23 FEBRUARY 1971 MDC G0757

CABLING AND CONNECTORS FOR USE ON A NUCLEAR STAGE

Final Report

CONTRACT NAS8-25620

MCDONNELL DOUGLAS ASTRONAUTICS COMPANY

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ABSTRACT

This report details the cable and connector data relevant to a reusable nuclear shuttle and makes appropriate recommendations. The environmental and functional requirements are defined, and radiation effects on organic and inorganic materials are presented. Attractive insulation materials and fabrication techniques for the steady-state radiation environment are coupled with candidate system concepts including flat, round, and ribbon cable approaches. Candidate wiring and connection concepts are reviewed and evaluated. Aluminum, permanent, connectorless, and conventional terminations are considered. Recommendations include the use of copper conductors, all-polyimide insulation, small-gage flat-conductor cable for major wire bundles, conventional round wire for power and short point-to-point installations, and extensive use of permanent and connectorless terminations to enhance reliability.

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Section 1

INTRODUCTION

This report contains the results of a study of cabling and connectors for use on a nuclear stage (NAS8-25620) performed by the McDonnell Douglas Astronautics Company — West (MDAC-West) during a 7-month period ending January 23, 1971. The primary purpose of the study is to provide NASA-MSFC with a summary of data to support recommendation of the most appropriate types of cabling and connectors for use in electrical networks for a reusable nuclear shuttle (RNS).

1.1 OBJECTIVES

The fundamental objectives of this study are to gather the relevant data on cable and connector systems and recommend cable and connector configurations that may be used for the RNS. The effects of the radiation environment anticipated on candidate components are considered, the state-of-the-art in cable and connectors is identified, and recommendations are made for further research and development.

1.2 SUMMARY OF FINDINGS

The study identified three types of cable networks applicable to a nuclear stage — the data handling network, emergency detection network, and power distribution. The data bus concept, chosen for data handling, uses redundant twinax cables. The feasibility of the data-bus concept for the Class 1 RNS is questionable because of the aft radiation environment. The weight, cost and system performance characteristics of flat conductor cable made its choice attractive for the large number of functions for emergency detection. Power cables, because of the relatively heavy gage requirements, are conventional round copper conductor cables. Minimum weight savings with aluminum conductors are not considered attractive because of the problems presently associated with aluminum terminations.

Removable connections were identified as a major source of system unreliability, therefore, flexibility was generally traded for increased reliability by using connectorless or permanent connections instead of conventional removable pin and socket connectors.

This study came to general concurrence with the Aerojet baseline for the location of the transition to organic insulation. Recommendations for change to the connector plate concept for engine-stage interface call for a connectorless or brazed transition in order to substantially increase reliability. Additionally, it is recommended that a combination of round wire and flat cable be used instead of the heavy gage round wire cable now proposed for the engine. Multiplexing above the run tank is recommended for the Class 1-H and Class 3 configurations. The NERVA baseline design now uses a shielded multiplexer on the engine. The present Aerojet guidelines do not include a configuration with a run tank.

Radiation-resistant organic insulations are required for the propulsion module of the Class 1-H or Class 3 and the tunnel of the Class 1. Low level development activity is underway in industry on systems using all-polyimide and polyimide tape with radiation resistant binders. These systems represent the most attractive candidate insulation systems found during the study.

For the Class 1-H and Class 3, modules forward of the propulsion module have virtually no radiation constraints on the cable system choice. A less expensive conventional polyimide with a Teflon-FEP binder (Kapton) represents a good choice of cable insulation for both round and flat cable configurations.

The following recommendations can be drawn from the study:

A. Copper conductors are recommended because of the inherent difficulties in aluminum terminations.

B. FCC in smaller gages should be used for all major bundle runs because of the advantages in weight and size. This includes the wiring installation in the CCM.

C. Conventional RWC is recommended for short point-to-point wire harnesses connecting electronic units together in specific areas.

D. A hybrid approach using woven ribbon cable is recommended for runs in the propulsion module which must branch out to engine area components from the stage-engine interface.

E. To achieve the reliability consistent with space resident hardware, extensive use of connectorless terminations in lieu of conventional connector concepts are recommended. This affects the present engine-stage interface concept.

F. A tunnel concept is recommended based on the minimal dimensional requirements and the associated requirement of a repressurization line. This assumes minor relief from the 15 x 60 foot space shuttle cargo bay limitation is feasible.

G. Multiplexing of engine related function is recommended forward of the run tank for the Class 1-H and Class 3 RNS. For the Class 1 RNS a penalty of about 1700 lb of cabling is incurred to run wires forward of the propellant module. The alternative of engine shielding would incur comparable weight penalties depending on the assumptions made as to semiconductor performance in a radiation environment. For attenuations comparable to those achieved with the run tank concept the shielding weights would be unacceptably large.

Development work required as a precursor to implement these recommendations includes development of connectorless termination and permanent layer termination concepts. Additionally, improved distribution approaches should be developed to increase the flexibility of parallel conductor systems.

1.3 RELATIONSHIP OF RNS STUDIES

This study was performed in conjunction with the ongoing MDAC-West Nuclear Shuttle Systems Definition Study, Contract NAS8-24714.

1.3.1 Present Contractor Studies

During the study period, NASA contractors have been identifying configurations of the reusable nuclear shuttle. Two fundamental and competing concepts have emerged. One is a single module RNS concept launched to orbit with a Saturn V booster. The second is a multiple module configuration assembled in space; it uses the cost-effective launch of a space shuttle system for the various component modules.

In order to assure that these concepts are covered in the potential application of cabling and connectors, three configurations were covered in this study. The first is represented by Figure 1-1. The MDAC-West studies have identified this as a Class 1 RNS. It is characterized by a large single propellant module and the NERVA engine. Figure 1-2 depicts the multiple module configuration of the RNS. It is characterized by eight propellant tanks sized to be compatible with the space shuttle, a propulsion module — also compatible with the space shuttle and containing the NERVA engine — and a command and control module (CCM) forward containing the bulk of the intelligence for RNS mission control. A third configuration has been

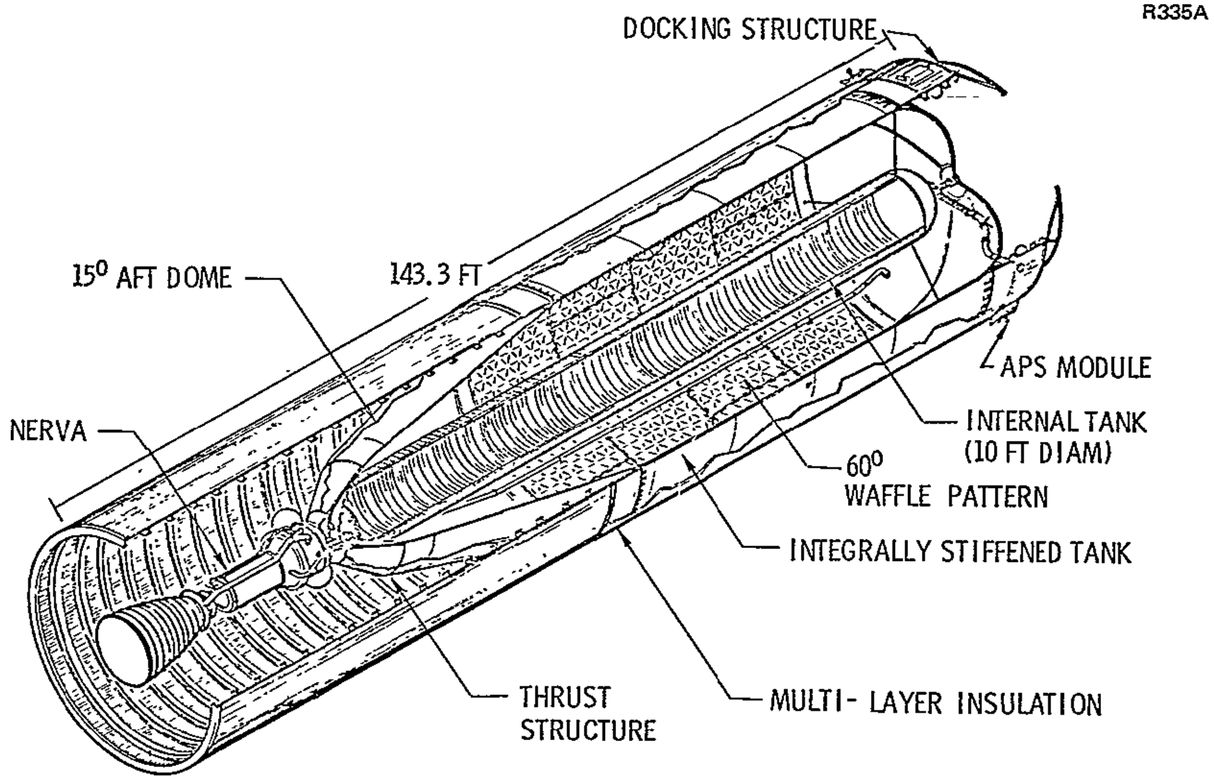


Figure 1-1. Class 1 RNS Load-Carrying Tank (33-Ft Diameter, 300,000 Lb LH_2)

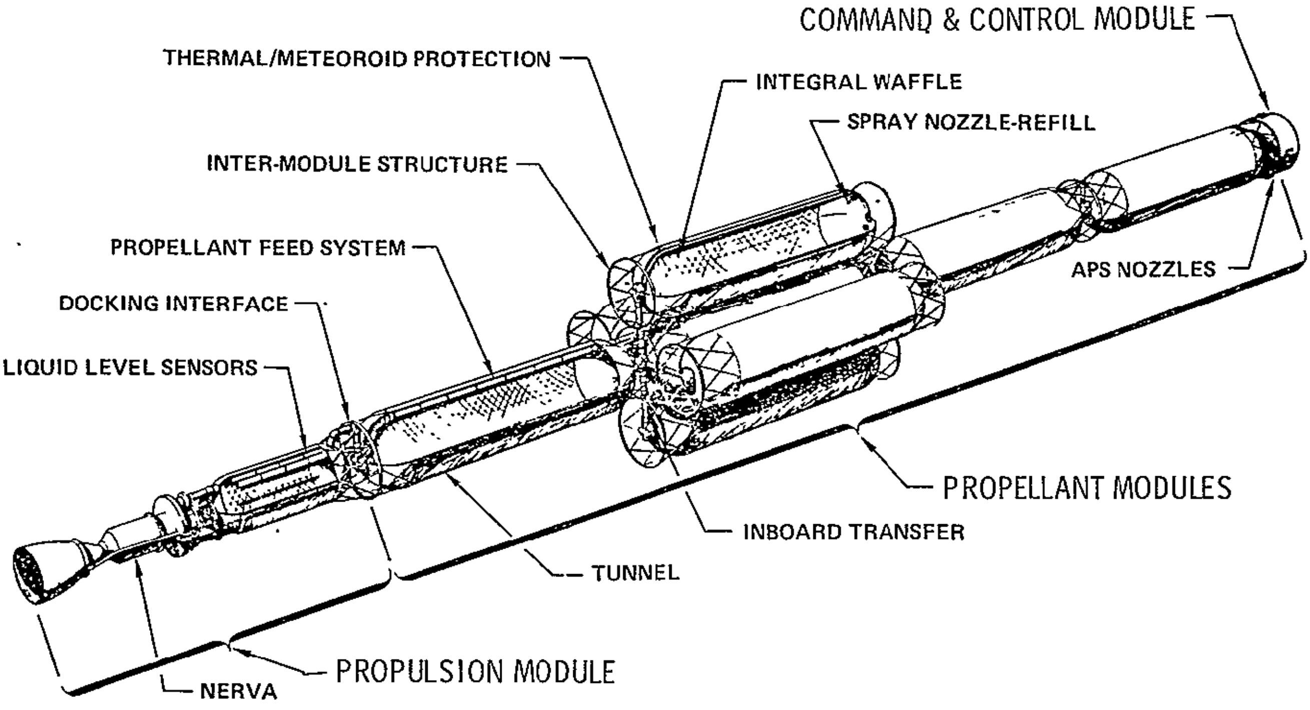


Figure 1-2. Class 3 RNS

identified by MDAC-West and is depicted in Figure 1-3. This has been identified as the Class 1 hybrid and uses the propulsion module from the Class 3 RNS and the large single propellant tank of the Class 1 RNS.

In all three configurations all functional components are generally mounted forward to minimize the induced radiation. The engine instrumentation and control equipment (NDICE) is included in the functional components. The forward mounting of the NDICE would require that a large number of conductors be run between the forward and aft sections of the RNS to interface with the engine. Multiplexing these signals is being considered, but the radiation environment in the aft portion of the vehicle is considered too severe to allow sensitive functional electronics to multiplex and decode these signals without shielding. A data bus concept is postulated to minimize the number of connections between assembly level modules. The multiplexing of instrumentation signals is accomplished in each separable module to minimize module interconnections. Three discrete modules have been identified.

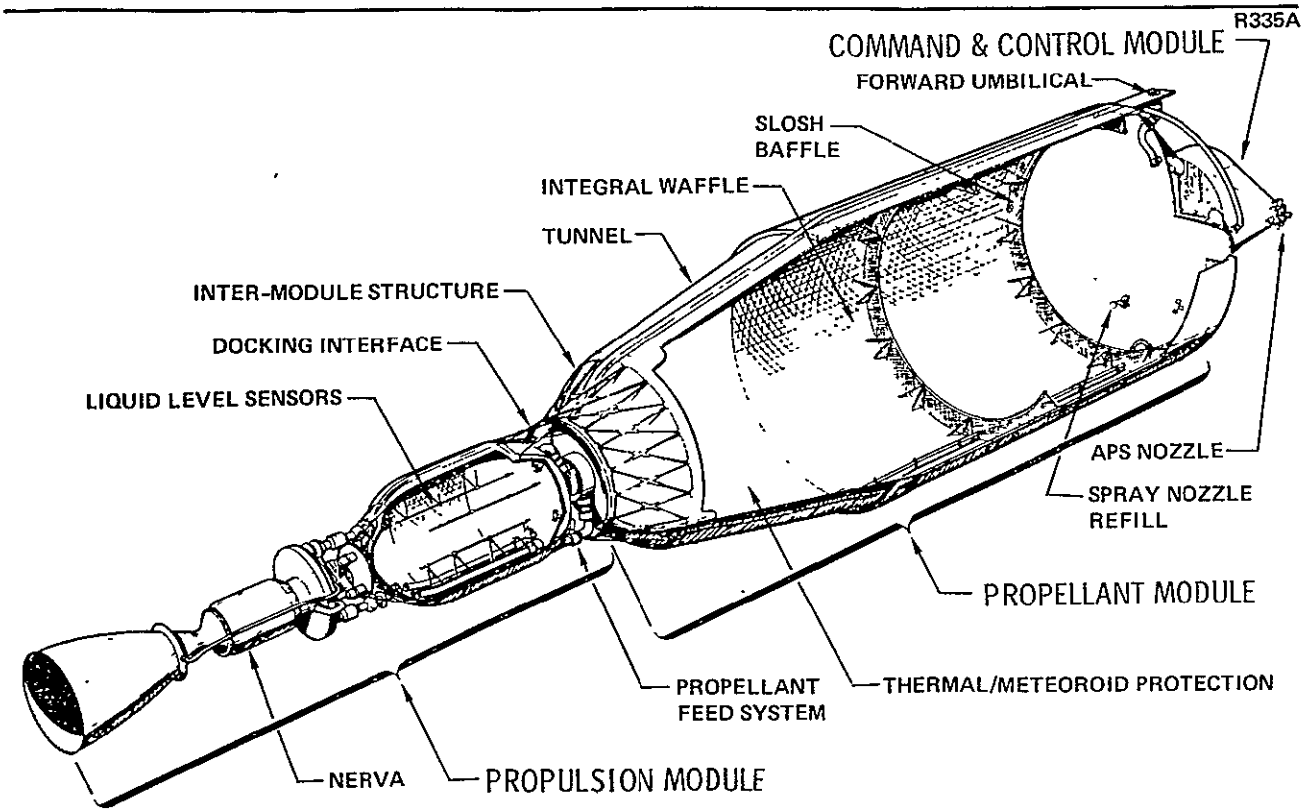


Figure 1-3. Class 1 Hybrid RNS

A. The propulsion module, which includes the NERVA engine and a small liquid hydrogen tank.

B. The propellant modules, which in the Class 3 RNS are assembled to provide the desired propellant capacity.

C. A command and control module (CCM), which is a single replaceable unit containing all functional components and located forward of the assembled vehicle.

The small tank on the propulsion module in the Class 3 and Class 1-H RNS allows for the installation of certain functional electronics shielded by the liquid hydrogen in this tank in the flight configuration.

1.3.2 RNS-Peculiar Requirements

The reusable nuclear stage imposes significant, and in some cases, unique requirements for cabling and connectors. The radiation environment precludes using current flightweight insulation in some regions of the stage. Long wiring runs in conjunction with high-velocity missions provide a major premium for light-weight concepts. Based on space shuttle transportation costs of $100 a pound to orbit and 10 RNS round trips, the value of 1 pound on the RNS can be traded for about $5,000. Current consideration of reusable nuclear stage applications imposes the further requirements of long life and, potentially, remote connect and disconnect for maintenance and assembly. Reliability has been identified as a primary goal for electrical network connections based on analyses performed by MDAC-West under the Nuclear Shuttle Systems Definition Study, which showed that these connections were a major potential source of unreliability.

1.3.3 Mission Definition

The primary role of the RNS is to economically transport large manned and unmanned payloads between a home-base earth orbit and outposts in lunar or geosynchronous orbits. Emphasis is on the lunar shuttle mission because it is more demanding than the geosynchronous mission. A representative RNS operational cycle for a lunar shuttle mission is initiated with its placement into a low circular earth orbit. Fueling with LH_2, assembling the payload, and performing checkout operation precede a single-burn, translunar, injection maneuver into a three-to-four-day transfer orbit. Lunar orbit operations (possibly conducted over 18-days) include deployment of cargo and taking on return cargo. Transearth injection is performed, followed by trajectory corrections as required. A single-burn operation of the RNS provides the required impulse for earth capture where up to 30 days are allowed to conduct maintenance, refueling, assembly, and checkout operations prior to the next translunar opportunity. Figure 1-4 depicts a representative RNS mission. Three-year lifetimes and 10 round trips are fundamental requirements of the RNS.

1.3.4 Maintenance, Repair, and Replenishment

A maintenance, repair, and replenishment strategy has been identified for the RNS. All vehicle classes are maintained by orbital replacement of modules. Repair is made on the ground. All maintenance modules are earth to orbit shuttle (EOS) compatible and can be delivered to earth orbit and returned to the ground for repair and recycling by the EOS. Maintenance operations due to failure are envisioned to occur relatively infrequently. However, certain subsystems do have wearout failure modes (potentially including the propulsion module, which includes the NERVA engine) and

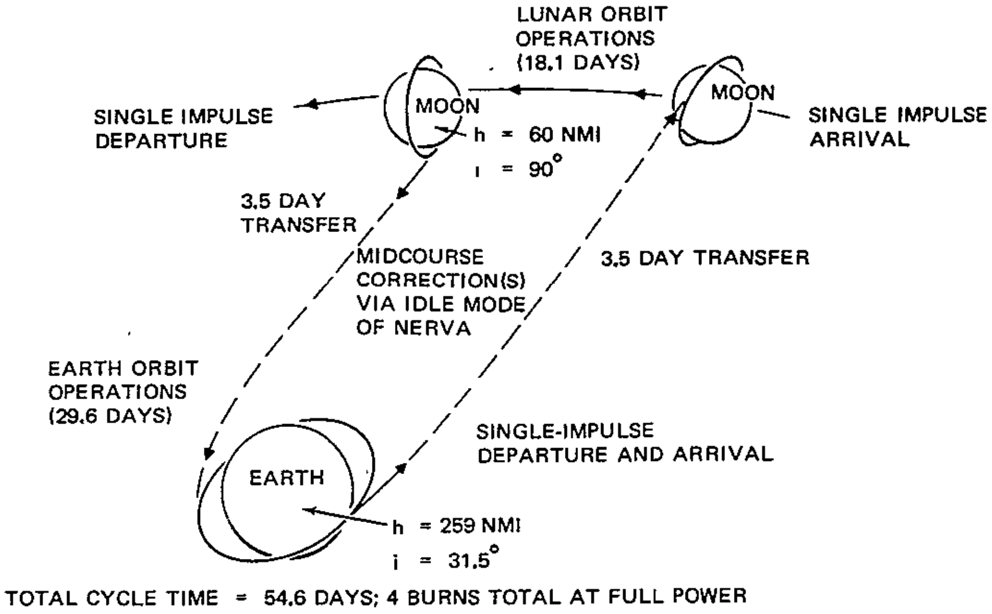


Figure 1-4. Representative Lunar Shuttle Mission Profile

require replacement on a more frequent basis. Replenishment of consumables is required, hence the CCM is returned to earth for checkout and replenishment after each round trip.

1.3.5 Aerojet NERVA Design Baseline

The Aerojet current baseline on engine wiring distribution and interface is described in the NERVA Engine Reference Data, 8130-CP090290-AFI, of September 1970. The reference stage being used by Aerojet closely approximates the Class 1 RNS. Figure 1-5 shows the wire harness installation and distribution throughout the engine, as well as the location of the engine-stage interface connector plate. This plate contains 46 connectors and is detailed in Figure 1-6.

The overall engine now shows round cabling used throughout the engine with organic insulation forward at the pressure vessel and reactor assembly (PVARA) and metal sheathed ceramic insulated wire aft. The box shown

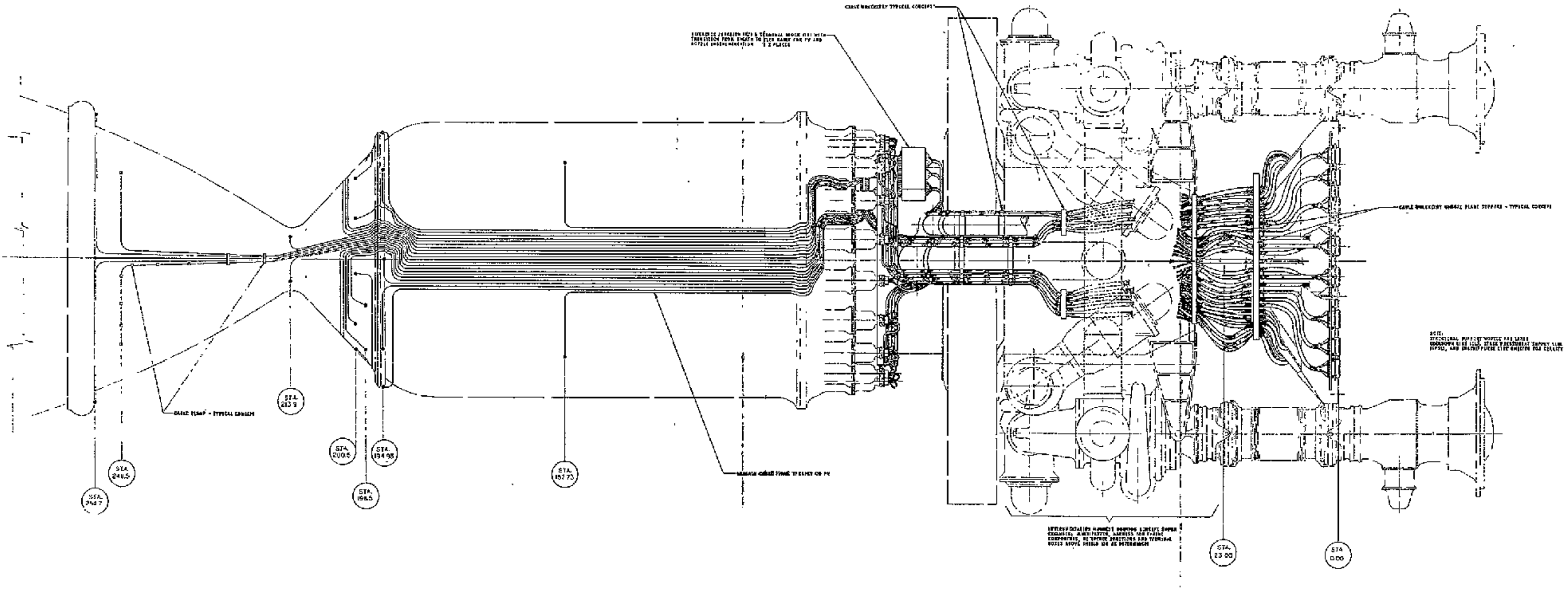


Figure 1-5.
75,000-Lb NERVA Flight Engine Layout (Aerojet Baseline)

FOLDOUT FRAME 1

FOLDOUT FRAME 2

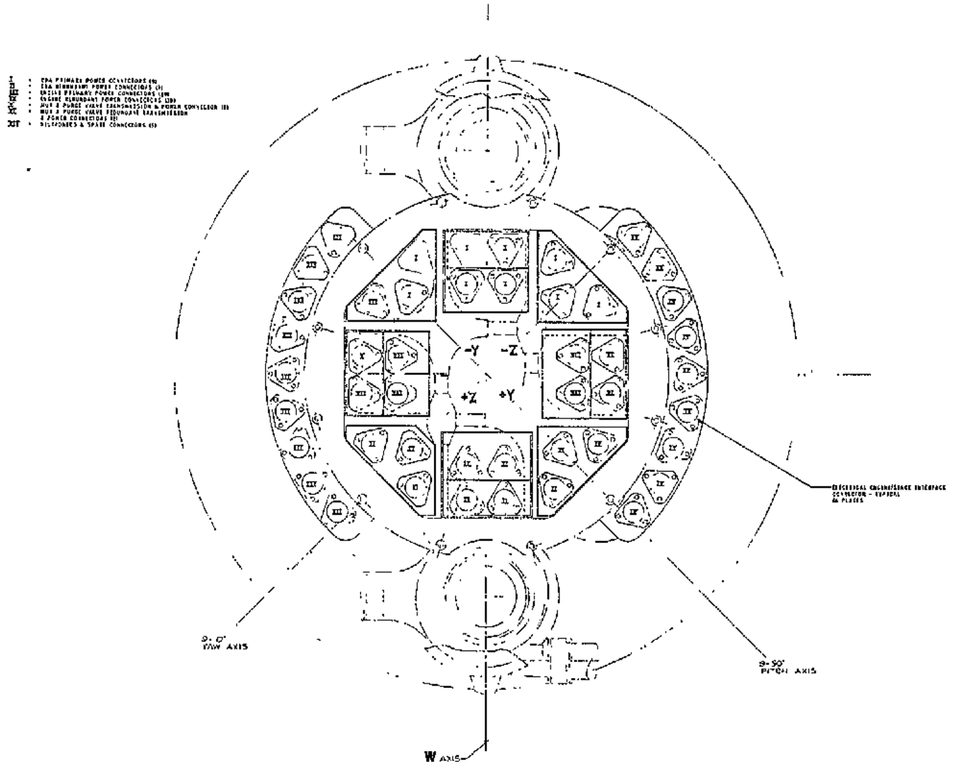


Figure 1-6. NERVA Engine-Stage Interface Connector Plate (Aerojet Baseline)

between the pressure vessel and the external shield contains the necessary connections to perform the transition from organic to inorganically insulated wiring.

Cables from the interface plate are "buckled" around the gimbal point and supported in such a way as to permit movement of the engine without stressing these cables. Wiring is routed throughout this area to gimbal actuators, fuel pumps, duct instrumentation and so on. Below the external shield, wiring is routed into the pressure vessel to control and instrument nuclear systems, and outside the pressure vessel to instrument external parameters on the vessel and thrust chamber.

1.4 OTHER RELEVANT STUDIES

Four primary sources of cable and connector information were used in conjunction with the data from the MDAC-West RNS study. Previous MDAC-West flat cable studies (Reference 4-6) and the Engineering Design Handbook (Reference 4-2) prepared by the ITT for the Army were heavily drawn upon. Additionally, the work at NASA/MSFC on flat cable and reliable connections was extensively used. The Battelle Radiation Effects Information Center (REIC) was used as the primary source of radiation effects data on organic materials.

1.5 APPROACH

The study was divided into six interrelated tasks. These tasks and the relationship between them are indicated in the study plan, Figure 1-7. The information requirements of each task are indicated by the inclusion of sub-task interrelationships. RNS design definition from previous and on-going MDAC studies was extensively used in Task 3 to determine the specific requirements imposed on the interconnection system. The radiation environment analysis performed in Phase II of the RNS study was refined in Phase III for the two classes and used directly in this study. The survey of organic insulation material radiation effects accomplished in Phase II provided the starting point for insulation system investigation. Previous MDAC flat cable studies provided the primary source for quantitative evaluation data of round and flat wire systems in Task 2. Maximum use was made of NERVA data published by Aerojet, the engine contractor.

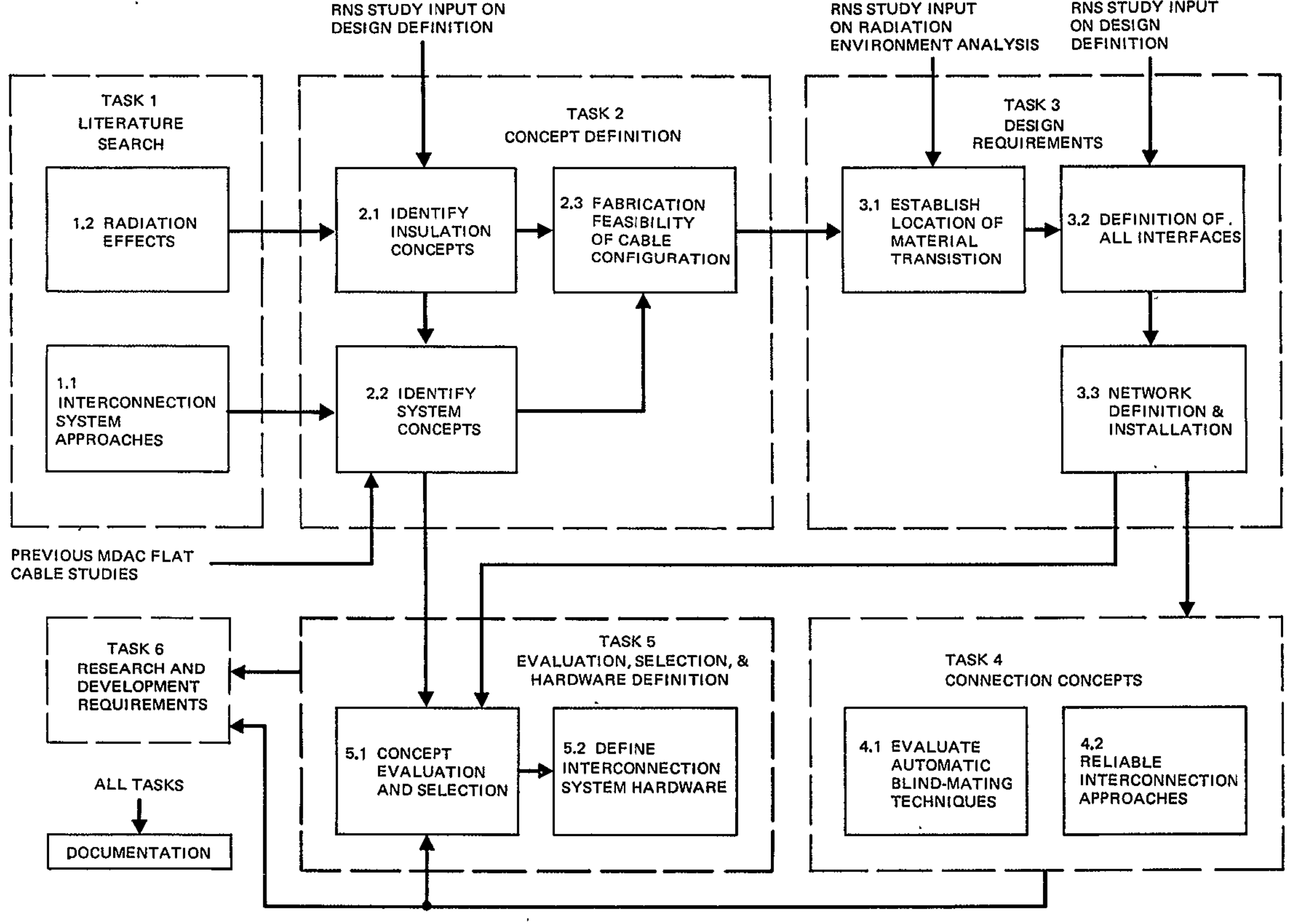


Figure 1-7. Study Plan Flow

The approach was motivated by the desire to employ a systematic investigation of the possible solutions to RNS requirements. The study plan was followed very closely throughout. A slight change in emphasis to organic insulation concepts (rather than ceramic) was made when it was found that radiation-resistant organic materials could be used above the PVARA.

The report is organized so that it is a more usable document for use by NASA and subsequent investigators than if a direct report of the results in each task were presented.

Section 2
REQUIREMENTS

2.1 ENVIRONMENT REQUIREMENTS

The environment that the cables and connectors must withstand includes both temperature and nuclear radiation. The effects of these two are not completely independent, however, since one of the effects of high temperature, during irradiation of organic materials, is to increase the amount of damage that is produced by a given radiation dose.

2.1.1 Temperature Requirements

The cables of interest are those forward of the NERVA pressure vessel and reactor assembly (PVARA). Aft of this point ceramic-insulated cables, which would withstand high temperatures, are assumed. Aft of the gimbal some cables will be routed adjacent to pipes carrying LH_2, and will remain cool during operation of the engine. On the surface of the run tank and the propellant module, the cables would either be at about the temperature of LH_2 if they are inside of the thermal insulation or at -89°F if placed outside of the insulation.

The greatest heating will occur in cables that are near the gimbal or below it, but that are not adjacent to pipes carrying LH_2. The expected heating in and near the gimbal, after a 30-minute firing, is shown in Table 2-1. (The surface emittance and solar absorptance were taken as 0.75 and 0.32, respectively.) The temperature in each part increases nearly linearly with time during the firing (Reference 2-1). This shows that the maximum temperature of any organic cable will not exceed 177°F, and the average temperature of cables in the region of the gimbal would be around room temperature.

2.1.2 Radiation Requirements

The design criteria and constraints imposed by the radiation environment due to NERVA operation are contained in this section. During three years of

Table 2-1

MAXIMUM COMPONENT TEMPERATURES OF NERVA ENGINE

	Temperatures (°F)	
	Thermal Soak	After 30 Min. Firing
Lower Thrust Structure	-14	64
Upper Thrust Structure	144	177
Gimbal Assembly	-85	96
Gimbal Actuator	-12	39

operation, the vehicle makes ten round trips, with a total burn time of 1 hour in each. The insulation must be designed to allow for a 10X safety factor (i. e., 10 times the actual expected dose).

Figure 2-1 is an engine sketch defining source regions and shield locations. Sources to be used for defining the radiation environment for RNS design are References 2-2 and 2-3. Table 2-2 summarizes the major radiation source regions. Equivalent point sources for gammas from the PVRA, valid at large distances from the core, are 1.9×10^{18} Mev/sec in the forward direction, 9.7×10^{19} Mev/sec in the radial direction and 6.3×10^{19} in the aft direction. The equivalent neutron sources in the same directions are 2.1×10^{17}, 1.8×10^{19}, and 1.2×10^{19} neutrons per second respectively.

Table 2-2

NERVA RADIATION SOURCES

Source Region	Strength (Mev/sec)
PVARA	8.95×10^{20}
Pump Discharge Line	9.87×10^{16}
Primary Nozzle ($\epsilon \leq 5:1$)	4.66×10^{18}
Nozzle Skirt ($\epsilon \leq 24:1$)	8.94×10^{16}
Total	9.00×10^{20}

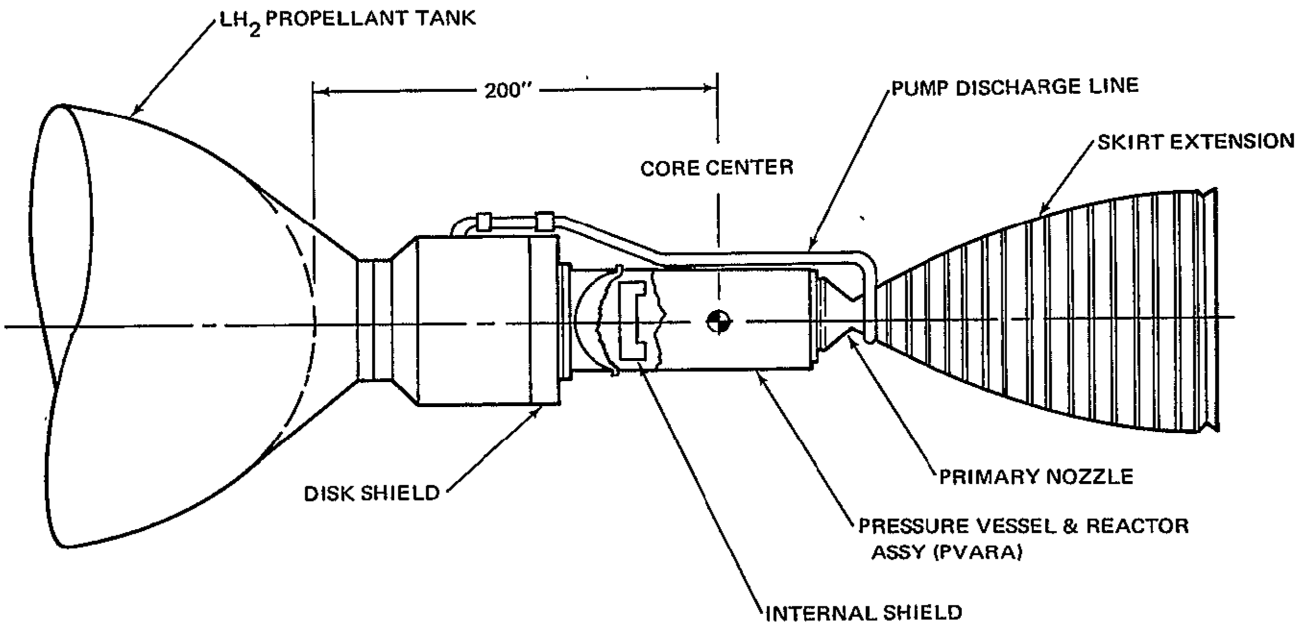


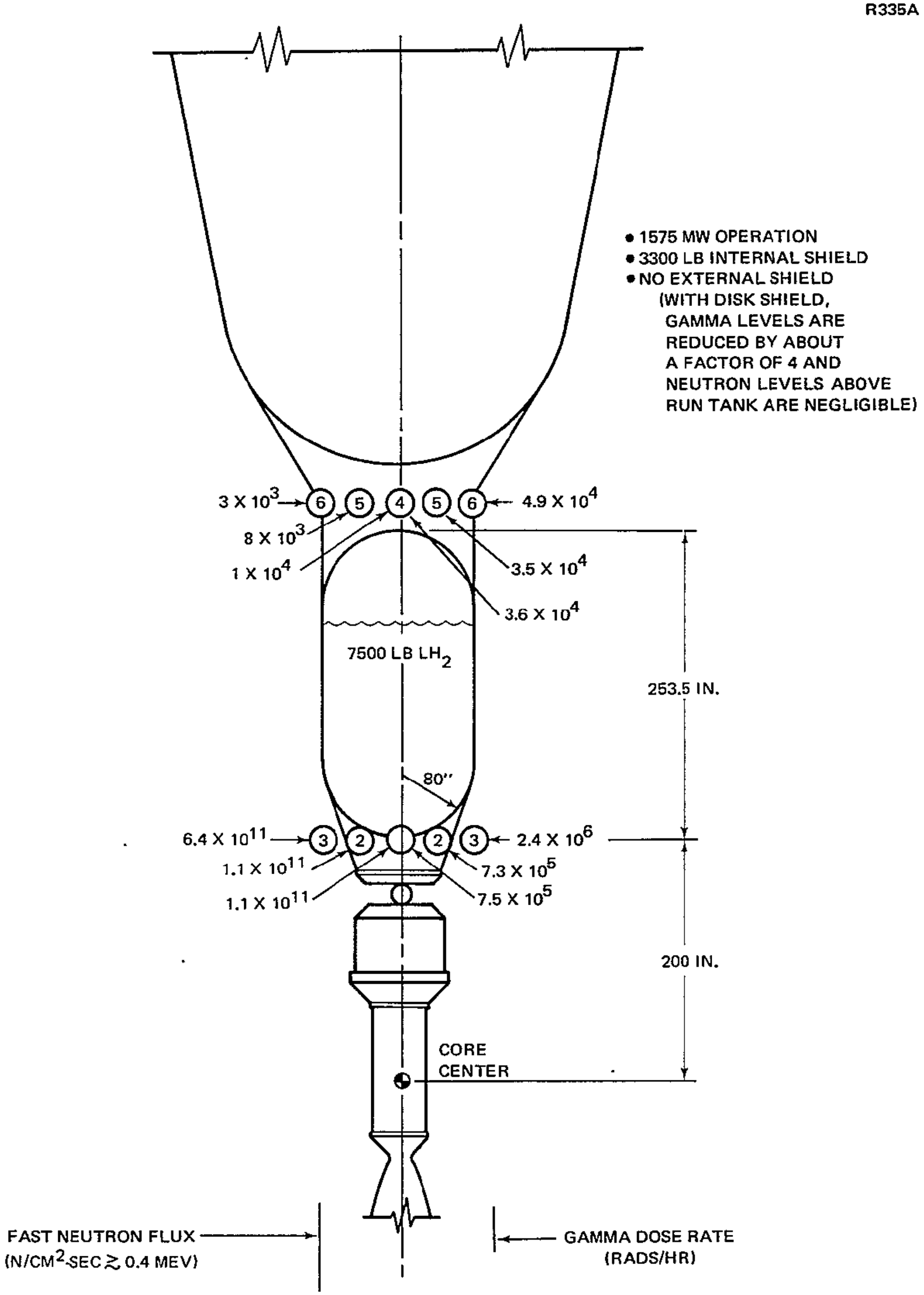
Figure 2-1. 75,000-Lb Thrust Full-Flow NERVA Engine with Disk Shield

An analysis was performed to determine the radiation environment that components mounted on the exterior tank surfaces would experience. Three potential configurations of the RNS were considered: the Class 3 RNS and the Class 1 hybrid RNS, both of which use run tanks, and the standard Class 1 RNS, which has the main propellant tank contiguous with the NERVA engine. Particular attention was paid to tank configurations using a small run tank. Interest here centered on radiation levels immediately forward of the run tank to determine feasibility of mounting electronic components without shielding, and aft of the run tank to determine electrical insulation material performance.

A computer program (PATCH Code) was used to generate the bulk of the data. This program employed the point kernel method to calculate the "direct" and "scattered" components of the dose rate. The direct component was operationally defined as the uncollided contribution from engine sources times a build-up factor to include the contribution from scattering in the engine (but not the tank). The scattered component was taken to be the summation over all LH_2 tank volumes of the singly-scattered dose rate times a build-up factor to represent multiple scattering along the scattered leg.

Figures 2-2, 2-3, and 2-4 show the expected gamma and neutron radiation levels during a trip of the RNS to lunar orbit and return for each of the potential RNS configurations. These radiation levels correspond to the case of no external shielding. A disk shield between the engine and the run tank would reduce the gamma dose rates at all radii by approximately a factor of 4 (Reference 2-4).

Although it is known that a given radiation dose causes more damage, in organics in general, if they are at a high temperature during irradiation, the average temperatures in the organic cable insulation used in the RNS, even in the hottest parts, are expected to be sufficiently low in most cases so that room-temperature data will apply. For those cables, if any, in which the average temperature is 160°F, it could be assumed that the effective dose is about 10^9 rads, to allow for their higher vulnerability.



- 1575 MW OPERATION
- 3300 LB INTERNAL SHIELD
- NO EXTERNAL SHIELD (WITH DISK SHIELD, GAMMA LEVELS ARE REDUCED BY ABOUT A FACTOR OF 4 AND NEUTRON LEVELS ABOVE RUN TANK ARE NEGLIGIBLE)

Figure 2-2. Radiation Environment of 10-Deg Hybrid Class 1 RNS

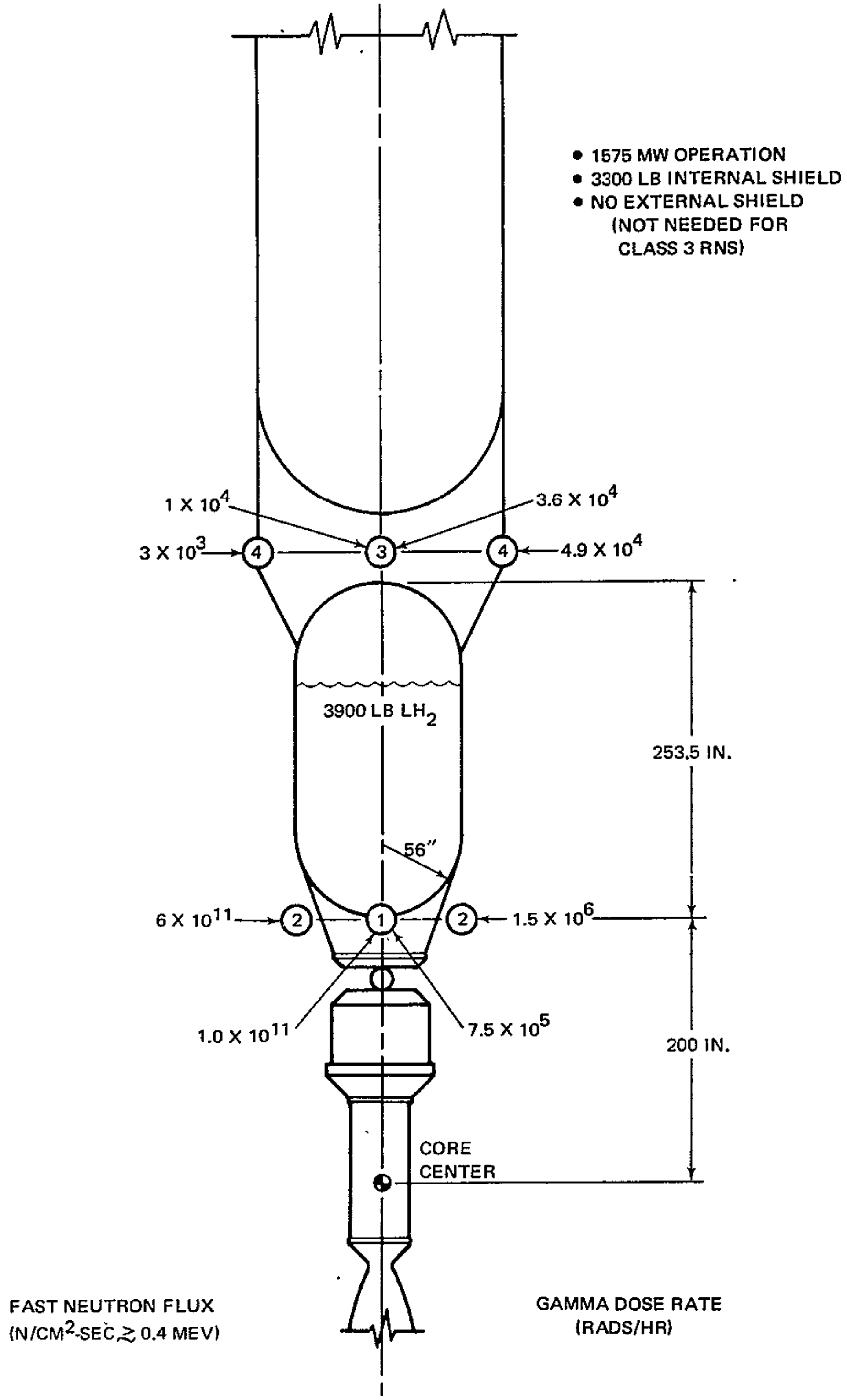


Figure 2-3. Radiation Environment of Class 3 RNS

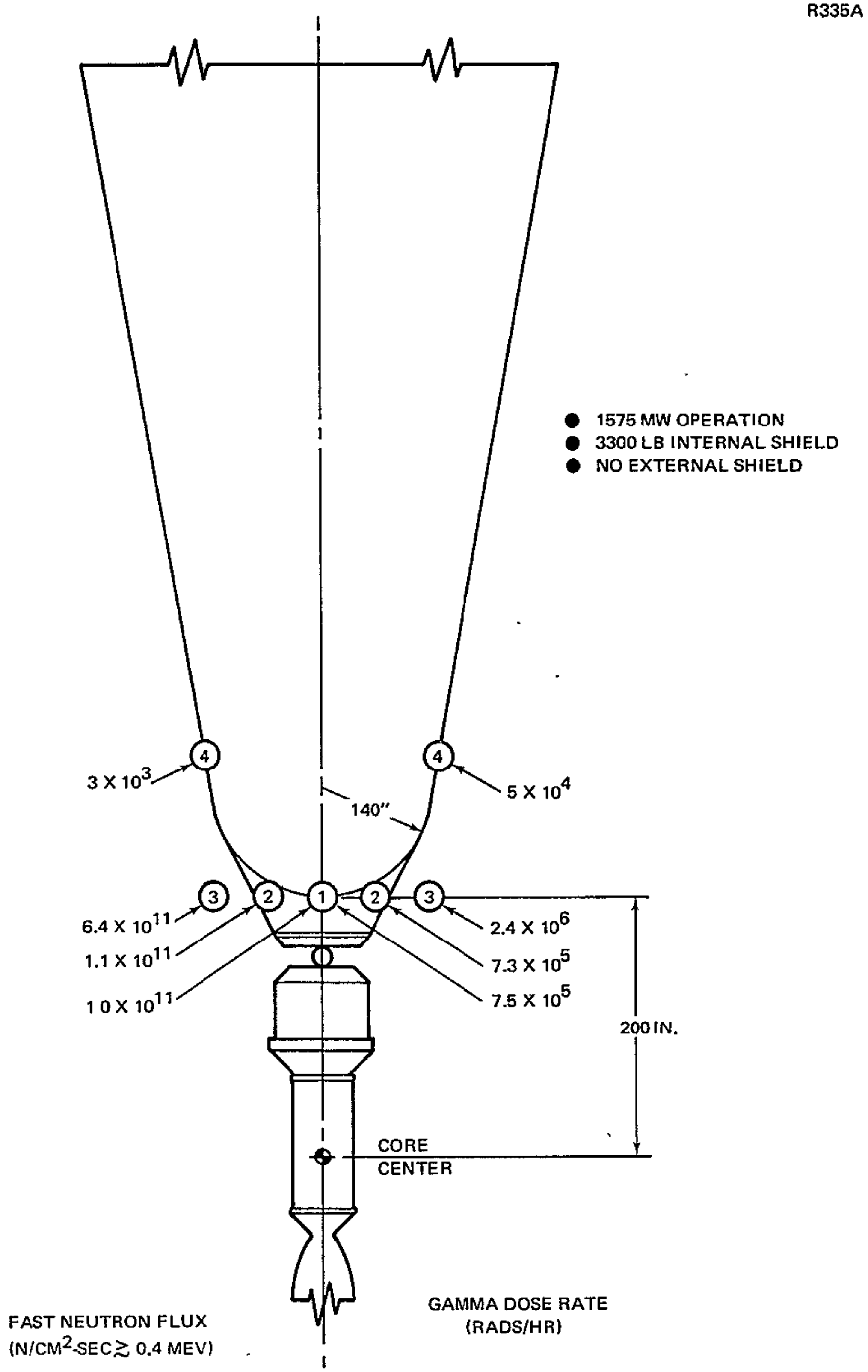


Figure 2-4. Radiation Envoronment of 10-Deg Class 1 RNS

2.2 FUNCTIONAL REQUIREMENTS

The various RNS environmental and functional requirements indicate that different type and sizes of cable will be used for each particular application. In addition to the usual current-carrying capacity and thermal considerations applicable to space-borne cabling, the RNS cabling is exposed to high levels of nuclear radiation in the area near the NERVA engine. Current-carrying requirements determine size of the conductor, while thermal and radiation effects place the limiting environmental constraints on the cable insulation. For high-speed digital transmission lines, the electronic characteristics of the cable are the major constraint. Choice of this type of cable depends on frequency of data transmission, length of transmission line, and allowable attenuation and distortion of the signal.

There are three major cabling networks in the RNS—the power distribution network, the emergency detection network, and the data bus. Each of these networks satisfies a different set of functional requirements.

The requirements for each of the three RNS classes considered were established during the course of Task 3 of this study as reported below. Table 2-3 is a summary of the results of this task.

2.2.1 Power Distribution Network

Power cable requirements for the Class 1-H and Class 3 RNS were based on the MDAC recommendation that batteries be mounted on the propulsion module to satisfy peak power demands. The Class 1 RNS is not amenable to this concept because of the absence of shielding for the battery installation aft of the propellant module.

2.2.2 Emergency Detection Network

The emergency detection system (EDS) monitors critical parameters throughout the RNS and responds to an emergency or out of tolerance condition by issuing safing commands. The EDS network consists, therefore, of instrumentation and command signals requiring low current flow (milliamps). Table 2-4 summarizes the EDS function count for each of the three RNS classes.

Table 2-3

CABLING FUNCTION DISTRIBUTION THROUGH EACH MODULE

Module	Function	Stage Lines	Engine Lines	Total Lines
Propulsion Class 1-H or 3	Data Bus			4
	EDS	120	3,000	3,120
	Power	--	6	6
Propellant Class 3 Tandem	Data Bus			4
	EDS	226	730	956
	Power	--	6	6
Propellant Class 3 Core	Data Bus			4
	EDS	306	730	1,036
	Power	--	6	6
Propellant Class 3 Outboard	Data Bus			4
	EDS	76	--	76
	Power	4	--	4
Propellant Class 1-H	Data Bus			4
	EDS	96	730	826
	Power	--	4	4
Propellant Class 1	Data Bus			4
	EDS	149	730	879
	Power	--	14	14

Table 2-4
EDS FUNCTION COUNT*

	Class 1		Class 1-H		Class 3	
	Monitor	Control	Monitor	Control	Monitor	Control
C&C Module	16	11	18	13	18	13
Power	6	4	8	6	8	6
Command & Control	6	4	6	4	6	4
Data Management	4	3	4	3	4	3
Propellant Module	34	23	11	7	80	48
Propellant Management	8	6	6	4	6 (x8)	4 (x8)
Command & Control	10	5	5	3	4 (x8)	2 (x8)
Engine	16	12				
Propulsion Module	-	-	27	19	27	19
Propellant Management			6	4	6	4
Command & Control			5	3	5	3
Engine			16	12	16	12
Totals	50	34	56	39	125	80

*Exclusive of requirements satisfied in the 700 lines between NERVA and the NDICE

These numbers, obtained from the MDAC RNS studies, do not include emergency engine functions under control of the NERVA system.

2.2.3 Data Bus Cable Requirements

A data bus concept of information transfer throughout the RNS was chosen because of the advantages offered by this architecture. Data are coded in digital format prior to serial insertion on the data bus, which utilizes time-share multiplexing to transmit numerous signals on a single (or dual) cable. MDAC data management trade studies for the RNS have identified a maximum bit transfer rate requirement of 500,000 bits per second. The cable used for data bus application must, then, be able to transmit digitally coded information at 0.5 to 1 MHz, for a length of 300 feet, without noticeable signal attenuation or distortion.

2.2.4 NERVA Engine Requirements

Based on Aerojet current estimates, there will be approximately 3,000 lines to interface with engine functions. These lines will carry instrumentation and command signals between the engine itself and the NDICE or other stage-mounted engine-related systems. With the use of an engine function multiplexer, this interface may be reduced to 700 lines. Aerojet is evaluating the possibility of locating this multiplexer on the engine. However, with the MDAC run tank concept, it seems quite feasible to place the engine function multiplexer above the run tank, where the environment is more amenable to electronic components. Table 2-5 is a summary of the Aerojet baseline engine wire harness interfaces, listed by component.

2.2.5 Interface and Transition Requirements

The RNS, as indicated by current studies, has two major types of physical interface — intermodule, and the engine-stage interface. In addition, there must be a transition from conventionally insulated wiring to wiring insulated by material relatively impervious to degradation by exposure to nuclear radiation. This transition is required on wires going to instrumentation control components below the internal shield of the NERVA.

Table 2-5
ENGINE WIRE HARNESS FUNCTION DISTRIBUTION

Module or Component	Power Contacts On Connectors	Total Contacts on Connectors or Total Conductors
Engine Interface (Station Zero)	480	633
Multiplexer	18	1,974
TPA (2)	50	272
Turbine Bypass (2)	20	73
Structure Support (2)	40	134
Purge System	42	105
Gimbal Actuator (2)	10	55
Nozzle Assembly	--	142
Nuclear Subsystem	180	1,038
Lower Thrust Structure	--	170
Upper Thrust Structure	--	27
External Shield	--	40
Lines	--	--
Turbine Inlet	--	29
Structural Support Coolant	--	35
Turbine Discharge	--	46
Pump Inlet (2)	--	18
Turbine Blocking	--	23
Structural Support Blocking	--	13
Stage Pressurant Supply	--	13
Cooldown Supply Line	--	26
Pump Discharge Line	--	15
Pressure Vessel	--	12

Intermodule Connections

The Class 1-H and Class 3 RNS concepts require launch of separate modules and assembly of these modules in earth orbit. The Class 1 RNS would have a similar requirement to provide for engine removal and replacement in earth orbit. Cabling connections between modules must be performed automatically, using blind mating connections. The blind mating assembly mechanism must be capable of providing a stable, reliable, and effective electrical interface.

Engine-Stage Interface

As previously stated, the current Aerojet documentation indicates an engine interface of 700 to 3,000 lines. This interface, according to the Aerojet baseline, is composed of connectors located on a panel at station 0 of the engine. Connections at this interface will be performed in a manufacturing area and, therefore, no particular requirements for connector mating exist for these connections unless based on maintenance level considerations.

Insulation Transition

The high level of radiation in the vicinity of the engine imposes requirements on cabling not encountered in chemical propulsion systems. The specific effect of this environment is that of degradation of organic cable insulation. This effect is discussed in detail in Section 3. To protect against radiation damage then, a transition to inorganic insulated cabling must be performed prior to routing engine functions aft of the NERVA internal shield.

2.2.6 Umbilical Requirements

The autonomous nature of the RNS reduces the need for umbilical connections. Launch is effected while in orbit without reliance on hard-wire connection to other support systems. Use of the operational intermodule connections will be made to perform manufacturing, ground and space shuttle checkout and monitoring functions. For the Class 3, then, no definitive umbilical requirement has been identified. For the Class 1 and Class 1-H propellant module an umbilical requirement of undetermined size has been identified. Requirements for umbilical connections are more significant for the Class 1 than for the Class 1-H vehicle, but even then, these requirements are minimal compared to previous Saturn vehicles, due to the orbital launch concept of operations.

Section 3
RADIATION EFFECTS ON MATERIALS

Radiation damage is of two types — permanent damage, which depends on the total integrated dose, and transient damage, which is a dose-rate effect. The expected neutron and gamma-ray dose and dose rates for various parts of the nuclear stage are given in Subsection 2. 1, "Environment Requirements". In organic materials, both neutrons and gamma rays contribute to the damage, whereas in ceramics only the neutron flux needs to be considered.

3. 1 PERMANENT RADIATION DAMAGE IN ORGANIC INSULATION

The main effects of radiation on organics is to cause cross-linking and scission. The damage is caused by ionization in the material (measured in rads) part of which is produced by the gamma rays, and part by the neutrons. The total expected dose at a given point on the vehicle can be calculated from the radiation environment data given in Subsection 2. 1. When the neutron flux, ϕ, is specified as the number of neutrons with $E > 10$ kev which pass through 1 cm^2, the neutron dose in rads in hydrogenous plastics can be found by multiplying ϕ by 2.3×10^{-9}. In plastics which lack hydrogen, such as Teflon and Kel-F, a factor of about 7×10^{-10} is used. If the neutron dose with $E > 0.5$ Mev is specified, conversion factors about 20 percent higher than these should be used. To a rough approximation, the neutrons will contribute about the same number of rads in the gimbal region as the gamma rays do, but at the top of the run tank the neutron dose is negligible.

Cross-linking (or attachment of molecular bonds in adjacent molecules) usually is the dominant damage mechanism at low doses. This causes materials to become more brittle. At a heavier dose the scission (or breaking of long polymers) dominates, causing the material to soften. Materials which are initially flexible usually fail by becoming too stiff; vibration from the engine could crack them. Materials which are initially hard may become harder after a low dose, but soften or melt at a sufficiently high dose. Many plastics show much greater damage if they are irradiated with oxygen present or at high temperatures.

Table 3-1 gives the doses (in rads) at room temperature that will cause threshold damage and significant damage (~ 20-percent degradation of mechanical properties). The type of damage expected is given under "Comments". To facilitate choice of an optimum insulation (disregarding radiation effects for the moment) column 6 (which is the reciprocal of the dielectric strength) indicates how thick the insulation must be (in mils/volt) in order to prevent voltage breakdown for a given applied voltage. (The voltage that will cause breakdown is approximately proportional to the thickness.) Column 7 (obtained by multiplying column 6 by the density) gives the areal density, in g/cm^2, needed to prevent voltage breakdown, per volt of applied voltage. Columns 6 and 7 can be used to calculate the thickness and weight, respectively, of insulation needed to prevent breakdown, for unirradiated material. The numbers must be modified for those (see below) in which radiation causes the dielectric strength to change.

TFE Teflon shows somewhat more radiation resistance when irradiated in vacuum than when oxygen is present, but it still fails at a dose of about 10^6 rads. FEP Teflon, when irradiated in vacuum, does not show serious mechanical damage until the dose reaches about 10^7 rads (Reference 3-1).

Kel-F samples showed a permanent decrease in volume and surface resistivity of one to two orders of magnitude after a dose of 2.1×10^7 rads in vacuum. The dissipation factor decreased (improved) somewhat (Reference 3-1).

The tensile strength of polyethylene increases until the dose reaches 10^8 rads, then begins to decrease, and is 25 percent below the initial value at a dose of 10^{10} rads (Reference 3-1).

Table 3-1

ORGANIC EFFECTS ON ORGANIC ELECTRICAL INSULATION (Page 1 of 3)

(1) Material	(2) Specific Gravity	(3) Reference	(4) Dielectric Strength (V/mil)	(5) Reference	(6) *Normalized Thickness (mils/volt)	(7) **Normalized Weight (g/cm^2 volt)	(8) Initial Mechanical Properties	(9) Radiation Damage Threshold (rads)	(10) Reference	(11) Dose Causing Significant Damage (rads)	(12) Reference	(13) Comments	(14) Reference
Phenolic, unfilled	1.3	3-6	200-500	3-5, 3-6	0.003	10^{-5}	hard	10^6	3-1	10^7	3-1	Becomes brittle	3-2
Epoxy (aromatic curing agent)	1.1- 1.4	3-6	405	3-5, 3-6	0.0025	$8x10^{-6}$		10^9	3-1	10^{10}	3-1	Becomes stiff, brittle	3-2, 3-5
Polyester, unfilled	1.1- 1.5	3-6	280-500	3-6	0.003	10^{-5}	flexible	10^5	3-1	10^6	3-1	Becomes brittle	3-2, 3-5
Mylar film	1.4	3-6	4500	3-5	0.0002	$7x10^{-7}$	flexible	10^6-10^7	3-1	10^8	3-1	Becomes brittle, cracks	3-3
Urea-formaldehyde	1.5	3-6	220-400	3-6	0.003	10^{-5}	stiff	$2x10^6$	3-1	$2x10^7$	3-1	Tensile str. falls	3-5
Polystyrene	1.0	3-6	600	3-5, 3-6	0.0015	$4x10^{-6}$	stiff	10^8	3-1	$4x10^9$	3-1	Softens, tensile strength decreases	3-1, 3-5
Acrylonitrile/ Butadiene/ Styrene (ABS)	1.0- 1.1	3-6	350-500	3-6	0.0025	$7x10^{-6}$		10^8	3-1	10^9	3-1	Hardens, tensile strength falls	3-3
Polyimide film	1.43	3-6	7000	3-6	0.00014	$5.0x10^{-7}$	flexible	$2x10^8$	3-1	$>10^9$	3-1	Becomes brittle eventually	
Polyvinyl Chloride	1.2- 1.4	3-6	300-900	3-6	0.002	$6.6x10^{-6}$		10^7	3-1	10^8		Insulation resistance and tensile strength decrease	3-2, 3-3, 3-5

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*Mils/volt needed to prevent breakdown

**gm/cm^2 volt needed to prevent breakdown

Table 3-1

ORGANIC EFFECTS ON ORGANIC ELECTRICAL INSULATION (Page 2 of 3)

(1) Material	(2) Specific Gravity	(3) Reference	(4) Dielectric Strength (V/mil)	(5) Reference	(6) *Normalized Thickness (mils/volt)	(7) **Normalized Weight (g/cm^2 volt)	(8) Initial Mechanical Properties	(9) Radiation Damage Threshold (rads)	(10) Reference	(11) Dose Causing Significant Damage (rads)	(12) Reference	(13) Comments	(14) Reference
Polyethylene	0.9-0.96	3-6	450-700	3-5, 3-6	0.002	$4.7x10^{-6}$	flexible	$\sim 3x10^{7}$	3-1	$\sim 10^{9}$	3-1	Tensile strength and breakdown voltage decrease (after first becoming more brittle)	3-1, 3-5
Polycarbonate	1.2	3-6	350-400	3-6	0.0027	$8x10^{-6}$		$2x10^{6}$	3-1	$3x10^{7}$	3-1		
Kel-F (Polychlorotrifluoroethylene)	2.1-2.2	3-6	400-600	3-5, 3-6	0.002	10^{-5}		10^{6}	3-1	$2x10^{7}$	3-1	Elongation increases, impact strength decreases	3-1
Polyvinyl Butyral	1.05	3-6	325	3-6	0.003	$8x10^{-6}$	flexible	$2x10^{6}$	3-1	$1.5x10^{7}$	3-1	Becomes brittle	
Cellulose Acetate	1.3	3-6	200-600	3-6	0.003	10^{-5}		10^{6}	3-1	$1.5x10^{7}$	3-1		
Polyamide (Nylon)	1.14	3-6	350-470	3-6	0.0025	$7x10^{-6}$	flexible	10^{6}	3-1	$5x10^{6}$	3-1	Stiffens, tensile strength increases	3-1, 3-5
Teflon (TFE)	2.17	3-6	400-500	3-5	0.0022	$1.2x10^{-5}$	flexible	$2x10^{4}$	3-1	$4x10^{4}$	3-1	Becomes brittle, cracks	3-1, 3-2
Teflon (FEP)	2.14	3-6	500-600	3-6	0.002	10^{-5}	flexible	10^{5}	3-1	$3x10^{5}$	3-1	Becomes brittle, cracks	3-1, 3-2

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*Mils/volt needed to prevent breakdown

**gm/cm^2 volt needed to prevent breakdown

Table 3-1

ORGANIC EFFECTS ON ORGANIC ELECTRICAL INSULATION (Page 3 of 3)

(1) Material	(2) Specific Gravity	(3) Reference	(4) Dielectric Strength (V/mil)	(5) Reference	(6) *Normalized Thickness (mils/volt)	(7) **Normalized Weight (g/cm^2 volt)	(8) Initial Mechanical Properties	(9) Radiation Damage Threshold (rads)	(10) Reference	(11) Dose Causing Significant Damage (rads)	(12) Reference	(13) Comments	(14) Reference
Styrene-Butadiene (SBR)	0.93-1.1	3-6	420-540	3-6	0.002	5×10^{-6}		10^6	3-1	10^7	3-1	Becomes brittle	3-3
Silicone Rubber	1.0-1.5	3-6	300-550	3-5, 3-6	0.0025	8×10^{-6}	flexible	10^6	3-1	3×10^6	3-1	Becomes brittle	3-1, 3-2, 3-3
Polypropylene	0.9	3-6	450-650	3-6	0.002	5×10^{-6}	flexible	10^6	3-1	10^7	3-1	Becomes brittle, cracks	3-1
Polyvinylidene Fluoride (Kynar 400)							flexible	10^7	3-1	10^8	3-1	Becomes brittle, tensile strength falls, compression set increases	3-2
Diallyl Phthalate							hard	$\sim 10^{10}$	3-1	$>10^{10}$	3-1	Becomes harder	3-1
Polyurethane	1.1-1.5	3-6	400-500	3-6	0.0022	7×10^{-6}	flexible	10^9	3-1	$\sim 10^{10}$	3-1	Becomes stiffer	3-1, 3-2

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*Mils/volt needed to prevent breakdown

**gm/cm^2 volt needed to prevent breakdown

Although polystyrene is in general very radiation resistant, its volume resistivity and insulation resistance permanently fall one to two orders of magnitude after doses as low as 4.5×10^6 rads and as high as 10^8 rads. Its other electrical parameters show little damage (Reference 3-1).

The diallyl phthalate data listed in Table 3-1 applies only to filled material, filled either with Orlon or with fiber glass. It shows little permanent change in any mechanical or electrical properties at a dose of 10^{10} rads, except that the dielectric constant falls 6 percent (Reference 3-1).

Polypropylene shows severe mechanical damage after a dose of 5×10^7 rads in air. No data on vacuum irradiations are available. The electrical properties do not change significantly (Reference 3-1).

After a dose of about 2×10^6 rads, polyurethane showed no significant change in electrical properties. No electrical tests have been performed at a higher dose (Reference 3-1).

Polyvinylidene fluoride is equally radiation-tolerant in vacuum and air, showing significant mechanical damage at 10^8 rads. Its volume resistivity decreased 3 orders of magnitude after a dose of 6.6×10^7 rads in vacuum (Reference 3-1).

Polyimides are available in the form of film (Kapton), varnish on wire, yarn, and machined blocks. Although it can withstand a dose of 10^9 rads, its use as a cable insulation is presently limited by the binding material. Kapton wire insulation is manufactured with a film of FEP Teflon on one side of a polyimide tape which is then wrapped around the conductor. The FEP Teflon begins to fail after a dose of about 10^7 rads in vacuum. Hughes Aircraft Company has developed a material called Pyrrone II which could be used as a binder on polyimide tape, in place of the FEP. Since Pyronne II is highly aromatic, it is expected to be much more radiation-resistant than FEP, and is being radiation-tested by Hughes and the Milo Wire and Cable Company. It is expected to be commercially available in about 1 year (Reference 3-11).

Another promising radiation-resistant binder for polyimide tape is a material called polyquinoxaline (PQ), developed by Whittaker Corp. as a gasket material. It shows good radiation resistance (with respect to mechanical properties) and may be useful as a polyimide binder (Reference 3-12). Dupont is developing an all-polyimide wire insulation called HI which withstands 5×10^8 rads with no significant mechanical or electrical damage (Reference 3-13).

In one type of silicone rubber, EC 1663, the dissipation factor at 60 Hz increased from an initial value of 0.735 to 3.04 after a dose of 2×10^6 rads. In two other types, LTV 182 and LTV 602, there was no significant change, and none of the three types showed any change in the other electrical parameters at this dose (Reference 3-10).

Since the total dose at the bottom of the run tank, including a safety factor of ten, is around 2×10^8 rads in organics, the following materials listed in Table 3-1 would not fail mechanically—epoxy, polystyrene, ABS, polyimide, polyethylene, diallyl phthalate, and polyurethane. Of these, the polystyrene is too stiff to make into flexible cables; the polyimide in the form of Kapton film is generally held together with a binder which is probably more vulnerable than the Kapton; and the diallyl phthalate, since it is filled, would be difficult to mold into the desired shape. This leaves epoxy, ABS, polyethylene, polyurethane and polyimide with alternate binders as the most promising candidates of the organics; of these, polyimide could be made thinner and lighter than the others for a given voltage.

Exclusively polyimide systems or polyimide systems with various binders appear to be the most attractive organic insulation approach. Organics in general cannot tolerate high temperatures as they might melt, and would be more vulnerable to radiation than is indicated by Table 3-1, which is based on room-temperature data.

3.2 PERMANENT EFFECTS ON CERAMIC INSULATORS

In ceramics and other crystals, the radiation damage is permanent, consisting of lattice defects produced when atoms are knocked out of their normal position by fast neutrons. The radiation dose is usually specified as the number of neutrons, with $E > 10$ kev, which pass through 1 cm^2 of cross-section area of the material. Thermal neutrons (those with $E < 0.025$ ev) have little effect on crystals unless the latter contain such materials as boron or cadmium, both of which have a high thermal neutron capture cross-section. Gamma rays can also produce lattice defects in crystals, but so inefficiently (compared to neutrons) that they can be ignored.

Table 3-2 gives the effects of radiation on ceramics. Columns 6 and 7 give an indication of the thickness and weight, respectively, of the insulation needed to avoid voltage breakdown for a given applied voltage.

The Scientific Engineering and Manufacturing Company (SEMCO) manufactures several types of single-conductor and multi-conductor cable configurations in both single and double sheathing. The conductors range in size from 14 to 36 gauge. The insulation material most used is magnesium oxide, which is hygroscopic and therefore requires protection by a sealant. A variety of conductor and sheathing materials are available. SEMCO magnesium oxide cable is currently in use in radiation environments, in and near reactors, and has proven performance in combined neutron and gamma-ray environments where the integrated neutron flux exceeds 10^8 n/cm^2. Wire and cable configurations are made specially to the customer's requirements and can be supplied with bare leads or terminated in connectors. Further efforts by SEMCO in research and development are by customer request only (Reference 3-14).

Physical Sciences Corp. (PSC) designs, develops, and manufactures complete cabling systems to meet the needs of nuclear power generating plants, nuclear research facilities, and aerospace companies. Their Silflex I is a cable insulated with inorganic, flexible, boron-free SiO_2 fibers, which withstands a temperature of 1,500°F and a radiation dose of 10^{13} rads; SILFLEX II is manufactured with inorganic, high purity SiO_2 fiber, and is designed to withstand 2,000°F and 10^{14} rads. PSC is also developing other new materials with advanced properties, which will be announced soon (Reference 3-15).

Table 3-2

RADIATION EFFECTS ON CERAMIC ELECTRICAL INSULATION

(1) Material	(2) Specific Gravity	(3) Reference	(4) Dielectric Strength (V/mil)	(5) Reference	(6) *Normalized Thickness (mils/volt)	(7) **Normalized Weight (g/cm^2 volt)	(8) Mechanical Properties	(9) Radiation Damage Threshold (n/cm^2)	(10) Reference	(11) Dose Causing Significant Damage (n/cm^2)	(12) Reference	(13) Comments	(14) Reference
$Mg\ 0$	3.65	3-4	50	3-7	0.02	.0019	hard	$4x10^{19}$	3-1	10^{20}	3-1	Dimensions change, cracks more easily	3-8
$Al_2\ 0_3$	4.0	3-4	220-340	3-7	0.004	0.00041	hard	10^{19}	3-1	$2x10^{20}$	3-1	Dimensions change, cracks more easily	3-8
Glass (hard)	2.2- 3.8	3-4	500	3-5	0.002	0.00013	hard			$>10^{16}$	3-1	Cracks form	3-2
Glass (Boron-free)	2.2- 3.8	3-4	500	3-5	0.002	0.00013	hard	10^{17}	3-1	10^{18}	3-1	Dimensions change, discolored, brittle	3-2
Quartz	2.65	3-4	400	3-7	0.0025	0.00017	hard	10^{21}	3-1	$>10^{21}$	3-1	Dimensions change, cracks more easily	3-8
Sapphire	4.0	3-4	220-340	3-7	0.004	0.00041	hard	10^{19}	3-1	$>10^{20}$	3-1	Dimensions change, cracks more easily	3-8
Forsterite	3.2	3-7	240	3-7	0.0042	0.00034	hard	10^{19}	3-1	10^{20}	3-1	Dimensions change, cracks more easily	3-8
Spinel	3.6	3-4					hard	10^{19}	3-1	10^{20}	3-1	Dimensions change, cracks more easily	3-8
Beryllium Oxide	3.0	3-4	250-700	3-7	0.003	0.00023	hard	10^{19}	3-1	10^{20}	3-1	Dimensions change, cracks more easily	3-8

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*Mils/volt needed to prevent breakdown

**g/m^2 volt needed to prevent breakdown

Probably any ceramic would tolerate the expected radiation, except glass containing boron. However, if ceramic-insulated cables are to be flexible, the ceramic must be in the form of fibers, such as fiber glass.

3.3 DOSE RATE EFFECTS

The maximum dose rate (including a 10X safety factor) will be about 3×10^3 rads/sec. The temporary change in electrical conductivity of materials is given by

$$(\sigma - \sigma_o) = A_\gamma \dot{\gamma}^{\delta} (\Omega \text{ cm})^{-1} \qquad \text{(Reference 3-1)}$$

where

σ_o = initial conductivity

A_γ = an empirical constant (on the order of 10^{-17} for typical plastics)

$\dot{\gamma}$ = gamma dose rate, rads/sec

δ = empirical constant (around 1.0 for most plastics)

Therefore a temporary change in conductivity on the order of $3 \times 10^{-14} (\Omega \text{ cm})^{-1}$ would occur, which would not cause significant leakage unless very high-impedance circuits were used. Similar leakage would occur in ceramic insulation.

Section 4
WIRING CONCEPTS

Multiconductor round wire cables (RWC) have been used for interconnecting components and electrical/electronic units in commercial, military, and scientific programs. Generally, the conductor sizes were selected for mechanical strength; the insulation configuration was selected for abrasion or cut-through resistance of the outer conductor in the wire bundle; an excess of shielding was specified to compensate for the random conductor placement in bundles; and each conductor was cut, identified, stripped, terminated, and inserted into the termination device individually. Other wiring concepts are described that offer major advantages for future systems.

4.1 CABLING CONFIGURATION CANDIDATES

Various known cabling candidates will be described together with their pertinent characteristics to be considered for electrical wiring use on the RNS.

4.1.1 Round Wire Cable

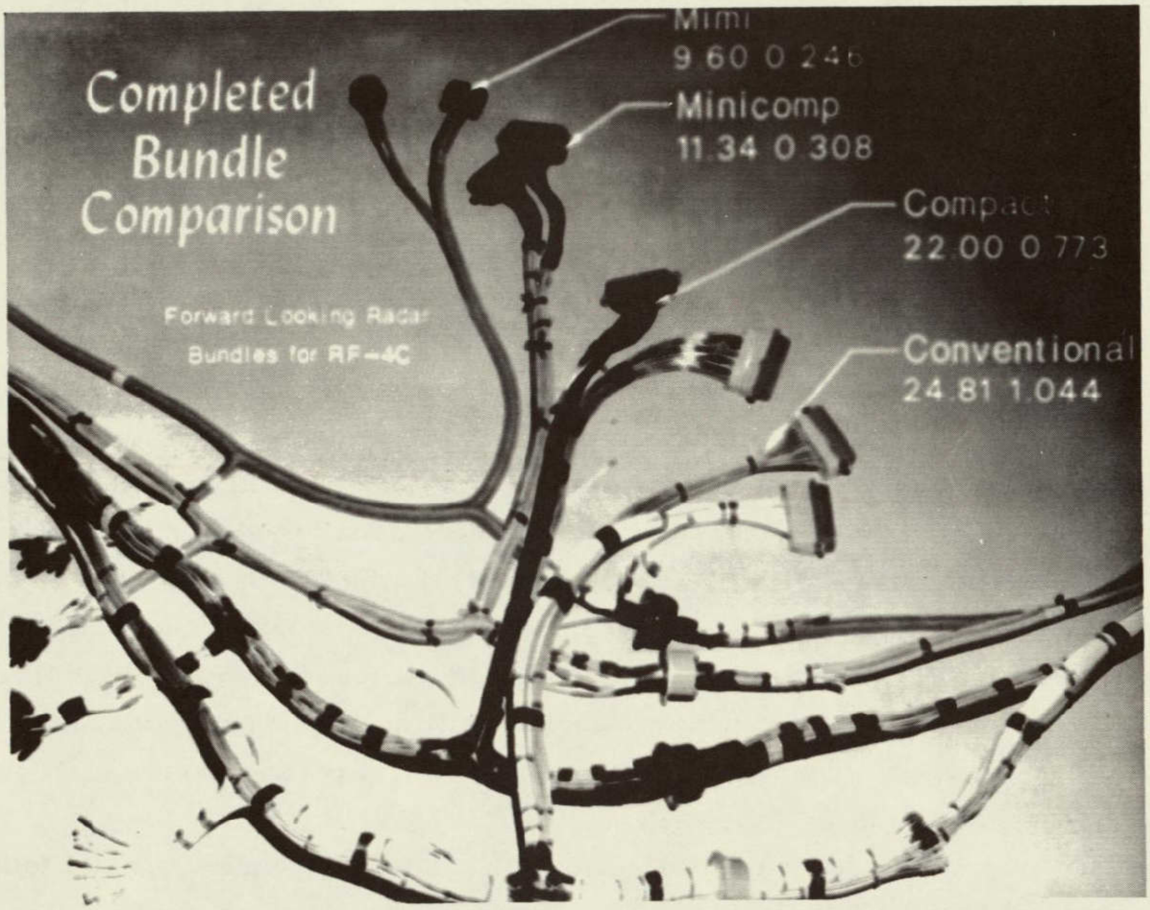
There are three general types of round wire cable (RWC) systems to be considered. Type 1 uses stranded copper conductors with a relatively thick-wall insulation system. This type is the standby and has been used for many years to provide adequate wiring systems. The conductor size is generally limited to 20 AWG minimum and 15 mils or more of composite insulation are used to provide the required electrical and mechanical protection to the conductors. Type 2 uses high-performance, thin-wall insulation systems together with high-strength alloy conductors to permit major reductions in weight and space. First, Teflon TFE and FEP insulations were used with typical 10-mil wall thicknesses for many major programs including the Saturn S-IVB. Next, various polyimide insulation systems with wall thicknesses of a minimum of 5 mils, and high-strength alloy conductors down to 24, 26 and 28 AWG sizes were used. This system provides a very low-weight, small cross-section, high-performance wiring system. However, the thin-wall insulation and notch sensitivity of polyimide is highly susceptable to handling and service damage.

Type 3 uses the basic Type 2 system with a protective outer braid to provide bundle mechanical protection equal to or greater than that provided by the thick-wall insulation of Type 1. The individual cables are properly twisted under the braid to provide additional flexibility and reduce axial stresses in termination and bend areas. North American Rockwell has used a contra-helical lay for such harnesses to assure that when the braided bundle is flexed, the cable ends will remain perpendicular to the center line.
Figure 4-1 shows a comparison of the MDAC-East wire harness systems that have been used on military fighter aircraft. The weight and sectional area savings of the micro-miniature compact type over the conventional type are listed as 65.5 percent and 66.4 percent respectively. These savings are largely the result of smaller wire gages in the compact system.

4.1.2 Flat Conductor Cable

Flat conductor cable (FCC) is made up of solid, flat, rectangular conductors—usually bare or plated copper, but other conductor materials such as aluminum can be used—laminated between layers or sheets of high-performance insulating materials.

Figure 4-2 shows typical cross-sections of various unshielded FCC constructions. The most widely used construction is the symmetrically laminated form (No. 1) with the individual conductors sandwiched between the plastic insulation sheets. An adhesive is used to keep the conductors properly spaced and to assure the integrity of the FCC when exposed to the various operating conditions. The extruded form (No. 2) is made with individual conductors similar to those used for the laminated construction. The insulation is applied by the extrusion process. This method would generally be applicable to ground application or for special electrical requirements where the weight of the added insulation thickness would be acceptable. Preinsulated and laminated (No. 3) is manufactured by the standard laminating process, except



BUNDLE TYPE	WEIGHT		SECTIONAL AREA	
	(LBS)	(%)	(SQ. IN.)	(%)
CONVENTIONAL	24.81	100.0	1.044	100.0
COMPACT	22.00	87.0	0.773	74.0
MINATURE COMPACT	11.34	45.2	0.308	28.5
MICRO-MINATURE COMPACT	9.60	43.5	0.246	23.6

Figure 4-1. Forward Looking Radar Bundles for RF-4C

the conductors are first coated with an insulating varnish. This allows the conductors to be laminated in close proximity to each other while assuring maximum insulation integrity between adjacent conductors. FCC with etched conductors is shown in Nos. 4 and 5. Solid copper foil is bonded to the bottom insulation sheet, or the copper foil is spray- or tower-coated with the insulation material. This assembly is then etched to provide the individual conductors. The top insulation layer is laminated (No. 4) or spray- or tower-coated (No. 5) to complete the cable. Woven cable (No. 6) uses commercial weaving practices to apply the insulation thread to space and securely hold the rectangular solid conductors in place. The woven thread is later impregnated to provide a sealed and mechanically sound FCC.

4.1.3 Ribbon Cable

Ribbon cable is a generic name for a number of round conductors fixed by an insulation system in a parallel plane configuration. Typical ribbon cable is shown in Figure 4-3. In general, various types of single and multiconductor in shielded and unshielded configurations can be used for ribbon cable. Various methods for fabricating ribbon cable are (1) adhesive bonding the adjacent insulation surfaces, (2) thermal fusing the adjacent insulation under heat and pressure, (3) direct extrusion of the insulation over bare conductors, (4) envelope Teflon insulated wires with a thin Teflon film between carefully matched roll calendars, and (5) braid a fabric about parallel conductors.

The first four ways depend on the insulation material, require special tooling for fabrication, and can degrade the basic insulation system; the braiding method seems to offer major advantages for future high-performance systems.

4.1.4 Special Cable Configurations

There are many special cable configurations that offer specific advantages over the standard type cabling previously described. Some are needed to meet special requirements while others provide potential advantages and must be considered in trade-off studies early in the program.

R335A

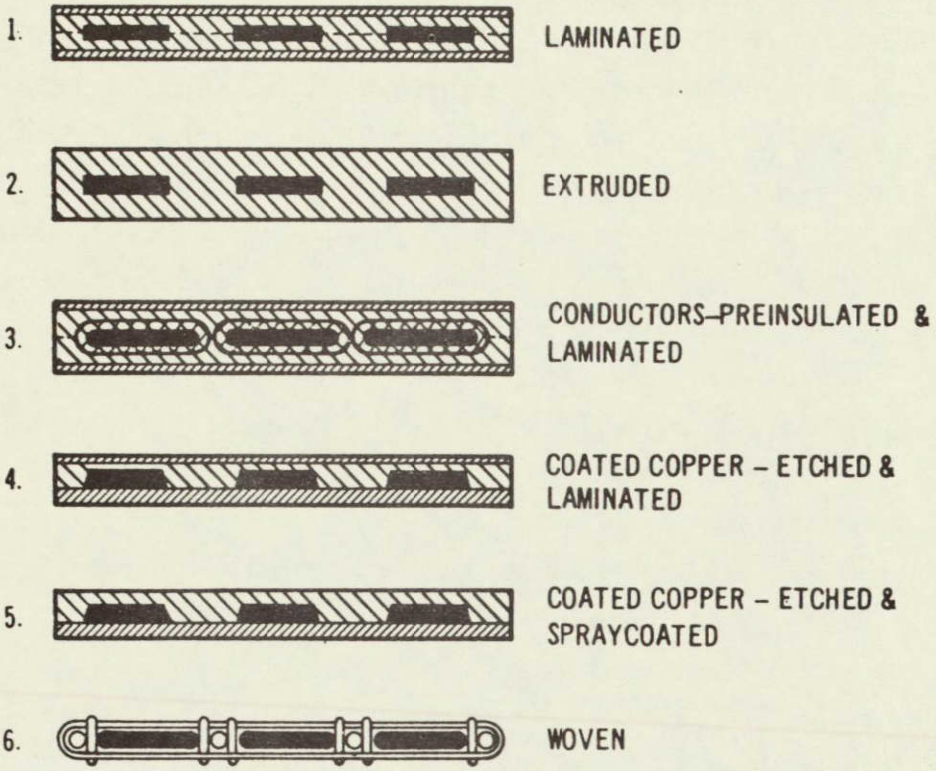


Figure 4-2. FCC Cross-Sections for Various Manufacturing Methods

R335A

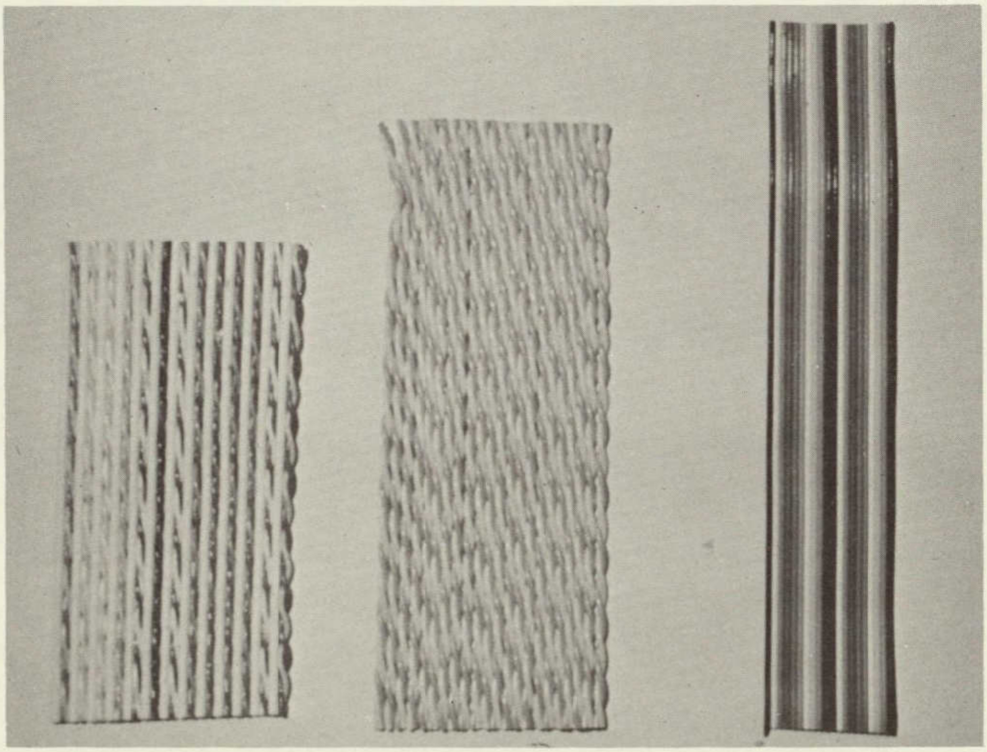


Figure 4-3. Typical Ribbon Flat Cable

Ceramic Insulated

Both very high temperatures and very high radiation doses can be withstood by various ceramic insulations, such as magnesium oxide. However, the brittleness and hygroscopic characteristics of the ceramics generally require the use of another high-temperature, high-radiation resistant material such as a stainless steel tubing to provide the mechanical integrity and permit the cable to be formed as required during fabrication and insulation. Such a system with various conductor materials has seen wide use in reactors. A similar system with inner and outer copper sheaths is described in AEC-NASA Technical Brief 67-10538 dated December 1967.

A second candidate system would use solid conductors with insulating oxide coatings. The conductor groups would be spaced and supported by preformed and fired silica insulators that can be spaced as required.

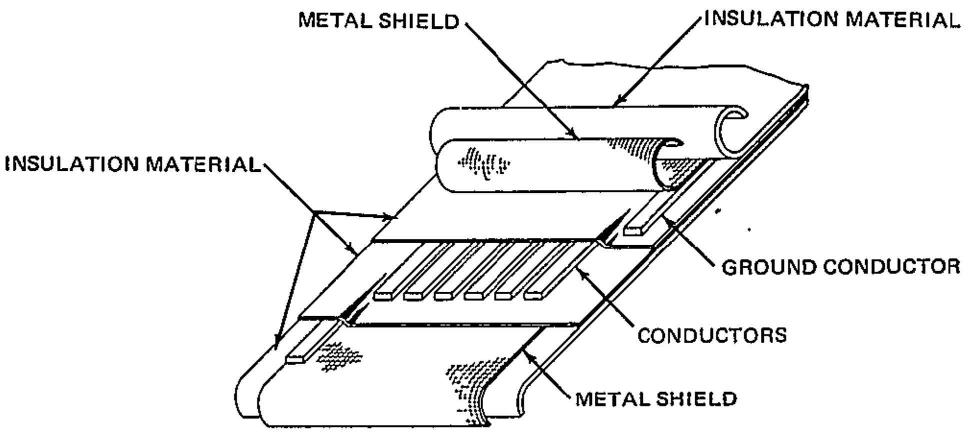
Shielded Wire

RWC uses a metallic braid over one or more configurated conductors or over the entire bundle where shielding is required to reduce electromagnetic interference. This shield may be fabricated from bare copper, silver plated copper, nickel-plated or nickel-clad copper, or stainless steel– depending on the temperature environment and corrosion resistance needed. The metallic braid should be so applied that a 20 to 40 degree angle occurs between the braid carriers and the bundle axis to provide a pushback quality to the shield for greater flexibility and easier termination. Table 4-1 provides additional information for shield selection.

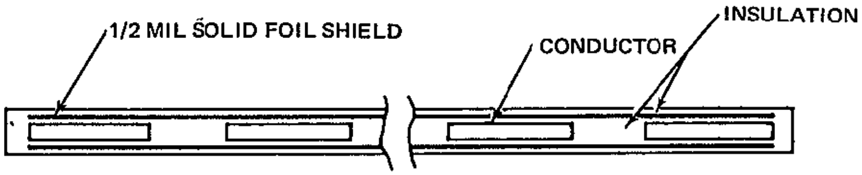
FCC shielding can be incorporated into the basic cable or separate preinsulated shield layers can be used. Figure 4-4 shows two integral shield configurations. Type 2 is easier to manufacture and terminate and is preferred. A typical separate preinsulated shield layer would have one to two mils of outer polyimide insulation and a 1-mil shield foil.

Coaxial Cable or Twinax

Coaxial cable has highly controlled electrical characteristics and is used to transmit radio frequency energy (500 kHz to 10,000 MHz). Its potential application is for the RNS data bus. A close substitute for this application is referred to as twinax.



TYPE 1 - WITH OFFSET EDGE CONDUCTORS



TYPE 2 - WITH NORMAL EDGE CONDUCTORS

Figure 4-4. FCC Shield Configurations

Table 4-1
BUNDLE SHIELD MATERIAL SELECTION CHART

Shield Material	Continuous Operating Temp (Air) Max ($^{\circ}C$)	Corrosion Resistance		Effectiveness
		Air Atmosphere	Liquid Atmosphere	
Bare Annealed Copper	105	Poor	Poor	Excellent
Tinned Copper	150	Good	Fair	Good
Silver-plated Copper	200	Good	Good	Excellent
Nickel-plated Copper	350	Excellent	Very Good	Good at audio frequency. Poor at radio frequency.
Nickel-clad Copper	500	Excellent	Very Good	Good at audio frequency. Poor at radio frequency.
Stainless Steel	550	Excellent	Excellent	Poor

Special Electrical Characteristics

Special electrical characteristics for specific characteristic impedance requirements can often be easily met by special ribbon and FCC configurations that maintain tight control of the physical location of conductors and use proper insulation systems. Magnetic fields can be tolerated by sensitive lines and can be reduced to a minimum by transmitting lines by using over-and-under FCC conductor configurations. In theory, if the signal and return lines occupied the same physical location, they would be immune to external fields and would be incapable of transmitting magnetic fields. The over-and-under FCC with 4 mils of insulation between signal and return lines approaches the ideal condition and is therefore more efficient than shielded or twisted RWC.

FCC Power Cable

Initially it was thought that the major advantages of FCC over RWC was limited to the small wire gages, AWG 20 and smaller, and that large power applications was best left with RWC. Then the Boeing Company conducted an extensive series of evaluations and tests (Reference 4-1) for a 250-ampere AC power circuit that indicated FCC offered major advantages in heat dissipation and lower net impedance. The Boeing Company used an aluminum conductor 3.30 inches wide by 25 mils thick to replace a 2/0 AWG aluminum RWC to minimize power cable weight.

4.2 ATTRACTIVE CANDIDATE INSULATION MATERIALS

A complete treatise on insulation materials for electrical cabling is beyond the scope of this report. However, the major insulation categories will be briefly described together with their physical and electrical characteristics. The reader is referred to Reference 4-2 for more detailed information.

4.2.1 Thermoplastic Insulation

The term "thermoplastic" is applied to those materials that repeatedly soften and become formable or plastic with the application of heat. These materials are formed around conductors by extrusion without the need for subsequent curing. The thermoplastic resins most commonly used for wire insulation are:

A. Various compounds of polyvinylchloride for limited environments.

B. Three densities of polyolefins.

C. Cross-linked polyolefins.
D. Nylons.
E. Fluorocarbons-including TFE and FEP Teflon.

Table 4-2 lists typical physical and electrical properties for the thermoplastic materials. In general these materials do not combine the required properties for RNS primary insulation. However, they are listed for general information and as a ready reference for subsequent insulation considerations. The resistance to radiation, as listed in Section 3, must also be considered. Whereas some of the fluorocarbons have seen extensive use in modern space programs, their susceptability to radiation damage makes them inappropriate for the aft portions of the RNS.

4.2.2 Thermoset Elastomers

Rubbers are thermoset elastomers. This means that the application of heat results in the formation of a material that cannot be reformed or melted. They are extruded cold or only mildly heated and later subjected to a heating cycle that causes them to cross link, or vulcanize, into their familiar form. Elastomers differ from other thermosetting polymers, such as phenolics, epoxies, etc., in that they exhibit high strength and modulus while stretched, and recover on release of stress. The basic polymers are extensively compounded to obtain the specific desired properties. The thermoset elastomers most commonly used are:

A. Natural Rubber—Good electrical properties.
B. Styrene-Butadiene Rubber — Similar to natural rubber.
C. Chloroprene Rubber — Neoprene, poorer electrical properties.
D. Butyl Rubber — Generally better electrical and mechanical properties.
E. Silicone Rubber — For extremely low temperatures.
F. Chlorosulfonated Polyethylene — High chemical resistance.
G. Ethylene Propylene Rubber — High chemical resistance.
H. Fluorocarbon Rubber — High operating temperatures.

Table 4-3 lists typical physical and electrical properties for typical thermoset elastomers. In general these materials are not suitable for primary insulation systems for RNS because of their limited mechanical properties. However, some of the silicone rubbers are especially resistant to nuclear radiation damage.

Table 4-2

TYPICAL PROPERTIES OF THERMOPLASTIC MATERIALS

Resin Type Compound	PVC* 1	PVC* 2	PVC* 3	PVC* 4	PVC* 5	Polyethylene (Unfilled) Low-density	Polyethylene (Unfilled) Medium-density	Polyethylene (Unfilled) High-density
Specific Gravity	1.35	1.38	1.37	1.21	1.20	0.920	0.935	0.947
Ultimate Tensile Strength (psi)	3,000	4,000	2,400	2,000	1,800	2,200	2,500	3,400
Ultimate Elongation (percent)	200	150	250	375	400	625	350	250
Volume Resistivity (ohm-cm)	8×10^{15}	8×10^{15}	4×10^{15}	1×10^{12}	1×10^{11}	1×10^{17}	1×10^{17}	1×10^{17}
Dielectric Constant (1 kHz)	5.0	4.8	5.7	6.0	6.0	2.25	2.29	2.32
Dissipation Factor (1 kHz)	0.10	0.08	0.12	0.15	0.15	0.0002	0.0002	0.0002
Rated Max Temp (°C)	105	80	80	60	60	75	---	---
Rated Min Temp (°C)	-40	-10	-40	-65	-55	-65	-65	-65

Resin Type Compound	Polypropylene (Unfilled)	Nylon 610	Fluorocarbon TFE	Fluorocarbon FEP	Fluorocarbon CTFE	Fluorocarbon VF-2	Polyurethane Jacketing (Ether Type)
Specific Gravity	0.902	1.08	2.18	2.16	2.16	1.76	1.25
Ultimate Tensile Strength (psi)	5,000	8,000	3,500	3,000	5,000	7,000	6,000
Ultimate Elongation (percent)	200	200	300	250	150	300	600
Volume Resistivity (ohm-cm)	1×10^{17}	1×10^{14}	1×10^{18}	1×10^{18}	1×10^{18}	1×10^{14}	2×10^{11}
Dielectric Constant (1 kHz)	2.22	4.5	2.0	2.1	2.3	8.0	7.5
Dissipation Factor (1 kHz)	0.0003	0.04	0.0002	0.0003	0.0023	0.019	0.060
Rated Max Temp (°C)	----	105	260	175	135	135	75
Rated Min Temp (°C)	10	-40	-65	-65	-65	-65-	-55

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*Refer to Reference 4-2 for detailed compound descriptions.

Table 4-3

TYPICAL PROPERTIES OF ELASTOMERIC COMPOSITIONS

Base Polymer	Natural	SBR	Neoprene	Butyl	Silicone
Specific Gravity	1.3 to 1.7	1.15 to 1.55	1.4 to 1.65	1.15 to 1.5	1.10 to 1.55
Ultimate Tensile Strength (psi)	1,500 to 4,000	800 to 2,500	1,200 to 2,700	500 to 1,500	500 to 1,500
Ultimate Elongation (percent)	300 to 700	350 to 650	300 to 700	300 to 800	100 to 600
Rated Max Use Temp (°C)	75	90	90	90	200
Rated Min Use Temp (°C)	-55	-55	-55	-55	-55 to -100
Volume Resistivity (ohm-cm)	10^{13} to 10^{15}	10^{12} to 10^{15}	10^{11} to 10^{13}	10^{13} to 10^{16}	10^{13} to 10^{16}
Dielectric Constant (1 kHz)	3.3 to 5	3.5 to 5	5 to 7	3.2 to 5	2.9 to 3.5
Dissipation Factor (1 kHz)	0.01 to 0.035	0.006 to 0.035	0.02 to 0.05	0.008 to 0.035	0.002 to 0.02
<u>Resistance to:</u>					
Water Absorption	excellent	excellent	good	excellent	good
Oil and Gasoline	poor	poor	good	poor	poor
Chlorinated Hydrocarbon	poor	poor	poor	poor	poor
Weathering	poor	poor	good	excellent	excellent
Ozone	poor	fair	good	excellent	excellent
Flame	poor	poor	good	poor	fair
Radiation	fair	fair	poor	poor	good

Base Polymer	Fluorinated Silicone	Hypalon (du Pont)	EPR	Fluorocarbon
Specific Gravity	1.4 to 1.8	1.35 to 1.7	1.25 to 1.45	1.9 to 2.0
Ultimate Tensile Strength (psi)	500 to 1,000	1,200 to 2,200	1,000 to 2,500	1,000 to 2,000
Ultimate Elongation (percent)	100 to 250	300 to 600	350 to 600	200 to 400
Rated Max Use Temp (°C)	200	90	90	200
Rated Min Use Temp (°C)	-55	-55	-55	-30
Volume Resistivity (ohm-cm)	10^{12} to 10^{14}	10^{12} to 10^{14}	10^{13} to 10^{16}	10^{12} to 10^{14}
Dielectric Constant (1 kHz)	6 to 7.5	9 to 11	3.2 to 5	7 to 9
Dissipation Factor (1 kHz)	0.03 to 0.06	0.05 to 0.08	0.007 to 0.035	0.02 to 0.05
<u>Resistance to:</u>				
Water Absorption	good	good	good	good
Oil and Gasoline	excellent	good	poor	excellent
Chlorinated Hydrocarbon	good	poor	poor	excellent
Weathering	excellent	excellent	excellent	excellent
Ozone	excellent	excellent	excellent	excellent
Flame	fair	good	poor	good
Radiation	good	fair	fair	fair

With the exception of the electrical properties, typical properties of both insulating and jacketing compounds are shown. The electrical properties shown are typical of insulating compounds containing little or no carbon black, but are not typical of many jacketing compounds which may contain varying amounts of black as reinforcing filler which can produce considerable variation of electrical properties.

4.2.3 Films

Film is defined as sheeting less than 10 mils thick. They are usually used when processing factors make extruded insulation impractical for RWC and as the primary insulation for laminating FCC. Major advantages of film are reductions in insulation size and weight and the use of material with superior mechanical properties. Film materials most commonly used for wire insulation are:

A. Cellulosics — For low-voltage noncritical application.
B. Polyesters — Excellent physical and electrical properties.
C. Fluorocarbons — TFE most generally used.
D. Polyimide — Excellent physical, electrical and thermal properties and high radiation resistance.

Table 4-4 lists the physical and electrical properties for film materials suitable for wire insulation. The polyester and polyimide have excellent physical and electrical properties and are widely used for high-performance insulation systems. The improved radiation resistance of polyimide makes it a principal contender for use on RNS.

4.2.4 Fibers

The principal uses of fibers for cabling are for protective coverings, reinforcements, and fillers. They are usually applied by serving or braiding followed in some cases by a coating or jacket. Fibers provide flexibility, mechanical strength, and in woven constructions provide additional positive separation between conductors. Fiber materials include cotton, rayon, nylon, polyester, glass, ceramic, asbestos, and various fiber combinations. Table 4-5 lists typical physical properties of the common fiber materials. A fiber combination for physical and radiation resistance is especially attractive for the woven ribbon cable for the RNS.

4.2.5 Inorganic Materials

The most common inorganic insulation is magnesium oxide. It is used in cables as a compressed powder or as beads through which the conductors are threaded. An external gas-tight metal sheath provides sealing and mechanical protection. Other inorganic materials used are aluminum oxide and boron nitride. Table 4-6 lists typical properties for these inorganic materials.

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Table 4-4

TYPICAL PROPERTIES OF FILMS

General Type	Cellulosic			Polyester	
Specific Compound	Cellulose Acetate	Cellulose Acetate-Butyrate	Cellulose Triacetate	Polyester	Polyester/ Polyethylene (1/0.5 mil)
Specific Gravity	1.30	1.20	1.29	1.39	1.20
Ultimate Tensile Strength (psi)	10,000	8,000	14,000	25,000	17,000
Ultimate Elongation (percent)	25	80	25	75	125
Volume Resistivity (ohm-cm)	1×10^{14}	1×10^{15}	1×10^{15}	1×10^{17}	2×10^{17}
Dielectric Constant (1 kHz)	3.8	2.9	3.2	3.25	2.7
Dissipation Factor (1 kHz)	0.020	0.015	0.016	0.005	0.003

General Type	Fluorocarbon		Polyimide
Specific Compound	TFE	FEP	Kapton (duPont)
Specific Gravity	2.2	2.15	1.42
Ultimate Tensile Strength (psi)	3300	3000	20,000
Ultimate Elongation (percent)	300	300	70
Volume Resistivity (ohm-cm)	1×10^{18}	1×10^{18}	1×10^{17}
Dielectric Constant (1 kHz)	2.1	2.1	3.5
Dissipation Factor (1 kHz)	0.0003	0.0003	0.003

Table 4-5

TYPICAL PROPERTIES OF FIBERS

Type	Cotton	Rayon	Nylon	Polyester	Glass	Asbestos
Specific Gravity	1.54	1.3 to 1.5	1.14	1.38	2.54	2.4 to 2.6
Tensile Strength (psi)	90,000	40,000	100,000	90,000	210,000	500,000
Elongation (percent)	5	25	25	20	2	---
Resistance to:						
Fungus	poor	poor	inert	inert	inert	inert
Flame	poor	poor	fair	poor	excellent	excellent
Abrasion	fair	fair	excellent	good	poor	poor

Table 4-6

PROPERTIES OF TYPICAL INORGANIC INSULATING MATERIALS*

Material	Magnesium Oxide	Aluminum Oxide	Boron Nitride
Melting Point (°C)	2,800	2,015	2,730
Volume Resistivity, ohm-cm			
at 300°C	10^{14}	10^{9}	10^{11}
at 1000°C	10^{9}	10^{6}	10^{7}
at 1500°C	10^{7}	--	--
Specific Gravity	3.6	3.8	2.2
Dielectric Constant (1 MHz)	9.7	9.5	4.2
Dissipation Factor (1 MHz)	0.002	0.008	0.001

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*The properties listed are those expected of a void-free construction, and in the case of compressed powders, would vary appreciably with the degree of compaction, particularly with regard to dielectric constant.

Physical Sciences Corporation (PSC) of Arcadia, California, has a series of special inorganic insulation systems suitable for electrical cables. DUROCK employs a flexible silico-ceramic compound that can be applied in ultra-thin layers from 0.3 to 0.5 mils for magnet wire; SILFLEX I employs a flexible, boron-free silicon dioxide fiber for single and multiconductor cable, and SILFLEX II employs a high purity silicon dioxide fiber that can be employed as a coaxial dielectric. Tables 4-7 through 4-9 list the PSC inorganic cable characteristics.

Table 4-7
INORGANIC INSULATED CABLE CHARACTERISTICS
PSC* INSULATIONS

	Durock	Silflex I	Silflex II
High Temperature Rating (°F)	1,000	1,500	2,000
Low Temperature Rating (°F)	-368	-425	-425
Gamma Radiation Rating (Rads)		1×10^{13}	1×10^{14}
Dielectric Strength (Volts/Mil)	300 to 600	150	150
Dielectric Constant	6.7 to 10.0	3.5	2.5
Moisture Resistance	Good	Low	Low
Flammability	Nonflammable	Nonflammable	Nonflammable
Flexibility	Good	Very flexible	Very flexible
Abrasion Resistance	Good	Low	Low
Availability			
Magnet Wire	X		
Thermocouple Cable		X	X
Coaxial Lead			
Signal Lead		X	X
Multiconductor Cable		X	X

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*Physical Sciences Corporation

Table 4-8

INORGANIC INSULATED CABLE CHARACTERISTICS PSC[a] CONDUCTORS

	Maximum Temperature Rating (°F)	Resistance (% of Copper)	Specific Gravity	Availability[b]
Copper	400	100	8.92	
Silver Plated Copper	400	100	8.93	
Nickel Plated Copper	500	122	8.92	
Aluminum	800	163	2.70	1
Aluminum Clad Copper	800	126	6.40	1
Nickel Clad Copper	1,000	141	8.92	1
S.S. Clad Copper	1,300	154	8.92	1 2
Nickel Clad Silver	1,500	109	10.40	1 2 3
Nickel 'A'	1,800	580	8.90	3
304 Stainless	1,700	4,224	7.93	
Copper/Constantan	400	--	--	
Iron/Constantan	1,500	--	--	2
Chromel/Constantan	1,500	--	--	2
Alumel/Chromel	2,000	--	--	2 3

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a. Physical Sciences Corporation

b. 1 = Durock
2 = Silflex I
3 = Silflex II

Table 4-9

INORGANIC INSULATED CABLE CHARACTERISTICS
CONDUCTOR SIZES

AWG Size	Stranding	Diameter (in.)	Resistance of Copper at 20°C (Ohms/1,000 ft)
16	19/29	0.058	3.85
	Solid	0.050	4.00
18	19/30	0.050	5.43
	Solid	0.040	6.39
20	19/32	0.040	8.60
	Solid	0.032	10.15
22	19/34	0.032	13.75
	Solid	0.025	16.70
24	19/36	0.025	21.80
	Solid	0.020	25.60
26	19/38	0.020	34.60
	Solid	0.0159	41.00
28	Solid	0.0126	65.00
30	Solid	0.0100	103.70
32	Solid	0.0080	164.00
34	Solid	0.0063	260.00
36	Solid	0.0050	414.00
38	Solid	0.0040	650.00

4.2.6 Improved Organic Materials

Vendor activity in the development of improved organic insulation materials is primarily in polyimides. A number of companies are active in developing new binder materials for use with polyimide tape and an all-polyimide insulation system.

DuPont is currently working on an all-polyimide insulation system, still in the experimental stages known as "HI" polyimide. Radiation tests on HI to 5.0 x 10^8 rads at 273°F showed no visible effects and the insulation subsequently passed electrical functional tests. The all-polyimide HI is a taped insulation system; early results show it to have improved performance over the polyimide-FEP combination tapes.

Several materials that have potential use as a binder for polyimide tape, having superior temperature and radiation performance to FEP, are in the advanced stages of development and test. Notably among these are Pyrrone II, developed by Hughes and Polyquinoxaline (PQ) developed by the Whittaker Corporation. Pyrrone II was developed to provide a high-temperature binder for polyimide insulated wire, thus increasing its temperature rating. Polyimide tape and film in combination with Pyrrone II have been tested successfully to 700°F continuously. Pyrrone II is also highly aromatic and is expected to prove to be radiation resistant. Radiation tests are currently being performed by NASA Langley. Pyrrone II is not available commercially, however, Hughes is willing to work with wire manufacturers in making samples of wire with Pyrrone II bonded polyimide tape and developing techniques for large scale production. Extensive data on Pyrrone II may be found in a report titled "High Temperature Electric Wire Insulations" by Dr. Norman Bilow and Kenneth L. Rose of Hughes Aircraft Company.

Polyquinoxaline (PQ) is one of four materials currently being developed by Whittaker Corporation, Research and Development Division; the other three are Polypheuylquinoxaline (PPQ), Polyimidizolequinoxaline (PIQ), and Polybenzimidosole (PBI). Of the four, only PQ is currently available. Developed primarily for a radiation-resistant gasket material, PQ has not yet been tried as a wire insulation. It is a viscuous fluid much like molasses in its natural state. In cured form as gasket material, it has shown good radiation resistance to 1 x 10^8 rads. Whittaker is willing to work with wire manufacturers toward the development of PQ into a wiring insulation system component, as a possible binder for polyimide tape.

4.3 PHYSICAL CHARACTERISTICS OF CONDUCTOR CANDIDATES

In the past, electrical conductors for missile and space vehicles have almost without exception been of a high conductivity (near pure) copper. Various copper alloy materials plus aluminum are considered for use on the RNS.

4.3.1 Copper and Copper Alloy

The high electrical and thermal conductivity of copper, coupled with its mechanical strength and resistance to corrosion, have established copper as the primary conductor material. Until recent requirements for minimum weight and space, the conductor used for flight application was limited to 20 AWG and larger, generally of stranded electrolysis-tough-pitch copper. With the use of wire sizes of 24 AWG and smaller, a high-strength copper alloy is used to retain the required mechanical strength for termination and handling. Table 4-10 lists the flex life of copper versus Alloy 63* with the conductors under various tensile loads. Improvements of an order of magnitude explains why the alloy conductors are used in the smaller wire sizes.

Table 4-10

FLEX LIFE OF COPPER VERSUS ALLOY 63

Load Material** (psi)	Soft Copper	Alloy 63
1,500	160 cycles	2000 + cycles
5,000	36 cycles	249 cycles
10,000	16 cycles	30 cycles
15,000	1**cycle	14 cycles

** Load psi exceeds material yield strength.

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*Texas Instruments

4.3.2 Aluminum

Table 4-11 compares the electrical and mechanical properties of aluminum and copper. This table shows that aluminum has twice the conductivity for the same unit weight, a tensile yield strength of about one-third that of copper, and a coefficient of linear thermal expansion (Tc) of about 1-1/2 times that of copper. The use of aluminum in lieu of copper will reduce the conductor weight by 50 percent. In addition, the aluminum conductor with polyimide insulation will fuse inside the insulation prior to burning through the insulation. This provides a system that will meet all known flammability requirements as well as provide controllable fuse characteristics. Thus a fault in one conductor will not result in the damage or destruction of adjacent conductors or equipment. This makes aluminum a major contender for the nuclear stage. However, the reduced yield strength with resultant cold flow characteristics, the increased Tc, the tendency to oxidize, and susceptibility to corrosion require that aluminum be used in electrical circuits with extreme caution. Texas Instruments has developed a copper clad aluminum conductor that can be drawn to 40 AWG for use in conventional stranded round wire cable. This conductor has much higher strength as well as higher conductivity than aluminum and yet retains most of the advantages of aluminum including the fuzing characteristics. It is also claimed that this conductor system can be crimped and handled the same as conventional cable with copper conductors.

A review of general circuit requirements shows that power and other low IR-drop circuits require a given conductivity. However, the majority of interconnecting circuits on the RNS require relatively small conductivities of 26 AWG or less. In the RNS sizes of 20 AWG and smaller, the use of aluminum conductors is very difficult to justify, while in the larger sizes it must be considered for all circuits.

4.3.3 Coatings

Bare copper conductors are usually coated with a metal to prevent corrosion and enhance termination. Coatings are applied by electroplating, hot dipping, and cladding. The least expensive coating is tin which limits corrosion and facilitates the application of solder. The tin, which is limited to a maximum 120°C operating temperature, can be applied by electroplating or hot dipping.

Table 4-11

PROPERTIES OF ALUMINUM AND COPPER

Symbol	Al	Cu
Atomic Weight	26.98	63.54
Density	2.70	8.89
Melting Point (°C)	660	1083
Specific Heat	0.226	0.092
Coefficient of Linear Thermal Expansion (cm/cm/°C)	24.7	17.6
Thermal Conductivity (Btu/hr/sq ft/°F/ft)	101	211
Electrical Resistivity (20°C micro-ohm/cm)	2.8	1.7
Electrical Conductivity (%IACS) (Equal Volume)	62	101
Electrical Conductivity (Equal Weight)	204	100
Current Carrying Capacity	80	100
Modulus of Elasticity	10	17
Tensile Strength (Annealed) (10^3psi)	12	38
Yield Strength (10^3 psi)	4	10
Hardness (Brinell)	50	103
Solution Potential (In NaCl 3% H_2O_3 N/10 Calomel Scale)	0.85	0.20

Silver-coated conductors are reliable for a continuous maximum temperature of 200°C. Silver is electrolytically applied to a thickness of 40 or 50 microinches. A red cuprous oxide formation, sometimes referred to as the red plague has occurred on silver plated conductors. However, proper application greatly reduces this condition and a dual coating will eliminate it. Nickel plating was developed for continuous service up to 300°C. The nickel is electro-deposited, does not exhibit any oxide corrosion and a flaw in the nickel is self-healing. It is normally deposited to 50 μin. minimum. Dual coatings of a layer of nickel (10 μin.) with a top layer of silver (40 μin.) combine to give the advantages of both systems.

4.3.4 Shielding

The most satisfactory shielding materials for RWC are copper and aluminum braided wires. The shield provides a high conductivity, flexible, mechanically sound structure giving an effective electrostatic and electromagnetic shield at the price of weight and cost increase. The percent coverage is usually between 85 and 95 percent and depends on the number of carriers, the number of ends per carrier, and the picks per inch. In general, shielding should be avoided where possible by using conductor twisting and bundle separation in RWC and by using conductor placement in FCC.

4.4 CABLE MANUFACTURING PROCESS DESCRIPTION AND EVALUATION

There are several feasible fabrication methods associated with wire currently in use for the organic materials (Reference 4-3). For round wire, the most common methods are extrusion and tape wrap; braiding and dispersion coating are also used. However, not all of the methods lend themselves to use as a primary insulation system for electrical wiring. For instance, braiding is primarily used as a covering for wire bundles or as a filler mat for laminates. Dispersion coats are generally used for primary insulation (magnet wires) and as a coating over primary insulation.

Flat conductor cable is generally laminated or extruded. Etching can also be used followed by a laminating or coating process.

Table 4-12 assesses the feasible methods that can be used for a range or organic insulation materials. A more detailed description of these processes and their evaluation, as they apply to the various cable types, is given in the following paragraphs.

4.4.1 Round Wire Construction Methods

There are several proven constructions for RWC which are summarized and evaluated in Table 4-13 and described as follows:

Extrusion

A process whereby plastic materials are forced through a shaping orifice or die to form a homogeneous solid cylinder of insulation around a conductor. Variations in the details of the process are required to process different

Table 4-12

FEASIBLE CABLE FABRICATION METHODS WITH ORGANIC MATERIALS (Page 1 of 2)

	Insulation Methods					
Material	Extrusion	Tape Wrap	Coating-Dispersion, Dip, Brush	Braid	Laminate	Comments
Phenolic, Unfilled	-	-	-	-	-	Too brittle -- not suitable for wire insulation.
Epoxy (Aromatic Curing Agent)	-	-	X	-	-	
Polyester, Unfilled	-	X	X	X	X	Tape wrap as Mylar film
Mylar Film	-	X	-	-	X	
Urea-Formalae-Hyde	X	X	X	X	X	Not suitable for wire insulation - rigid
Polystyrene	X	X	X (base coat)	-	-	Rigid - not attractive for wire insulation.
Acrylonitrile/Butadiene/Styrene (ABS)	X	-	-	-	-	Rigid - not suitable for wire insulation
Polyimide	-	X	X	-	X	
Polyvinylchloride	X	X	-	-	X	Outgas, low temp.
Polyethylene	X	X	-	-	X	Outgas, low temp.
Polycarbonate	X	X	X	-	X	Rigid - not recommended for wire insulation.
Kel-F (Polychlorotrifluoroethylene)	X	X	-	-	X	
Polyvinyl Butyral	X	-	X	-	-	Self-bonding coating
Cellulose Acetate	X	X	-	-	X	Replaced by mylar film in tape applications
Polyamide (Nylon)	X	-	X	X	X	Primarily for jacketing material

X = Feasible fabrication approach

Table 4-12

FEASIBLE CABLE FABRICATION METHODS WITH ORGANIC MATERIALS (Page 2 of 2)

Material	Insulation Methods					Comments
	Extrusion	Tape Wrap	Coating-Dispersion, Dip, Brush	Braid	Laminate	
Teflon (TFE)	X	X	X	X	X	Thermosetting
Teflon (FEP)	X	X	X	X	X	Thermoplastic
Styrene - Butadiene (SBR) (Rubber)	X	-	-	-	-	Poor resistance to chemicals, oil, and high temperature
Silicone Rubber	X	X	X	-	-	Poor abrasion resistance
Polypropylene	X	X	-	X	X	
Polyvinylidene Fluoride (Kynar 400)	X	X	X	-	X	
Diallel Phthalate	-	-	-	-	-	Rigid, brittle - not suitable as wire insulation
Polyurethane	X	-	-	-	-	Primarily for potting, molding and encapsulating applications

X = Feasible fabrication approach

Table 4-13

EVALUATION OF MATERIAL AND METHOD FOR ROUND WIRE (Page 1 of 3)

Material/Method	Description	Relative Cost	Current Use	MIL-Specification
Polyester Film				
Wrap	Heat-sealable, double wrap usually used mostly as insulation over shields.	Moderate	Aerospace - jacket over shields on AGE cables	MIL-C-13777
Polyimide				
Tape Wrap	Multi-wrap, heat sealable, usually used with dispersion coat of TFE or FEP.	High	Aerospace Aircraft	MIL-W-81381
Coating	Toxic varnish, good characteristics — primarily used for magnet wire insulation where cryogenic and radiation resistances are desired.	High		
Polyvinyl Chloride				
Extrusion	Thermoplastic compound widely used as wire insulation.	Inexpensive	Aircraft Aerospace (AGE) Commercial	MIL-W-5086 MIL-W-16878
Tape Wrap	Upper temperature limit prevents use of thermosetting adhesive Not commonly used for primary wire insulation.		Commercial - For insulating splices and covering wire harnesses	
Polyethelene				
Extrusion	Good extrusion characteristics. Requires "tailoring" for each use Anti-oxidants required for electrical use to prevent degradation when exposed to light or heat.	Low	Aerospace Aircraft Commercial	MIL-C-17 MIL-W-76
Tape Wrap	Limited temperature range precludes the use of thermo-setting adhesive. Not widely used for wire insulation.	Low	Commercial splicing where temperature allows.	--
Kel-F (Polychlorothrifluoroethylene)				
Extrusion	Can be transparent. Has been used as jacket over cable, but is stiff and cracks.	Moderate		
Tape Wrap and Film	Heat sealable, flexible at low temperatures. Laminates well to other materials.		Flexible circuits (film configuration)	
Teflon (TFE)				
Extrusion	Requires "sintering" to make homogeneous and partially amorphous. Easily combined with fillers.	High	Aerospace Aircraft Commercial	MIL-S-16878 MIL-W-22759
Tape Wrap	Requires "sintering" to make homogeneous.	High	Aircraft replaced by extrusion in most applications)	MIL-W-16878

Table 4-13

EVALUATION OF MATERIAL AND METHOD FOR ROUND WIRE (Page 2 of 3)

Material/Method	Description	Relative Cost	Current Use	MIL-Specification
Teflon (TFE)				
Coating	Dispersion coat over wrapped insulation. Fused at high temperature to continuous film.		Aerospace	
Braid	Braided over wire bundles to provide high temperature jacket. Not intended for use as primary insulation.	--	Aerospace Aircraft Commercial	--
Teflon (FEP)				
Extrusion	Meltable and lower temperature capability, otherwise similar to TFE. Can be extruded in a manner similar to other thermoplastic materials. Does not require sintering.	Moderate	Aerospace	MIL-C-17 MIL-W-16878 MIL-W-22759
Tape Wrap	Heat sealable, good characteristics. Essentially free of pin holes and inert to virtually all known chemicals and solvents.	Moderate		MIL-W-22759
Coating	Dispersion coating provides low permeability, excellent heat sealability, high dielectric. Water based. May be fused at lower temperature than TFE.	Moderate	Aerospace	MIL-W-81381
Braid	May be braided over wire bundles to provide high temperature jacket. Not for use as a primary insulation because of porosity.	--	Aerospace Aircraft	
Polypropylene				
Extrusion	Low dielectric constant coupled with high strength and abrasion resistance allows use as thin wall insulation system. Low specific gravity allows more product per unit weight and possible cost savings. Poor low temperature flexibility.	Moderate		
Tape Wrap				
Braid	Primarily woven in form of mats and cloth. Not used as primary insulation. Used as base cloth in laminates.		Aerospace	
Polyvinylidene Fluoride (Kynar 400)				
Extrusion	Hard material with good tensile strength. However, tends to become brittle and exhibit poor impact resistance when extruded over large stranded conductors.	Moderate	Aerospace	MIL-W-5086 MIL-W-81044
Tape Wrap	High strength and toughness temperature stability -80 to +300°F. Tensile strength may be increased by orientation techniques.			

Table 4-13

EVALUATION OF MATERIAL AND METHOD FOR ROUND WIRE (Page 3 of 3)

Material/Method	Description	Relative Cost	Current Use	MIL-Specification
Polyvinylidene-fluoride (Kynar 400) (Cont)				
Coating	By dipping. Fused at high temperature after solvent evaporation primarily.			
Polyester				
Extrusion	Good abrasion resistance	Low	Aircraft (jacket on wire)	MIL-W-5086
Braid		Moderate	Aircraft (jacket on wire)	MIL-W-5086

materials. Most materials are heated to a softened or semimolten point and forced through the die with a screw. With this system the length of the finished wire is limited primarily by the length of conductor. Some materials, TFE teflon for example, must be forced through the die with a ram. In this case, the length of the finished wire is normally limited by the amount of insulation material that can be held in the ram cylinder. After extrusion through the die, the material must be cured. With some materials this consists simply of cooling, but others require heating.

Wrapping

Thin tapes or ribbons of insulating materials are wound helically over the conductor. Usually two or more layers of tape with successive layers wound in the opposite direction are used. The helix can be adjusted so that each turn around the conductor partially overlaps the previous turn, or so that the edges just contact, or so that there is a space between turns. After wrapping, the tape must be held in place. Usually this is accomplished by heating so that the tape surfaces that are in contact fuse together.

Dip Coating

The conductor is passed through an applicator containing a liquid form of insulating material, the adhering material is dried or solidified by heating. The liquid form of the insulation may be a dispersion or a solution. Often many coats of material must be added by repeated dipping and heating. In some cases the material must be drawn through a die for sizing before solidification.

Braiding

Many filaments of insulating material are woven in place as a cylinder over the conductor. Usually the braid is lacquered or dip coated to make it more homogeneous. Braided insulations alone will wick moisture and become unsuitable for most applications. Because of this, they are normally used only in combination with homogeneous insulation materials that provide a moisture barrier.

Table 4-13 shows that the polyimide thin films, the prime candidate for the majority of wiring in the RNS, can be readily tape wrapped and that there is a need for a high performance bondable sealant to be used with the basic polyimide film.

4.4.2 Ribbon Cable Construction Methods

There are five basic ways to construct a ribbon-type cable after the individual constructions, or insulated conductors, have been selected.

Adhesive Bonding

Using individually insulated conductors, an adhesive is applied to the bonding area of the insulation and the two insulations are glued together within a guide or closing die. The most common materials used in this construction are polyvinylchloride or nylon. Extreme care must be used in selecting the adhesive because most adhesives are solvents, that leach out the plasticizer, thus greatly lowering the electrical properties and tending to make the insulation brittle.

Thermal Fusing

Thermal fusing also uses individually insulated conductors; by applying heat to the insulation the components are bonded. The bonding edges of the insulation are heated and the wires are passed through a closing die, which fuses the insulation together under pressure. The most common materials used in this construction are polyvinylchloride and polyethylene. Care must be exercised here to not overheat the insulation — allowing the conductors to cut through the soft, heated material and short circuit. Insufficient heat will cause poor bonding with resultant separation.

Direct Extrusion

By use of a number of bare conductors and a multi-die, the ribbon cable may be actually extruded as one integral unit. Nearly any type of thermoplastic insulation may be used for this construction. This is by far the best way to produce ribbon cable, but the tooling is very expensive. This method, therefore, allows a smaller flexibility in the selection of conductors without retooling, while still maintaining a reasonable cost.

Envelope

With Teflon, an envelope type construction is usually used since it cannot be cemented or melted. A number of individual Teflon insulated wires are run parallel through a very carefully matched roll calendar, which encloses them in a thin Teflon film, or envelope, formed from two Teflon tapes introduced onto the rolls, between the rolls and the conductors. This technique is also very costly and inflexible because of the tooling involved, but is the only way of producing a high quality Teflon ribbon cable.

Braided or Woven

Conventional braiding machines can be used to weave a braid about parallel conductors to form ribbon cable. The braid thread materials that have been used include cotton, nylon, glass, and Dacron. However, one of the major advantages of braiding is that any material that can be made into thread can be used for braiding. The use of parallel threads between conductors assures a positive uniform spacing. Various combinations of conventional round wire, both shielded and nonshielded, can easily be woven into a ribbon cable. The woven cable can be impregnated with various insulations to provide improved mechanical and electrical properties.

Of all the construction methods listed, braiding is the prime candidate for RNS. This method places no restriction on the basic RWC systems used and permits any fiber or combination of fibers that meet the program requirements.

4.4.3 Flat Conductor Cable (FCC) Construction Methods

FCC is made up of solid, flat, rectangular conductors – usually bare or plated copper, but other conductor materials such as aluminum can be used – held in place by various insulations applied in different methods. There are a number of proven constructions for FCC summarized and evaluated in Table 4-14 and described as follows:

Laminated

The most widely used construction is the symmetrically laminated with individual conductors sandwiched between plastic insulation sheets. Polyester fluorocarbons (FEP and TFE) and polyimides are the most common insulation sheets used for missile and space programs. The laminating machine uses rollers to bring the insulation sheets into contact with the conductors going through guides at the entrance to the rollers to assure proper conductor spacing. A suitable adhesive such as polyester or urethane is used with Mylar sheets while FEP is used with polyimide to provide insulation between conductors as well as to bond the sheets and conductors together. High density cable, with conductors having approximately 0.010 in. separation, have been made by laminating together conductors that have been pre-insulated with a polyimide type tower coat.

Coating and Etching

The etched FCC construction permits certain advantages over the laminated construction. A sheet of copper or other conductor metal is first bonded to an insulation sheet or is tower coated with multi-layers of very thin insulation material. The latter provides a very uniform and homogeneous insulation sheet that has a high bond strength to the conductor sheet. Next, the conductor side is continuously etched to create the required parallel conductor pattern. This method of manufacturing conductors provides dimensional stability, tight tolerance, and eliminates conductor "swimming." Subsequent insulations on the conductor side can be made by tower coating the insulation material or by lamination, as previously described. It should be noted that a tower coating potentially results in a high performance cable, strippable with a strong alkali, with no adhesive required.

Extrusion

The extrusion process is usually used for ground applications or for special electrical requirements where the weight of the added insulation thickness would be acceptable. Thermoplastic materials that repeatedly soften and become formable or plastic with the application of heat are extruded around the flat conductors without the need for subsequent curing.

Table 4-14 is broken down by method and material. Laminating, etching, and extruding methods are included. The woven process is omitted because commercial weaving practices are followed and there are very many combinations of weaves and materials that can be used.

Table 4-14

EVALUATION OF METHOD AND MATERIAL FOR FLAT CABLE

Method/Material	Description	Relating Cost	Current Use	MIL Specification
Laminate				
Polyester	Two outer polyester films (2 to 4 Mils) with polyester or urethane adhesive.	Low	Commercial equip. ground support equipment and flight with maximum temp. of 150°C.	MIL-C-55543
H/FEP	Two outer polyimide films. (1 to 2 Mils) with FEP inner films (1 to 3 Mils)	Medium	Ground support and flight equip. with max. temp. of 200°C.	MIL-C-55543
FEP	Two films of FEP (3 to 6 Mils)	Medium	Computers and flight equip. requiring special electrical characteristics and/or cryogenic operating temperatures with max. temp. of 175°C.	MIL-C-55543
All Polyimide	Two outer layers of polyimide with polyimide adhesive.	High	Flight equip. for very high operating temperatures (above 200°C) and extreme vibration.	--
Etched				
All Polyamide	Conductor foil with polyamide coating one side; conductors etched, then polyamide coated other side	High	Limited to high temp (200°C+) high vibration flight equip.	--
Polyamide - H/FEP	Conductor foil with polyamide coating one side, conductors etched; then H/FEP laminated other side.	Medium	Ground equip. and flight equip. with max. temp. of 200°C.	MIL-C-55543
Extruded				
FEP	Homogenous extrusion with conductors and insulation placed in one process.	Medium	For ground equip. where weight is not critical and special electrical characteristics are required.	--

The laminating method is that which is generally used in the fabrication of flat conductor cable because it efficiently and economically handles the majority of materials used. The polyester films provide very good mechanical properties at a relatively low cost. The transparent films can be provided in a flame retardant configuration. For maximum and minimum operating temperatures encountered on most programs the polyester system is adequate. The polyimide/FEP insulation system is the most popular today for high performance operation. The outer layer of polyimide provides excellent mechanical properties except for notch sensitivity and resistance to strong alkali. The inner FEP provides a filler and adhesive and improves the electrical characteristics. All teflon insulations can be made with parallel films of FEP or with sintered TFE, if properly spaced and toleranced rollers are used, to corrugate the insulation around the cable. The teflon insulation remains extremely flexible through very low operating temperatures and can be used at cryogenic temperatures. The all-polyimide system provides a very high-temperature system, above 200°C. The polyimide adhesive is very difficult to apply and requires very high curing temperatures. The yield is low and manufacturing process expensive. However, this construction is easy to chemically strip, and can provide a highly reliable density cable with 10 mils or less between conductor edges.

The etched construction can be used with any insulation material that can be bonded or coated to a conductor film and which later can survive the conductor etching processes. The polyamide tower-coated insulation on the conductor film provides a very good basic composite for a number of subsequent insulation systems. After the conductors are continuously etched, using one of the methods for printed circuit boards, then a number of methods can be used to apply insulation to the second side. The polyamide tower coat process suggests methods that can possibly be developed for the applications of inorganic insulations in very thin layers with no lamination processes required. The etched process can also provide special printed circuit pattern ends to facilitate cable termination.

The extruded construction seems to have the least potential for application to nuclear stages because of the increased weight for insulation thicknesses required and by the requirement that the insulation be thermoplastic.

4.5 COMPARISON OF CABLE SYSTEMS

In making comparisons between various cable systems, the many applicable factors must be carefully evaluated. The availability and past experience of existing systems must be carefully compared with the potential advantages of new systems, as well as their attendant problems in both known and unknown areas. The highlights for comparison are given in the following paragraphs. The hardware requirements schedule for RNS (1974 technology) permit this program to properly evaluate the new systems for the many potential advantages they offer.

4.5.1 Performance

Performance, both electrical and mechanical, of the selected systems is of primary importance. The requirements must be met with a high degree of probability or reliability over the life of the program.

Electrical Performance

The use of randomly routed RWC conductors in wire bundles is a very inefficient method to interconnect modern sophisticated electronic systems. The only known parameter for single conductor cables randomly routed in bundles is its dc component. All other characteristics, such as return path, structure ground plane, and spacing to other conductors are random and unpredictable. Thus, in the past, cable in conventional RWC systems has been grossly overdesigned and the electronics systems have been designed for variable cable impedances. One of the apparent results has been in the use of excessive shielding to assure electromagnetic compatibility. This established practice has added many pounds to the wire harnesses, has greatly increased the cost for cable and terminations, and has lowered the reliability by increasing the probability of electrical failure in the bundle and termination areas. A second result of the randomly routed RWC conductors is the resultant large number of bundles required to provide electrical separation between the various circuit functions. This has resulted in many small bundles that required separate routing and support with a degradation of mechanical strength and ruggedness for each.

The use of FCC permits first the selection of the desired electrical characteristics for the interconnecting circuits and assures that these characteristics will be repeatable from unit to unit. In addition, positive control of each conductor in each harness run can eliminate most shielded cable. Special physical arrangements of FCC can be used to meet specific transmission line requirements and provide electromagnetic control to reduce the susceptability to external fields and to greatly reduce the emission of fields.

The use of ribbon cable provides performance similar to that of FCC as each conductor can be positively placed and controlled. In addition, the use of twisted pairs provides magnetic field attenuation not possible with standard FCC.

Mechanical Performance

As described earlier, the RWC minimum size has been limited in the past by the strength characteristics of the individual conductor cables. This has been 20 and 22 AWG for copper conductors and 24 to 26 AWG for the high-strength alloy conductors. In other words the RWC is not load sharing and the larger the bundle the higher the probability that a single cable can be damaged by handling, termination and subsequent bundle bending in the cable run area, especially in the termination area. The geometry of the RWC makes it especially susceptible to cut-through from sharp objects or abrasion. The single small-radius layer of insulation on one outside conductor of RWC must resist mechanical damage while the entire flat surface of the FCC resists it. Tests conducted by MSFC (Reference 4-4) have verified the improved thermal capacity of the FCC over equivalent RWC. The current carrying capacity may be uprated for FCC for the same conductor cross-section as follows:

FCC Cable Configurations	Uprating Factor In Air	Uprating Factor In Vacuum
Single-Layer	1.50	1.55
Three-Layer	1.35	1.50
Ten-Layer	1.05	1.05

Additional thermal advantages can be realized if a FCC mounting heat sink is considered.

Reliability

The use of FCC for interconnecting harnesses has potentially increased reliability over RWC in a number of specific areas. The high tensile strength of the insulation layers and cable construction, which provides mechanical load-sharing, provides a major increase in effective strength. The percentage increase becomes even greater in the small conductor sizes. The abrasion resistance is greatly improved as a result of the geometry of the harness cross section. The mechanized FCC termination system, made by cable layer, is simpler and more reliable, and quality control is much simpler. The FCC harness assemblies are simpler, lighter, and require less space; the improved heat dissipation assures lower operating temperature; and the system performance can be improved with assurance of repeatability.

4.5.2 Weight

From previous studies (References 4-5 and 4-6) the weights for FCC supports and clamps are considerably less (up to 80 percent) than those used with RWC. This saving results primarily from cable stacking and simplification of clamping and supports for FCC. However, the cable provides the major weight savings of 60 to 70 percent for the smaller conductors (Figure 4-5). For comparison, RWC per MIL-W-81381/2 with 7-mil H/film insulation and alloy conductors, and FCC cable per MIL-C-55543 were considered. High-density FCC was used for 20 and 22 equivalent AWG sizes. The FCC weight-saving increases as the conductor cross-sections decrease. The majority of the RNS circuits requirements can be satisfied with wire sizes of AWG 24 and smaller.

4.5.3 Space

Figure 4-6 shows the space savings that can be achieved through the use of FCC. The areas compared are for typical interconnecting harnesses requiring three separate bundle runs. The 80- to 90-percent space savings shown are particularly advantageous in tunnel and other congested areas where a minimum height is available for harness runs. This attribute of FCS is directly applicable to the electrical cabling through the many tank areas of the RNS. Again the RWC per MIL-W-81381/2 with 7 mil polyimide insulation and alloy conductors was compared with FCC per MIL-C-55543.

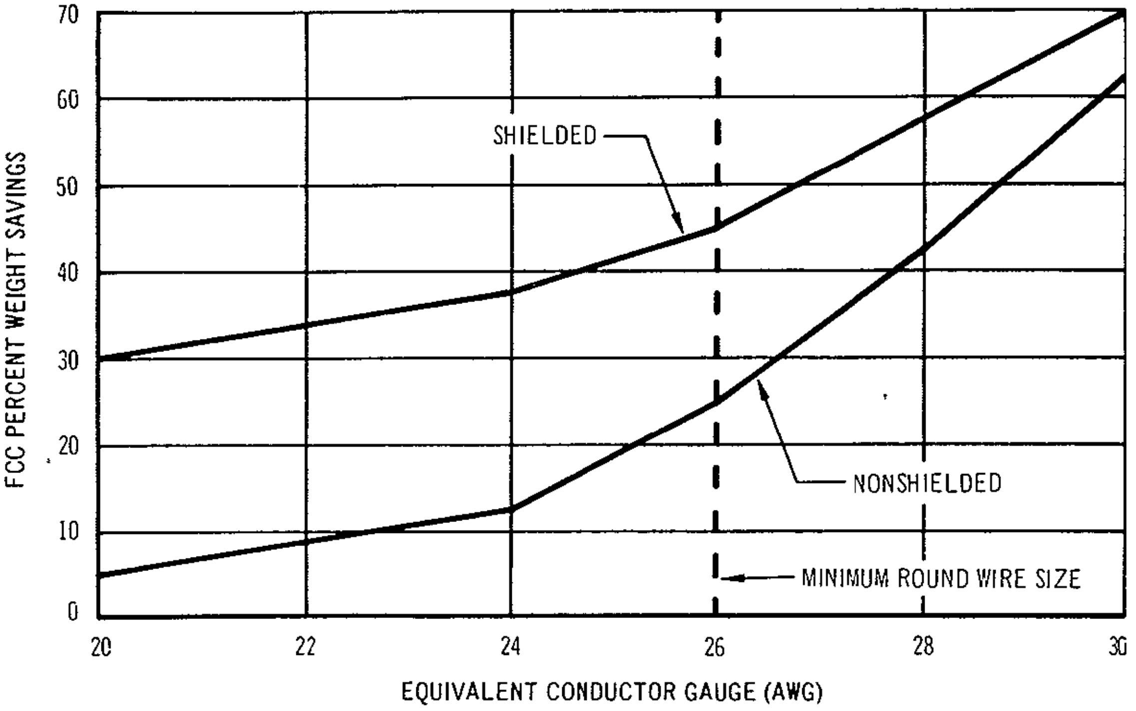
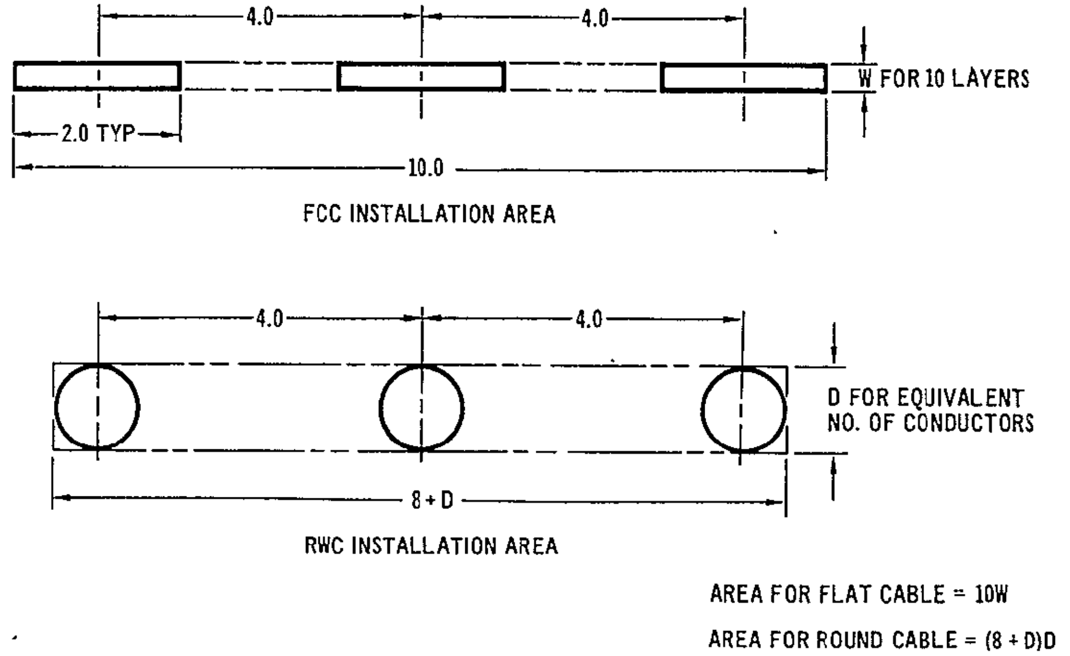


Figure 4-5. Weight Saving Chart -- FCC Versus RWC



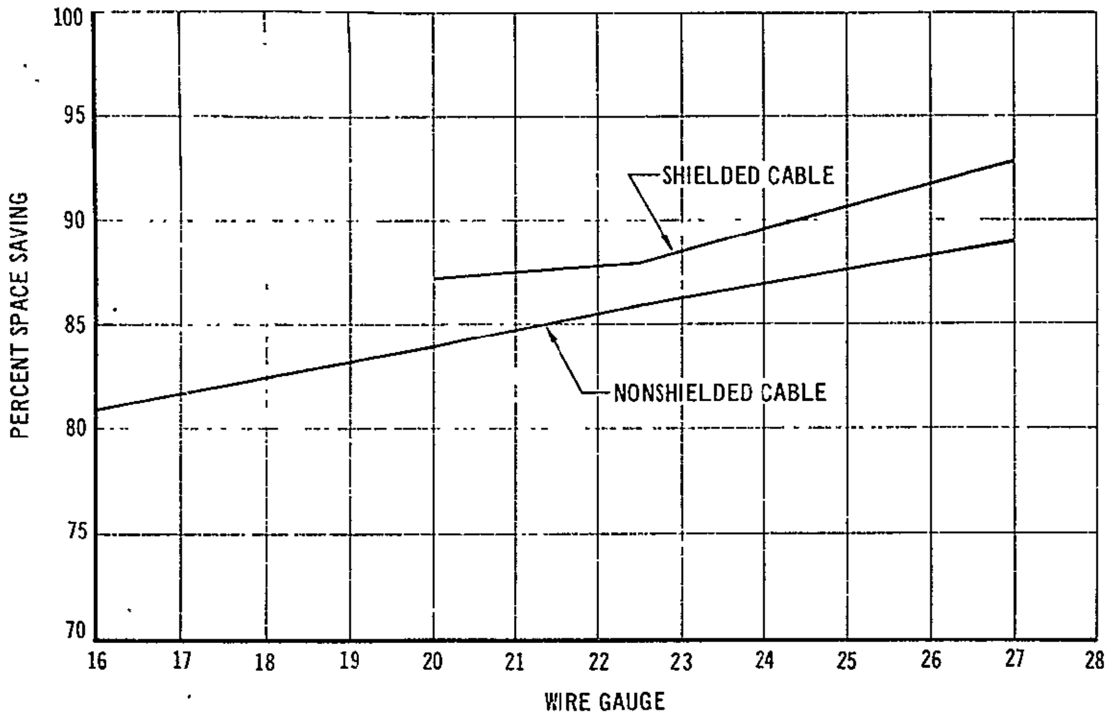


Figure 4-6. Space Saving Chart—FCC Versus RWC

4.5.4 Cost

To arrive at realistic cost comparisons, the cost of materials, design development, harness fabrication, and installation must be considered. Table 4-15 lists these comparisons developed on MDAC-West programs (References 4-5 and 4-6) and those performed by other agencies. The saving percentages shown are average and can vary from program to program. However, the 80 percent shown for recurring harness fabrication is realistic for all programs using properly designed FCC systems.

Figure 4-7 shows the cable cost comparison, which indicates a small cost saving for FCC in the smaller gages and for RWC in the larger gages. The final cables to be selected for the RNS will probably be of special configurations with cable costs about the same for either system.

Table 4-15

COST COMPARISON – FCC VERSUS RWC

Item	Subitem Percentage of Major Item	FCC Cost Saving in Percent	
		Subitem	Major Item
Engineering			-5
System	25	-10	
Harness Layout	25	-10	
Production Drawings	25	0	
Schematics, etc	25	0	
Development			+20
Materials			+22
Cable	40	0	
Connectors	40	20	
Clamps	5	+50	
Supports	15	+75	
Harness Fabrication			+80
Harness Installation			+40

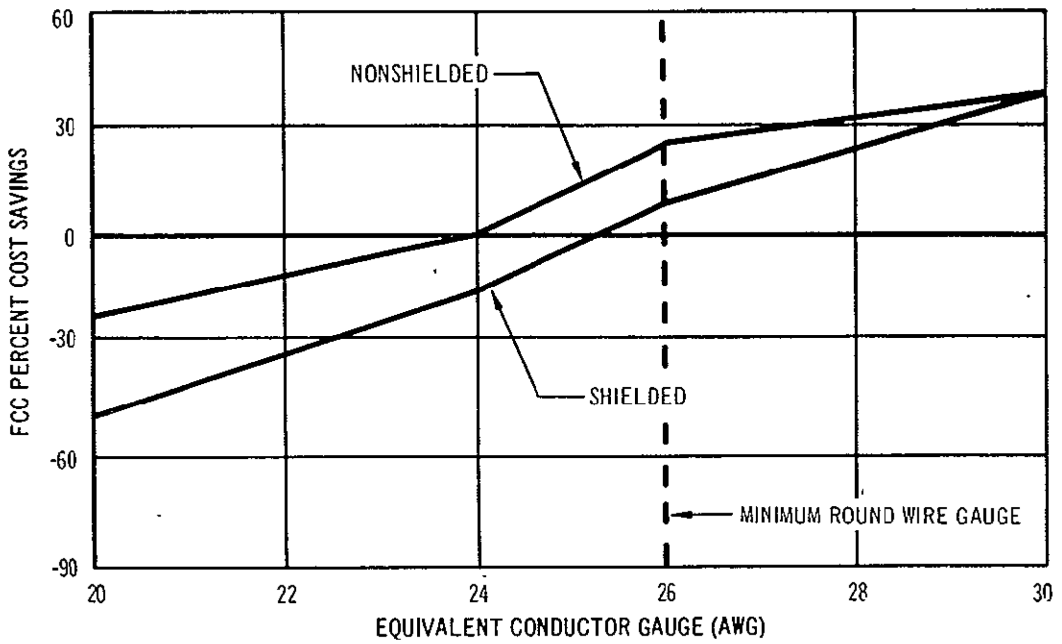


Figure 4-7. Cable Cost Comparison – FCC Versus RWC

4.5.5 Availability

Both RWC and FCC are currently available in the primary polyimide insulation systems. The RWC has considerable more manufacturing experience and testing and has seen more general rise. In addition, there are more hardware companies, government agencies, and prime contractors actively engaged in its development and use. Therefore, the selection of RWC with existing polyimide primary insulation and high performance binders presents the least risk and cost with the highest probability of the availability of both the qualified cable together with qualified termination devices. On the other hand FCC with polyimide/FEP insulation systems have been successfully applied to a number of completed and existing programs. Sufficient numbers of tests have been conducted by MSFC and the U.S. Army Electronics Command at Ft. Monmouth, New Jersey, to provide a high degree of confidence that this cable system will meet the most stringent space program requirements. However, the termination devices including electrical connectors are limited in development, qualification, and availability and this restriction imposes the major obstacle to the general use of FCC systems.

4.5.6 Applicable Specifications

The applicable specification for RWC with primary polyimide insulation is MIL-W-81381. There are approximately eight vendors on the QPL to assure adequate sources for present and future programs. RWC basically in accord with this specification are currently being used by Lockheed on the L1011, by the Martin and Grumman Companies and by MDAC on the Upstage Missile and the F15 aircraft. Numerous other RWC insulation systems are covered by MIL-W-16876, MIL-W-81044, and MIL-W-22759.

The applicable specification for FCC for various types of primary insulation, including polyimide, is MIL-C-55543. To date there are no vendors on the QPL although a number of vendors have made FCC that passes the major performance requirements of the specification. FCC has been used by General Dynamics on the Standard Missile, by MSFC on an early Saturn IU Unit, on the Pegasus, on the Apollo Telescopic Mount, by Boeing Aircraft on the Upper deck entertainment system of the 747, by Bendix on the lunar experimental packages, by Hughes on the lunar Surveyor Spacecraft, and by MDAC-West on the Spartan Warhead Section. Although there have been the normal problems associated with new programs, the use of FCC has successfully met the special program requirements for which it was used.

4.5.7 Application to RNS Requirements

From the previous discussion, it can be concluded that RWC, ribbon cable, and FCC can successfully be used for wiring on the RNS. In general the requirements must be carefully considered for each area of application and the system selected which best meets the RNS requirements.

Feeding many separate devices in an area with a few conductors to each can usually be best accomplished with RWC. The routing, support, and termination to existing type round connectors makes RWC the first choice for these requirements.

Harness requirements for many conductors through an area that have common termination areas at both ends can usually be accomplished by FCC with major savings and improvements.

In between these two extremes are the many actual requirements for the program harnesses. These might use RWC, FCC or perhaps a ribbon cable with woven construction which would retain many of the advantages of both RWC and FCC.

Detailed evaluation and selection for the RNS will be accomplished in Section 6.

Section 5
CONNECTION CONCEPTS

The interconnections are one if not the most important consideration for all electrical cabling systems.

From a reliability aspect it is highly desirable to have all conductors continuous between active electronic units. For this study consideration will be given up to the interconnections to electronic units (black boxes) and devices (switches, transducers, valves, etc.), but will not include the inside of these devices. The continuous circuit path could be provided by making all junctions in a strong, highly reliable structural manner and encapsulating all junctions for mechanical and environmental protection.

From other aspects such as production testing, installation, and maintenance, conventional connectors are highly desirable at all utilization equipment and between production manufacturing break areas.

Then there are the operational disconnect requirements for umbilicals and flight disconnects that preclude the possibility of a permanent structural type junction for these interfaces.

The following paragraphs describe and evaluate the various connection concepts for use with the RNS.

5.1 DESCRIPTION OF CANDIDATE APPROACHES

Various types of conventional and unconventional interconnecting concepts are included to present the reader with the basic fundamentals of electrical interconnecting systems.

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5.1.1 Connectors

Many different types of electrical connectors have been developed and used successfully over the past years. These can generally be divided into categories such as rectangular and cylindrical. Most conventional connectors use pins and sockets for mating halves of the connectors and wire terminations to these are usually made by soldering or crimping. Figure 5-1 shows some typical electrical connectors of both the rectangular and cylindrical families.

5.1.2 Connectorless Terminations

Connecterless terminations are characterized by a very high pressure gas sealed termination junction. Typical examples are wirewrap, Termipoint (AMP), and a recent junction system for hybrid microelectronics by Bunker Ramo (see Subsection 5.6). All of these systems use junctions in which the contact areas are loaded above the elastic limit and a constant force is maintained on the junction. A connectorless termination concept particularly applicable to the RNS is shown in Figure 5-2.

The two conductor layers to be joined are stripped of insulation in the contact area, registered over each other in a zero-insertion force manner, and a high-pressure spring-action force is applied to accomplish a gas sealed electrical junction and effect strain relief and environmental sealing.

5.1.3 Permanent Junctions

Permanent junctions are defined as those which cannot be readily separated and rejoined with simple hand tools. Permanent joining methods include soldering, brazing, welding, and crimping. Many connections use both permanent junctions and conventional contacts as typified by the conventional connectors which use permanent junctions between the external wires and the connector contacts.

5.2 FLEXIBILITY OF CONNECTION SYSTEMS

There are different degrees of circuit assignment flexibility which can be achieved with various connector systems.

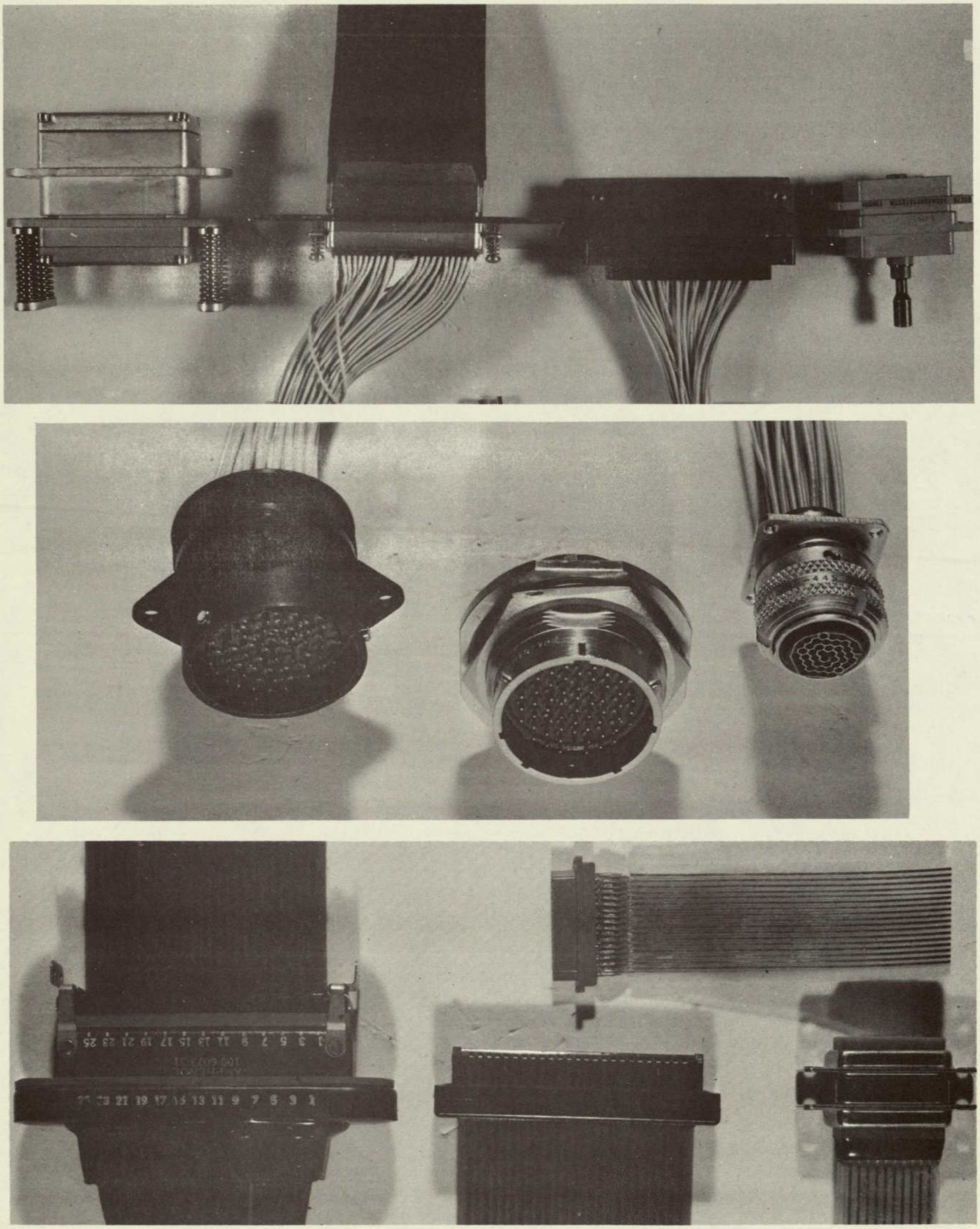

Figure 5-1. Typical Electrical Connectors

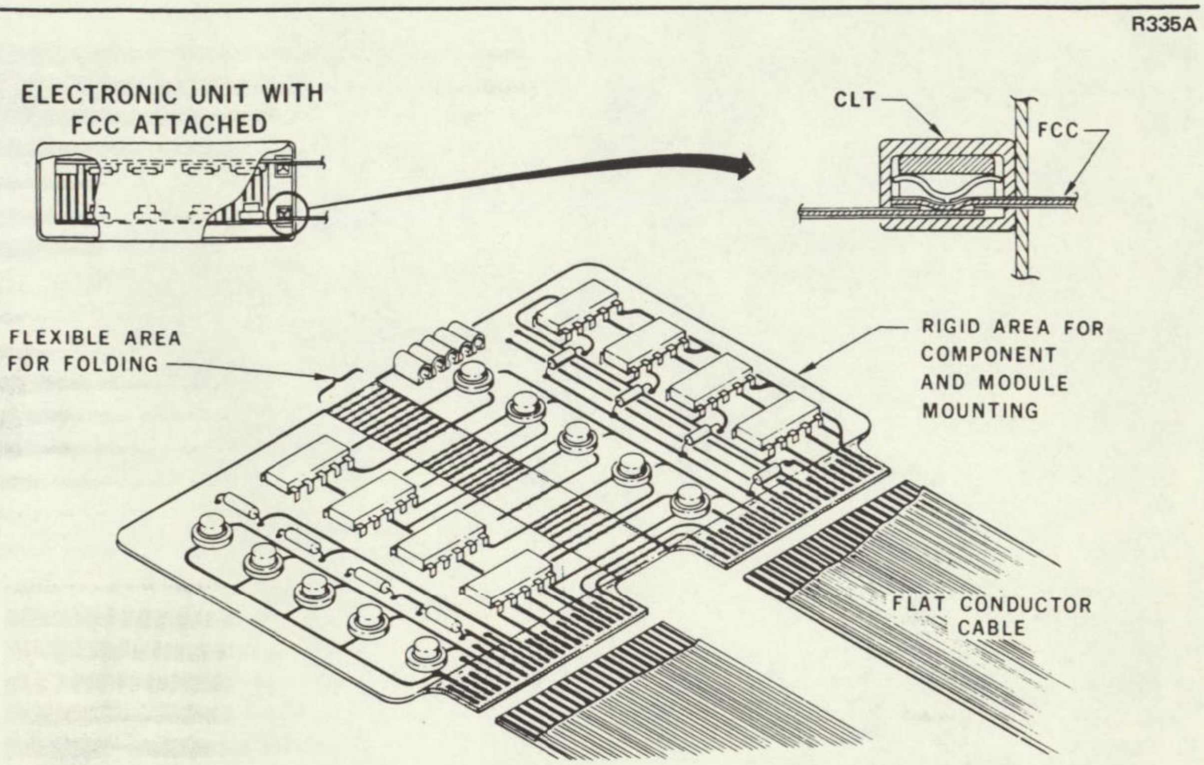

Figure 5-2. Connectorless Termination System

Conventional rectangular and cylindrical connectors offer 100-percent flexibility in initial design and redesign when used with randomly oriented RWC. That is to say, any conductor can go to any pin so long as their gage sizes are compatible. These connectors also retain a high degree of rework capability for changing pin assignments by reorienting crimp removable contacts or by removing and reinstalling the wires in connector solder pots. When these connectors are potted in the rear wire entrance area they lose their rework capability.

Rectangular connectors used with fixed parallel conductor layers (FCC) are least flexible in their ability to make circuit assignment changes. Figure 5-3 shows the rear of two such plugs at opposite ends of a two-ended harness. The circuit changes are limited to relocating and reorienting the cable segments.

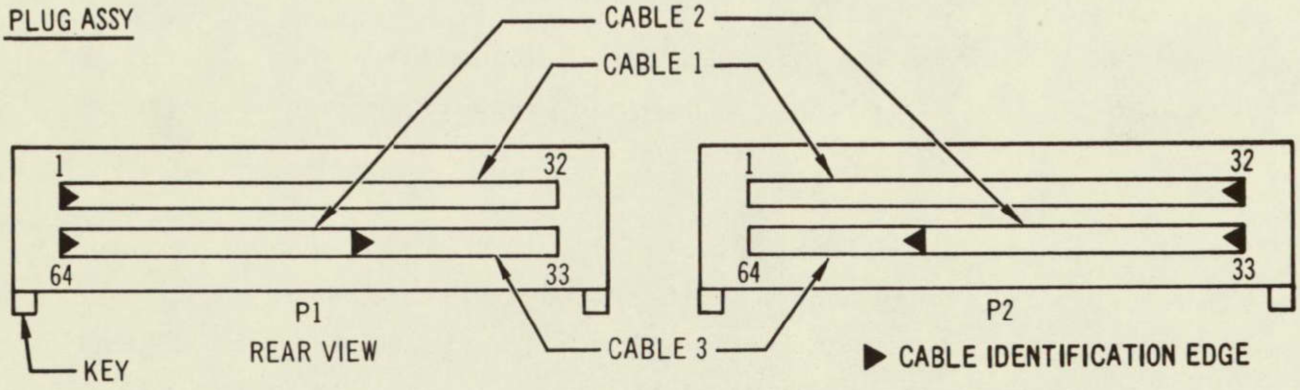

Figure 5-3. Typical FCC Connector Cable Control

Connectorless terminations have wide ranges of circuit change flexibility depending on the type selected. Wirewrap and Termipoint systems have 100-percent flexibility while those depending on fixed conductor locations for automatic termination registration have little flexibility.

Permanent junctions generally have a high degree of circuit flexibility in initial design when used with random wiring and are quite limited in rework and when used with fixed parallel conductors.

5.3 RELIABILITY OF CONNECTION SYSTEMS

In general, the reliability for connections is in the reverse order of their flexibility for design, installation, and maintenance.

The elimination of all junctions would theoretically provide the most reliable electrical interconnection system. This could be achieved with one flexible printed circuit which included both the external wiring and electronic unit internal wiring although it would not be very practical.

The second most reliable system would be one in which permanent structure-type junctions could be made directly between the harnesses and the electronic unit. This again is limited in practicality by testing, manufacturing, and maintainability requirements.

The third most reliable system would utilize connectorless terminations as shown in Figure 5-2 where there is one high-pressure gas-sealed electrical junction between the harness and the electronic unit.

Then, the least reliable is the conventional pin and socket connector system. Each circuit path through such a connector has two permanent type junctions (the wire termination to the pin and socket) and the pin-and-socket junction between the connector halves.

5. 4 TERMINATION OF ALUMINUM CONDUCTORS

The principal problems involved with terminating aluminum conductors arise from four properties of aluminum: oxide formation, cold flow, coefficient of thermal expansion (Tc) and susceptability to corrosion. Section 4 compares the properties of aluminum and copper and shows that aluminum has a higher temperature coefficient of thermal expansion (24.7 to 17. 6), a lower modulus of elasticity (10 to 17) and a much lower yield strength (4 to 10). Therefore, any successful termination system for aluminum conductors must overcome these obstacles.

Numerous aluminum conductor crimp termination systems have been developed and evaluated by AMP Incorporated (Reference 5-1) and the Burndy Corporation. A typical termination for round wire is shown in Figure 5-4 and for foil conductor in Figure 5-5. In each case terminal perforations plus very high crimping pressures and crimp contact area reformations assure that oxides will be penetrated and that many cold-weld contact areas will be created. These contact areas react individually to the stresses and excursions resulting from temperature cycling and current loadings to maintain gas sealed junctions. The complete junction area must be adequately sealed to prevent subsequent corrosion. The Boeing Aircraft Company has done extensive development and evaluation on additional aluminum foil termination systems for power applications.

R335A

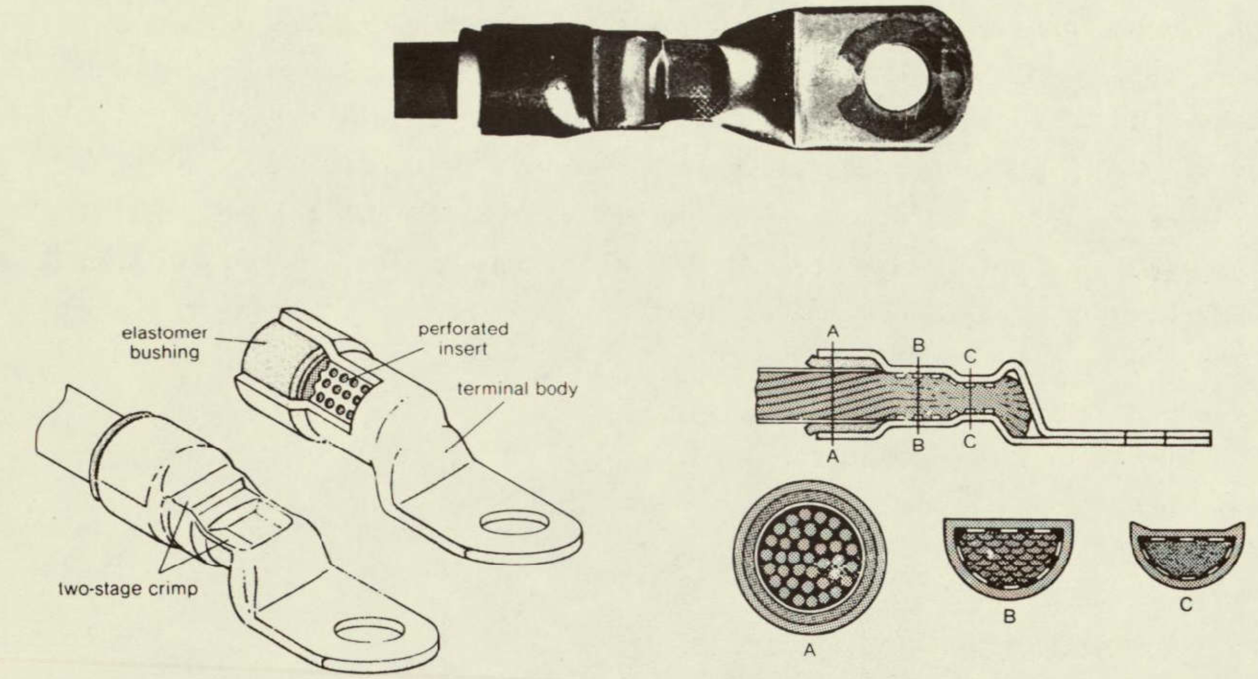

Figure 5-4. Crimp Termination for Aluminum Stranded Conductors

R335A

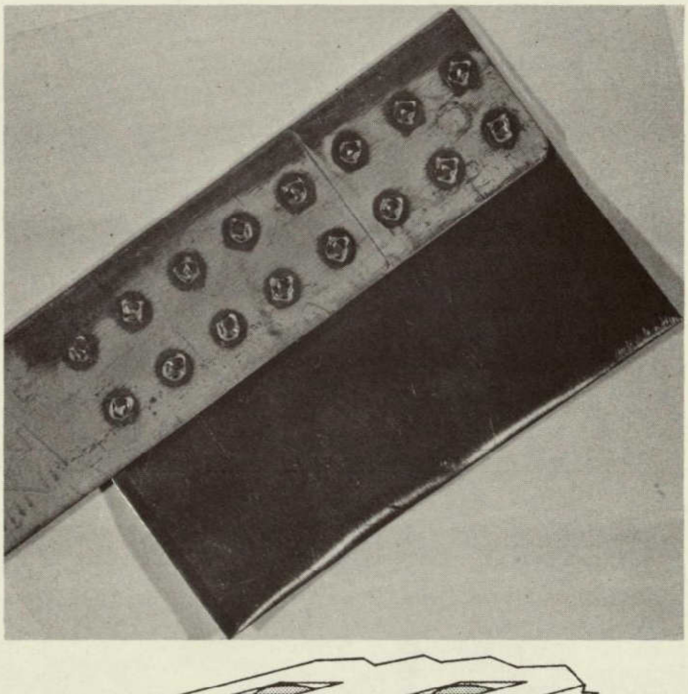

Figure 5-5. Crimp Termination for Aluminum Foil

Welding followed by joint potting or encapsulation offers much promise in aluminum conductor termination. Figure 5-6 shows a tungsten inert gas (TIG) weld junction made by MSFC on a typical aluminum large power application. Eight separate layers of 0.010-in. 1100 aluminum foil were TIG welded on three sides to high strength weld compatible 2219-T87 aluminum plates. The structural-type weld, verified by cross sectioning weld samples, precludes all possible failures resulting from the aluminum cold flow, high Tc, and low yield stress. The welded junction area would be subsequently encapsulated to provide sealing and mechanical protection.

Welded terminations of the type described are preferred over the crimp type which are especially subject to failures after long life with many temperature and current cycles.

5.5 ELECTRICAL CONNECTORS

Many electrical connectors are currently available for high-performance high-reliability applications. Since the connectors play such an important

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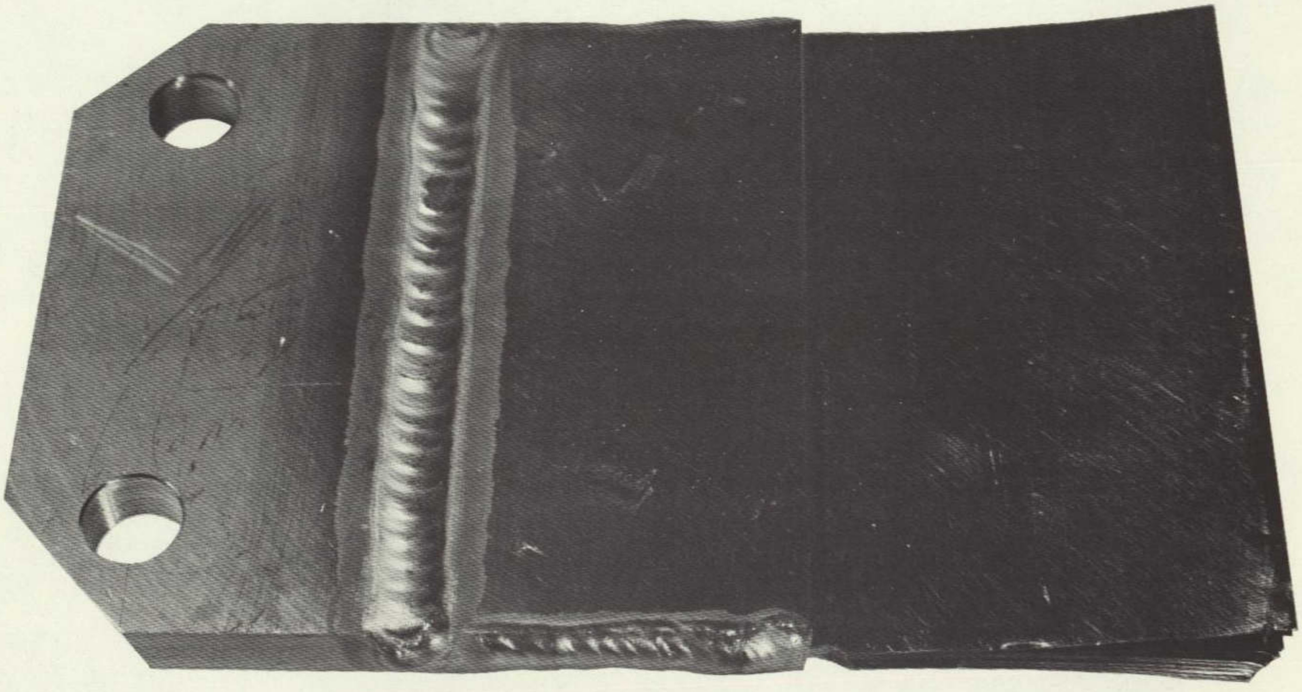

Figure 5-6. Welded Termination for Aluminum Foil

part in the interconnecting wiring harnesses, it is very important that proper consideration be given to the materials, finishes, and connector configurations.

5.5.1 Insulation Materials

The insulator bodies of high performance connectors are generally made from diallyl phthalate and epoxy molding compounds which have excellent physical and electrical characteristics. Resilient materials of high performance thermoset elastomers and silicone compounds are used for seals and other nonrigid insulator requirements.

High performance materials suitable for use in very high radiation (above 10^{15} rads) is currently available from Physical Sciences Corporation. Durock silico-ceramic insulation is used extensively in hermetically sealed connectors, feedthroughs, and electrical penetration assemblies. Durock is unique in its ability to withstand extreme temperatures (up to 2,000°F) while providing a hermetic seal and remaining relatively impervious to radiation (rated at 10^{15} rads). Components with Durock have been successfully used in the NERVA, Saturn, Centaur, SNAP 27 and on the Apollo program at temperature ranges from -426°F to +1,000°F.

5.5.2 Conductor Materials

Connector contacts are made from machinable copper alloys. Proper conductivity must be provided by the nonspring members. Phosphor bronze and beryllium copper are used for the spring members. Many contact schemes use spring members which do not carry the circuit current. This permits a very low electrical conductivity material to be used and reduces the probability of losing contact pressure during and after overload conditions.

The connector shell is usually made from a high grade aluminum alloy which is easily machinable, molded, etc., depending on the selected manufacturing process. Nonmagnetic requirements are often specified for all connector materials.

5.5.3 Finishes

Typical contact platings are shown in Table 5-1. Plating is used to prevent mechanical, electrical, and chemical deterioration of the mating surfaces of the contacts and must be considered for each particular application.

Table 5-1

CONNECTOR AND CONTACT DATA

Connector Specification	Applicable Contact Specification	Contact Plating	Contact Size	Accept Wire Gage (AWG)	Contact Terminal Type	Contact Rating (amps)
MIL-C-5015		Gold over silver	16		Solder*	22.0
			12			41.0
			8			73.0
			4			135.0
MIL-C-22992		Gold	0			245.0
MIL-C-26482		Gold over silver	20		Solder	7.5
			16			13.0
			12			
	MIL-C-23216	Gold over silver	20	24	Crimp	3.0
				22		
				20		7.5
			16	20		7.5
				18		
				16		13.0
			12	14		17.0
				12		23.0
NAS 1599	NAS 1600	Gold or silver or nickel	20	24	Crimp	3.0
				22		5.0
				20		7.5
			16	20		7.5
				18		15.0
				16		20.0
			12	14		25.0
				12		35.0
MIL-C-25955		Gold over silver	20	30	Crimp	
				24		
				22		
				20		7.5
MIL-C-27599		Gold over silver	20		Crimp	7.5†
			16			13.0

*Available with crimp/removable contacts under manufacturer's part numbers.

†Maximum contact rating for individual contact. Hermetic contacts rated at 5.0 and 10.0 amps, respectively.

Connector shell finishes are both conductive and nonconductive. Electroless nickel is one of the better conductive finishes while hard anodize provides a durable nonconductive finish.

5.5.4 Shielding Provision

Two types of shielding provisions are provided by connector systems. The first provides a low impedance path between the connector halves. Often, the connector is designed to assure that this shell-to-shell contact will be made prior to the circuit contacts on mating and will be broken after the circuit contacts on disconnecting.

The second is an RF peripheral shield which is made around the entire mating surface and at each cable-bundle entry into the back of the connectors.

Adequate shielding provisions have been supplied on both cylindrical and rectangular connectors for both RWC and FCC.

5.5.5 Round Configurations

Round connectors provide the most efficient form factor for mechanical packaging, manufacturing, retainer systems and mechanical integrity. They are available in many different MIL-SPEC configurations as shown in Table 5-1. The NAS-1599 series is an environment-resisting family of miniature connectors, utilizing rear contact insertion and removal, designed to meet the missile and space high-altitude requirements. Connectors to MIL-C-83723 also utilize rear insertions, rear removable contacts, and provide contact sizes to "O" gage. The MIL-C-26500 connectors, used in the past, have been largely replaced by newer specifications. The MIL-C-81511 series, not shown in Table 5-1, has very-high-contact density as well as high performance characteristics. In general, the cylindrical connectors will be the first choice for small electronic units and devices which must be interconnected with RWC.

5.5.6 Rectangular Connectors

Rectangular environmentally sealed connectors are used for a number of specialized requirements. They do provide a more efficient form factor for many packaging problems; they can be used readily for rack and panel application; when used with a center jack screw they provide a high nonoffset force for mating and unmating; and they permit terminations on a "layer" basis which is so important to ribbon and FCC terminations.

This layer termination is further expanded to the wafer concept as shown on Figure 5-7. Layers of cable can be terminated and sealed to the wafers at an automatic termination station. Then, different layers of cable and wafers can be routed separately to the required connector shells and assembled. This layer-wafer connector system should be considered for all areas where there are many circuits through a connector. It will easily accommodate ribbon cable and FCC and will aid in the placement control of conductors. A comparison of electrical connector types is shown in Table 5-2.

5.6 CONNECTORLESS TERMINATIONS

Connectorless terminations are very attractive for high density, low weight, high reliability applications. They are characterized by a large reduction in the number of electrical junctions and by their high-pressure gas-sealed joints.

5.6.1 Existing Systems

Wirewrap and Termipoint (AMP) shown in Figure 5-8 have been successfully used on many programs with a high degree of reliability. Both of these systems use very high-pressure multi-point contact areas to provide gas-sealed electrical junctions. They also contain metal memory to retain these high pressure junctions throughout the life of the junctions while they are subjected to extreme environments. The wire tensile forces and the Termipoint spring clips provide these memory forces. Both can have the wiring removed from the termination posts and replaced with new wires.

5.6.2 Prototype Systems

MDAC has developed a prototype electrical distributor which utilizes a connectorless termination system. Figure 5-9 shows this system both in the zero-insertion and in the activated positions. Very high pressures are

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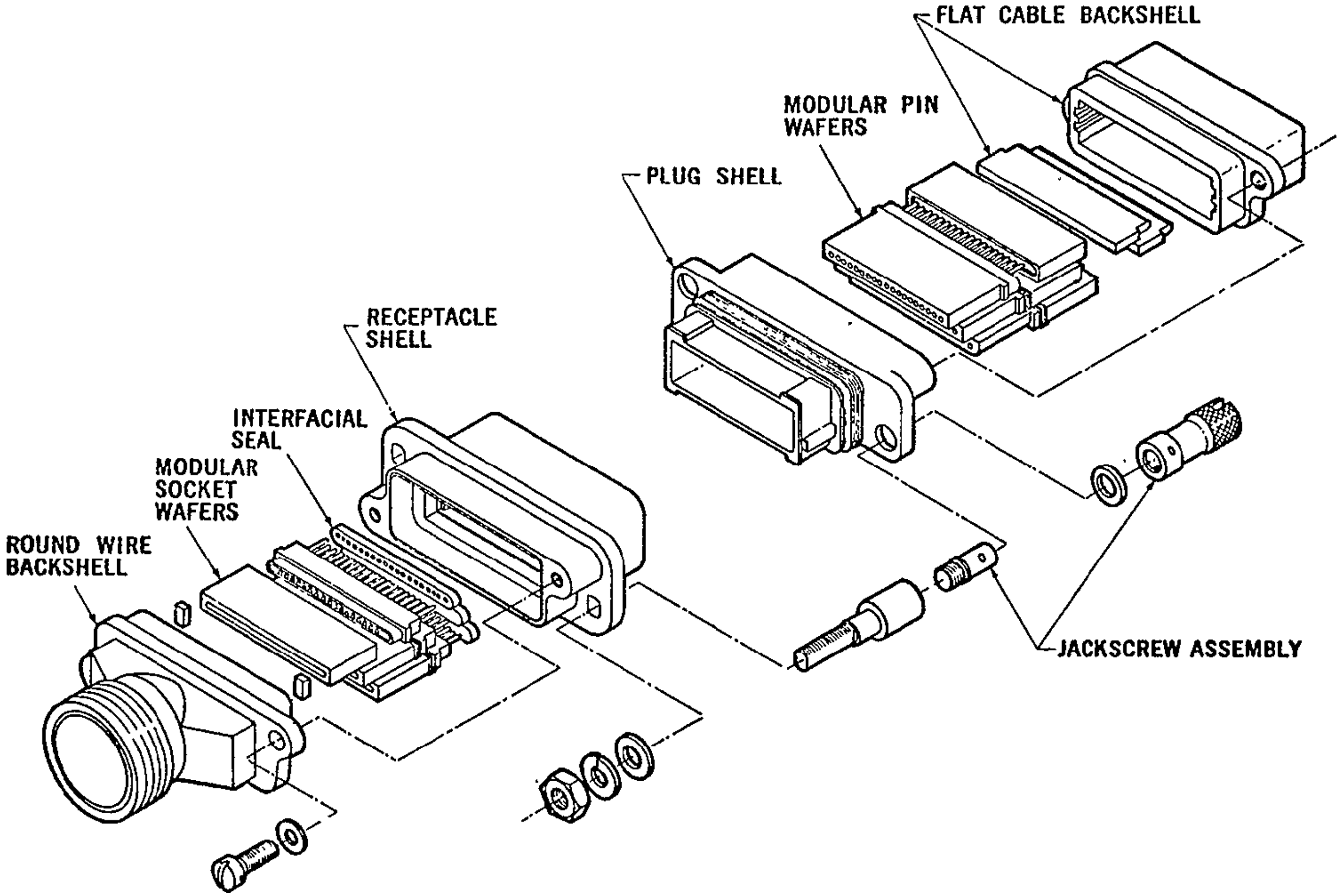
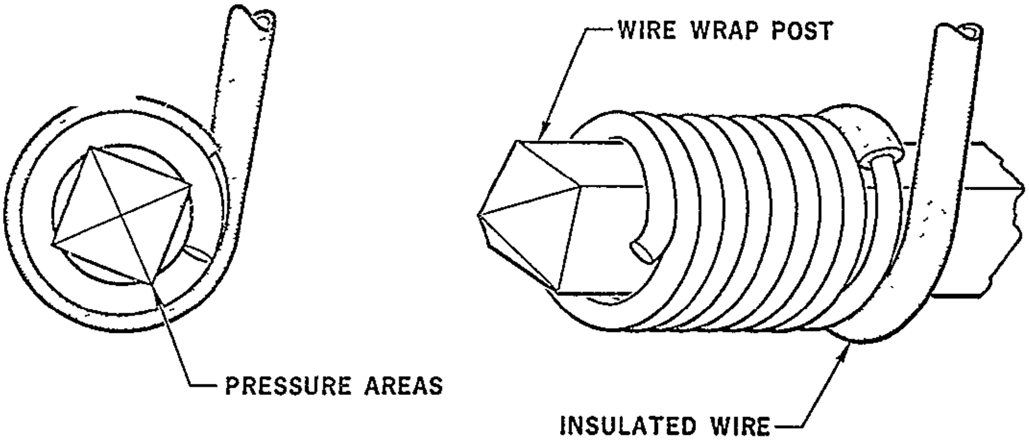


Figure 5-7. Wafer Type Rectangular Connector

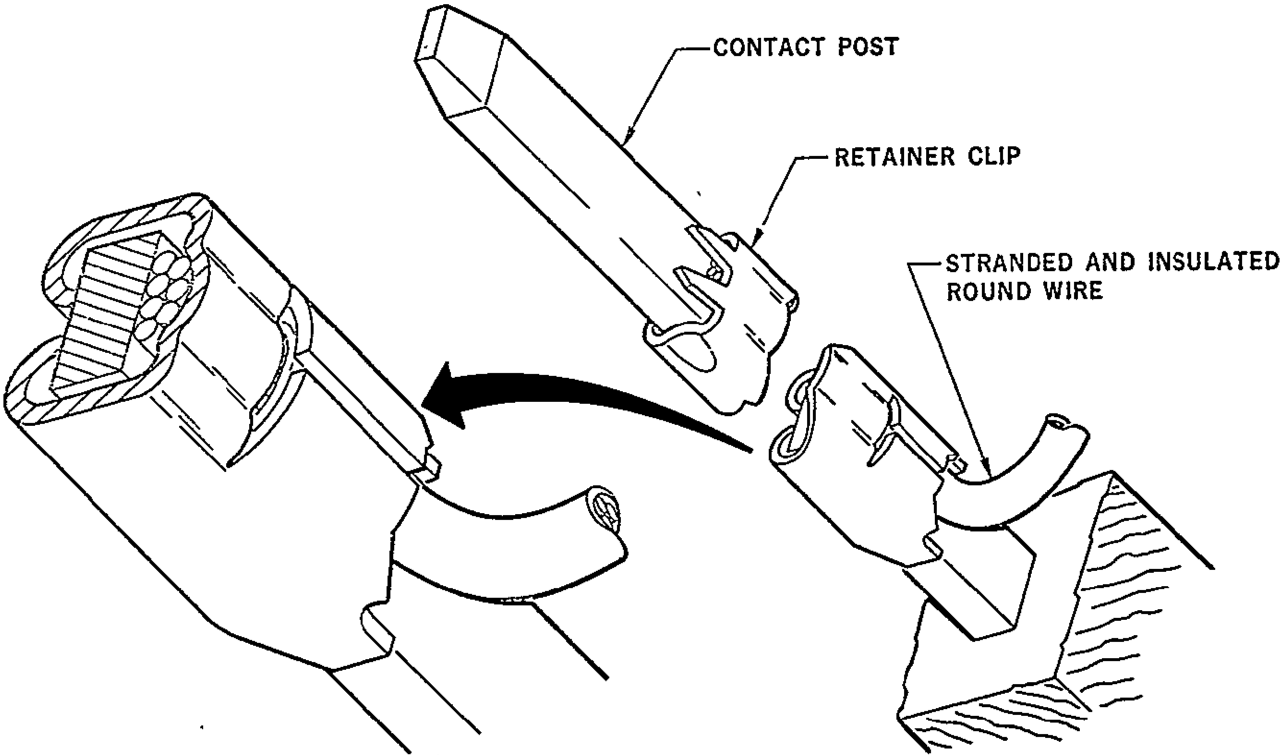
Table 5-2

COMPARISON OF ELECTRICAL CONNECTOR TYPES

Type	Advantages	Disadvantages
Round	1. Available qualified to numerous specs. 2. Most optimum shape for mechanical strength and coupling mechanisms. 3. Long history and experience. 4. Individual contacts replaceable.	1. Not adaptable to automated termination and insertion of conductors. 2. Requires more space for mounting and replacement.
Rectangular		
One Piece Insert	1. Adaptable to rack and panel and blind mating. 2. Individual contacts replaceable. 3. Good utilization of panel space.	1. Large and heavy 2. Coupling hardware awkward and limited.
Wafer	1. Permits automatic termination and sealing of a layer of cable to the control wafer. 2. Extreme ease in assembling wafers in connectors. 3. Easy to reliably replace cable segments with wafers in the field.	1. Can't replace individual contacts. 2. Difficulty in providing pressure seals.
Zero Insertion	1. Provides maximum contact pressures with no contact wear. 2. Permits use of more desirable contact finishes.	1. Requires special hardware design.
Connectorless	1. Provides the minimum number of electrical junctions. 2. Zero insertion force advantages. 3. Minimum weight and space. 4. Provides highly reliable junctions.	1. Requires new hardware design. 2. Connecting devices must be integrated with electronic unit design and harness type selection.



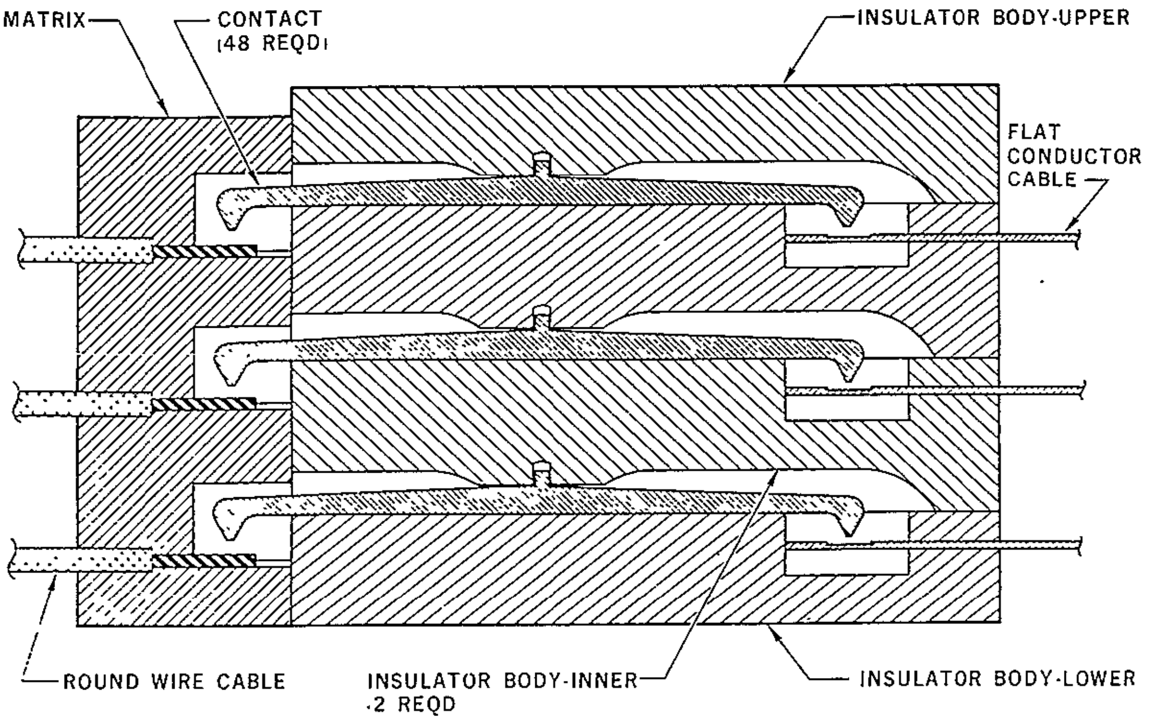
WIRE WRAP



TERMIPOINT

Figure 5-8. Existing Connectorless Terminations

Zero Insertion Position



Contacts Activated

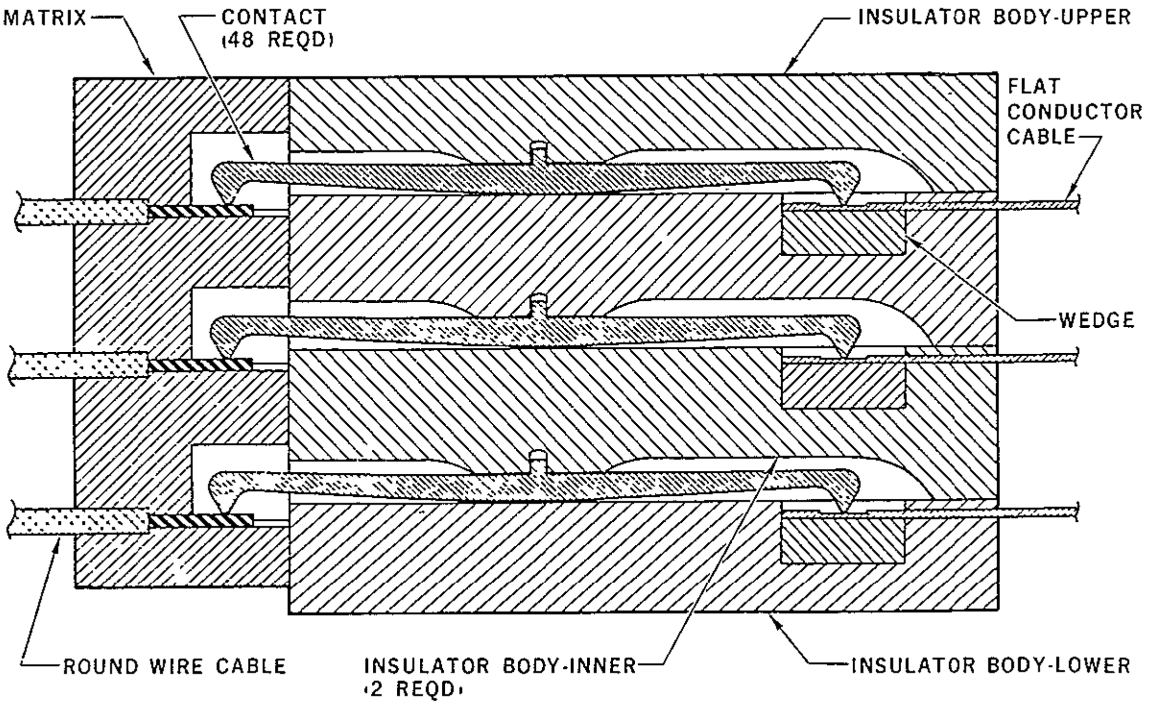


Figure 5-9. Connectorless Termination System

made and retained in each contact area. Temperature, current (dry circuit, rated current and maximum overload), and dynamic tests were successfully passed. A complete modular electronic packaging system with connectorless interconnections is shown in Figure 5-10. All input-out cabling as well as the interconnecting matrix utilize the connectorless termination system shown in Figure 5-9.

Bunker Ramo Corporation has developed a connectorless termination system for use with hybrid micro-electronic packaging, Figure 5-11. This system utilizes plated contact buttons in the contact areas between adjacent substrates.

These crushable buttons make the required connectorless terminations and the spring forces are retained by the axial tension forces in the bolts holding the substrates together. Input-output cables with permanent junctions to a connectorless termination substrate would complete the system.

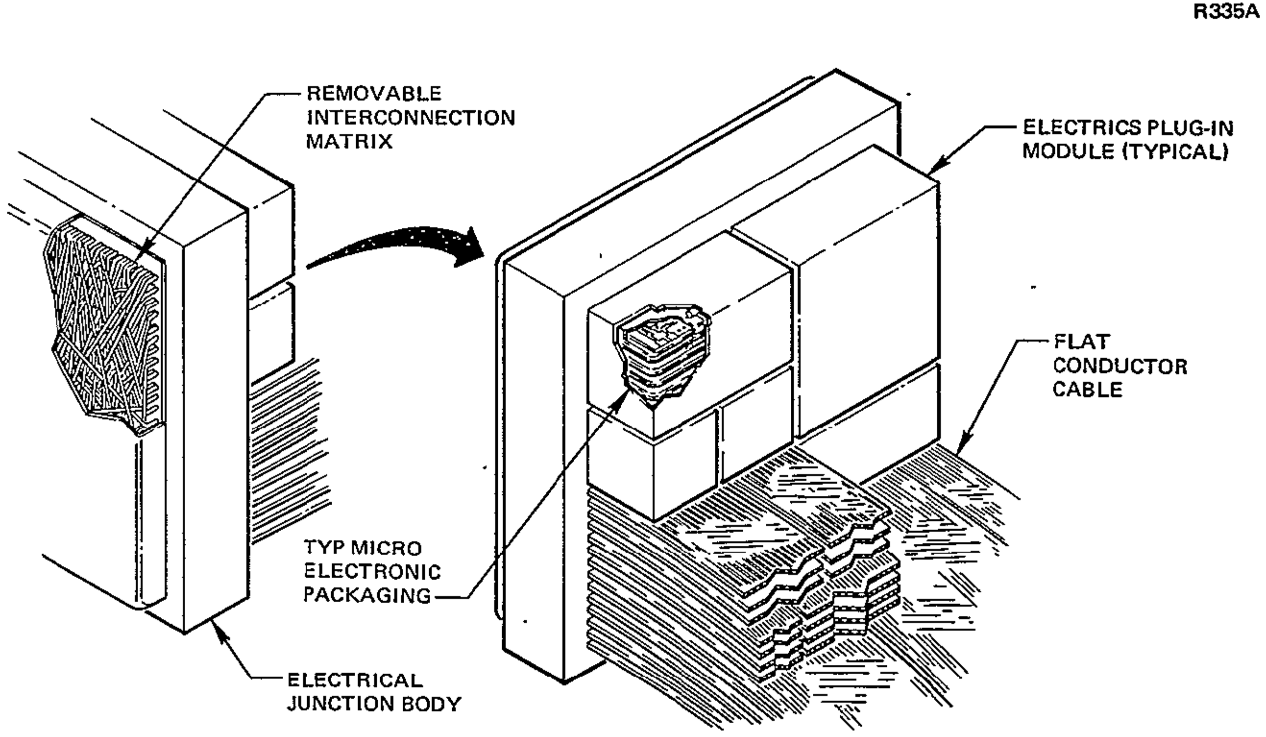


Figure 5-10. Packaging with Connectorless Termination System

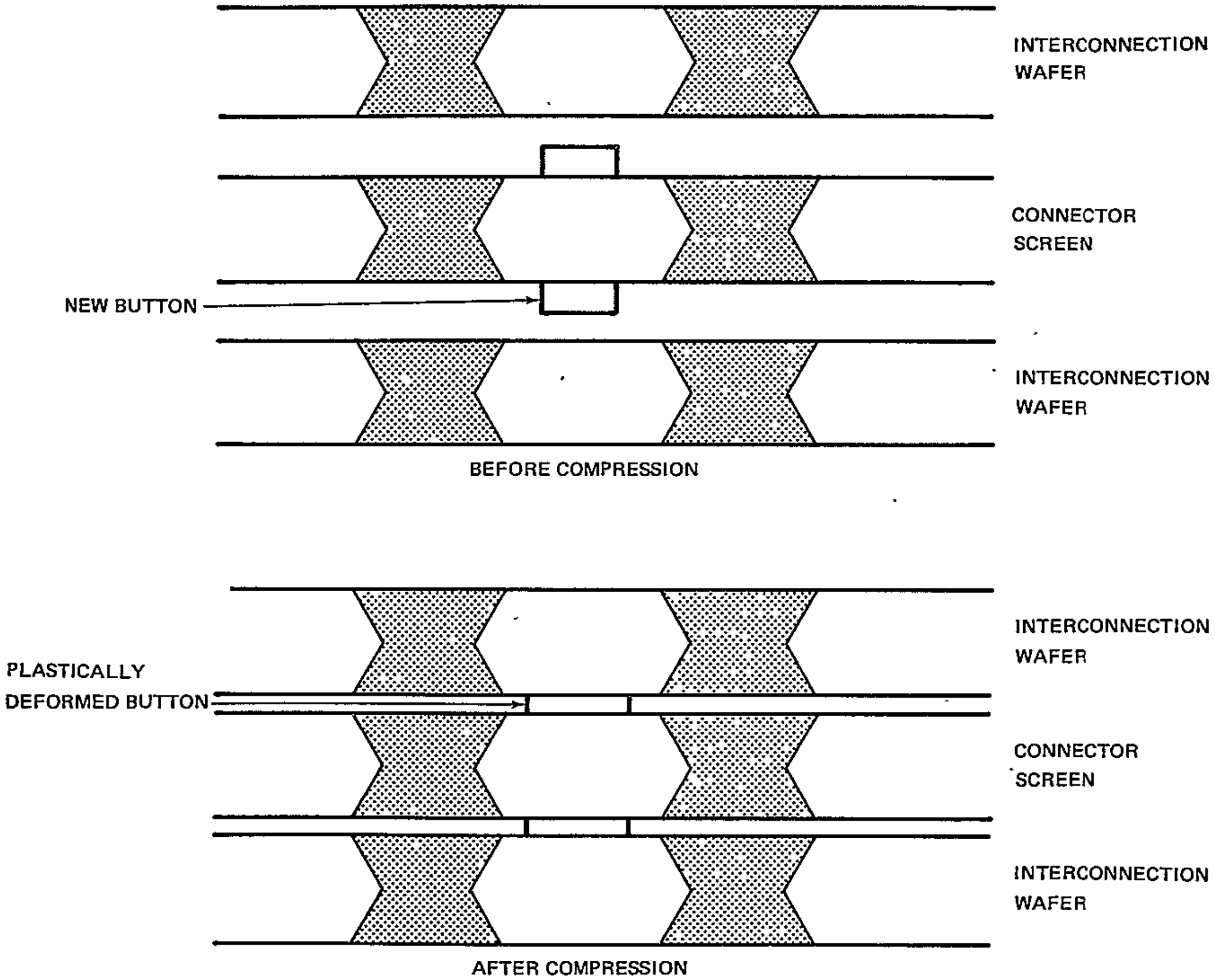


Figure 5-11. Connections with Plastic Button Deformation

5.6.3 Requirements for Future Systems

Requirements for connectorless terminations are summarized as follows:

A. Utilize the minimum number of electrical junctions.

B. Multiple contact points with high-pressure, gas-sealed junctions.

C. Adequate spring force to hold the contact points together during all conditions of manufacturing tolerance operational and environmental conditions.

D. Capability to connect and disconnect without destroying either half of the connection (expendable accessories may be used if they do not degrade the connection).

E. Provide adequate sealing and strain relief.

F. Permit reconnection of selected circuits without disturbing the remaining junctions.

5.6.4 Advantages and Disadvantages of Connectorless Terminations

The use of connectorless terminations must be carefully weighed against the use of conventional connectors. The advantages are listed below:

A. Utilizes fewer electrical junctions.

B. The high-pressure gas-sealed junctions provide potential maximum reliability.

C. Offers weight and space advantages.

D. Resultant cost savings.

The disadvantages are listed below:

A. Lack of proven and qualified hardware.

B. Little experience with types suitable for wire harnesses.

C. More difficult to rework and retain original high quality.

5.7 PERMANENT JUNCTIONS

Permanent electrical junctions are defined as those made in such a manner that they cannot be easily disconnected and reconnected. The different types are described as follows:

5.7.1 Solder Junctions

Solder junctions are the oldest used for many successful applications. An alloy, usually about 60-percent tin and 40-percent lead is used first for tinning and then joining with the proper flux and heat application. Solder junctions properly designed and made offer a high degree of reliability and can be inspected. However, all solder junctions have very low yield stresses under continuous loads at room temperatures and above and should therefore be used in near zero-stress applications.

In addition to soldering into connector solder cups and wires twisted together or around terminal posts, there are two improved gang methods which offer much promise for future application. The first is a solder sleeve application by Raychem, as shown in Figure 5-12. Here, the preinsulated solder sleeves, properly spaced, are gang soldered by focused IR heat. The cabling shrinks simultaneously to seal and strengthen the joint. The second, developed by Bell Telephone, utilizes IR heat through a quartz pressure plate and suitable resilient pads to complete all solder joints in 10 seconds, Figure 5-13.

5.7.2 Welded Junctions

Various types of welds have been successfully used for electrical junctions. Resistance welding melts the base materials with no filler required.

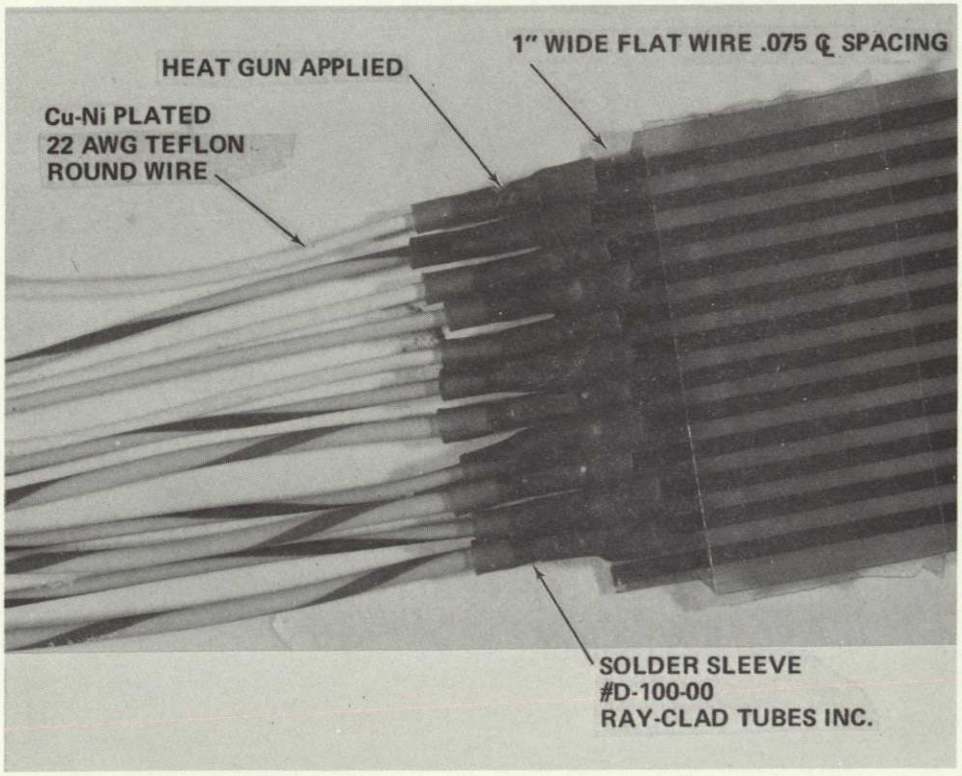


Figure 5-12. Ganged Solder Sleeve Application

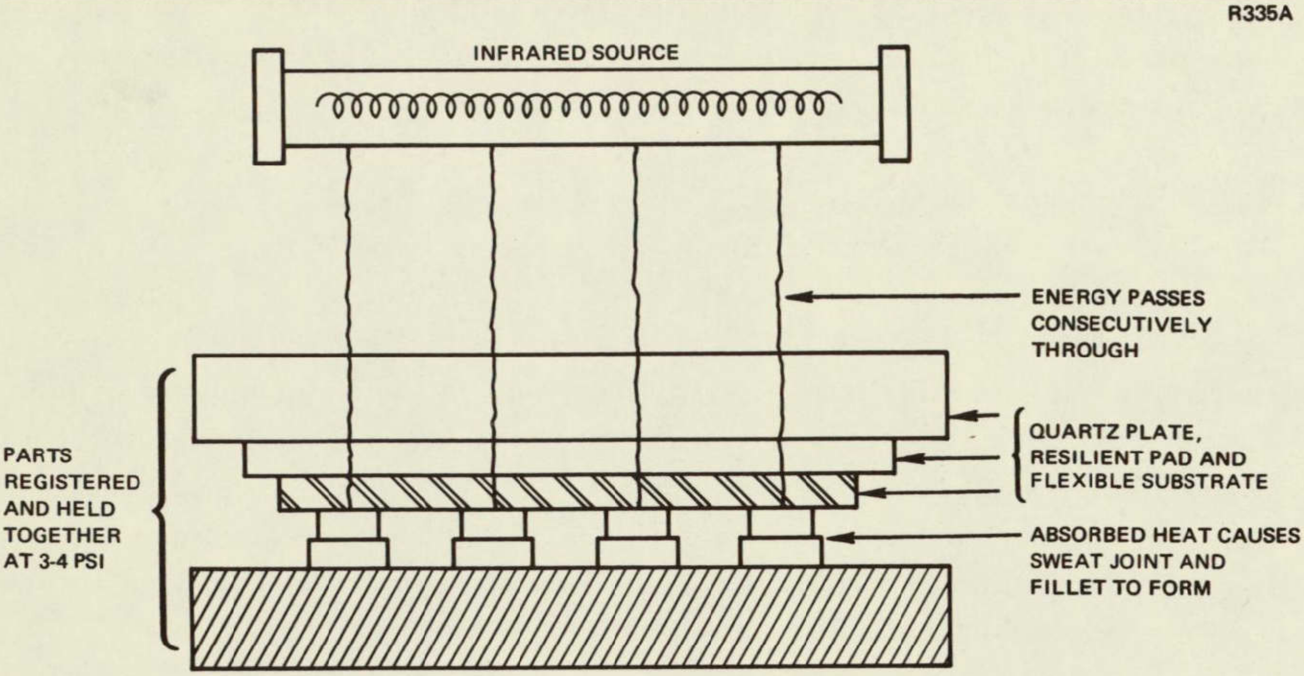


Figure 5-13. Infrared Ganged Soldering

Capacitive discharge is usually used with electrical junctions to reduce the total heat required. Ansley West uses preheated electrodes and pressure to penetrate through thermo-plastic insulation, then completes the electrical junction with a capacitive discharge. Western Electric has developed Thermal Compression bonding techniques (Reference 5-2) for various electrical junctions which give high quality joints with wide tolerances in materials and manufacturing settings. A tungsten inert gas (TIG) weld for splicing FCC to RWC is described in reference 4-6. This junction is adaptable to automatic termination and the weld fillet provides very inspectable joints.

5.7.3 Brazed Junctions

Brazing is similar to soldering except a much higher temperature is required (although less than welding) and a much stronger joint is obtained (approaches strength of welding). In one application, a wire coated with brazing alloy is joined to component terminals by brazing. The component lead alloy need not be closely controlled, as required with welded joints, and the resultant junction fillets are readily visually inspected. Brazing offers much promise for future high-strength, high-reliability junctions.

5.7.4 Crimped Junctions

Crimped electrical junctions offer many advantages and are preferred for electrical connector junctions. The use of MIL-SPEC contacts with MIL-SPEC tooling gives a high degree of reliability. However, it is recommended that additional materials, practices, and controls be employed on the RNS to help eliminate errors and give an even greater degree of reliability. These are:

A. Use only one size crimp barrel (inside and outside diameters) color coded with one size wire having the same color code.

B. Use single nest color coded crimp tools to match the color-coded wire and contact.

C. Preclude all chance of the insulation from getting inside the crimp area. Then cover crimped junctions where required with transparent shrink tubing.

D. Do not use preinsulated splices.

E. Maintain a constant inspection alert for any abnormalities in the crimping, components, tooling, and procedures.

See Subsection 6.6.1 and Figure 5-14 for a permanent crimp-junction transition for FCC to RWC.

5.8 IN-ORBIT BLIND MATING CONCEPTS

Blind mating concept for in-orbit assembly and maintenance would require connector concepts analogous to the umbilical concepts of ground launched vehicles. A conceptual design and tolerance evaluation is shown in Subsection 6.6.3.

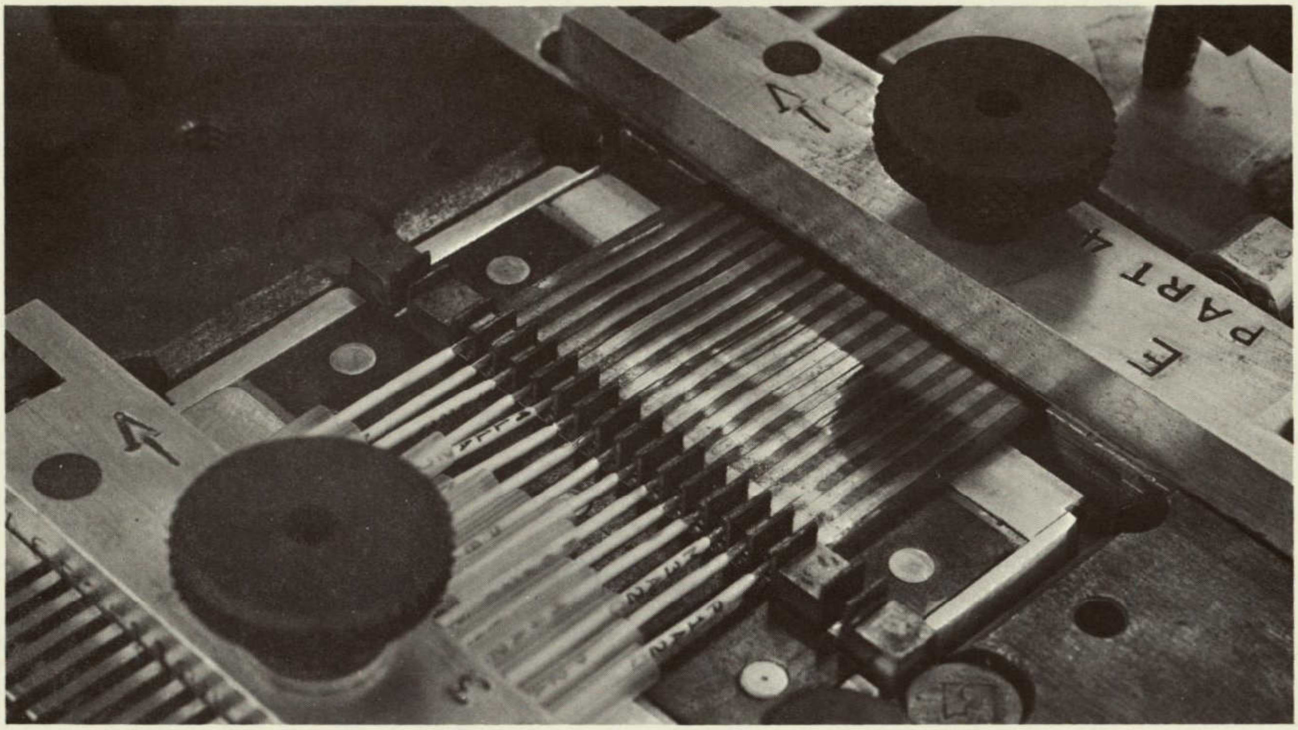


Figure 5-14. Tooling for FCC to RWC Ganged Crimp

Section 6

EVALUATION AND SELECTION OF APPROACHES

The primary criteria for evaluation are reliability, weight, and radiation resistance.

The nature of a reusable vehicle indicates that an effective performance penalty for weight is propagated according to the number of reuses, hence, weight was a primary evaluation criterion used in selection concepts.

Reliable distribution and connection of electrical signals is crucial to the concept of a reusable nuclear stage. Because of the large number of junctions, electrical connections have been identified as one of the major contributors to RNS unreliability. Mil handbook 217B indicates that a failure rate of 0.016 failures per 10^6 hours can be expected for conventional crimp connections. This relatively poor reliability is based partly on past lack of quality control and the inability to properly inspect the finished product. For wirewrap, a form of connectorless termination, the expected failure rate is 0.0000037 failures per 10^6 hours. There is clear motivation to minimize the number of junctions in the electrical networks based on reliability. It is the concern for reliability that suggests alternatives to the conventional pin and socket connectors. There can be no substitute, however, for inherently reliable connection concepts and production techniques. Reliability was a fundamental evaluation criterion in the selection of interconnection concepts.

The radiation environment envisioned for three classes of the RNS has been established in the RNS studies. This indicates a requirement for inorganic insulation in the immediate vicinity of the reactor. Presently, inorganic ceramic insulation is relatively heavy. Hence, a transition to organic insulation as close to the radiation source as possible will permit substantial weight savings.

6.1 EVALUATION OF POWER WIRING

6.1.1 Criteria

The selection of power wiring was based on an allowance of a 1-volt drop in power signal from source to load. A 1-volt drop in the return path was also allowed. In the case of the Class 1-H and Class 3 RNS this drop was allowed from the CCM to the batteries on the run tank, and an additional 1-volt drop was allowed from the batteries to the engine interface. For the Class 1, a 2-volt drop was allowed from the CCM to the engine based on the high weight penalty incurred if enough wiring were installed to achieve only a 1-volt drop. The integral structure configuration of this RNS class and the inability to locate batteries aft motivates the use of the vehicle skin as a power return.

6.1.2 Power Cable Sizing

Power for the propulsion module, if supplied by a local battery, will not require heavy, high current capacity cables from the CCM to the propulsion module. The most demand for power occurs during burn 1 of the mission—1,050 Whr.

The power cabling may then be sized to handle the long cooldown periods and the recharging of the propulsion module batteries. A propulsion module cooldown power requirement of 200 W exists and a battery recharge (peak demand) allowance of 300 W is made for a total of 500 W. A peak current demand of approximately 20 amps between the prime power source in the CCM and the local battery on the propulsion module is then estimated.

Class 3 RNS

For 1-V drop and 240-ft run— each way

Resistivity $\frac{1\ \text{V}}{20\text{A}} \times \frac{1}{240} = 0.208 \quad \frac{\Omega}{1,000\ \text{ft}}$

Copper 3 AWG-8 at 0.706 $\frac{\Omega}{1,000\ \text{ft}}$, 60.0 lb/1,000 ft

$6 \times 60.0 \times 0.240 = 86.3$ lb

Aluminum 5 AWG-8 at 1.09 $\frac{\Omega}{1,000 \text{ ft}}$, 27.0 lb/1,000 ft

10 x 27 x 0.240 = 64.8 lb

Savings for Al = 21.5 lb = 25 percent

Class 1-H RNS

For 1-V drop and 100-ft run — each way

Resistivity $\frac{1 \text{ V}}{20\text{A}} \times \frac{1}{100} = 0.5 \quad \frac{\Omega}{1,000 \text{ ft}}$

Copper 2 AWG-10 at 1.10 $\frac{\Omega}{1,000 \text{ ft}}$, 37.5 lb/1,000 ft

4 x 37.5 x 0.100 = 15.0 lb

Aluminum 2 AWG-8 at 1.09 $\frac{\Omega}{1,000 \text{ ft}}$, 27.0 lb/1,000 ft

4 x 27.0 x 0.100 = 9.8 lb

Savings for Al = 5.2 lb = 33 percent

Run Tank Cables — Class 1H, Class 3 RNS

1 V drop 24 feet - 125 amps between propulsion module local battery and engine actuator area.

Resistivity $\frac{1}{125} \times \frac{1}{24} = 0.333 \quad \frac{\Omega}{1,000 \text{ ft}}$

Copper 2 AWG-8 at 0.706 $\frac{\Omega}{1,000 \text{ ft}}$ and 60.0 lb/1,000 ft

4 x 60.0 x 0.024 = 5.73 lbs

Aluminum 3 AWG-8 at 1.09 $\frac{\Omega}{1,000 \text{ ft}}$ and 27.0 lb/1,000 ft

6 x 27.0 x 0.024 = 3.89 lb

Class 1 RNS

No battery near the engine.

For 2-V drop, 110-ft run, (125 amp) — vehicle skin return

Resistivity $\frac{2\text{ V}}{125\text{A}} \times \frac{1}{110} = 0.145 \quad \frac{\Omega}{1,000\text{ ft}}$

Copper 7 AWG-10 at 1.14 $\frac{\Omega}{1,000\text{ ft}}$, 40.0 lb/1,000 ft

14 x 40.0 x 0.110 = 61.8 lb

Aluminum 7 AWG-8 at 1.09 $\frac{\Omega}{1,000\text{ ft}}$, 27.0 lb/1,000 ft

14 x 27.0 x 0.110 = 41.5 lb

6.2 EVALUATION OF CABLE CONCEPTS

Proper comparison must be made between the various cable concepts prior to the cabling system selection.

6.2.1 General Comparison Between Basic Systems

Table 6-1 gives the advantages and disadvantages of the three basic wiring classes.

The point-to-point wiring system has been used almost extensively on flight programs of the past. It uses conventional round wire cable. Individual circuit requirements are defined between all electronic units in the systems. Random round wires are routed between the assigned connector pins of each unit and then formed into multibranch harnesses. Ground rules for circuit isolation plus the random routing of conductors in each bundle dictate the separation of circuit classes into separate bundles isolated from each other plus the use of excessive shielded cable.

The parallel conductor wiring system utilizes FCC and ribbon cable with the physical location of each conductor controlled in relationship to each other conductor. This system generally has little versatility in accommodating pin assignment requirements or changes at the electronic units. The two-ended cable assemblies can be designed and manufactured for a small fraction of the cost of the point-to-point cable assemblies. In general, the parallel conductor system requires an external means of accomplishing electronic unit initial pin assignment and changes. The parallel conductor geometry generally requires a rectangular connector for efficient

Table 6-1

COMPARISON OF INTERCONNECTING WIRING SYSTEMS

Class	Advantages	Disadvantages
Point-To-Point	1. Maximum circuit flexibility 2. Ease in design change and rework to change pin assignments. 3. Utilizes simple proven cable and connectors. 4. Extensive design and manufacturing experience.	1. Expensive design and fabrication costs for harnesses. 2. Requires separate bundles with support and clamping for various circuit classes. 3. Utilizes excessive shielded cable to compensate for uncontrollable location of individual conductors in bundles. 4. Unpredictable electrical performance and variation in performance from unit to unit.
Parallel Conductor	1. Minimum design and harness cost. 2. Maximum reliability and system performance 3. Mechanical load sharing and improved physical characteristics such as abrasion, notch and cut through. 4. Simple harness runs with minimum support structure and clamps. 5. Eliminates most shielding requirements.	1. Requires means of addressing and changing pin assignments. 2. Some restriction in multiplane bending. 3. New design fabrication and installation technology required. 4. Limited hardware and termination processes available.
Hybrid	1. Major advantages of parallel conductor system in harness run area. 2. Versatility of termination in junction areas. 3. Permits the efficient integration of existing electronic units with round wire connectors to a more desirable parallel conductor interconnecting system.	1. Does not include the weight and cost saving of the FCC system. 2. Requires special fabrications and handling of the hybrid bundles.

termination. It readily accommodates the connector wafer concept which holds so much promise for future applications.

The hybrid wiring system utilizes parallel conductors for the major length of the harnesses but can transform to random round wire conductors in the termination area. One hybrid system uses round wire woven in a ribbon pattern in the cable run area and permits the round wires to assume a random round bundle configuration in the termination areas.

6.2.2 Typical Trade Study For Cable System Selection

Considering the typical electrical cable requirements through the Class 3 propellant module, the central core module was taken as representative and a trade study which considers the various cable types and conductor size implications was performed.

The twinax cable requirement was accepted as firm because of the relatively small quantity of cables and the special electrical requirements for the data bus system.

Subsection 6.1 of this report contains a weight tradeoff study for aluminum and copper round wire cable systems. The weight for six cables 240 feet long with No. 8 AWG copper conductors and high performance Kapton insulation is 86.3 pounds. The weight for ten cables 240 feet long with No. 8 AWG aluminum conductors and high performance polyimide insulation is 64.8 pounds. The weight for two flat conductor cables 240 feet long with aluminum conductors 2.8 by 0.025 inches and polyimide/TFE insulation is 46.3 pounds with 4 mils of polyimide and 2 mils of TFE. There is a potential weight savings of 21.5 pounds by using the No. 8 aluminum round wire and of 40 pounds by using the aluminum flat conductor cable. This relative small weight saving is more than offset by the potential problems of termination, low strength, work hardening and corrosion associated with the use of aluminum conductors. Therefore, it is recommended that conventional type copper conductor round wire be used for all power cables. This will permit existing proven termination methods and connector hardware to be used.

An 893-conductor complement was assumed through the propellant module. These are further defined as:

10 percent requiring 20 AWG conductivity = 90
80 percent requiring equivalent of twisting and shielding with 27 AWG conductivity = 713
10 percent requiring equivalent of 27 AWG conductivity = 90

The smallest size round wire to be considered is No. 22 AWG to maintain the required mechanical integrity and reliability in both the conventional round wire and the ribbon cable. The flat conductor cable will use 4 x 40 mil copper conductors to meet the No. 27 AWG electrical requirements and 6 x 140 copper conductors to meet the No. 20 AWG electrical requirements. The mechanical load sharing characteristic of the flat cable together with the ganged termination system prevents stresses from being applied to single conductors and provides a high performance and high reliable cable system even when small cross sections are used.

Table 6-2 summarizes the tradeoff study for conductor systems to meet the 893-conductor requirements previously defined. The flat cable system uses copper conductors with polyimide insulation in accord with MIL-C-55543. Shielding requirements are met by providing 15 separate shield layers of 1 mil copper foil laminated between sheets of polyimide. This shielding method provides increased flexibility, lower costs, and improved reliability in the harness runs and especially in the termination areas.

The ribbon cable and conventional round wire systems use the same stranded copper conductors with polyimide insulation. The ribbon cable is woven in layers to the dimensions shown and installed by layers the same as flat conductor cable. The round wire is bundled in circular configurations in the conventional manner.

Table 6-2 shows the major weight and cross sectional area advantages of the flat conductor cable over the two round wire systems. Weight savings of 920.2 pounds (70 percent) and 846.9 pounds (69 percent) over ribbon cable and conventional round wire are real and significant. Cross section area

Table 6-2
CABLING TRADEOFF THROUGH PROPELLANT CLASS 3 RNS PROPELLANT MODULES

Cable Type	Number of Conductors	Cable Description	Cross Section	Area (Sq. In.)	Weight (Per 240 ft.)
Flat Cable					
27 AWG	803	(22) 3 in. wide at 38 conductors	3.0 x 0.33	0.990	238.0
Shields	15 Layers	(15) 3 in. wide,	3.0 x 0.105	0.315	60.0
20 AWG	90	(5) 3 in. wide at 19 conductors	3.0 x 0.075	0.215	84.8
			(TOTAL)	1.520	382.8
Ribbon Cable					
22 AWG	90	(3) 1-1/2 in. wide at 30 conductors	1.50 x 0.195	0.292	68.3
22 AWG 2SJ	357	(15) 3 in. wide at 24 pairs	3.00 x 1.88	5.640	1,133.0
20 AWG	90	(3) 2-1/4 in. wide	2.25 x 0.225	0.503	102.7
			(TOTAL)	6.435	1,303.0
Round Wire					
22 AWG	90	0.045 in. OD	2.61 Dia.	5.37	64.7
22 AWG 2SJ	357	0.115 in. OD			1,068.0
20 AWG	90	0.050 in. OD			97.0
			(TOTAL)		1,229.7

savings of 4.92 square inches (71 percent) over ribbon cable and 3.85 square inches (65 percent) over conventional round wire are realized. In addition, the 2.61-inch diameter round wire bundle could impose a major routing problem. The bundle could be broken up into a number of smaller bundles with increased cross section area together with routing and support complications. As a minimum, increased support structure provisions and a major increase in support hardware would be required.

6.3 RECOMMENDED WIRING CONCEPTS

Based on the preceding trade study for the propellant Class 3 central core, and on previous government, other prime contractor, and MDC cable studies, a number of conclusions can be reached that are applicable to all RNS configurations studied.

6.3.1 Multiplexing and Data Bus

Multiplexing of engine-related functions is recommended forward of the run tank for the Class 1-H and Class 3 RNS. For the Class 1 RNS, a penalty of about 1,700 lb of cabling is incurred to run wires forward of the propellant module. The alternative of engine shielding would incur comparable weight penalties, depending on the assumptions made on semiconductor performance in a radiation environment. For attenuations comparable to those achieved with the run tank concept, the shielding weights would be unacceptably large. This implies a potential basis for selecting between alternate RNS concepts.

Data bus will provide additional benefits in weight reduction, system redundancy, increased capacity, and potential increased reliability.

6.3.2 Terminations

Major reliability improvements can be achieved by reducing the number of electrical junctions or breaks in the conductors to a minimum and by using highly reliable methods for the remaining junctions. Extensive use should be made of brazed permanent junctions and connectorless terminations. Solder terminations should be used with caution and, where used, all mechanical and thermal stresses, both external and internal, should be reduced to a minimum. The ground rules listed in Subsection 5.7.4 should be used for all crimp terminations. These will eliminate the possibility of having insulation in the crimp splice areas; or of using the wrong combination of crimp device, cable, and crimping tool; and will provide the optimum crimp terminations for each wire size.

6.3.3 Insulation Systems

Improved insulation systems should be considered for the very high-radiation environments encountered in the engine area. These systems have the potential for weight reductions, major mechanical flexible improvement, and ease of termination with increased reliability in the termination areas.

All polyimide insulation systems are prime candidates in the radiation environments that cannot be met with teflon binders. A number of manufacturers are currently developing all-polyimide, round-wire insulation systems as described in Subsection 3.2. All-polyimide, flat-conductor cable systems have been developed and tested. Individual conductors, with pre-insulated tower coatings, are laminated with polyimide film and polyimide adhesives. Etched construction, starting with a polyimide type coating on copper foil, uses etching to provide the required conductor pattern, and then has a polyimide type tower coating applied over the conductors. Additional development and testing will be required for both round and flat-all-polyimide insulation systems.

Polyimide systems with FEP for binder insulation are recommended for those areas of minimum radiation, such as the CCM. These existing insulation systems for both round and flat conductors are lower in cost and provide excellent mechanical and electrical properties to meet the RNS requirements. These insulation systems follow from years of background in development and qualification testing and are available from numerous sources.

6.3.4 Conductor Systems

Nickel-plated copper conductors are the first choice for the RNS for both round wire and flat conductor cables. The use of these conductors, which have a long history of experience and success, will efficiently and reliably meet the majority of circuit requirements. If smaller than 22-AWG, round-wire sizes are used, a proven high-strength alloy should be used to provide additional mechanical strength for the smaller sizes. Very small copper flat conductors, of AWG 27 and smaller, can be used because of ganged termination methods and the load-sharing characteristics of flat conductor cable.

Aluminum conductors could provide high-percentage conductor weight savings, up to approximately 50 percent, in power cable application. They could be used, with proper plating, for the termination systems selected, for both round and flat conductors. However, from the power cable sizing evaluation of Subsection 6.1.2, it can be seen that the total weight saved, 21.5 lb maximum for Class 3 RNS, would be relatively small. To eliminate the major problems of aluminum termination rk hardening, corrosion susceptibility, low strength, high creep rate, and poor thermal coefficient of expansion compatibility; it is recommended that aluminum conductors not be used on the RNS.

6.3.5 Tunnel Concepts

A tunnel concept is recommended, based on the minimum dimensional requirements and the associated requirement of a repressurization line. This assumes that minor relief from the 15- by 60-ft space shuttle cargo bay limitation is feasible. The use of parallel conductors (flat cable or ribbon cable) in the tunnel areas will provide the most efficient rectangular, low-profile wiring system. The conductor placement control, plus the use of shield layers rather than shielded cable, will provide major space reductions.

6.3.6 Cable Configurations

This report considers four cable configuration types: (1) coaxial and twinax, (2) conventional round wire, (3) round ribbon cable, and (4) flat conductor cable.

6.3.6.1 Coaxial and Twinax

High performance transmission line cables are recommended for use with the data bus systems. The total number of conductors required is small, and the electrical characteristic requirements are quite demanding.

Therefore, it is recommended that coaxial or twinax cables be used for all transmission line requirements. Special ribbon and flat conductor cables are currently being used successfully for many airborne and ground-based computer systems, and these special systems should be given consideration on RNS if the total transmission line requirements grow appreciably beyond the current anticipated requirements.

6.3.6.2 Conventional Round Wire

This proven wiring system should be considered where many small cables with few conductors are required to directly interconnect many valves, electronic components, and electronic assemblies. These cables should be kept as short and simple as possible so they can be treated as a component assembly rather than a major wire harness.

6.3.6.3 Ribbon Cable

Ribbon cable of the woven variety has some of the major advantages of both conventional round wire and flat conductor cable. The conductors woven in planer fashion can be used for the major cable lengths and for layer termination in rectangular junctions. In those areas where multiplane bending is required for a cable with few conductors and where termination is required to round wire connectors, the ribbon cable can change to the conventional round configuration.

6.3.6.4 Flat Conductor Cable

Flat conductor cable is the first choice for the majority of cable runs on the RNS. FCC will provide very light-weight, high-strength, highly reliable interconnecting harnesses to meet most of the major cable run requirements; excluding the transmission line, power cable, and small multibranched harnesses previously described. The elimination of a high percentage of shielding requirements and the use of shield layers between layers in lieu of individual cable shielding provide even greater advantages.

6.3.7 System Flexibility

The cabling system recommended for RNS must provide the system flexibility to accommodate design errors, design changes prior to delivery and block or negotiated changes after approval and acceptance of delivered hardware. This concept of wiring flexibility has not received proper consideration in past programs. Conventional multibranched round wire harnesses could always be reworked to make minor pin assignment changes and harnesses could have major rework or be replaced for major wiring change requirements. However, rework of existing harnesses always results in a reduction of reliability, and major harness replacement is very difficult and expensive.

The parallel conductor system recommended for RNS provide the lightest weight, most efficient, and most highly reliable interconnecting system known. But it does require incorporating devices for making and changing pin assignments as required. These devices range from the equivalent of a multilayer printed circuit device having permanent junctions to all interconnecting wiring, to devices having plug-in matrixes that interconnect with high-reliability connectorless terminations. It must be understood that the proper incorporation of these change devices provides the heart of the interconnecting system. The interconnecting change devices permit all harnesses to be designed and manufactured prior to the final pin assignments, they will easily accommodate design error corrections and design changes, and they will provide efficient major system changes with minimum changes to the wire harness segments and terminations. For example, a major system could be changed by replacing the pin assignment change devices, and adding, replacing, or deleting minor cable segments. This could all be done with a minimum of rework time on the RNS modules.

6.4 DISTRIBUTION OF WIRING IN ENGINE AREA

Figure 6-1 shows the interface between the NERVA engine and the propulsion module run tank. The structural attachment on the forward structure is at the same station as the electrical interface.

6.4.1 Cable Selection

The cabling in the tunnel of the propellant and propulsion modules is expected to be exclusively flat cable. A potential exception may be the use of round wire to supply the heavy current demands of the engine actuator. At the engine-stage interface of the Class 1-H and Class 3 RNS, a continuous run of wire (FCC) would be most desirable. This would require a pigtail concept from the run tank with wires being routed and connected to engine modules using connectorless terminations at the time of engine mating. Should this approach be unacceptable from a manufacturing or contracting point of view, the alternate of a connectorless termination of the wire between the two components is recommended, rather than the connector panel approach resulting from the Aerojet guideline stage concept, which approximates a Class 1 RNS. The Class I RNS requires an alternate interface concept because of the requirement for engine replacement. For the Class 1 RNS, a connectorless concept, such as those described in Subsection 5.6, would be more desirable than the baseline connector panel; however, substantial development would be required. The Class 1 RNS potentially faces a significant reliability degradation when compared with the two alternate RNS concepts.

Wiring continuing to the PVARA would be flat cable to the organic-inorganic transition while the relatively small percentage of wires that are routed to various components in the engine area are made of ribbon or round wire to allow for individual line distribution. This hybrid approach makes use of the advantages of both flat and round cable concepts.

Wiring that crosses the shield and runs to the pressure vessel region is supported by and routed along large fluid ducting that crosses this plane. Ducting utilized will be the pump discharge line and both the turbine inlet and discharge lines.

6.4.2 Flexibility Across Gimbal Plane

Figure 6-2 shows the cable and routing scheme used to absorb the gimbaling deflections. This requirement is common to all configurations, Class 1 hybrid and the Class 3. The left hand portion of the view shows the upper thrust structure of the NERVA engine. This is the structural interface between the NERVA and the run tank thrust structure on the stage. Shown also is one loop of the dual pump main feed systems on the NERVA engine. This loop consists of a tank shutoff valve, a series of two-gimbaled joints, and a section of untied bellows. This flexible element system will provide

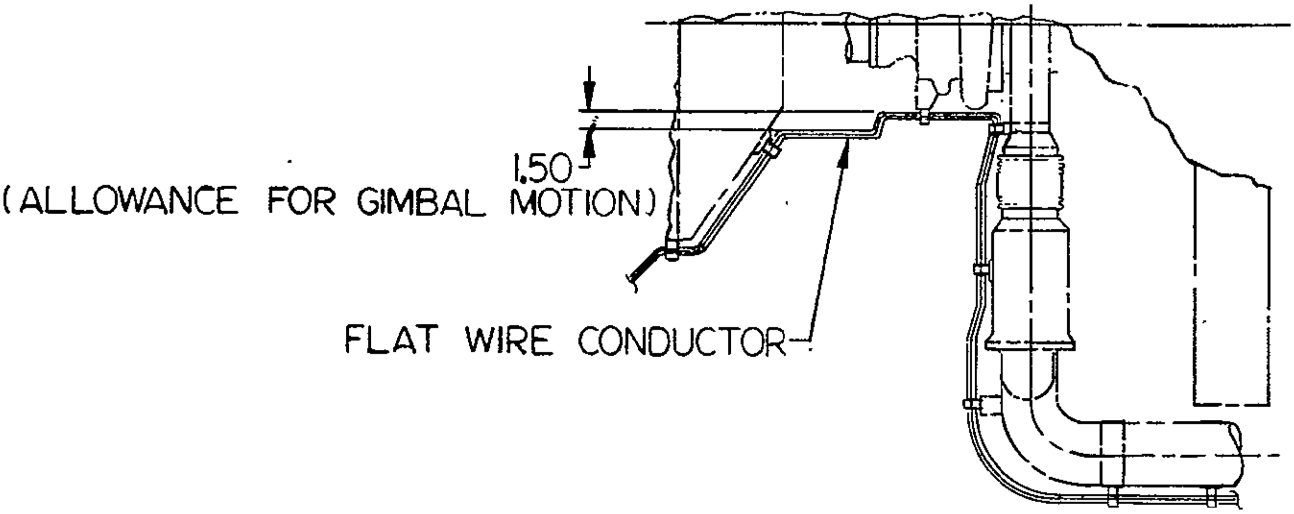


Figure 6-2. Flat Cable Across Gimbal Area

for the gimbal deflections of the main feed system. The above terminate in turbopump inlet. The gimbal axis is noted through the center of the untied section of bellows located in the main feed duct.

6.5 TUNNEL LAYUP

Figure 6-3 is a conventional external tunnel configuration integrating the electrical and fluid requirements. For the Class 1-H the required pressurization duct is about 6 inches. For the Class 3 RNS the required duct size is about 2 inches. The pressurization duct is supported on two nonmetallic standoffs. These standoffs are bonded to the tank wall. Supporting standoffs are located strategically along the entire run of ducting. The standoffs in this design also form the support for both the flat cable and the round power and data cables. The cabling is supported in conventional TA type mounting clips. These clips are bolted to the standoff and therefore serve to integrate with the supporting of the pressurization duct. This is envelope-efficient and therefore reduces the weight of external fairing required for the tunnel. The entire assembly is then shrouded by an aluminum fairing and the conventional

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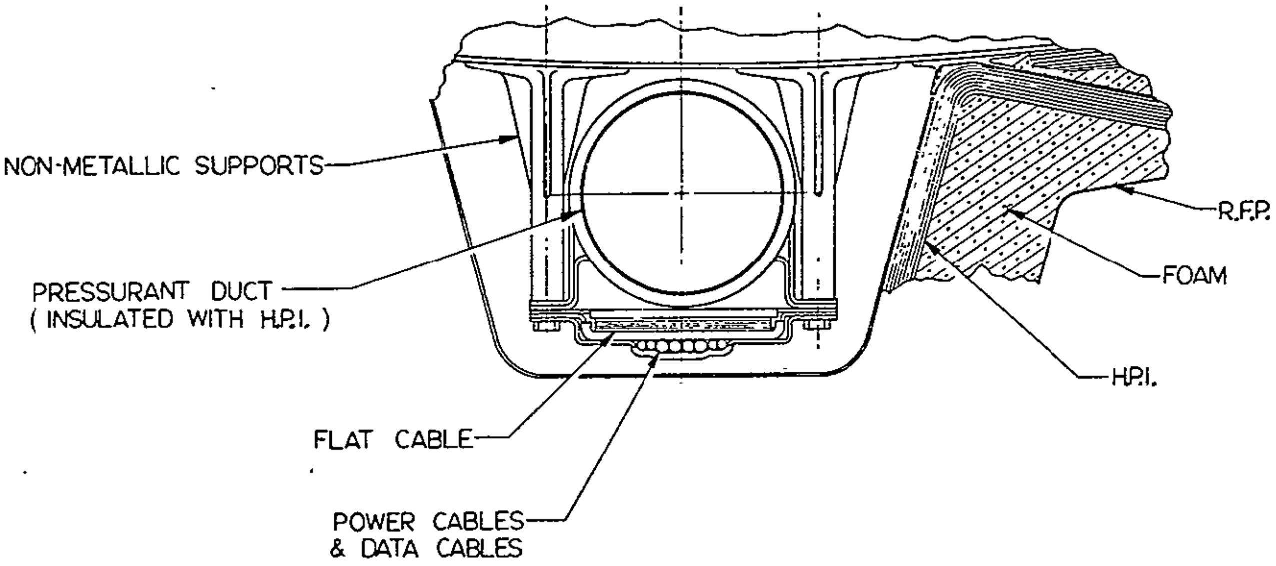


Figure 6-3. External Tunnel Cross Section

high performance insulation scheme. This system consists of the high performance insulation covered by a foam blanket and finally supported by reinforced fiber glass external wrapping. Figure 6-4 shows a flush type tunnel configuration. This type of tunnel arrangement would not violate the external diameter constraint of a Class 3 type propellant module. The conventional HPI foam glass configuration is boxed out to permit space for the series of round and flat cables that are required. In order to meet the envelope requirement, the 2-inch diameter nominal pressurization duct has been configured to a series of circular sections in order to not violate the envelope constraint. All the functions running in this cutout; namely, the pressurization duct, the round power cabling, and the flat cabling; are all bedded in a foam blanket and finally a fiber glass shroud covers the boxed out assembly.

6.6 TERMINATION CONCEPTS

The RNS has many electrical junctions which must be made between the various modules. These junctions must have the highest reliability while

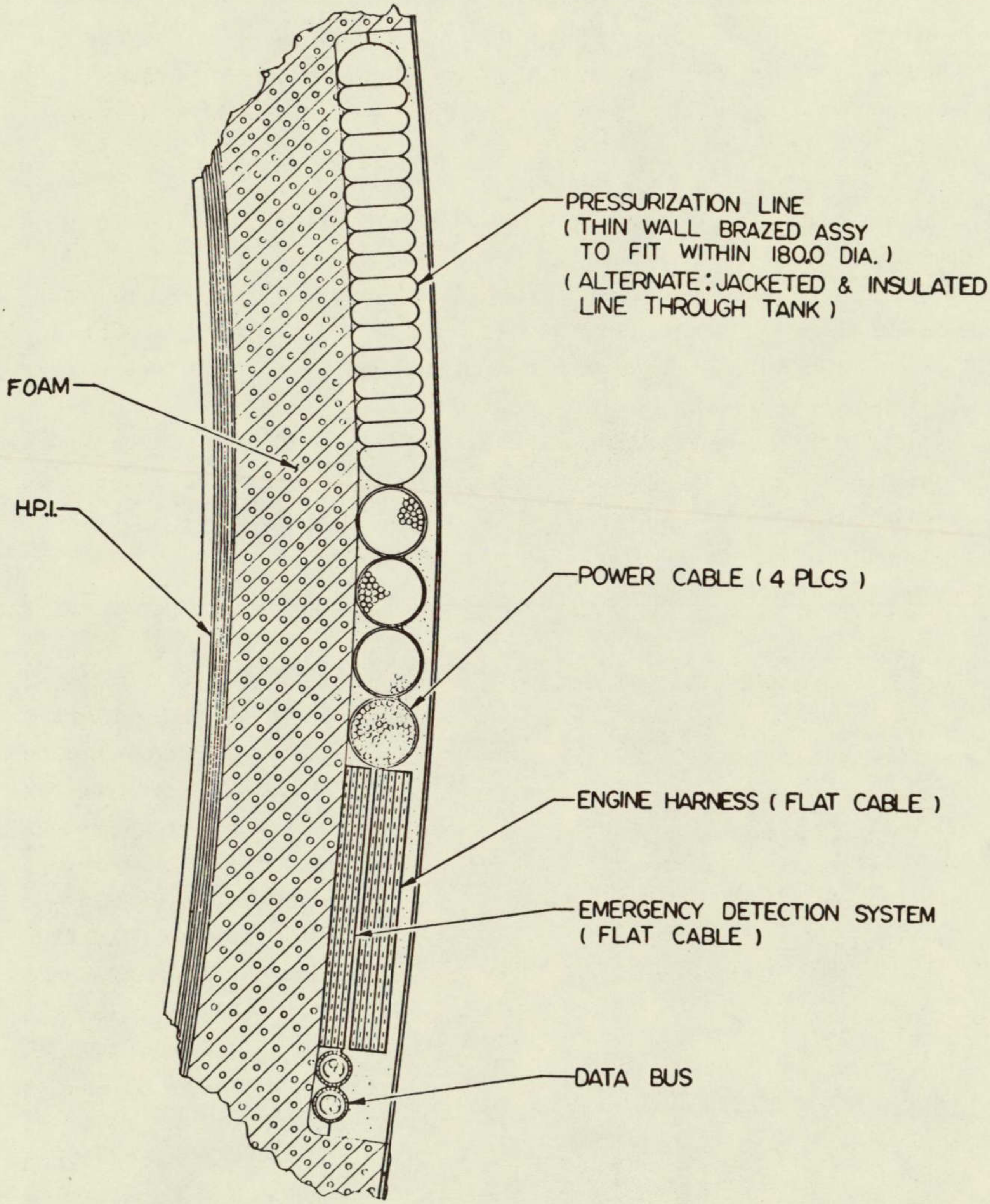


Figure 6-4. Flush Tunnel Cross Section

meeting the program requirements. In general, conventional pin and socket type connectors should be used only where they are absolutely required. Permanent and connectorless termination junctions should be given prime consideration for the majority of electrical junctions between modules. This will increase the reliability as well as provide weight and space savings.

6.6.1 Inorganic-Organic Transition

This transition should be made with permanent junctions accomplished by crimping or brazing as defined in Subsection 5.7. The junctions should preferably be made on the bench with a layer or row of terminations made simultaneously. If this is impractical, then the termination process can step from junction-to-junction without disturbing the adjacent junctions. One such type of permanent junction is currently being made on the Spartan vehicle in the warhead section as shown by Figure 6-5. Fifteen junctions are simultaneously crimped to form the highly reliable permanent junction as well as provide a transition from TWC to FCC. The junction area is then encapsulated to provide environmental protection and mechanical strength.

R335A

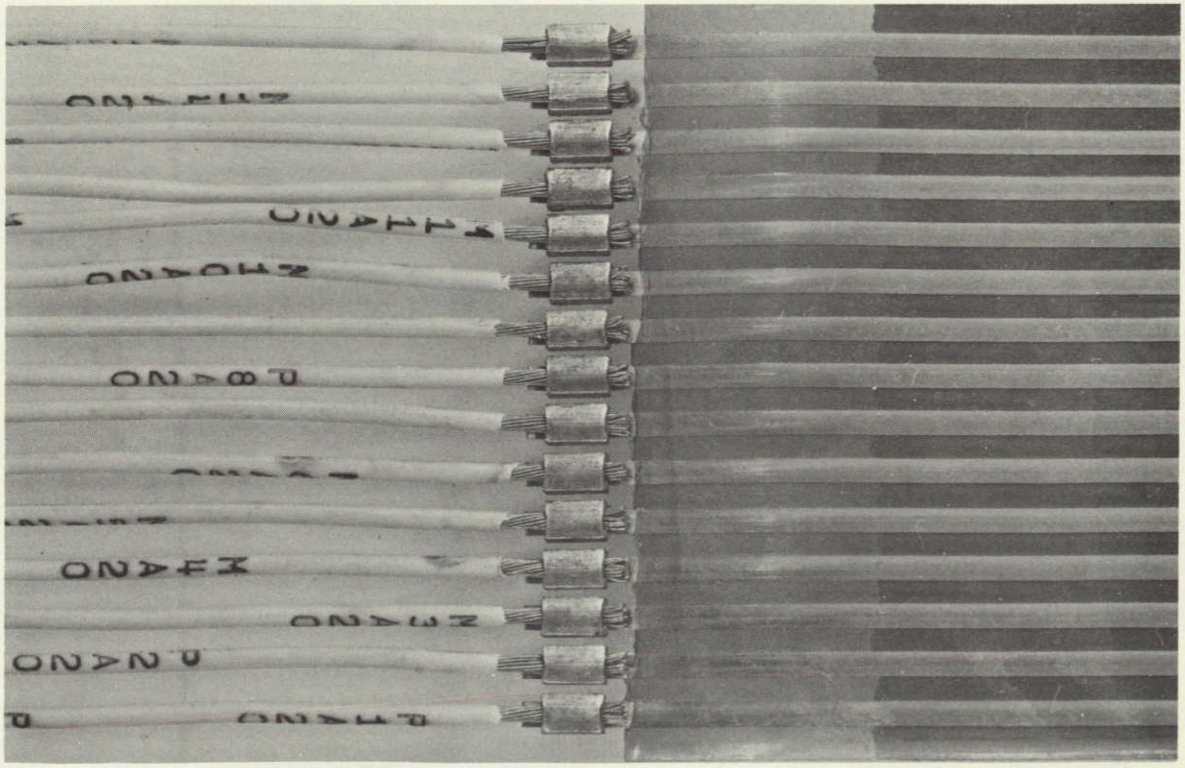


Figure 6-5. Ganged Crimp Junction Transition -- Spartan Warhead

The RNS inorganic-organic transition would have layers of inorganic cables with permanent junctions to the organic FCC, ribbon cable, or RWC. The required spacing would be provided by the accessories and tooling. Then the completed junction layer would be encapsulated to seal, protect, and add mounting provisions. The transition layers would then be bolted or clamped together and to the supporting structure. Figure 6-6 shows a sketch of this permanent junction system scheme.

6.6.2 Organic-Organic Transition

This transition should also use permanent or connectorless terminations in lieu of connectors wherever practical. The permanent junction assembly can be patterned after Figure 6-6. In those cases where it is impractical to make a permanent junction because of space or accessibility for the required tooling it is recommended that connectorless terminations be used. Modular junction hardware would accept layers of conductors from each side of the junction. The conductors of these layers would insert in a zero-force manner

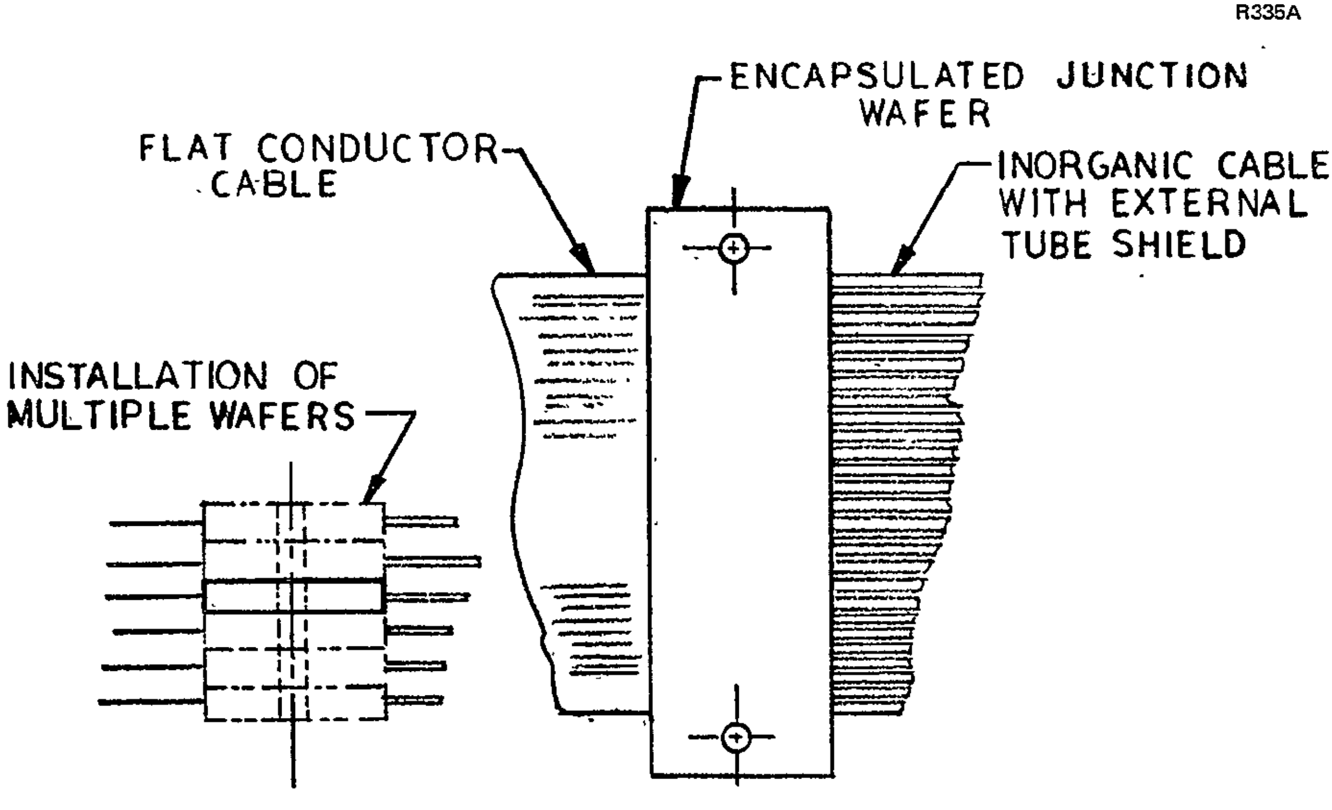


Figure 6-6. Permanent Junction Assembly

and overlap each other. Then the spring-action activating force would be applied to obtain multiple gas sealed junctions directly between the mating conductors. The principle is shown in Section 5.

6.6.3 Blind Mating Connections

Figure 6-7 shows the baseline deployable electrical panel configuration used in both configurations of the RNS vehicle. Electrical panel deployment is initiated after hard docking and fluid line deployment and coupling is accomplished. This figure shows the panel in the engaged position. Noted is the propellant tank separation plan which in some cases would be a propellant-to-propellant module interface plane, and in other cases the propulsion-to-propellant module interface plane. Panel travel to engage is noted. The electrical panel consists of a series of panel-mounted connectors. The cable routing to these connectors is shown. Both round and flat cable connectors are mounted on the deployable panel.

Figure 6-8 shows the method for connect and disconnect of the electrical panel. The lower panel is aligned to the vehicle upper panel by three conical

R335A

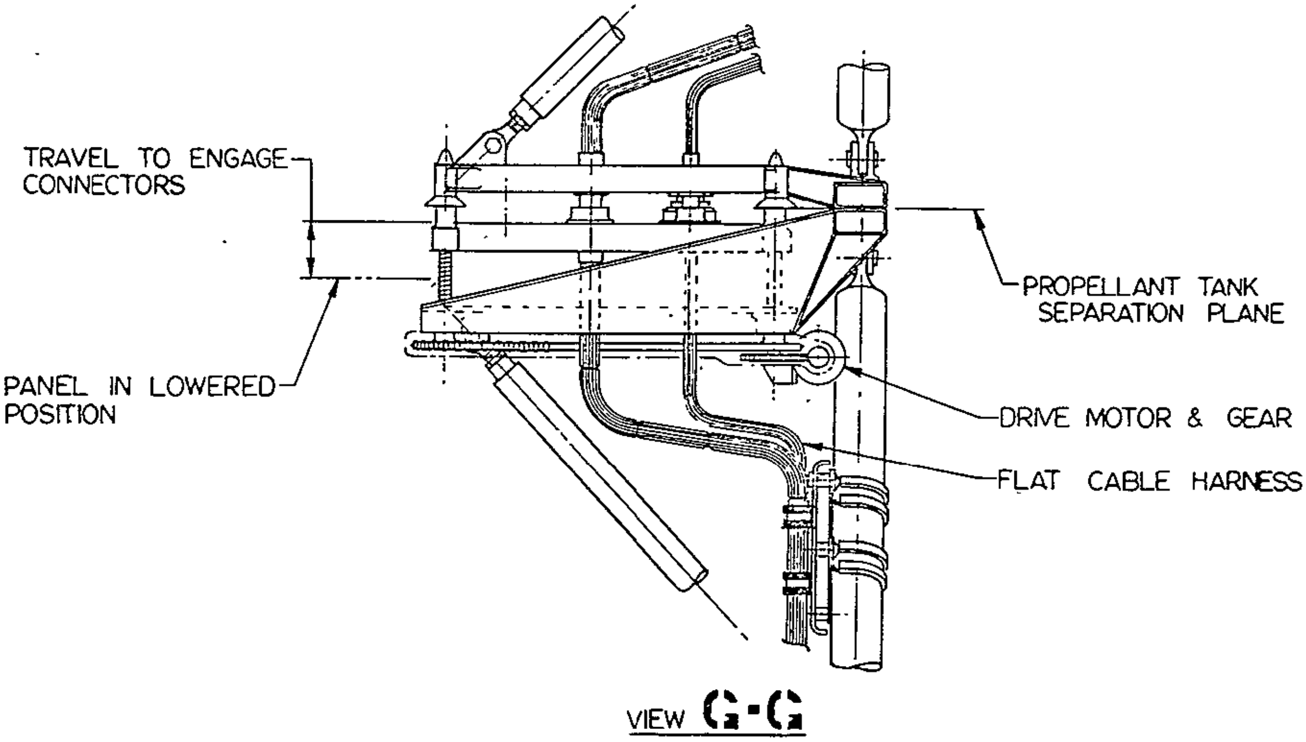
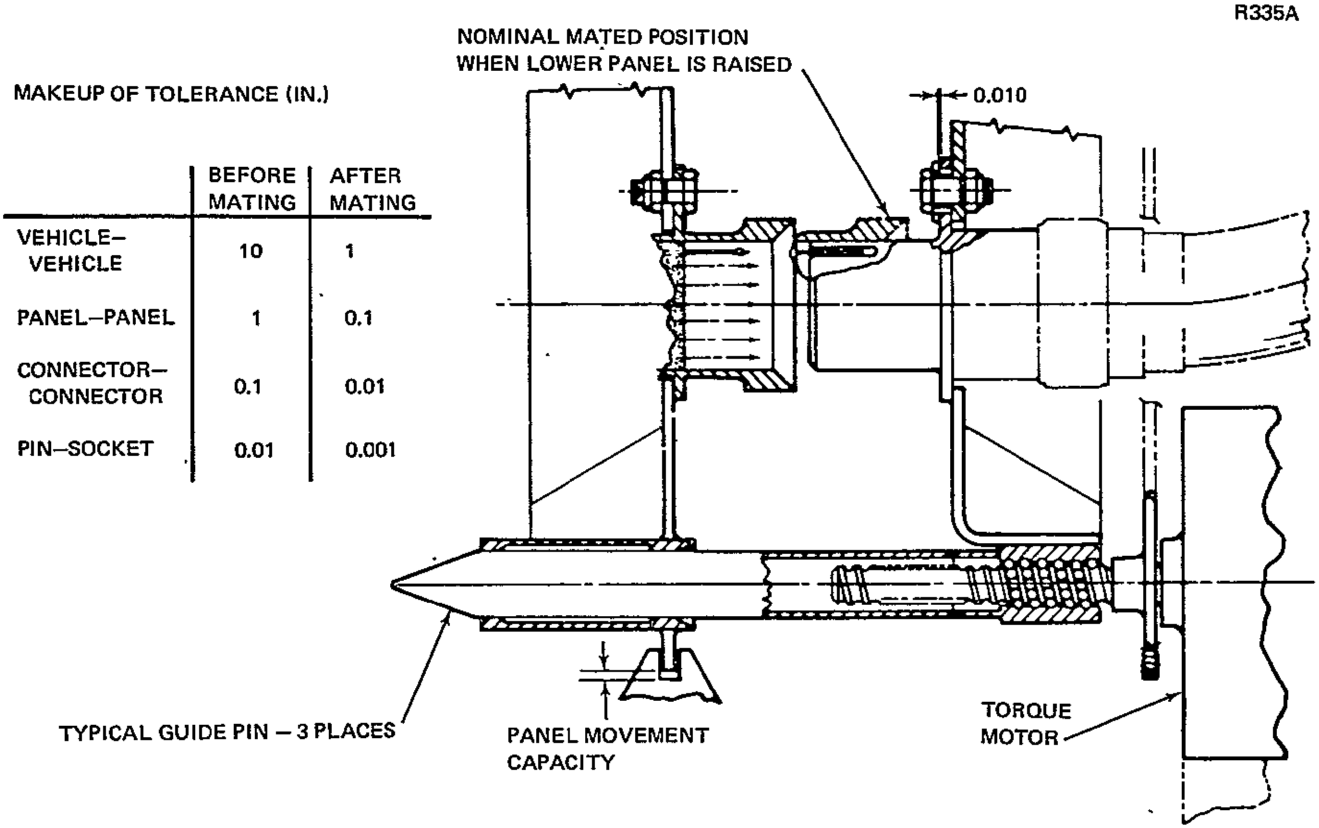


Figure 6-7.. Blind Mating Connector Plate



MAKEUP OF TOLERANCE (IN.)

	BEFORE MATING	AFTER MATING
VEHICLE–VEHICLE	10	1
PANEL–PANEL	1	0.1
CONNECTOR–CONNECTOR	0.1	0.01
PIN–SOCKET	0.01	0.001

Figure 6-8. Automatic Connect-Disconnect Mechanism

guide pins. Ball bearing screw jacks, chain driven via electric or pneumatic motors, raise the lower panel to the first engage position. This aligns the connectors with their mating holes to within pin engagement tolerances without actually engaging the pins. Position-switch talkback is obtained before the final pin-engagement stroke is initiated. This prevents pin binding and ensures reliable mating and demating. Table 6-3 summarizes design system tolerances.

Table 6-3

MAKEUP OF TOLERANCE (in.)

	Before Mating	After Mating
Vehicle - Vehicle	10.0	1.0
Panel - Panel	1.0	0.1
Connector - Connector	0.1	0.01
Pin - Socket	0.01	0.001

Figure 6-9 shows a plan view of the deployable electrical panel configurations. In the design shown, a pressurization line is integrated on the same panel as the electrical connectors. In the RNS vehicle configurations only two fluid lines cross the interface plane; namely, the propellant feed duct and the pressurization duct. Integration of the pressurization duct, which is a relatively small diameter duct, on the electrical deployment panel will greatly reduce additional deployment requirements. This figure gives the general arrangement of the electrical and the pressurization functions and their position on the panel.

6.7 FEEDTHROUGH ON PROPELLANT MODULES

Figure 6-10 shows two concepts for electrical feedthroughs into hydrogen tankage. Feedthroughs of this type are required for both liquid level sensors and other tank internal cabling. In both concepts glass sealed electrical feedthroughs are used. Both concepts utilize a dual static seal where the connector is bolted to the face plate. The face plate in these configurations would contain a cluster of connectors depending on the requirements. The

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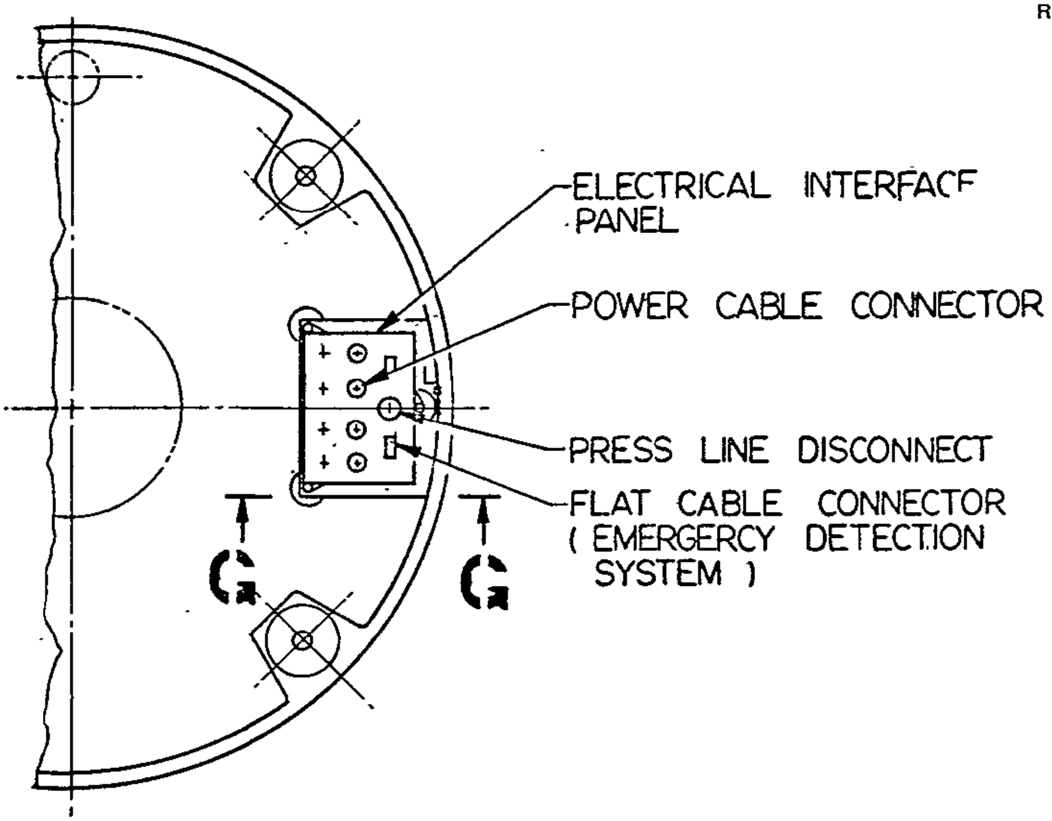
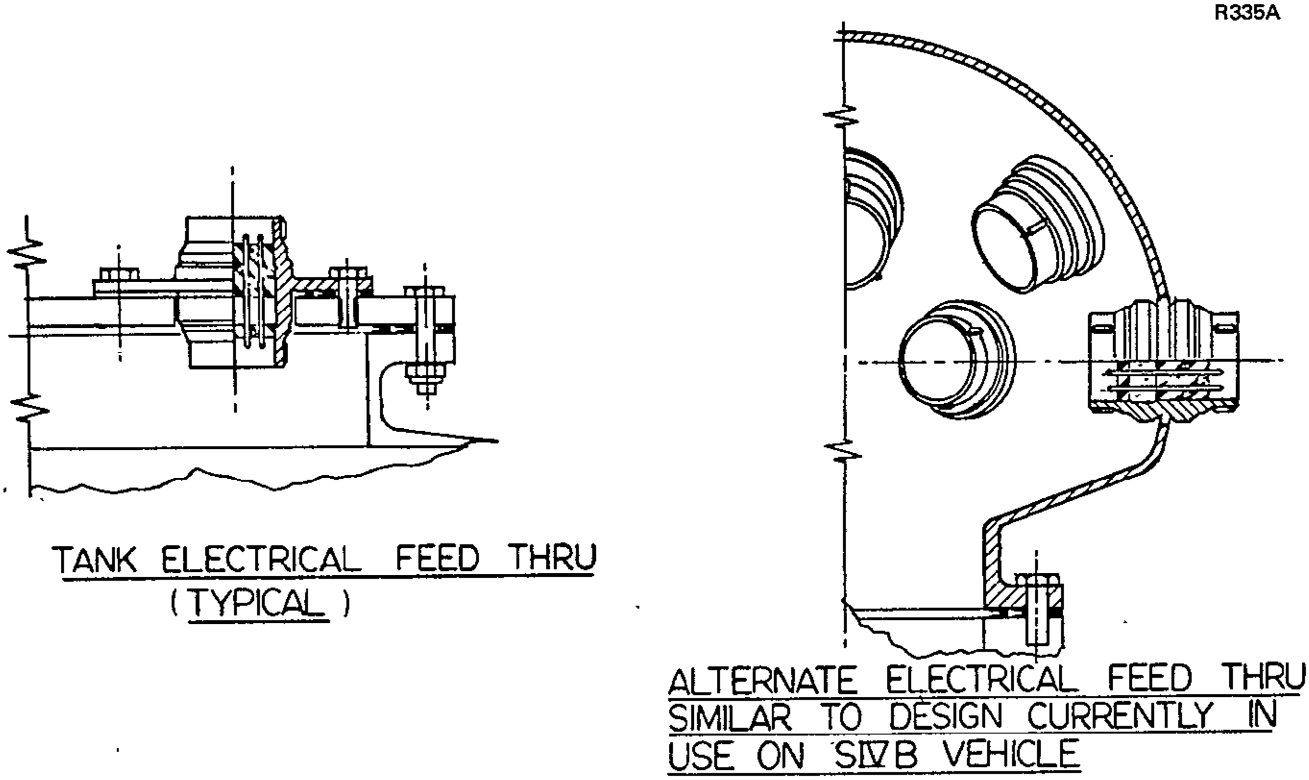


Figure 6-9. Blind Mating Connector Panel Location



TANK ELECTRICAL FEED THRU (TYPICAL)

ALTERNATE ELECTRICAL FEED THRU SIMILAR TO DESIGN CURRENTLY IN USE ON SIVB VEHICLE

Figure 6-10. Tank Electrical Feedthrough Configurations

plate itself would then be bolted into a single port in the tank again using the baseline dual static seal design. The upper portion of the figure depicts a flat plate design. Should the number of connectors be in excess of the space limitations in a flat plate design of this type various spherical configurations could be used. One such is shown in the lower portion of this figure. This type of design would limit the tank diameter penetration and provide the additional space required. A spherical configuration of this type was used on the Saturn S-IVB. The spherical configuration has the same capability as the flat plate design; namely, that of being able to remove each connector independently via the static seal concept. The examples shown utilize round conventional cable connectors. The design is directly applicable to a flat cable installation by configuring the type of connectors.

6.8 INBOARD PROFILES WITH CABLING LAYUP

The inboard profile drawings for the Class 1, Class 3 and Class 1 H vehicles are shown in Figures 6-11, 6-12, and 6-13 respectively. These drawings show the general cable routing, the location of the electrical panels at the interfaces, and the flat and round cable wire supporting techniques used. The NERVA engine shown on the Class 1 hybrid and Class 3 vehicles is the latest NERVA configuration; namely, the outboard pump-mounting arrangement, the upper thrust structure parting plane, and the externally located PSOV shutoff valves.

This configuration differs from that shown on the Class 1 inboard profile as the earlier NERVA engine configuration did not reflect the requirement for inflight maintenance. The early configuration shrouds all the equipment located above the biological shield; namely, the pumps, shutoff valves, and related control valving. The updated configuration with the outboard pump spacing permits manipulator access to all the related equipment above the shield. Cable routing from the engine to the stage across the gimbal plane is shown in one continuous run in all three configurations.

6.8.1 Class 1 RNS

Figure 6-11 is an inboard profile drawing of the Class 1 vehicle. The general cable arrangement mounting and routing is shown. Both round and flat wire cabling cross the engine to stage interface. This cabling is run to the aft umbilical interface which primarily serves for ground and prelaunch functions only. Additional cabling is routed external of the aft skirt through a tunnel running the length of the vehicle to the forward skirt region. The forward portion contains the docking adapter for the payload, and located in this region is an automatic electrical connect panel. This panel serves as the interface between the payload, command and control module, and propellant tank.

6.8.2 Class 1-H RNS

Figure 6-12 is an inboard profile drawing of the Class 1 hybrid. This drawing shows the baseline propulsion module, the remote interface between the propulsion module and the 33-ft diameter baseline propellant tank. Cable routing from the propulsion module run tank to the NERVA engine is covered in Subsection 6.4. Flat cabling distribution is shown from the engine upper thrust structure to the bottom of the run tank, along the run tank tunnel configuration, and up to an electrical interface panel. The interface panel is located at the docking interface between the propulsion module and the propellant module. From this point cable is routed along the external surface of the conical tank bottom. It proceeds to penetrate the heat block and then runs external to the vehicle in a faired tunnel to the forward portion of the stage. The forward portion of the propellant tank contains a payload adapter with the required docking provisions, and at this interface, which is the command and control module interface, a second automatic electrical deployment panel is located. Tunnel routing cables emanate to this panel.

Figure 6-13 is an inboard profile drawing of the Class 3 RNS. This modular vehicle contains the propulsion module, eight propellant modules, and the command and control module. The baseline NERVA engine to run tank cabling interface is shown. From this point flat cable is routed via external tunnel configurations to the respective interfaces. At each interface the baseline automatic electrical panel is utilized. The philosophy for routing and supporting cabling is similar to that used on the Class 1 vehicle and the Class 1 hybrid vehicle. The tunnel routing configuration shown is the alternate tunnel configuration described in Subsection 6-5. The flush tunnel configuration permits the space shuttle 15- by 60-ft envelope constraint to be met.

6.8.3 Command and Control Module Inboard

Figure 6-14 is an inboard profile drawing of the command and control module. The command and control unit is basically a 15-ft-diameter unit being capable of an EOS launch. The unit shown contains outriggers which support the APS nozzles to prevent plume impingement on the Class 1 hybrid propellant module. For the Class 3 command and control module, the ratio of diameters does not require the addition of an outrigger configuration.

The unit shown contains the cryogenic auxiliary propulsion system and a storage system for fuel cell reactants. Various concepts for integration of these reactant storage systems are presently being investigated. The left hand plan view on this drawing shows the conventional probe/drogue docking system which is used to dock the command and control module to the parent vehicle. The location of the baseline deployable electrical interface panel is also shown. Electrical and mechanical equipment are peripherally mounted on the circumference of the module. A 12-inch-diameter feedthrough duct runs from interface to interface to permit refueling with the command and control module in place. Also shown is a deployable antenna. The right hand view of the command and control module depicts general equipment placing of both the electronics and reactant storage spheres. Flat cable routings are shown to the various black boxes, and the upper section shows the general supporting clamp that is used with the flat cable installation. This general cable routing concept and mounting design is typical for any electronics required in the forward skirt region of any of the propellant modules.

Section 7

RESEARCH AND DEVELOPMENT REQUIREMENTS

The results of this study are directly applicable to the ongoing RNS studies. While no further general cable and connector study is recommended, specific areas of investigation and development that derive from reusable or space-resident weight or reliability requirements should be considered.

7.1 RNS-PECULIAR REQUIREMENTS

7.1.1 Improved Insulation System

Further Development and evaluation of proposed radiation-tolerant insulation systems, both inorganic and organic, should be made. Test results of sample cables should be tabulated for their electrical, mechanical, and radiation resistance properties. Tests should be made as required to complete the data required for proper evaluation and selection for the RNS. The organic all-polyimide or polyimide with alternate binders should be investigated for the flexible silico-ceramics, and substitute ceramic approaches for the MgO with stainless sheath are among those systems which should be evaluated.

7.1.2 Automatic Blind Mating Connector Systems

This connector system will be required at a number of places for mating and unmating in flight. Development of full-scale hardware, which represents the maximum size blind-mating requirement for RNS, should be initiated. Electrical connectors, available production or prototype, should be included with all accessory hardware to thoroughly evaluate the selected automatic blind-mating connector system. This is a critical part of the RNS cabling system.

7.2 GENERAL SPACE RESIDENT AND REUSABLE REQUIREMENTS

7.2.1 Permanent Junction Study

The use of permanent junctions offers many advantages in reliability, space, weight, and cost. There are a number of single-termination permanent-junction systems currently available for high reliability applications. However, multi- or layer-permanent junction systems will be required for the RNS. A study should be performed to define, develop and evaluate suitable permanent layer terminations.

7.2.2 Connectorless Termination Study

Terminations between modules and to electronic units that must be connected and disconnected for testing, installation, and maintenance can be greatly improved by the use of high-pressure, gas-sealed, multicontact, connectorless terminations. A study should be performed to define, develop, and evaluate suitable connectorless termination systems.

7.2.3 Electrical Distributor Study

The need for a method to provide reliable and efficient initial pin assignments and subsequent pin assignment changes for parallel conductor systems has been clearly defined in Subsection 6.3.7.

The development and evaluation of a distribution concepts would potentially take the form shown in Figure 5-10.

7.2.4 Aluminum Cables

A study should be made of all existing and proposed aluminum cable systems. This should include copper-clad aluminum plus other high-strength aluminum-alloy conductors. All cable types—RWC, FCC, and ribbon cable—should be included in the study. Termination methods for the aluminum conductors should be given special consideration. Advantages of aluminum conductors include major weight reductions and fusable conductors that will melt and open on overload without rupturing their insulation or that of adjacent conductors.

7.2.5 Reliability Versus Flexibility

A continual tradeoff between reliability and flexibility seems necessary in the selection of cabling concepts. Space-resident or reusable hardware demands for reliability could result in operational inflexibility with developed hardware.

Different approaches should be evaluated and the system selected for optimum flexibility and reliability with minimum weight and space requirements. This should include the achievement of circuit function flexibility, which could be provided by point-to-point wire harnesses or the use of parallel conductor harnesses with circuit change devices.

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