in or from major cable runs.

Prepare a flat cable "Handbook" suitable for use by engineering, manufacturing, and quality control as a guide for flat cable applications.

Establish production manufacturing techniques and process control guidelines including flow plans, outline procedures for sub-assembly of selected cable/connector configurations per flat cable Handbook, and inclusion of non-destructive inspection criteria and techniques of usage in the preparation of a "Preliminary Inspection Plan". Included will be visual inspection requirements for flat cable, terminations, and connector hardware.

Summary

The accomplishment of the tasks of the Flat-Cable Systems Engineering Study will provide the necessary tools for general flat-cable application to future airborne and ground electronic systems. The most economical, light weight, and reliable interconnecting systems can then be employed to provide a total wiring concept from component to module to black box to interconnecting harnesses.

CONCLUSIONS

The completed Flat Cable Development and Application Programs prove the feasibility of using flat-cable interconnecting harnesses on a typical aerospace vehicle stage. The Flat Cable Engineering Study contract now in progress will provide the remaining requirements for flat cable applications including a production shielded termination system, completion of flat cable specifications, and preparation of a Flat Cable Handbook which tells "how" to apply flat cable to future design. This handbook will include circuit design, hardware selection, development and installation, plus sections on process standards, manufacturing techniques, and quality assurance.

The utilization of flat cable interconnecting systems for aerospace programs, with major advantages of weight, space, and cost reduction and inherent increased reliability is inevitable. The results of the NASA/MSFC contracts to the Douglas Aircraft Company, Inc. will be a major contributing factor to the successful system application of flat cable.

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