NASA Contractor Report 159272

Space Platform Utilities Distribution Study

A. E. LeFever

ROCKWELL INTERNATIONAL CORPORATION
SPACE OPERATIONS AND SATELLITE SYSTEMS DIVISION
DOWNEY, CALIFORNIA 90241

CONTRACT NAS1-15322-TASK 10
JULY 1980

National Aeronautics and
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FOREWORD

This report, Space Platform Utilities Distribution Study, is submitted by Rockwell International Corporation, Satellite Systems Division, to NASA/Langley Research Center, as required by Contract NAS1-15322, Task 10.0, dated June 29, 1979.

The program was conducted under the direction of Mr. E. Katz, Project Manager of Large Space Structural Systems and Mr. A. N. Lillenas, Project Engineer.

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1.0 INTRODUCTION

The development of large space systems is dependent on assessment of technology requirements, especially those where consideration of the unique environment and logistics of space demands new and different approaches from those characteristically used on the earth. In the area of utilities distribution the installation, attachment, and component elements used to distribute the utilities require study to identify the need for development of advanced technology for cost-effective, Shuttle-compatible, large area space systems that can be assembled or deployed in orbit to perform missions in the 1985 to 2000 time frame.

This study was conducted as Task 10.0 of Contract NAS1-15322, Concepts and Requirements for Space Platform Utilities Distribution Systems. It is directed to generating generic concepts for the installation of power, data, and thermal/fluid distribution lines and connections; analyzing the impact of inclusion of fiber optics for data transmission; analyzing the impact of high voltage versus low voltage for distribution of power; and identifying areas of technology which would require development to implement the design and construction of space systems to perform those missions.

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2.0 SUMMARY

Three baseline space platforms, erectable platform P-1, Rockwell International study (Reference 1), and deployable platforms A/B and H, McDonnell Douglas study (Reference 2), were selected as configurations around which the utility distribution systems were designed.

The three platforms are documented as to platform structure and distribution systems, in the referenced reports, for electrical power, electric data transmission, and Freon coolant distribution requirements.

The distribution systems are then designed for configuration, hardware, and installation details on a model system definition for each of the baseline platforms. In both the Model P-1 and Model A/B, the proper approach appeared to be ducting to the extent possible from the standpoint of installation and interconnections. The Model H, which could conveniently be prefabricated, lent itself to discrete and separate bundles of power, data, and coolant installed as normal ground-fabricated aerospace equipment.

Techniques for mounting, attachment, compensation of thermal expansion, and line connections are shown. Some line installations to be made remotely by the RMS are detailed as to attachment devices activated by an RMS end effector. In a ducted distribution system it is noted that the distribution layout may be different for the three systems—power, data, and coolant—and some compromise is required for a single integrated ducting layout design.

Generic concepts for implementation of distribution systems and the distribution architecture and routing configurations are characterized. Temperature control possibilities of ducted systems are shown. The effects of integrating portions of distribution line runs and the different generic approaches to compensate for thermal expansion differences between the utility system and the platform system are illustrated. Different methods of mounting distribution lines to the structure are shown with examples of attachment concepts.

Power distribution alternates of high voltage versus low voltage were made. The analysis indicates that line resistance, current, and power loss generally vary proportionally with variations of design input parameters; but the line resistance (number/size of conductors) ratio between high- and low-voltage distribution is the one outstanding consideration, with possibilities of one or two orders of magnitude difference.

The impact of fiber optics on data distribution is discussed. The recognized advantages of fiber optics are higher communication rates and immunity from RFI and crosstalk. Fiber optics are secure from detection and potentially economical in terms of size and weight. There are disadvantages, however, of temperature effects, radiation effects, and lack of a broad range of available components.

The fiber-optics field is highly developmental at the present time, and growth in technology is proceeding at a very rapid rate. The most significant advantage offered by fiber optics is the possibility of generic changes in the methods of data transfer, in the architecture of distribution systems. At the present time, during early development of fibers and accessory components, it is difficult to make any tradeoff with the rather small and simple model systems baselined herein.

From the development of the model platforms, three separate component areas emerged as candidates for future development. The present state of the art of these components does not support the model platform systems.

First is connections, both electrical and fluid, where the general character of initial engagement, final insertion and compatibility with EVA or remote RMS installation is not presently acceptable for on-orbit assembly of utility systems.

Second is an RMS end effector appropriate for handling and installing small hardware items such as regulators, duct sections, and connector plates. This area is recommended as a candidate for a NASA standard configuration development.

Third is a continuous rotary joint with very low fluid leakage rates and rotary couplers for high-data-rate channels not available in present designs.

3.0 STUDY APPROACH

The general objective of the Task 10.0 study was to select concepts and develop requirements for the distribution of utilities (power, data, and thermal) for erectable and deployable space platforms. The general approach for this task was (1) to review several recent space platform concept definitions, (2) analyze and normalize the suggested platform payload utility requirements, (3) determine utility distribution requirements for the selected payload models, (4) analyze selected alternatives for the distribution systems, (5) suggest utility line installation procedures for the model platforms, and (6) recommend technology development requirements to enhance the future applications of utility distribution systems to space platforms.

The three platforms, baselined in Section 4.0, are individually configured with utility distribution systems based on a selection of alternatives that seems appropriate for each platform. These modeled systems are described in Section 5.0. The development process of each configuration is not fully described although some learning factors are enumerated in Section 5.4.

The basic mission features of each platform are maintained, but the baseline descriptions of the platforms are considered as Phase A designs, and changes that permit or enhance the implementation of utilities distribution are made.

The payload manifests are normalized to represent a *class* of utility magnitudes rather than a specific set of experiment parameters (Appendix A). The redefined baseline systems (model platforms) are described in Section 5.0 to illustrate the hardware and configurations required to implement the distributions.

The model systems were then configured for both high-voltage and low-voltage power distribution with the apparent significant difference being the line size of the electrical conductors. An analysis of the alternate approaches was made, and the analysis illustrating cause-and-effect parameters is shown in Section 6.0, along with fiber-optics data distribution considerations.

During the development of the model platforms, generic concepts were considered for the distribution types, utility line configurations, interference and thermal effects, and mounting and attachment techniques. These are detailed in Section 7.0.

From the development of the model platforms, three areas were identified as requiring technological development, more than mere development of design, and possibly bordering on basic research. Those areas represent problems to be solved so that the 1985-2000 time frame platforms can be effectively implemented.

4.0 BASELINE PLATFORMS

4.1 ROCKWELL PLATFORM P-1

The baseline platform is illustrated in Figures 1 and 2. The system consists of a utilities module attached to a pentahedral matrix payload accommodations platform. The platform is constructed in orbit with a series of cylindrical struts, structural unions or joints, utilities distribution cables, and service lines. Payloads are attached to a variety of mounts, pallets, or equipment platforms. The utilities module has four solar electric propulsion (SEP) arrays which will supply an average of 25 kW to the payload platform. Heat dissipation thermal radiators are rigidly mounted to the canister structure that contains the energy.

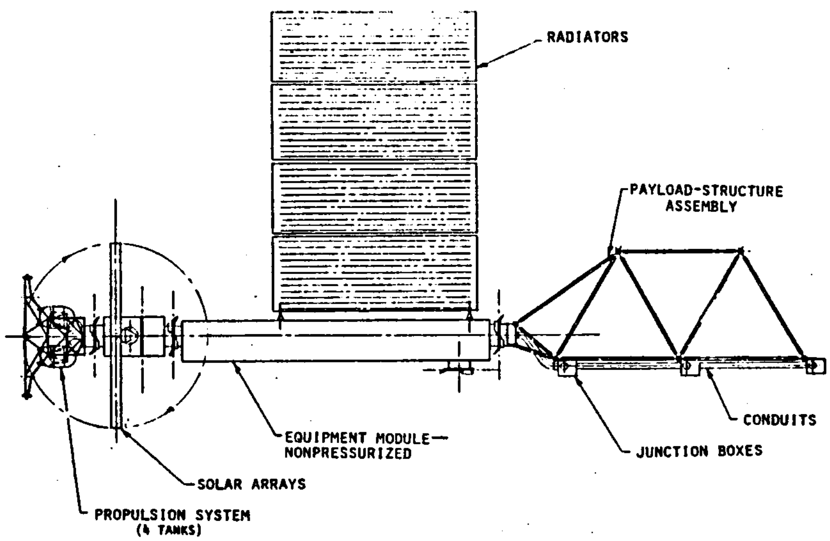


Figure 1. P-1 Platform—Side

The power subsystem is shown in Figure 3. In this concept, each payload interface would be identical and would include primary 28 V dc at 5-kW peak capability, up to 2-kW 28 V dc backup power, and 2-kW maximum 115 V ac power. Regulators are located on the platform to buck HV dc to 28 V dc near the payloads.

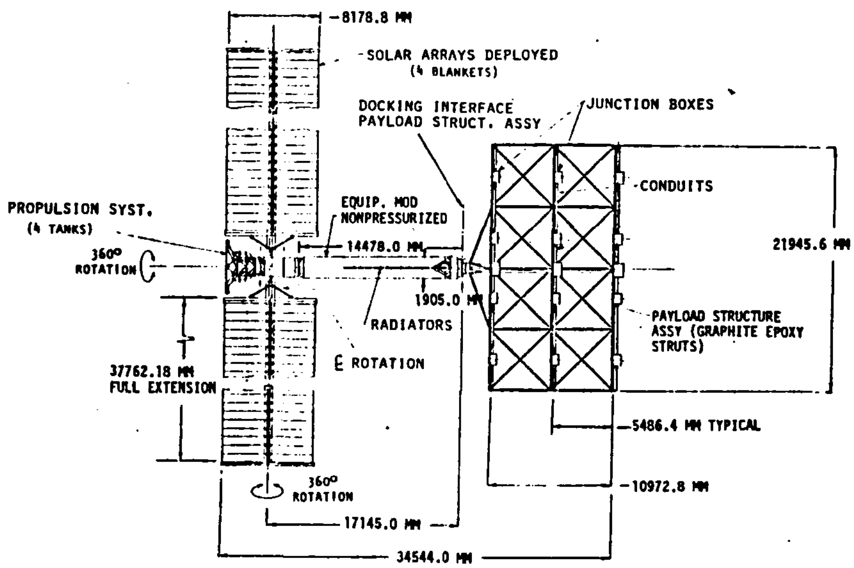


Figure 2. P-1 Platform—Top

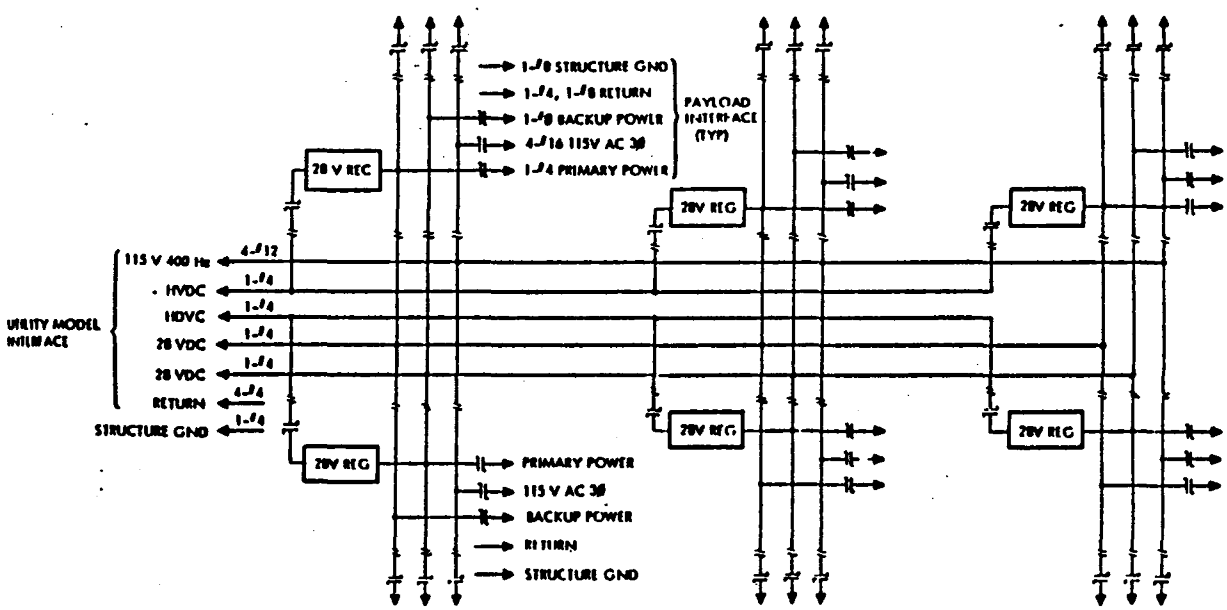


Figure 3. Power Distribution

The thermal control subsystem is shown in Figure 4. It consists of two Freon-21 loops with nonredundant payload interfaces capable of being supplied from either loop. An accumulator is included in each loop and is pressurized to maintain loop pressure above vapor pressure under all operating conditions. The payloads are connected into the loop in parallel and each payload contains a metering valve to limit fluid flow to that required to maintain desired temperature.

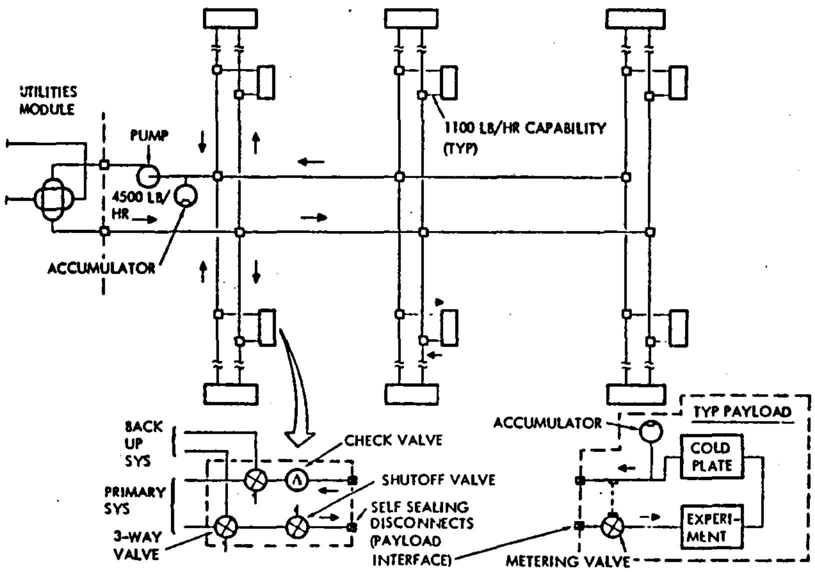


Figure 4. Coolant Distribution

Data distribution is shown in Figure 5. Note the small multiplexer provided at each pallet/experiment interface to reduce the number of wires needed between the experiment and the transmission system on the utility module.

The summary of payload characteristics suggests 27 suitable payloads with the following parameters:

	Minimum	Maximum	Average
• Pallets per payload	0.3	4.0	1.16
• Kilowatts per pallet	0.7	4.5	1.75
• MB data per pallet	0.0001	2.0	0.54

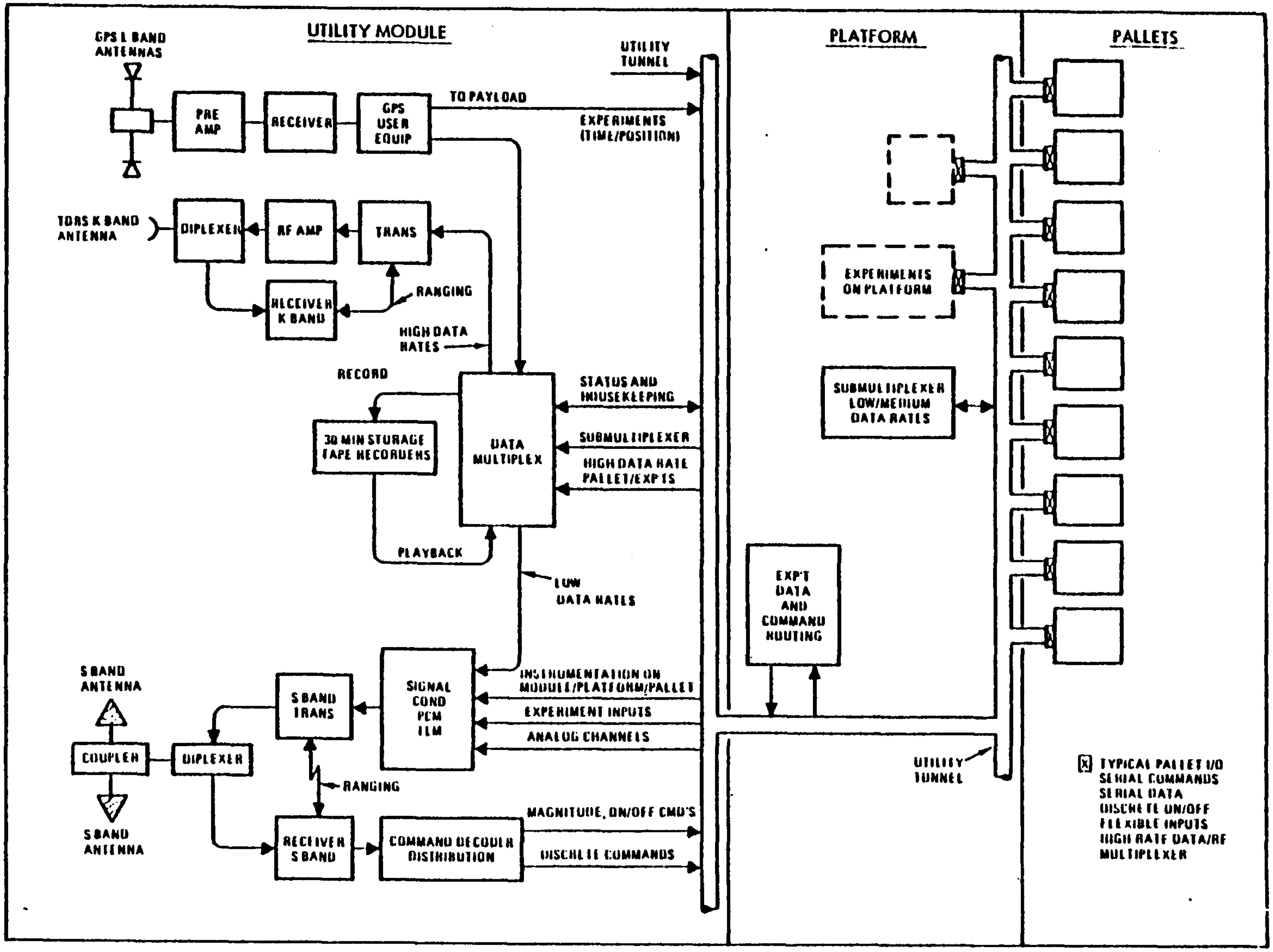


Figure 5. Data Distribution

4.2 MC DONNELL DOUGLAS PLATFORM A/B (MINIMUM 90°)

The baseline platform is illustrated in Figures 6, 7, and 8. The system incorporates two deployable structure platforms joined with a gimbaling/berthing interface mechanism. The deployed structural frame incorporates a central strongback which interfaces with the orbiter berthing adaptor by means of a passive berthing/umbilical interface mechanism. In addition, the central strongback interfaces with additional platforms by means of an active berthing/umbilical interface mechanism. The interface mechanism provides 360-degree rotation, utilizing slip rings to transfer electrical power and rotational swivel joints for fluid transfer. Services to and from the orbiter are routed through the interface umbilical into the strongback and to the appropriate payload or subsystems umbilical.

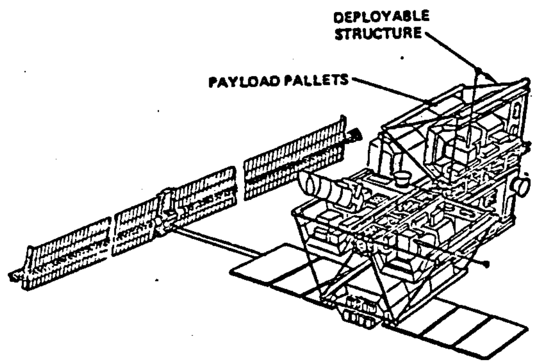


Figure 6. A/B Platform

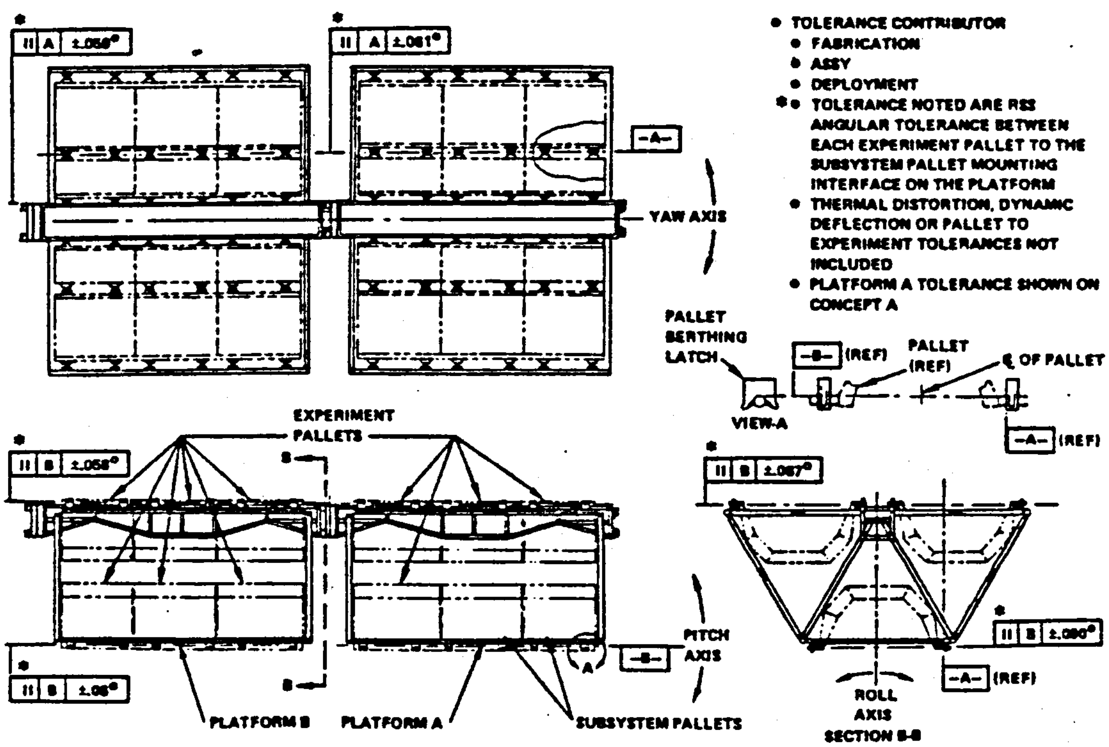


Figure 7. A/B Platform Sections

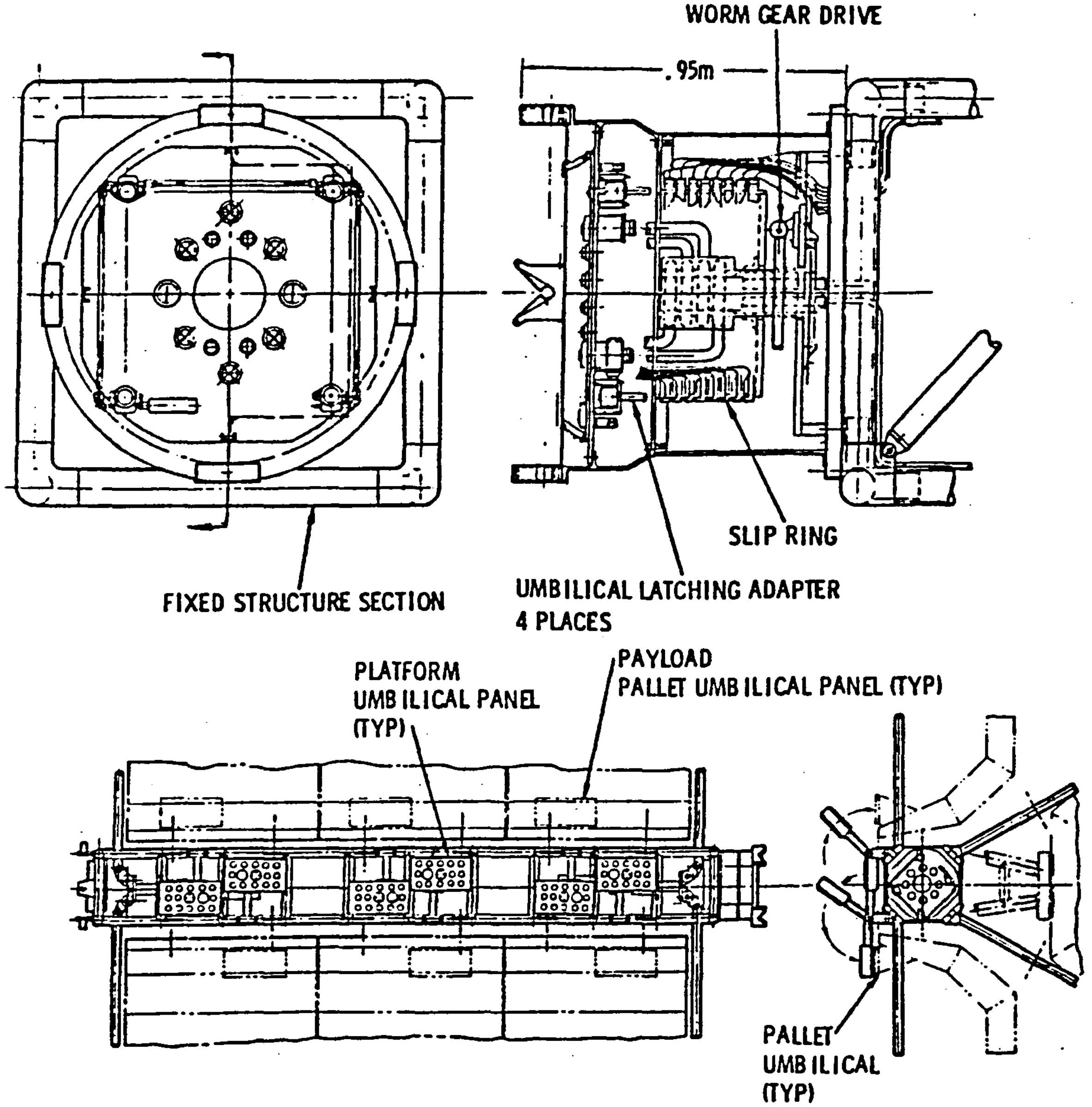


Figure 8. A/B Platform—Details

The power subsystem is shown in Figure 9. The system supplies power to the pallets at high voltage (113 to 168 V) to reduce I^2R losses and/or cable weight. Load switching and regulators are designed as a part of the pallet configuration. ".... Payloads normally use converters and regulators for isolation even when appropriate voltages are available" (Reference 2). The power distribution box is located on the platform structure (central strongback); the umbilical wiring between the platform and the subsystem becomes quite simple; a distribution box of identical design may be provided for the second platform and wiring across the gimbals simplified.

The thermal control subsystem is shown in Figure 10. The distribution system has a temperature control valve at each payload interface that controls the pallet outlet temperature by modulating each pallet flow.

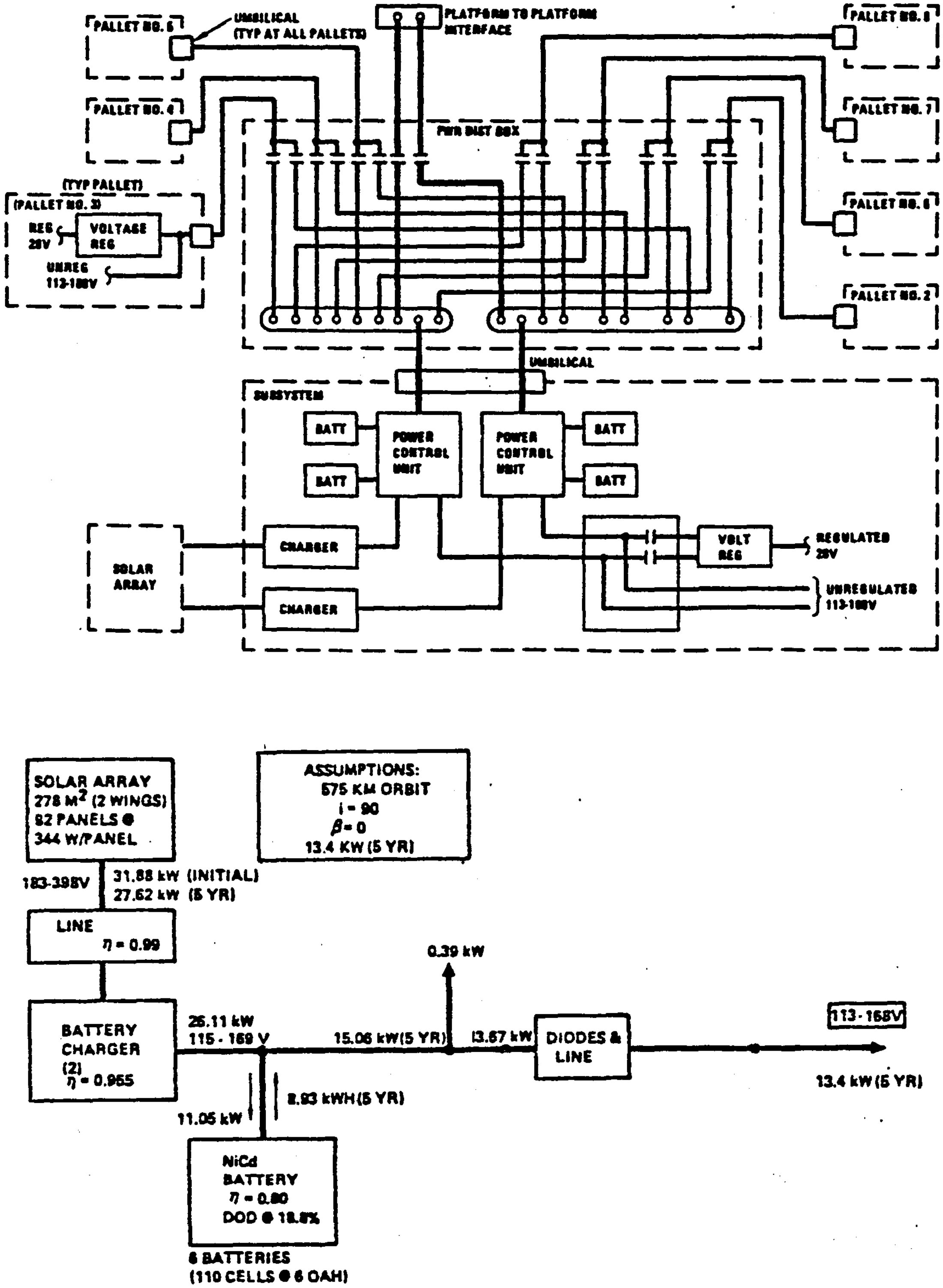
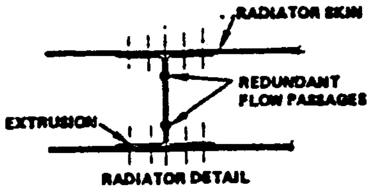
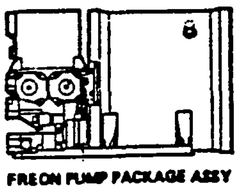


Figure 9. Power Distribution

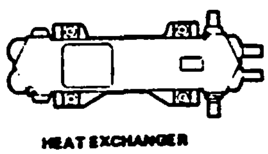
RADIATOR PANELS (NEW)



PUMP PACKAGE (SPACELAB)



PAYLOAD HEAT EXCHANGER (ORBITER)



CHARACTERISTICS

STRUCTURAL AREA = 85.5 M^2 (171 M^2 RADIATOR AREA)

QREJ = 12.22 K WATTS AT 3000 LB/HR FLOWRATE

3000 LB/HR F-21 AT 46 PSID

	SUBSYSTEM COOLANT F21	PAYLOAD COOLANT F21
INLET PRESSURE (PSIA)	150	200
WEIGHT FLOW (LB/HR) (LOOPS)	2077 (2)	2045 (1)
DIFFERENTIAL PRESSURE (PSID)	3.4	5.7

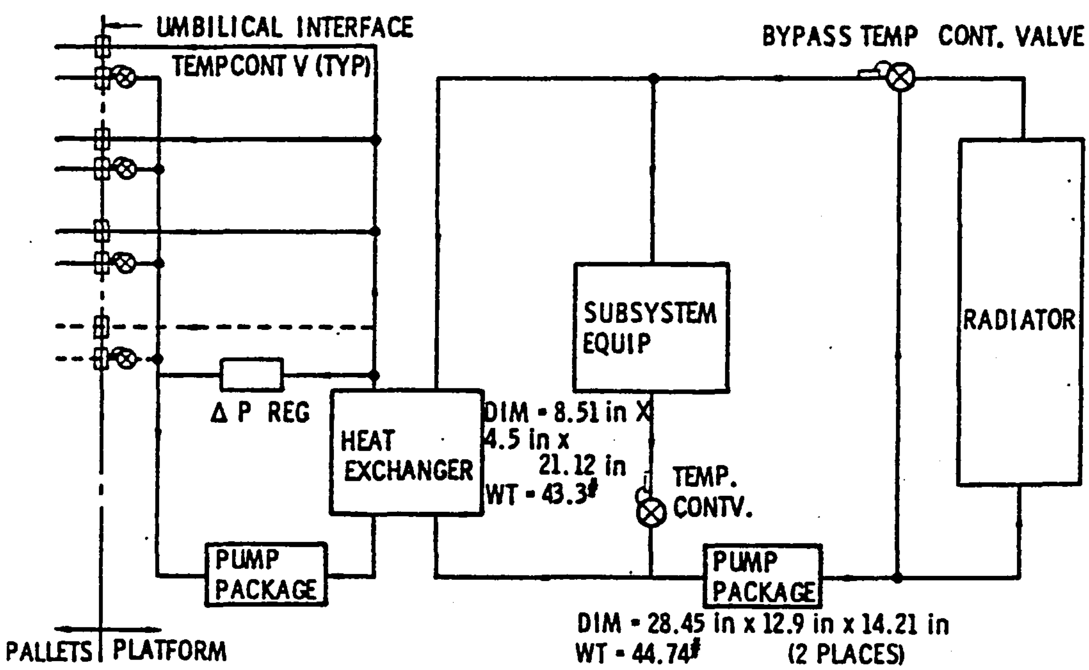


Figure 10. Coolant Distribution

The avionics signal interface with the payload pallets is not specifically detailed.

The summary of payload characteristics suggests 20 suitable payloads with the following parameters:

	Minimum	Maximum	Average
• Pallets per payload	0.3	2.0	1.075
• Kilowatts per pallet	0.03	7.4	1.056
• MB data per pallet	0.001	100	13.972

4.3 MC DONNELL DOUGLAS PLATFORM H

The baseline platform is illustrated in Figures 11 and 12. The platform is comprised of a center strongback which is in three sections—two deployable and one fixed section. There are provisions for 18 berthing ports; 10 gimbaling adaptors are interconnected to the strongback into berthing ports as required.

Power, coolant, and data distribution baselines and the payload summary are the same as for the platform A/B.

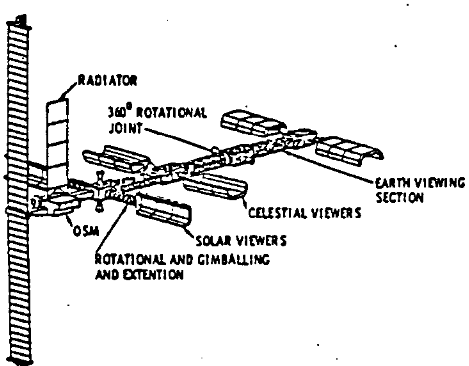


Figure 11. H Platform Configuration

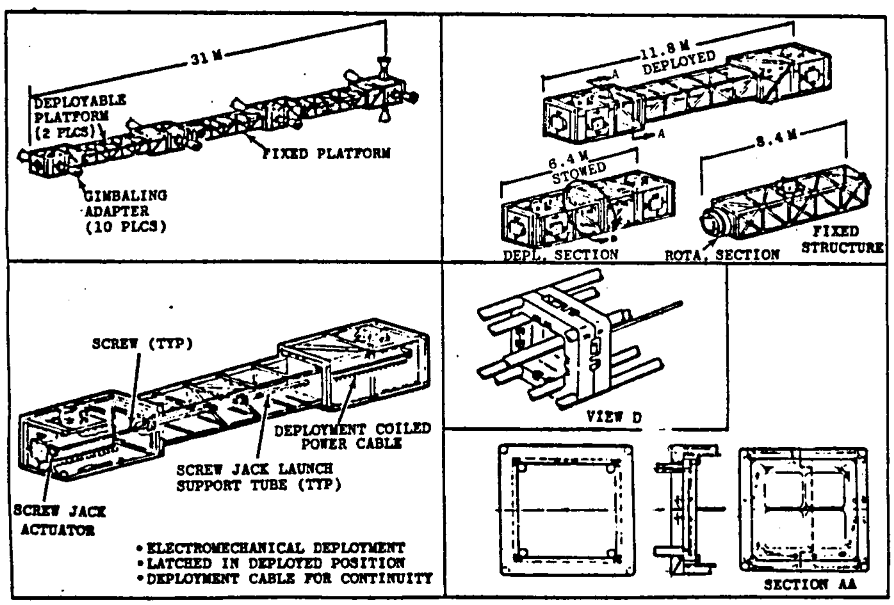


Figure 12. Platform H—Details

5.0 UTILITY DISTRIBUTION MODELS

5.1 MODEL P-1

The P-1 model is shown in Figure 13. The distribution system consists of 10 separate subassemblies which are interconnected during, and as a part of, the installation. When the adjoining subassemblies are installed, the interconnections are automatically made at the physical mounting points. The subassemblies are all pre-wired and laid on as rigid lines by the RMS during the construction phase of the platform.

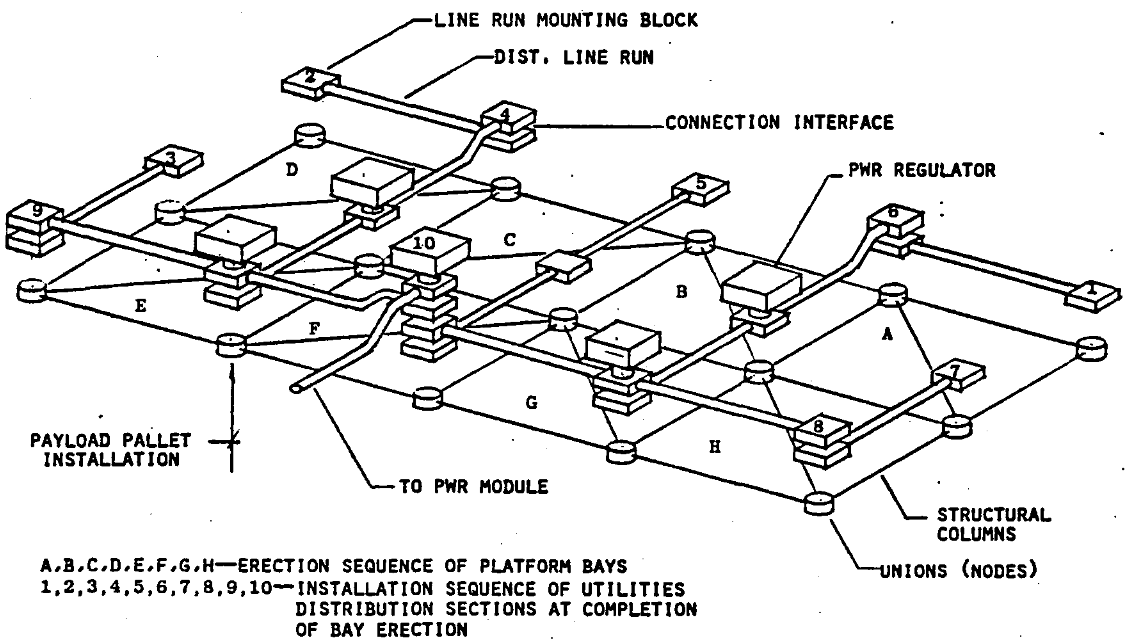


Figure 13. P-1 Model

The system distributes the following utilities:

- *Coolant*—Freon 21, four lines. Primary input, primary return, redundant input and redundant return, 2.54-cm-diameter thin-wall steel tube.
- *Primary Power*—28 V dc, eight No. 4 wires maximum. Regulator output to pallets, and output parallels.
- *High-Voltage DC*—130 V dc, four No. 4 wires source output to regulators.

- *AC Power*—115 V, 400 Hz, 3-phase four No. 12 wires source output to regulators.

- *Data*—RG143 coax, four lines, primary two-line bus, redundant two-line bus.

- *Command and Control*—TSP, four No. 12 TSP lines, primary two-line bus, redundant two-line bus.

- *Chassis Ground*—One No. 4 wire—bus.

The distribution schematics are shown in Figures 14, 15, and 16. As evident on the coolant system schematic, all pallet interfaces are identical (left side of pallet trunnion) so that risers can be uniform for any location or orientation. Branch points are shown where connections are made to the individual pallets. Each branch point feeds power coolant and data. Note that six of the pallets may be oriented in either direction, which requires a slight deviation from the simplest line run layout (seven 2-bay runs) but is probably more realistic.

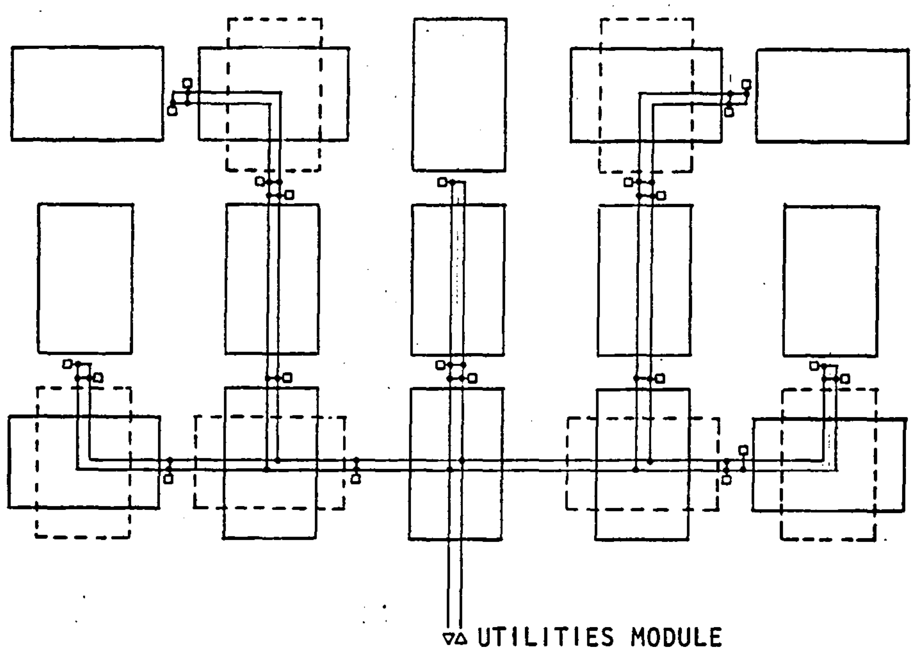


Figure 14. Coolant Schematic

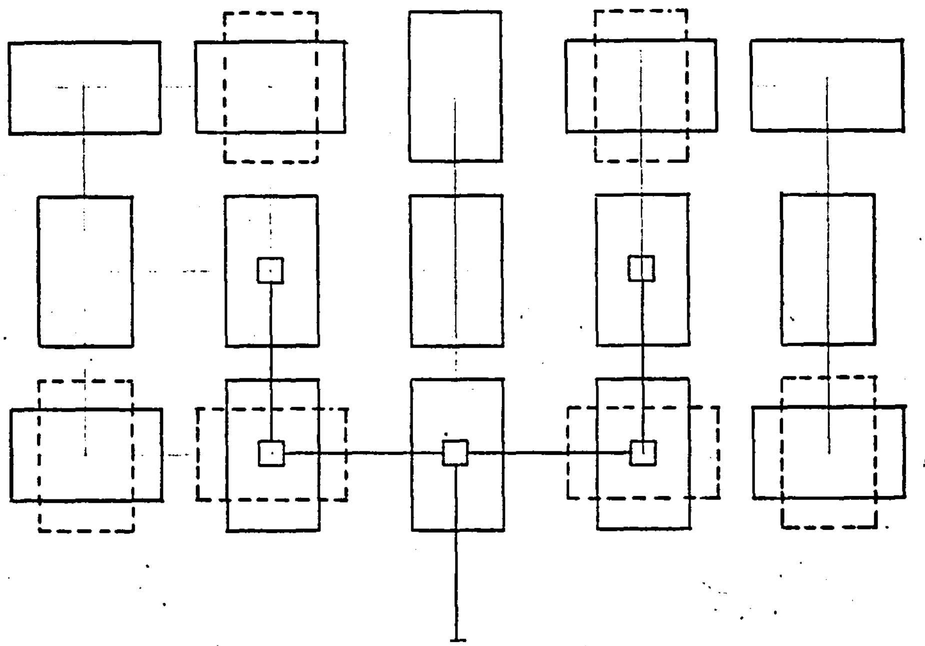


Figure 15. High Voltage Schematic

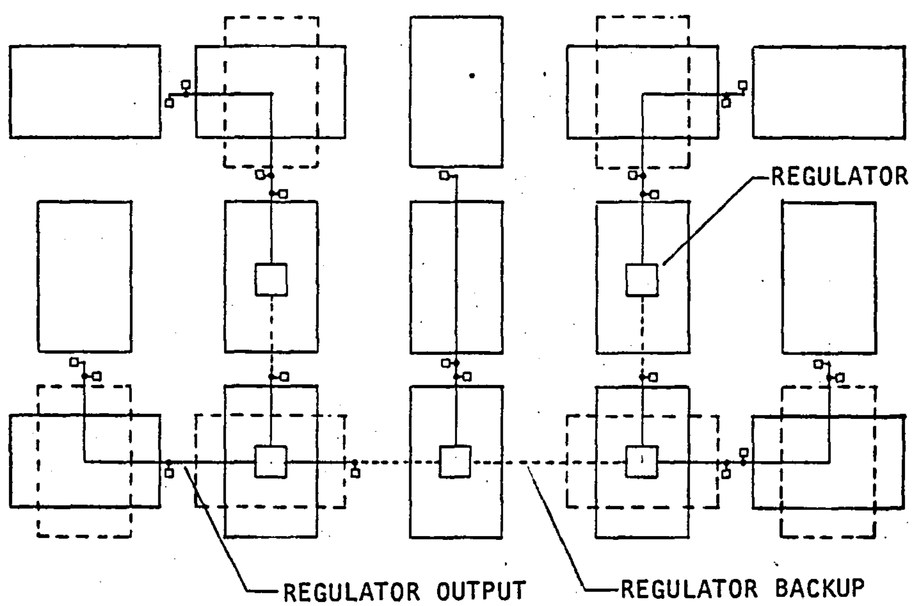


Figure 16. 28 V dc Schematic

The 28 V dc power regulators are each assigned to three pallet locations regardless of orientation. The regulators are also paralleled by the 28-V bus for makeup of power deficiencies, assuming some high-power pallet may be located at any mounting point. Detail analysis is given in Section 6.1.

The high-voltage input power to the regulators is a simple series run to each of the five regulators.

Data lines essentially duplicate the coolant system schematic. Data junctions and amplifiers are located at the mid-run connection plates.

The electrical distribution runs are enclosed in a composite (graphite-epoxy) tray mounted to the backup fluid distribution lines. The tray is for containment only and is not rigidly attached to any structure. The tray is free to expand differentially with respect to the fluid tubing. The tray walls provide EMI shielding between the ac, dc, and data lines. Thermal stability may be provided by selective radiation coatings on the tray sides.

The mounting blocks are all installed to be rigid with the structure, but the utility runs are not. Each line run has a single-point rigid mount. The other one or two points are a linear slip-fit, or a linear expansion mount; see Figure 17. Expansion of the electric lines is accomplished by slack (bends in the lines). Expansion of the fluid lines is by a bellows joint next to the mounting block. Typical configuration is shown in Figure 18.

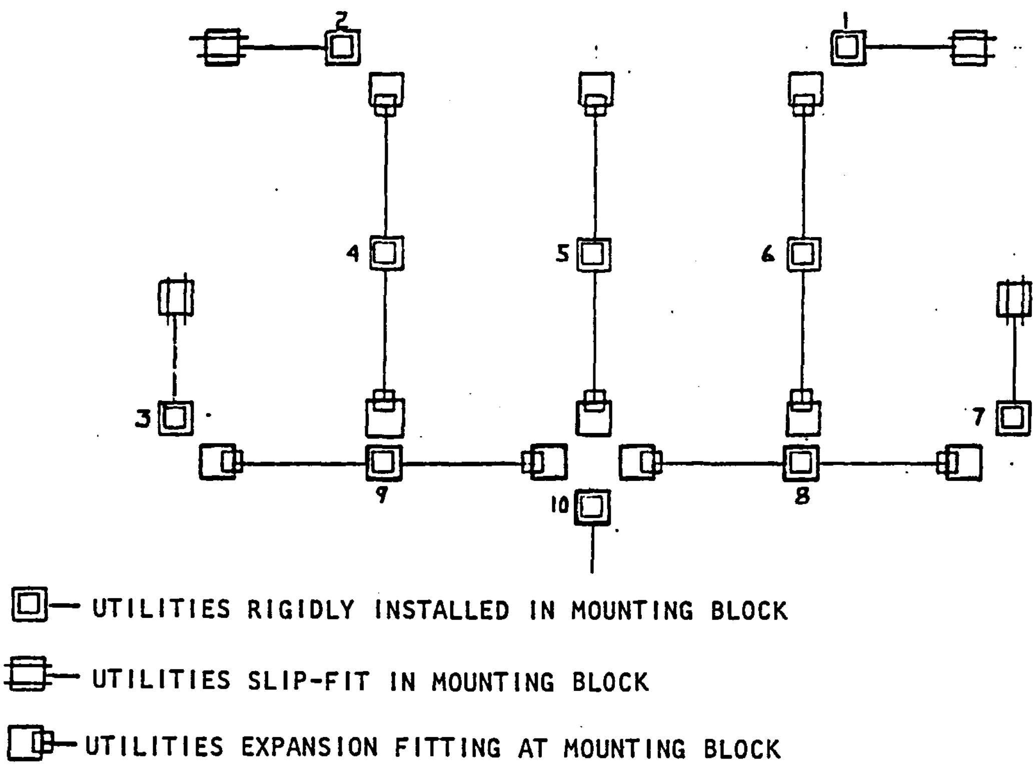


Figure 17. Mounting Configuration

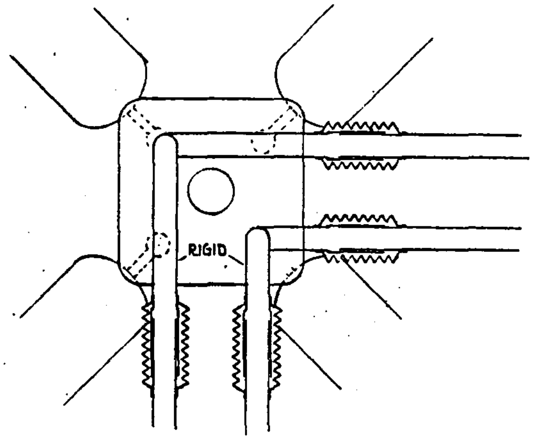


Figure 18. Fluid Expansion Fitting

At each pallet take-off point, a standard interconnect plate is mounted on the line run to accommodate a riser—approximately 3.6 m—to the pallet lip. The riser, identical for all pallet locations, is furnished as a part of the payload (Figure 19). The interconnect plate also serves as a junction box to reduce the eight-wire power bus to a four-wire riser bus.

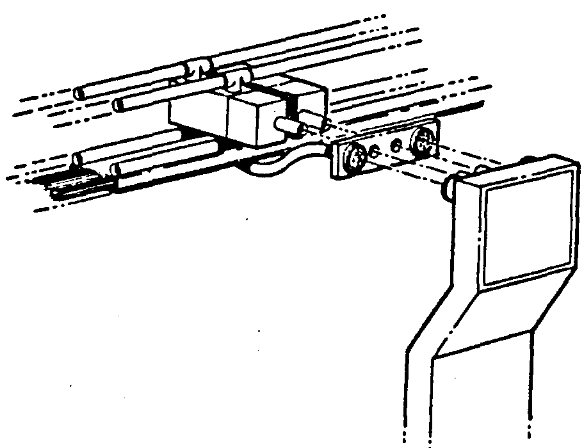


Figure 19. Pallet Riser

5.1.1 Installation

The distribution system is installed during assembly of the platform structure. The platform is assembled one bay at a time. As each bay is assembled in sequence, the corresponding distribution subassembly is installed by the RMS to the underside of the unions. See Figure 20.

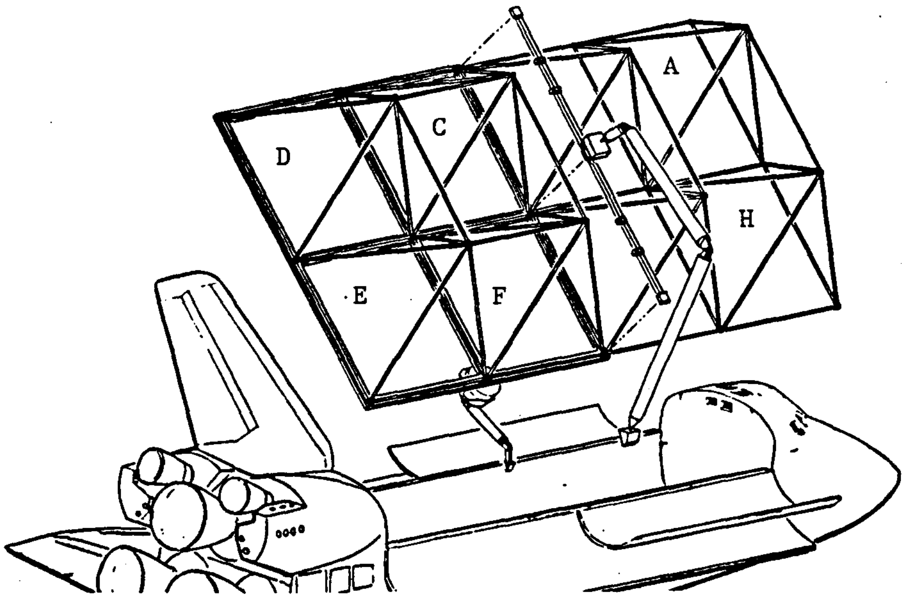


Figure 20. Installation

Subassemblies would in installed in the following schedule:

Completion of Bay No.	Subassembly (Figure 13)
A	1
B	-
C	-
D	2
E	3,4
F	5
G	6
H	7,8,9,10

Intersurface columns for bays A and D are postponed until after installation of subassemblies 1 and 2. Lower surface columns between bays A, B, C, D, and E, F, G, H are postponed until after installation of subassemblies 4, 5, and 6. Subassemblies 8, 9, and 10 have free access after the structure is complete.

Each subassembly would consist of a 5-1/2 meter run with two mounting points, or an 11-meter run with three mounting points. The subassemblies are completely prefabricated and require only structural mounting and connection to form the distribution system. Subassemblies 4, 6, 8, 9, and 10 incorporate preinstalled buck regulators with shunt over-voltage protection.

The utilities lines are laid onto the underside of the structural unions or the underside of a previously installed line. Where the mounting block is accessible to the RMS, the block may be laid on and attached by the RMS end effector; see Figure 21. Where the block is inaccessible (regulators in the way), a self-energizing latching adaptor can be made to mount the line onto the union or previous line.

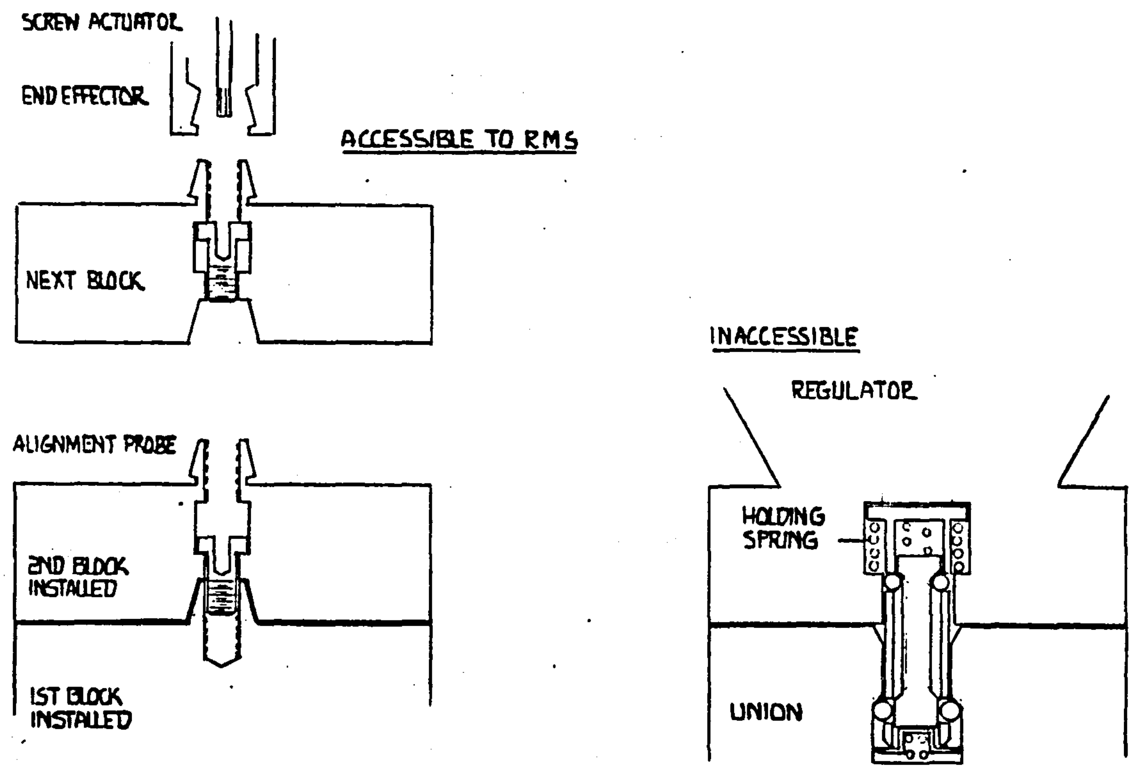


Figure 21. Utilities Block Installation

5.1.2 Configuration

The distribution line runs are configured approximately as shown in Figure 22. The four coolant lines, periodically connected by spacers, form the structure of the runs. The electric lines are encased in a graphite-epoxy tray to provide mounting and RFI shielding (Figure 23). Sufficient space is available so that line junctions can be made inside the tray area. The five separate parts of the line runs may be covered with a thermal coating material (Reference 3) for heat rejection.

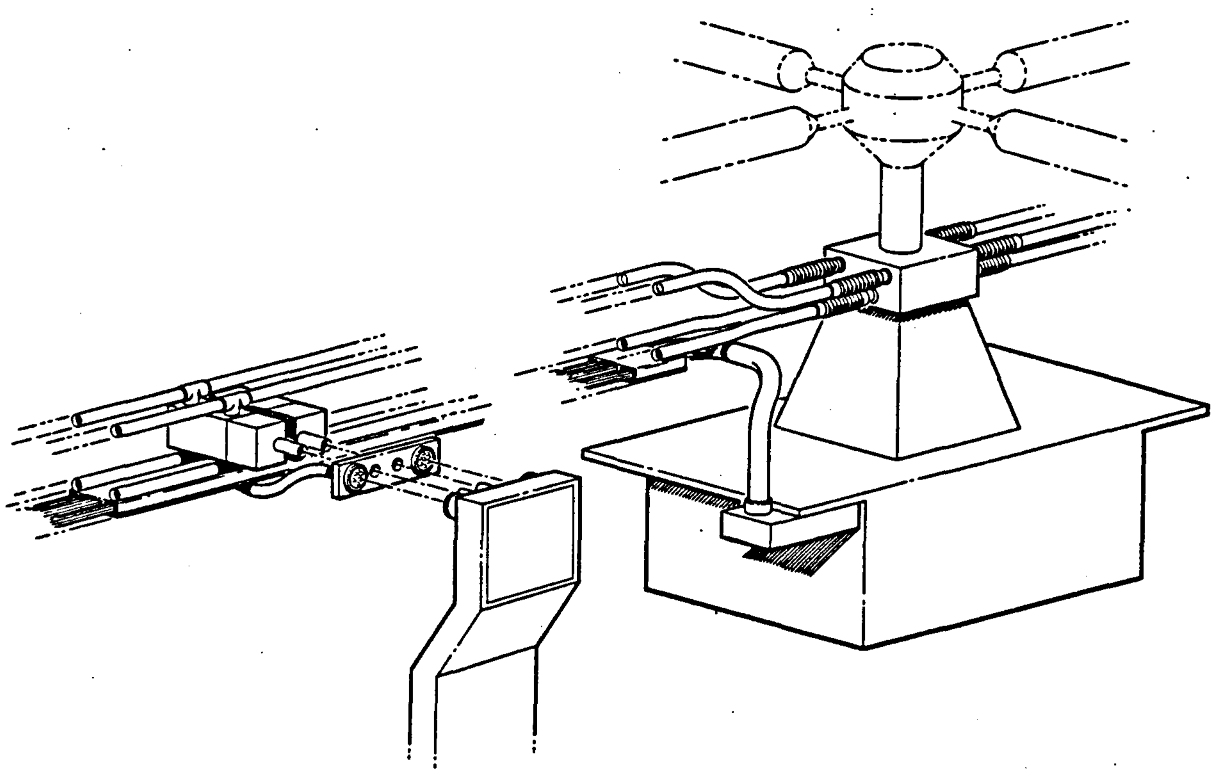


Figure 22. Distribution Line

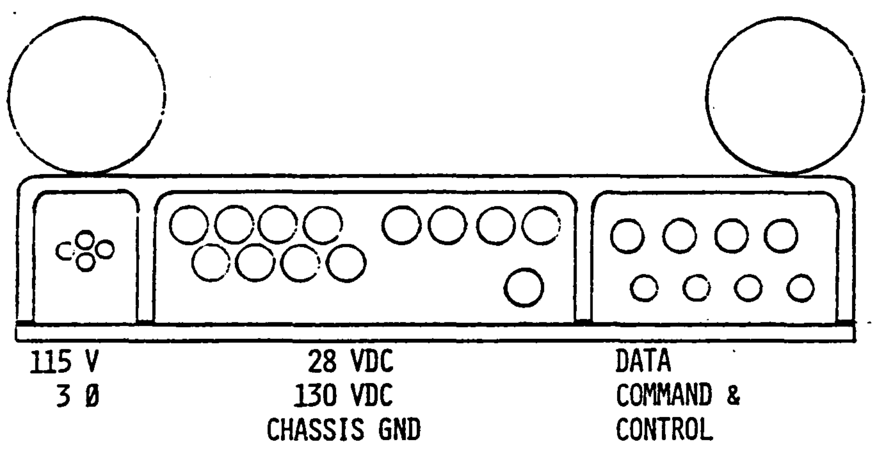


Figure 23. Electrical Distribution Tray

5.2 MODEL A/B

The A/B model distribution elements are shown in Figure 24. The distribution system is entirely prefabricated on the platform structure except for an interconnect bus to be installed after deployment.

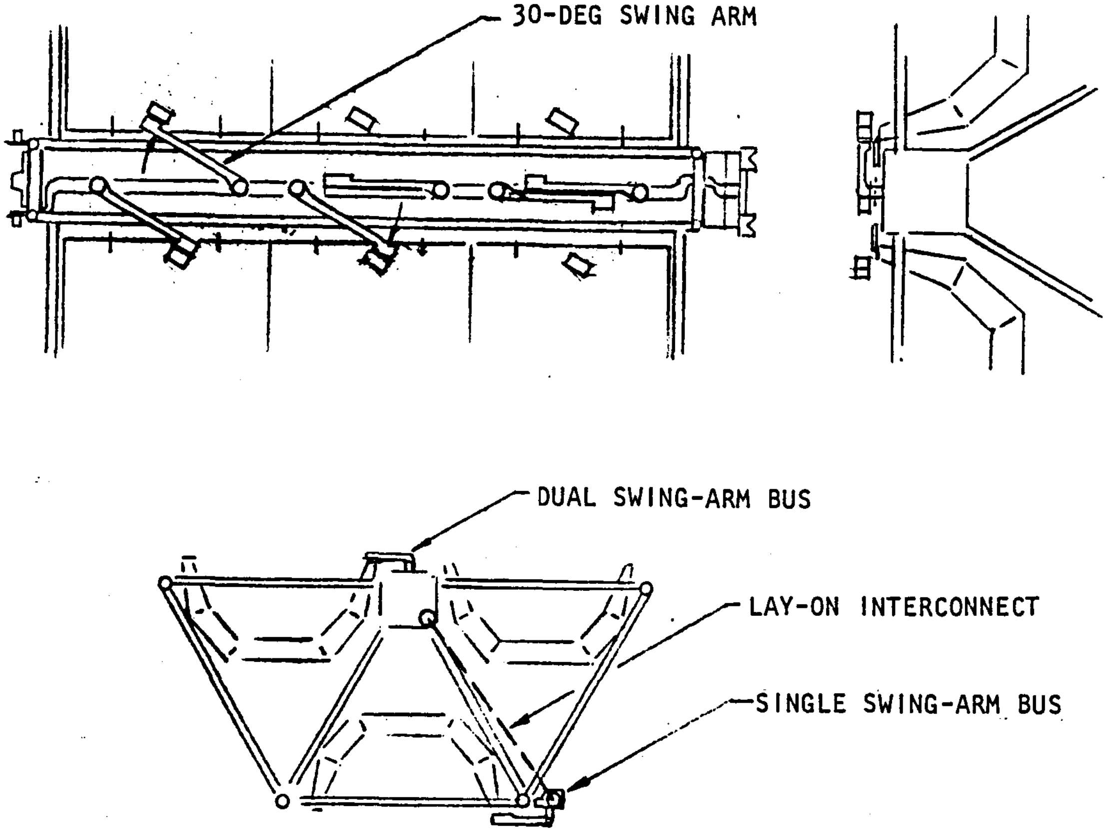


Figure 24. A/B Model

At present, there is no standardized pallet design for deployable pallets, but the design, when it is made, will probably require pallet-to-orbiter interface to be at the level of the orbiter longeron for accessibility—disconnect prior to removal from the cargo bay. An interface at the bottom of the pallet, as shown in the baseline for the three lower-level pallets, would be superfluous.

The platform system, then, is integrated into each strongback, and into one of the lower longitudinal columns of each section with an erectable interconnection between the two longitudinal runs. The two sections are connected by a continous fluid/electric rotary joint.

Branch points to each pallet location are made through vertical-axis swing arms to reduce the excursion to a maximum of 30 degrees. The strongback bus incorporates a dual swing-arm system and the lower bus a single-sided system. Cargo bay stowage would not be impaired by the addition to the lower longitudinal column; see Figure 25.

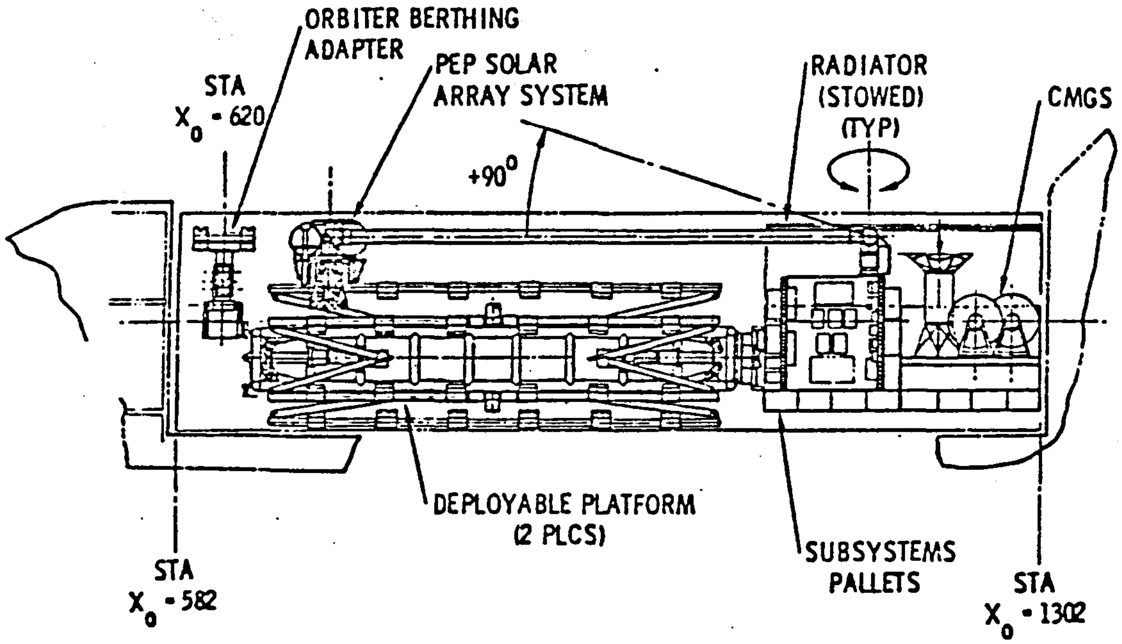


Figure 25. Launch Configuration

Installation of the interconnect bus can be made after deployment, upon a simple 30-degree rotation of the berthing adaptor (Figure 26).

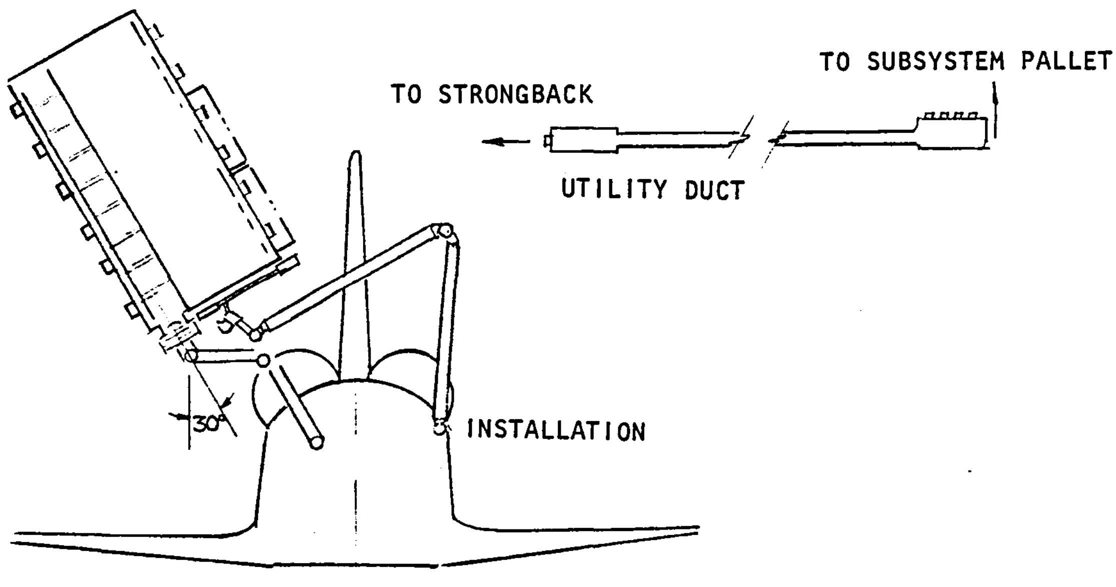


Figure 26. Rotated Installation

The system distributes the following utilities:

- *Coolant*—Freon 21, four lines. Primary input, primary return, redundant input, redundant return, 1.91-cm-diameter thin-wall steel tube.
- *Power*—High-voltage dc, 113 to 168 V, four No. 8 conductors.
- *Bus Data*—Ten No. 20 TSP. Multiplex bus—branch to each pallet.
- *Dedicated Data*—256 No. 20 TSP; 16 dedicated TSP to each pallet.

The system schematic is shown in Figure 27. All systems have essentially the same routing.

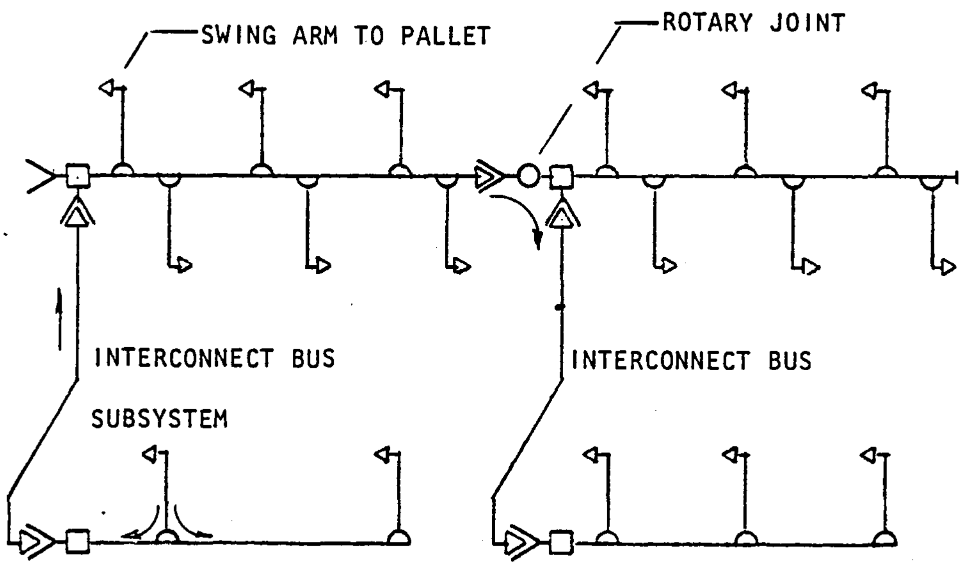


Figure 27. System Schematic

Restricted angular movement would permit the coolant to be routed through flexible hose rather than a rotary joint. Coolant valves and electrical break-out junctions could be a part of the linear run configuration.

The longitudinal line runs, the lay-on interconnect, and the pallet swing arms are all run in a tray (duct) configuration as shown in Figure 28. The swing arms are all configured as shown in Figure 29 to minimize the height of the folded stowage outline and to permit bend of the utilities in a single axis during deployment without twisting. The coolant lines in the bend section are flexible hoses.

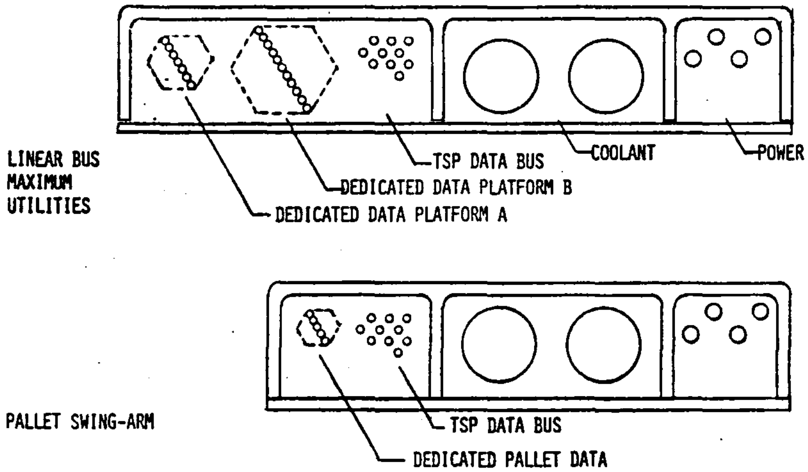


Figure 28. Tray Configuration

The pallet swing arm actuator and the latch actuator are driven on command through power connections from the orbiter bay.

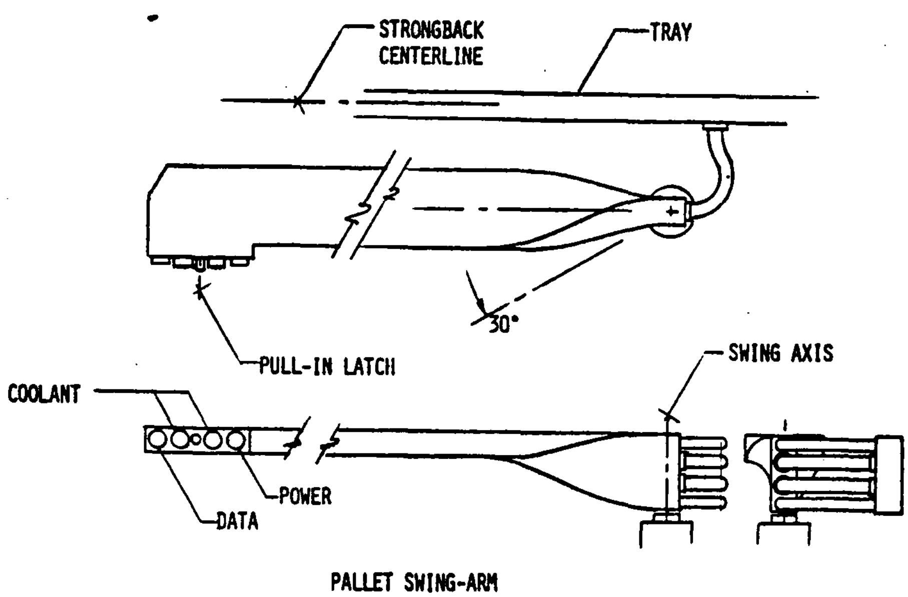


Figure 29. Swing Arm Configuration

5.3 MODEL H

The Model H distribution is preassembled on the three sections of the platform and is, for the most part, statically attached as with conventional spacecraft. The end sections of each of the two deployable platforms contain a distribution box at the point of the platform interface adapter for junctions and branching. All J-box functions can be integrated at these four locations; see Figure 30. All gimbaling adapters are attached to these four end sections to pick up the pallet installations as shown in Figure 12.

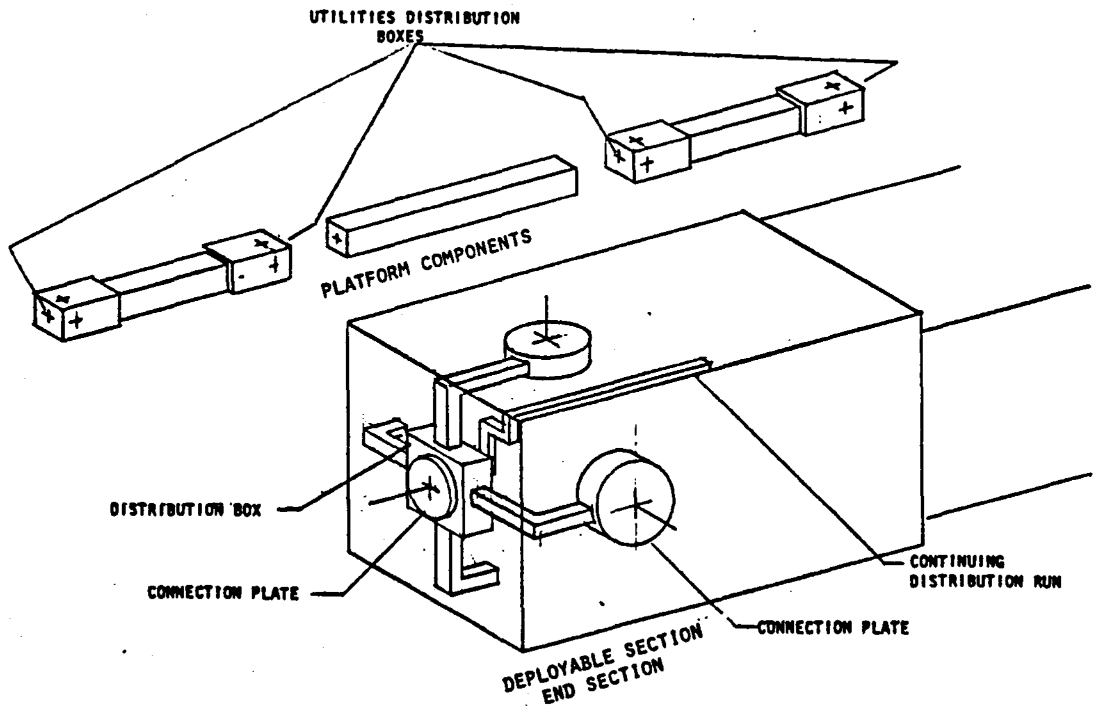


Figure 30. Model H End Sections

The distribution runs between J-boxes and along the fixed center section of the platform are distributed in bundles separated by the width of the structure. Power, data, and coolant are located in separate areas of the cross-section. Wiring bundles include sections of slack between attachment points, and fluid lines have bends or bellows sections with axial slip-fit attachment fittings.

Line run installations along the two deployable sections of the platform are shown in Figure 31. Installation along the center portion is static, and the continuation to the two end portions is made separately between the electric lines and the fluid lines. Electric lines are coiled in the end portions to extend on deployment with a slack length of approximately 2 m (6.6 ft). Fluid lines are installed in three separate segments which are connected together at the end of deployment travel. Bellows in each of the end portions permit the fluid connections to be made, without critically matching the tubing length to the length of the deployed beam.

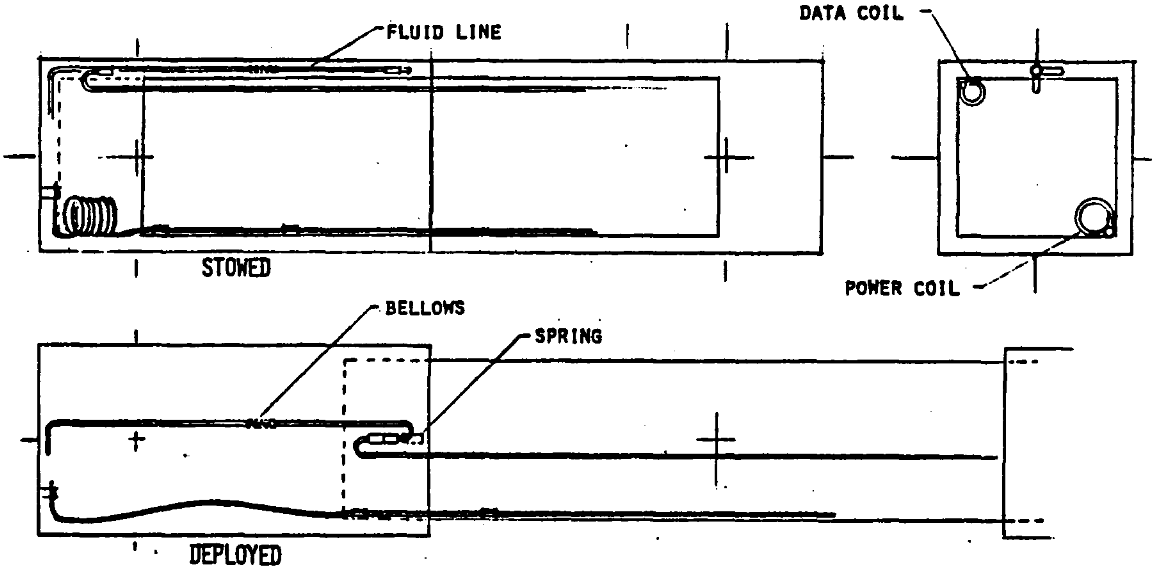


Figure 31. Deployment Connections

The utilities are distributed throughout the platform through various path elements, shown in Figure 32. These include a total of 17 docking connections and 10 gimbaling adapters (rotary joints) for the maximum 14 payload pallets. Note that a standard pallet configuration will incorporate feed-through line runs to service two additional pallets.

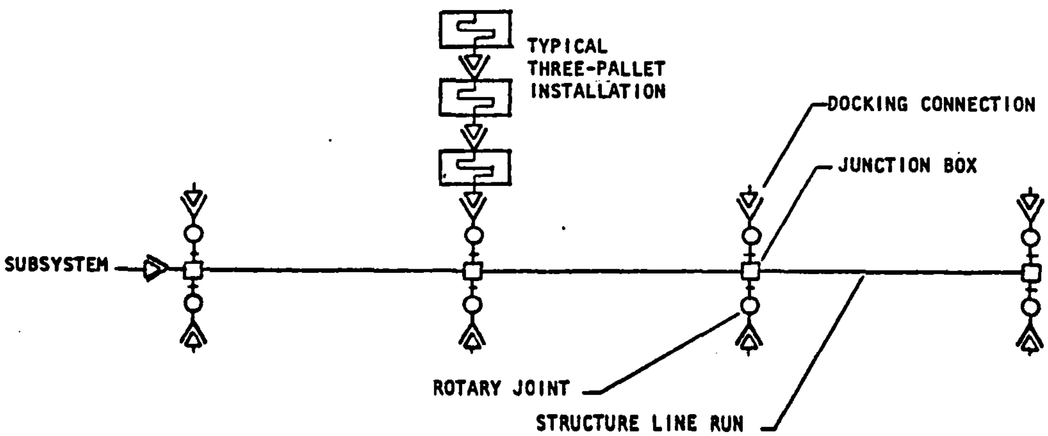
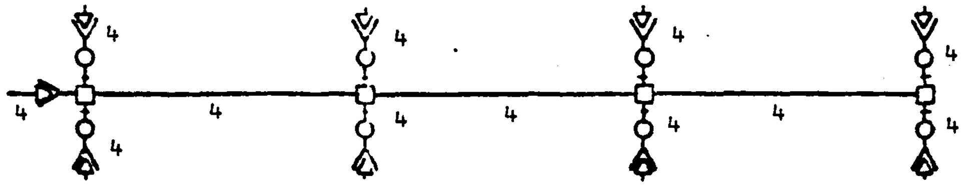
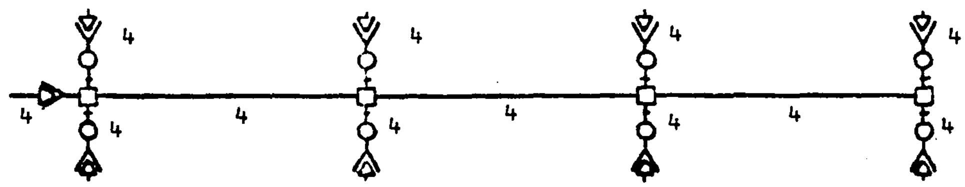


Figure 32. H-Model Distribution Path Elements

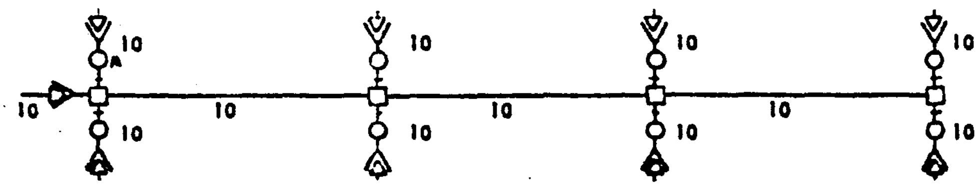
Assuming a maximum of three pallets on one gimbaling adapter with one pallet opposite, the total line quantities shown in Figure 33 indicate a rather large number of data transfers across the rotary joints—174 data slip rings [3 × (10 + 48)].



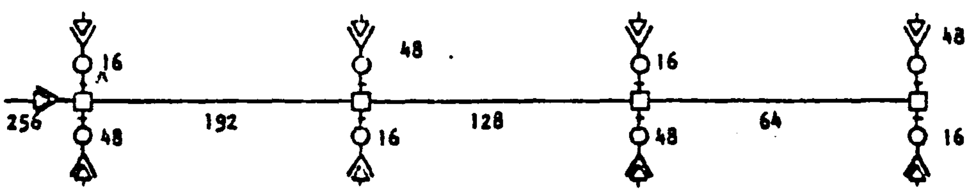
POWER (NO. 8 CONDUCTORS)



COOLANT LINES



BUS DATA (TSP)



DEDICATED DATA (TSP)

Figure 33. Model-H Conductor Quantities

5.4 DEVELOPMENT

Some interesting conclusions were brought out in the development of the P-1 distribution system, the most noteworthy being the interaction of separate requirements of the different utilities and platform constraints.

The initial direction was to follow the duct layout of the baseline description (Figure 34) where tubular ducts were imposed atop the mounting surface of the platform. An attempt was made to configure an offset mounting layout similar to Figure 35 to free the node area for pallet mounting to the top of the unions. The duct mounts to the structure and to other duct sections appeared to be complex and nonuniform. Duct interconnections would be directionally sensitive and highly scheduled. The only plausible alternative was to configure a layout where the distribution would run below the nodes, mounted to the underside of the structural unions and laid onto the underside of the columns.

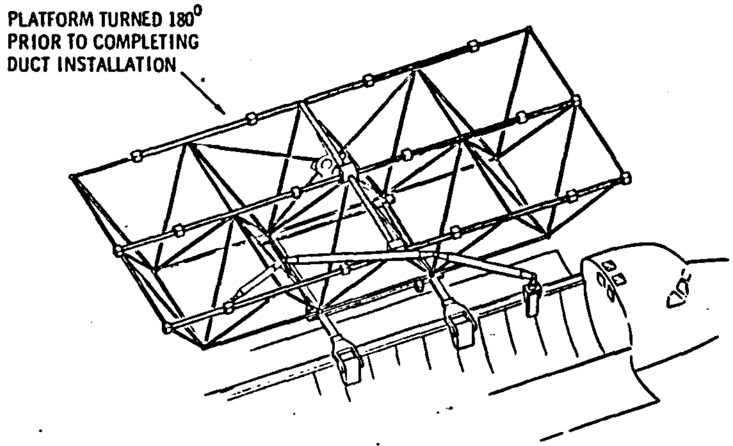


Figure 34. Duct Installation

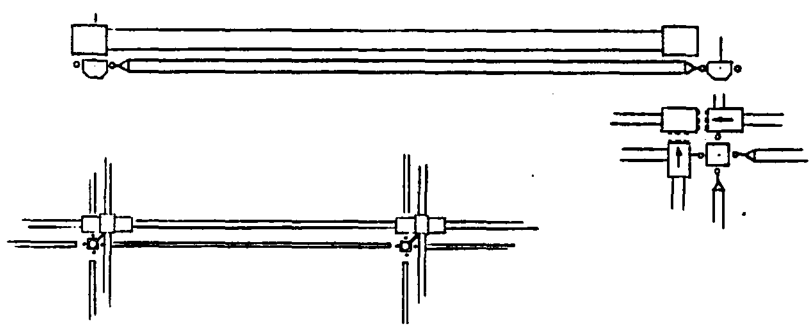


Figure 35. Mounting Layout

Electric and fluid distributions were considered separately, which appeared later to be an acceptable approach.

The 28 V dc power distribution was configured first without regard to any other requirements. The dc regulators were mounted to the unions and the line runs were attached to the columns as shown in Figures 36 and 37.

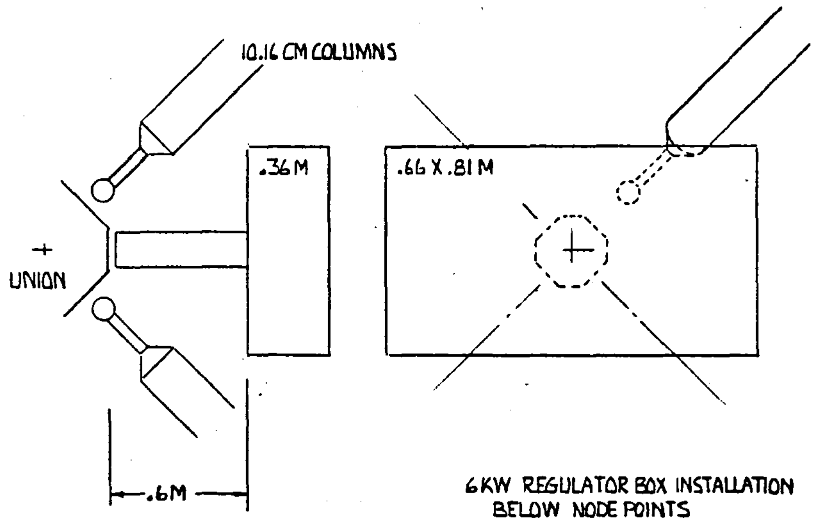


Figure 36. Regulator Box Installation

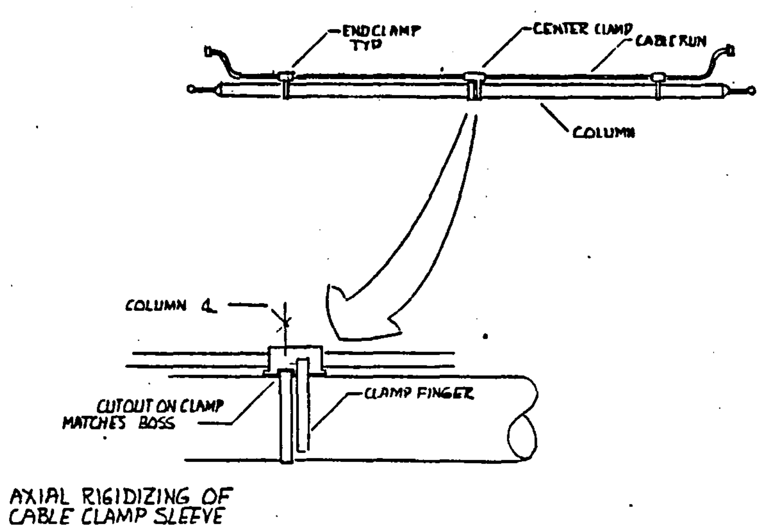


Figure 37. Column Attachment

A layout, Figure 38, was devised where each of the five regulators could supply power to a central location (junction box) which could feed a set of pallets mounted in any orientation. The junction box locations were picked so that flexible branch-cable runs (Figure 39) could selectively route the pallet connector to either of two positions after the pallets are installed.

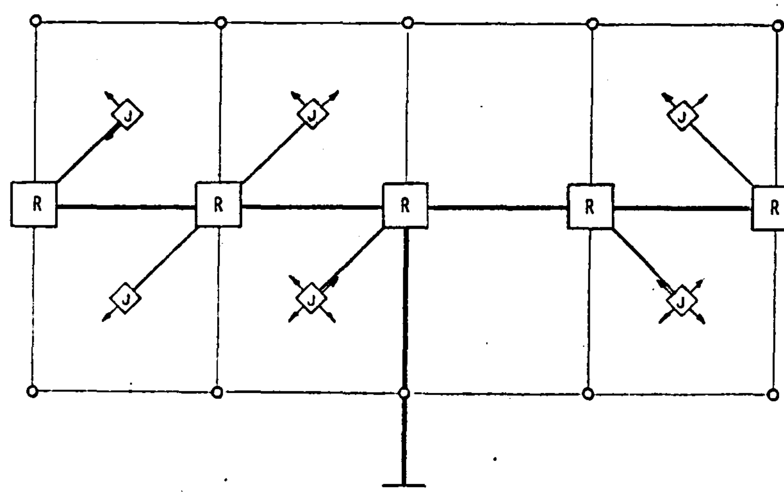


Figure 38. Power Layout

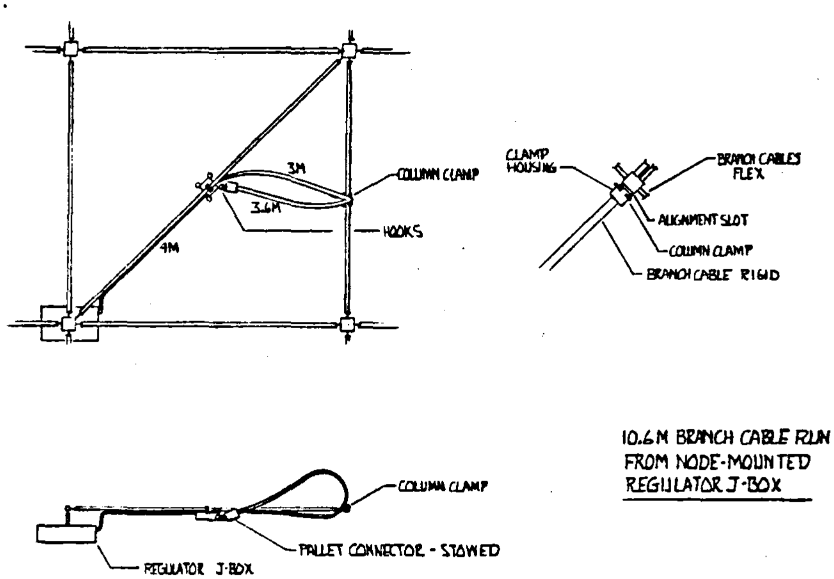


Figure 39. Branch Cable Run

This configuration minimizes the number of connectors in the distribution while supporting any orientation of all pallets. Wire sizes were evaluated for line losses using 28 to 32 V dc regulators and high- and low-voltage distributions were compared.

When the fluid distribution was considered it became obvious that the central bay branch point layout was not acceptable. It would be extremely difficult to configure a four-pallet branch of two fluid lines each which could parallel the electric lines to the alternate locations for each pallet; see Figure 40. The swivel and/or flexible sections of the fluid lines would be extremely complex.

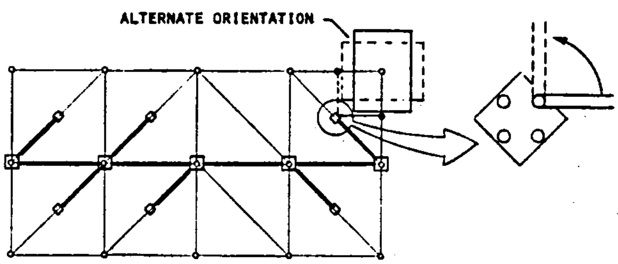


Figure 40. Four-Pallet Branch

The fluid line routing leading up to the model system configuration was then developed, with tradeoff of preliminary designs of both electric and fluid concepts, retaining the best features of each.

At this point it was evident that the "best features of each" effect would not have prevailed if the distribution system had initially been devised as an integration of the different utilities and of the installation factors.

6.0 CONFIGURATION ALTERNATIVES

6.1 HIGH VOLTAGE VERSUS LOW VOLTAGE

A comparison is made of the high- and low-voltage distribution systems of Figures 41 and 42. They are generic models of equivalent load requirements with different distributions.

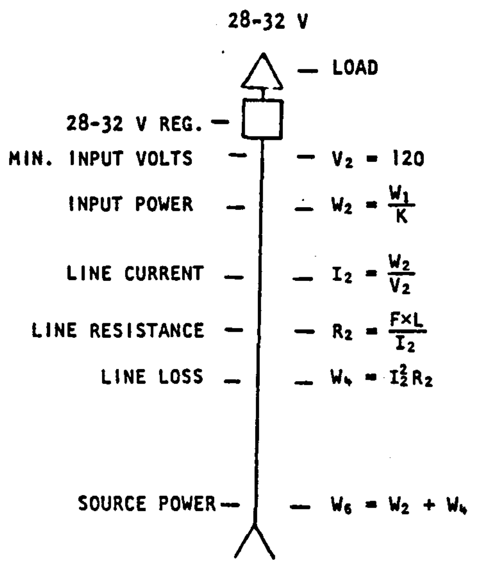


Figure 41. High-Voltage Model

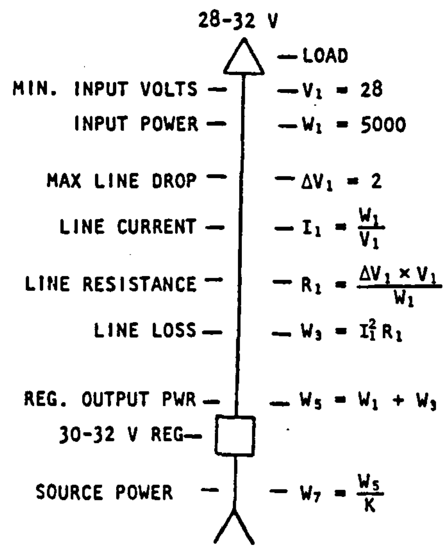


Figure 42. Low-Voltage Model

In the high-voltage system, Figure 41, the regulator is located at the load so there is essentially no difference in regulator output and load input. The regulator then has an output voltage limit the same as the load input limit. The requirement of this system is that the wire size of the distribution should not be so small that the distribution current exceeds the current capacity of the wire. Therefore, the distribution resistance, R_2, has a maximum value dependent on current capacity rather than voltage drop.

In the low-voltage system, Figure 42, the regulator is located at the power source so there is a significant difference in regulator output and load input. The regulator then has an output limit different from the load input limit. The requirement of this system is that the wire size of the distribution should not be so small that the voltage drop exceeds the difference in voltage limits. Therefore, the distribution reference, R_1, has a maximum value dependent on voltage drop which is more restrictive than the current capacity requirement.

In both systems the source is an unregulated supply equivalent to the 113 to 168 V source in the baseline model A/B. The maximum voltage drop (ΔV_1), the maximum resistances (R_1 and R_2), the line losses (W_3 and W_4), and the line currents (I_1 and I_2) apply to the roundtrip circuit.

In the high-voltage system, in the formula for maximum resistance, R_2:

L = the total round trip path lengths in meters.

F is a factor that applies to the wire size, and is the product of resistance (ohms per meter) and current-carrying capacity (amperes), so that

$\frac{L \times F}{I}$ is the maximum resistance for the current capacity equal to I_2.

The factor F varies approximately as shown in Figure 43, data derived from wire table, Appendix B.

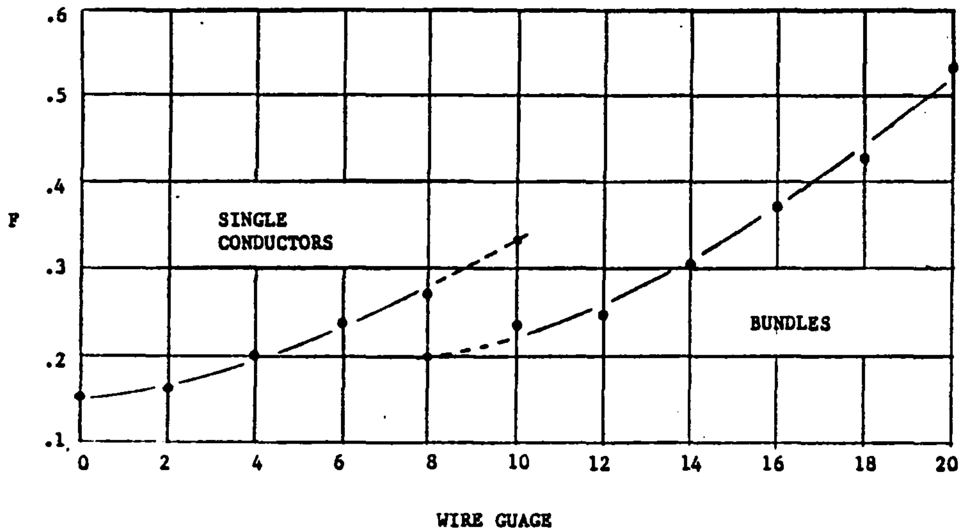


Figure 43. Wire Factor F

As a baseline, the two systems were analyzed with the following inputs:

W_1 = 5000 W
V_1 = 28 V
ΔV_1 = 2 V (HV reg., 30-32 V)
K = 0.9

V_2 = 120 V
L = 30.5 m
F = 0.26391 (8-gauge wire)

The following four parameters were calculated:

	High Voltage	Low Voltage	High/Low Ratio
• Source power (watts)	5928	5952	0.9959
• Line loss (watts)	376	357	1.0434
• Line current (amperes)	46	178	0.2593
• Line resistance (ohms)	0.174	0.0112	15.5235

The significant feature here is the ratio of line resistance in terms of number of wires. The high-voltage system can function with a substantially smaller distribution bundle.

In this example, the high-voltage current of 46 amperes requires one (0.511 theoretical) No. 8 wire (0.5 cm dia., 5 cm bend radius, total 2.5 kg) while the low-voltage line resistance of 0.0112 ohm requires eight (7.98) No. 8 wires (1.8 cm dia., 18 cm bend radius, total 20 kg).

Each of the inputs were varied individually from the baseline value to half and double values to assess the changes of high/low ratios. The results are noted in Table 1.

Table 1. Input Effects on Parameter Ratios

		Baseline Value	Half Value	W_6/W_7	W_4/W_3	R_2/R_1	I_2/I_1	Double Value	W_6/W_7	W_4/W_3	R_2/R_1	I_2/I_1
Regulator Input Voltage	V_2	120	60	1.063	2	.5	2	240	.9686	.5	2	.5
Maximum Voltage Drop	ΔV_1	2	1	1.034	2	2	1	4	.9375	.5	.5	1
Total Path Length	L	30.5	15.25	.9686	.5	.5	1	61	1.063	2	2	1
Regulator Efficiency	K	0.9	0.8	1	1.125	.888	1.125	0.95	1	.9474	1.055	.9474
Load Power	W_1	5000	2500	1	1	1	1	10,000	1	1	1	1
Wire Factor	F	0.264	0.132	.9686	.5	.5	1	0.528	1.063	2	2	1

Ratio values tabulated are compared to a baseline value of 1.0.

There is only a minor effect on the source requirement for any variations so that source power is not a serious tradeoff—as resistance ratio is.

Except for a minor effect from regulator efficiency, and no effect from load power, the resistance ratio varies in direct or inverse proportion to the input values.

The high/low-voltage tradeoff would be especially important on a system which has capability for high regulator input voltages (V_2), a restrictive low-voltage drop (ΔV_1) (broad output voltage regulator), long distribution path length (L), and/or capability for utilizing smaller wire gauge (F).

The comparison was made of the generic models where the regulator of the high-voltage system is placed adjacent to the load; this represents the extreme case. If there is substantial length between the regulator and the load, that portion of the distribution would take the form of the low-voltage system.

An actual system comparison would be different from the generic model because of branching, regulator locations, etc., and the significance of conductor reduction should be individually assessed.

6.2 FIBER OPTICS

The fiber-optics field is highly developmental at the present time. Growth in technology is proceeding at a very rapid rate, so that studies based on industry surveys through early 1979 may already be somewhat outdated. The following discussions are taken from those studies and thus represent a conservative view of the art and its projections. Breakthroughs in technology in the near term will undoubtedly extend the possibilities of fiber-optics utilization, but the direction of changes and possibilities can only be conjectured.

6.2.1 Present Advantages

Higher Communication Rates

Over 1-GHz/km signal frequencies are so far below the carrier frequencies that data rates to present perceived limits do not affect the transmission losses.

Immunity

The fiber cable is immune to RFI/EMI, EMP, crosstalk, ringing echos, short-circuit loading, and ground loops which can affect the performance of electric cables. It is ideal for use in a noisy environment.

Security

Fiber optics do not radiate so that secure communication systems can be distributed.

Economics

Distribution cables are small and lightweight (on the basis of communication rate) and are potentially available at a few cents per foot. Depending on the multiplexing scheme, cable weight could be reduced by 35 to 75 percent.

6.2.2 Present Disadvantages

Temperature Effects

Low-temperature operating requirements impact design in two ways. Fibers protected by plastic coatings and strength members become brittle and lack flexibility; for some applications this is unacceptable. Plastic claddings on fiber cores have indices of refraction that are sensitive functions of temperature. Since fiber-optic light acceptance angles and transmission are affected by these indices, plastic claddings are unacceptable at low temperatures.

Large space structures (LSS) require extremely high radiation resistance, wide temperature range operation, and cable flexibility. Flexibility is required at hinged joints and connectors during assembly. If assembly is carried out when the structure is illuminated by the sun, required flexibility can be achieved. In the shadow of the earth, cold temperature extremes will make all cladding and protective coatings extremely brittle although light transmission can still be achieved.

Radiation Effects

The performance of the present state-of-the-art fiber-optics components is expected to be marginal when exposed to the natural radiation environment. Permanent radiation-induced losses result in either increased bit error rates (BER), low signal-to-noise ratios, or system failure.

Components

Laser light sources are needed for gigahertz bandwidths, but laser diodes require very stable temperatures, have short expected lifetimes, and lack radiation degradation test data. Avalanche photodiodes are a high risk, relatively unstable devices when exposed to radiation, wide temperature extremes, and aging. Connector tee and star coupler development needs significant improvement. Connectors are expensive. Multi-pin connectors are only available in extremely limited configurations and have long lead times. Couplers are still in early stages of development, are extremely expensive, and require materials not capable of withstanding temperature extremes and vacuum.

Two types of fibers appear feasible for small satellite usage—ultrapure silica and IR transmitting plastics. Multi-mode, single-fiber cables appear most feasible (if connectors are required) due to their relatively low connector loss; but without connectors with adequate signal-to-noise margin to allow poor input light coupling efficiency, multi-fiber cables offer greater reliability and redundancy.

Certain functions now performed by electric lines cannot be performed by fiber optics even where the fiber may offer significant advantages in other functions. For example, the large number of cables required on Model A/B (Section 5.2) cannot be replaced by fibers for lack of any component techniques for fiber rotary joints.

6.2.3 Conceptual Advantages

The most significant advantage offered by fiber optics is the possibility of *generic* changes in the methods of data transfer. Some changes are already apparent; undoubtedly many more have not yet been conceived. This situation is similar to the state of development of micro-circuits in the late 1960's. The utility of micro-circuits has far surpassed the expectations of that time.

Fiber optics, for example, can lead to the integration of data distribution with structural elements. Optic fibers are theoretically compatible with incorporation into composites, such as graphite-epoxy, considered for use as structural columns in erectable systems.

Preliminary development has been started on the integration of fiber optics into structural joints. Figure 44 illustrates a fiber-optics connector, under development by Rockwell International, to be integral with a ball-socket joint equivalent to those shown in Rockwell P-1 model platform.

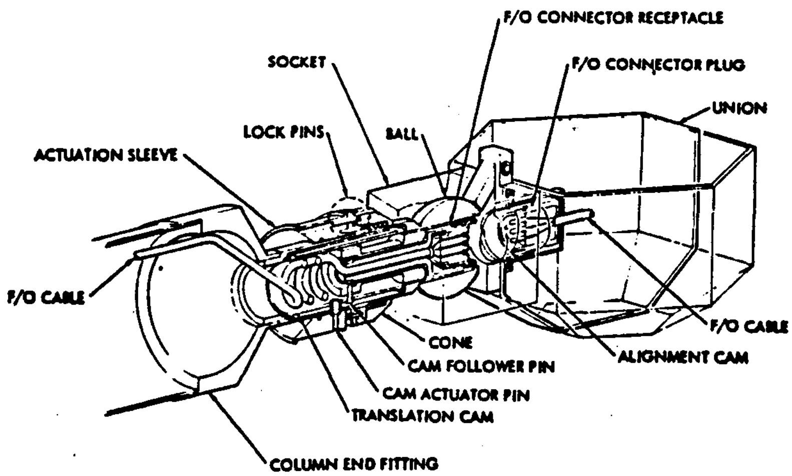


Figure 44. Fiber-Optic Connector Assembly

6.2.4 Architecture

The development of high-reliability, radiation-hard microcomputers has initiated a trend toward distributed architectures in avionics. Such architectures require high levels of interprocessor communications which may exceed the capacity of current 1-MHz avionics multiplex buses.

Fiber-optic data busing techniques offer the means of implementing distributred architectures. In distributed architectures, microcomputers are integrated into each subsystem with interconnecting hardware or fiber-optics data buses. A typical distributed avionics data bus system would be comprised of stations, each with a microcomputer for localized data processing.

Figure 45 shows a system type with four daisy chain minor buses interconnected into a main bus system. Daisy chains are more fully described in Figure 46.

A fiber-optics busing system can be designed compatible with near future requirements. Significant avionics system improvements can be achieved. Fibers, light sources, and detectors are available a decade faster than required for 10-Mb/s data transfer links. Low-loss, radiation-hard fibers are available with losses less than 5 dB/km, making fiber length a negligible factor in link design.

Driving functions for fiber-optics busing systems appear to be coupler and connector light loss and ability to withstand space environments.

Radiation-induced light losses of 300 dB per kilometer can be expected. A 100-foot daisy chain will degrade 10 dB at 10^5 rad (Si) radiation levels.

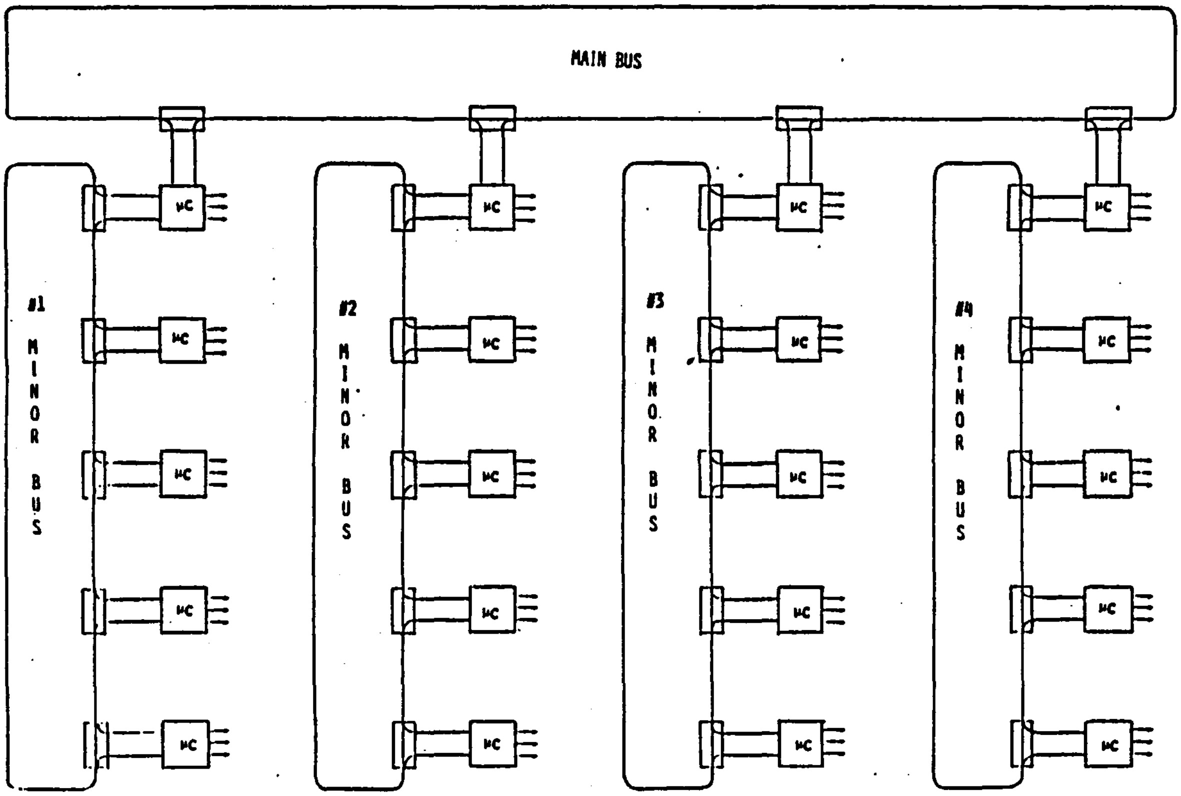


Figure 45. Daisy Chain Bus Configuration

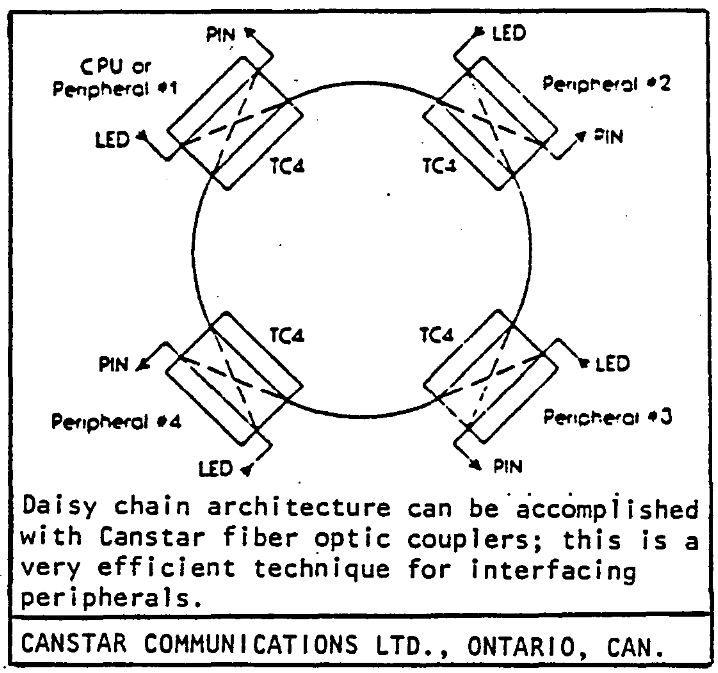


Figure 46. Ring or Daisy Chain

Light sources of the GaAlAs type, similar to the RCA C30119 or C30123 types of devices, operate at 0.83 to 0.85 micron wavelengths. These devices are very compatible with the fiber transmission characteristics, have long lifetimes, and are relatively radiation resistant. Pin diodes compatible with the operating components are also available as detectors. Longer wavelength operation at 1.05 and 1.26 micron wavelengths offers possible future system improvement but, at present, light sources are not proven reliable or radiation resistant. Detectors also are not available which are compatible with spacecraft requirements.

Present-day and near-future data rates are not driving functions in fiber, source, or detector choice.

Fiber length is also not a driving function in system design. Fibers are available with a light loss of 5 dB/km at wavelengths of 0.85 micron. A 100-foot bus will attenuate light 0.17 dB, which is negligible.

Coupler and connector choices are of extreme importance. Typical connectors lose 1 dB. Twenty stations in a chain with each having input and output connectors will result in a 40-dB overall connector loss. Usually, between 20 and 43 dB of excess light is available in a typical fiber-optic link. This excess gain rapidly disappears if excess numbers of couplers and connectors are used.

6.2.5 Light-Source Considerations

Three types of light source are used with fiber-optic data links: laser, laser diodes, and LED's. Lasers are required for long links, or high-data-rate links. Both lasers and the lower power laser diodes require temperature control and have relatively short lifetimes. LED's or similar devices, IRED's operating in the infra-red region, are most commonly used for short, medium data rate (less than 50 Mb/s) links. LED's or IRED's operate in the 0.79 to 0.85 micron wavelength region with enough power output to be useful in bus systems similar to that in Figure 45. GaAlAs devices have been manufactured with lifetimes of 111 years. The estimates of lifetimes were projected from accelerated aging testing at high temperatures. GaAlAs devices are relatively radiation hard. They also emit at an excellent wavelength for matching to fiber transfer characteristics and allow usage of silicon pin or avalanche detectors. They are the logical choice for a near-future avionics data bus system using fiber optics.

The speed of both the light source and detector using IRED's and pin diodes can be greater than the 10-Mb/s requirements of the proposed MIL-STD-1553 BFO standard for fiber-optics multiplexing.

6.2.6 Cabling Considerations (Geometries)

The decision must be made whether single or multi-fiber cables will be used; both have advantages and disadvantages. Current thinking is that single fibers offer the most advantage.

A few years back, multi-fibers were considered optimum. Even with strand breakage, significant light could be transferred. With half the strands broken, increased attenuation is only 3 dB. From a reliability viewpoint, multi-fibers are clearly superior.

Bundles of fibers carry light in only a small percent of their cross-sectional area; this causes difficulties in several ways. Light must be coupled from the light source into the fiber bundle. Only a small percentage is coupled into the fiber light-carrying cores. The rest is lost in cladding, protective coverings, or in wasted space between the fibers.

Besides the losses coupling the light source into the bundle, similar losses also occur each time a connector or coupler is used. Five to 10 dB loss per connection for multi-fibers drastically limits data link design to ultra-simple bus systems.

Single fibers do exist with sufficient reliability to be used in spacecraft. Redundant busing techniques can be effectively used to further increase reliability. A single-fiber connector will lose about 1 dB per connection, which is significantly better than the 5 to 10 dB loss of multi-fibers.

6.2.7 Coupler Tradeoffs

The severe shocks and vibrations, wide temperature ranges, radiation levels, and deep vacuums of space seriously limit choice of coupler configuration.

Improved developmental couplers are available; however, most couplers are of the types shown in Figure 47 (Reference 4). These couplers are expensive, heavy, and for most applications must be hand-tailored if optimum performance is required. Thus, mixing regions shown usually have an index or refraction greater than that of the core.

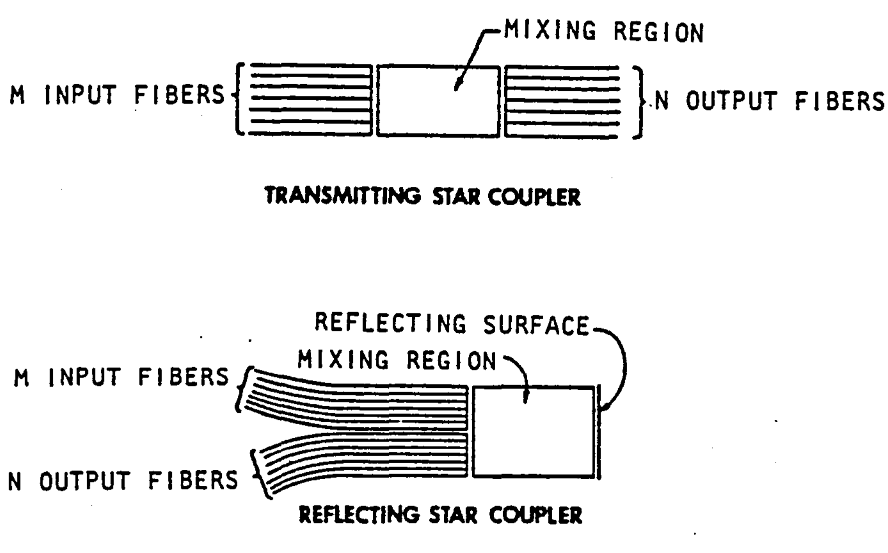


Figure 47. Transmitting and Reflecting-Type Star Couplers

The mixing region usually has either a round or square cross-section, with the outer surfaces being reflective. The square cross-section illuminates the opposite face more evenly. This mixing region is usually filled with oil or transparent epoxy. Outgassing of epoxy offers potential problems. Changing optical properties of oil with temperature, and possible leaks in vacuum, need further evaluation.

6.2.8 Configuration Tradeoffs

Figure 45 presented a preferable bus configuration. Figure 48 shows a similar system using star couplers. While not as rugged environmentally, for more than five stations on any bus this latter configuration will have less light attenuation and offers more potential for link expansion.

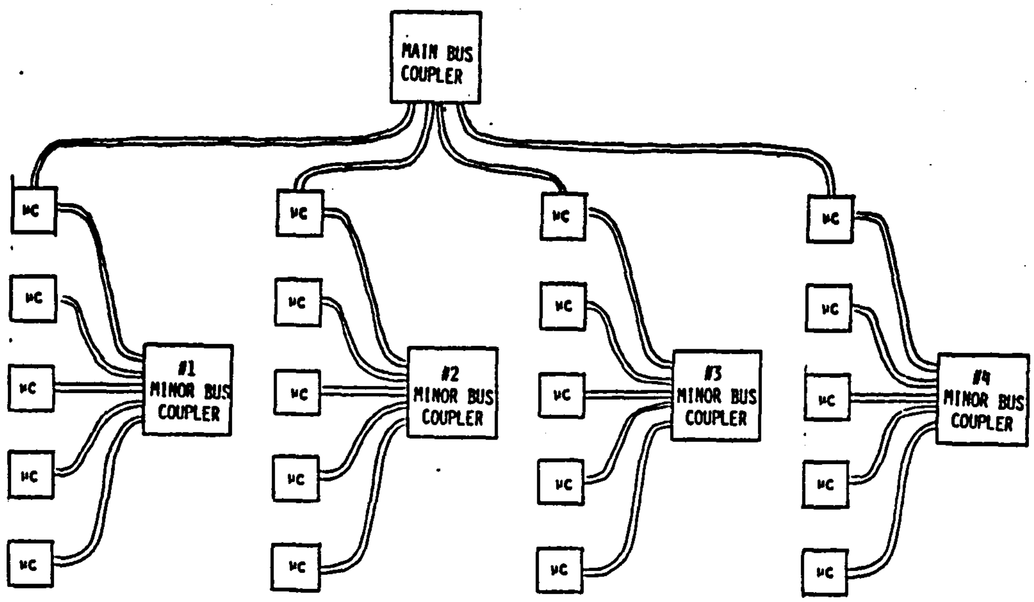


Figure 48. Radial Coupler Bus Configuration

Figure 49 shows another configuration similar to Figure 45 where passive coupling between buses is accomplished. This type of system is limited to "no connector" busing, and has the further disadvantage of only one station at a time being able to transmit.

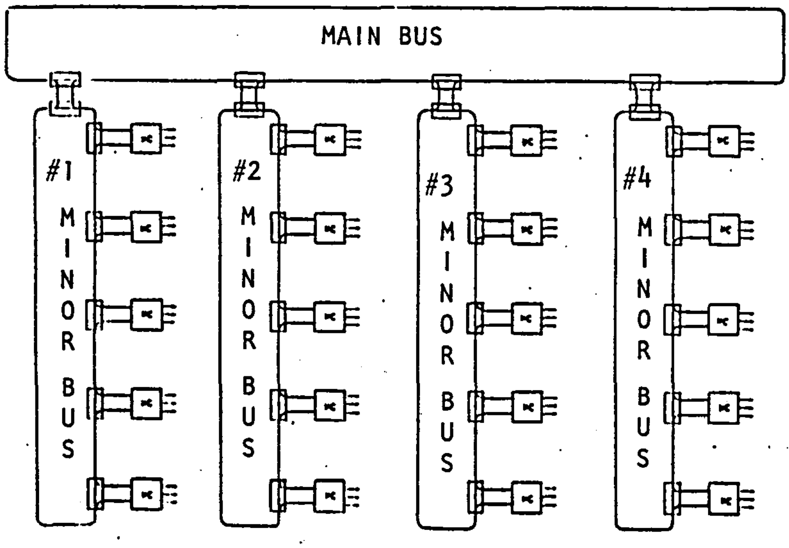


Figure 49. Daisy Chain Bus Configuration (Passive Bus Coupling)

6.2.9 Future Architecture

Fundamental improvements in data systems architecture are possible with the technology advances in fiber optics and other areas.

Certain recent developments in computer technology, microprocessing, bubble memories, and fiber optics appear very promising for use in data distribution systems.

Since the appearance of the low-cost microprocessor, much work has been done in the area of distributed processing (dividing the workload of a large central computer among several smaller, lower-cost computers). This approach is favored by many organizations for future avionics processing for reasons of reliability, maintainability, cost-effectiveness, and ease of system growth.

Several different processing architectures are possible (Figure 50). The least-complicated architecture is the simple linear bus arrangement, where all of the units are connected to a single bus. This method allows only one message at a time to be "in transit" in the entire system, and a failure of the bus isolates part of the system. Parallel buses could be included, but this would require more ports on each microcomputer unit. Another problem with the simple linear arrangement is that most types of buses have a limitation on the number of units that can be connected to a single bus.

To remedy the above problems, the system could be organized into several sets of units, with each set having its own bus. The sets would then be connected together by one "major" bus, resulting in the major/minor architecture shown in Figure 50(B). Note that in this system, a bus failure still isolates at least one unit, and that a failure of the major bus would isolate an entire set of units (not from each other, but from the system as a whole).

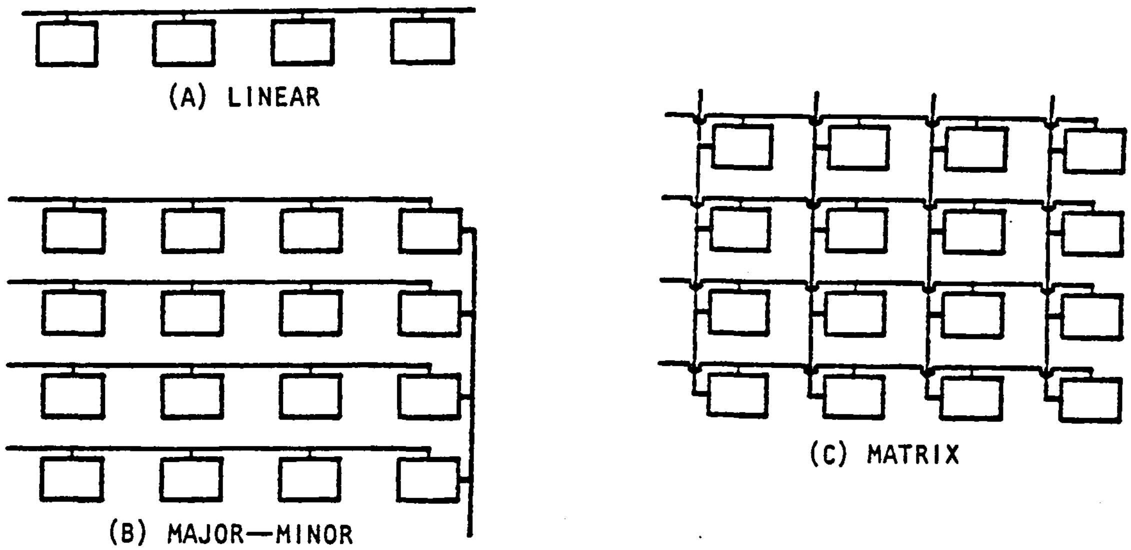


Figure 50. Distributed Processing Architectures

Better tolerance of single-point bus failures can be built into the system by adopting a matrix busing scheme as shown in Figure (C). This architecture allows communication between all units in the matrix even after several bus failures have occurred. Each unit requires only two input/output ports, and the number of units on a single bus is equal to the square root of the total number in the system.

6.3 SUMMARY

In summary, fiber optics will probably have a significant impact on data distribution systems of the future because of the broad character of changes and improvements it will support. At the present time, however, during early development of fibers and accessory components, it is difficult to make any alternate tradeoff with rather small and simple model systems as baselined herein.

7.0 UTILITIES CONCEPTS

7.1 LINE DISTRIBUTIONS

Distribution of utilities may take several forms. Individual utilities may be configured in different ways as noted in Sections 6.1 and 6.2. Power systems could be distributed at the user voltage level or at a higher-source voltage level. Data could be distributed over TSP, coax cables, or fiber-optics lines. Coolant distribution has no alternate forms equivalent to those above.

All utilities can be distributed either as a primary loop to the individual user or to a secondary loop (Figure 51). All users essentially have an internal loop within the payload for all utilities, but a group of payloads, as in Figure 52 could be configured as a secondary loop since the near payloads must act as a distribution path, in any case, to the outer payloads. High-/low-voltage regulators for dc power are a secondary loop.

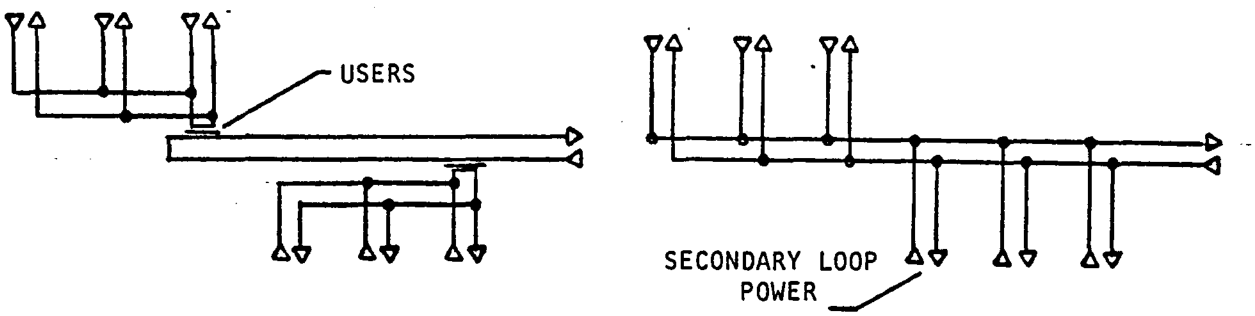


Figure 51. Payload Groups

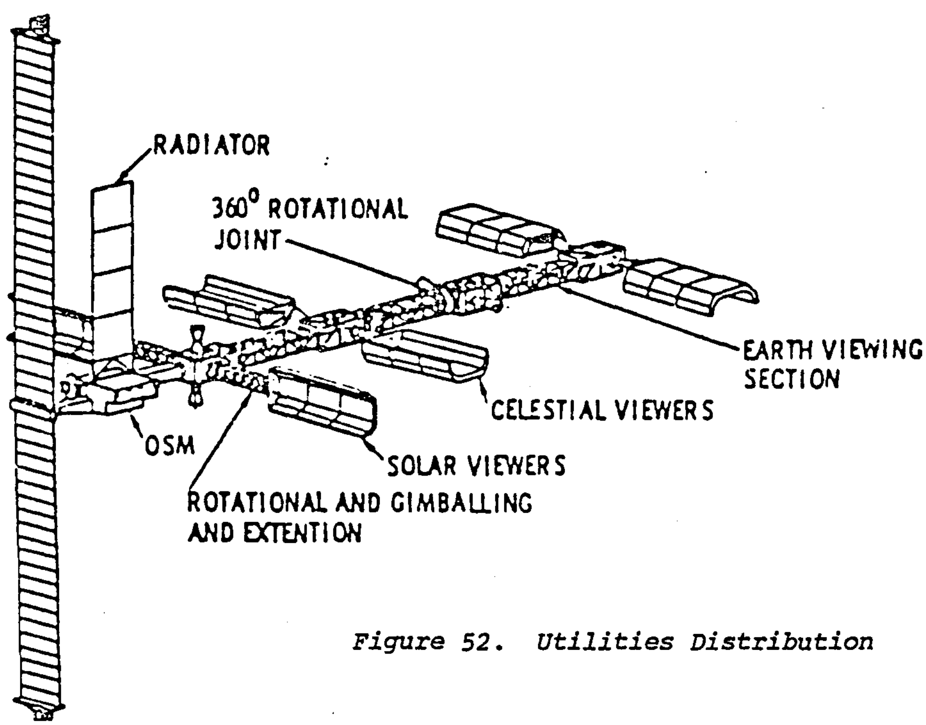
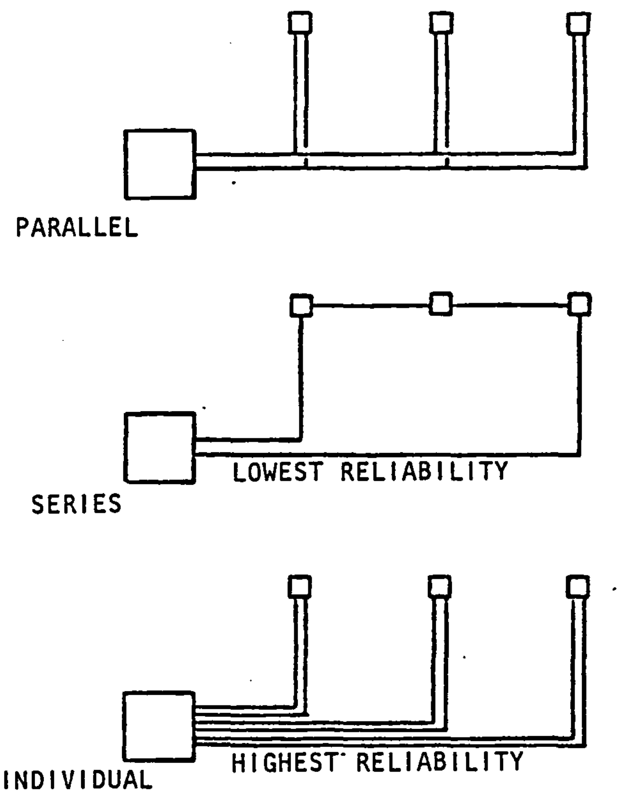


Figure 52. Utilities Distribution

All utility loops can be distributed either as parallel, series, or individual (dedicated systems); see Figure 53. Line sizing depends on whether the loads are defined or are subject to undefined replacements, additions, or changeouts.



	PAYLOADS VARY	PAYLOADS DEFINED
PARALLEL	BUS SIZED FOR MAX PLATFORM	SAME
	BRANCH SIZED FOR MAX P/L	BRANCH SIZED FOR EACH P/L
SERIES	ALL LINES SIZED FOR MAX PLATFORM	SAME
INDIVIDUAL	ALL LINES SIZED FOR MAX PAYLOAD	ALL LINES SIZED FOR EACH P/L

Figure 53. Distribution Types

Individual systems have the greatest reliability but, with variable payload manifests, the capacities of each line run must be sized for a maximum requirement.

The branch runs of the parallel system are secondary loops. In most cases, the parallel system would be minimum size and weight because the main bus (primary load) would take advantage of smaller size lines for equivalent capacities.

Special distribution considerations for data systems are given in Section 6.2.

7.2 LINE RUN CONFIGURATIONS

7.2.1 Line Routings

Utilities can be distributed in several configurations.

1. As individual lines or small groups of lines (Figure 54)
   (a) Laid on over the platform structure
   (b) Integrated into the structure

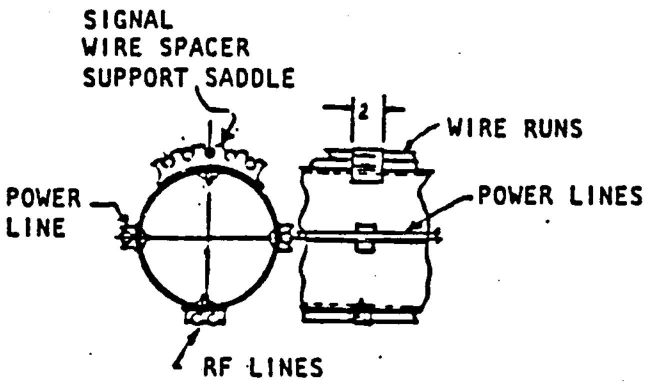


Figure 54. Utilities in Lines

2. As bundles of individual or total utilities; laid on over the platform structure (Figure 55).

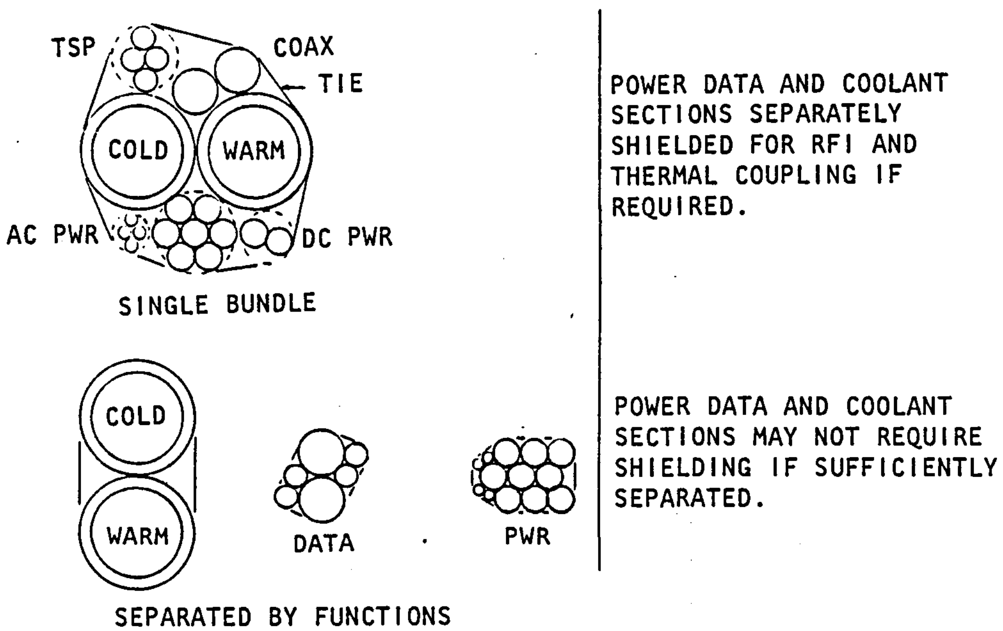


Figure 55. Utilities in Bundles

3. In container trays, to support the line runs which require the structure to integrate the assembly and connections (Figure 56).

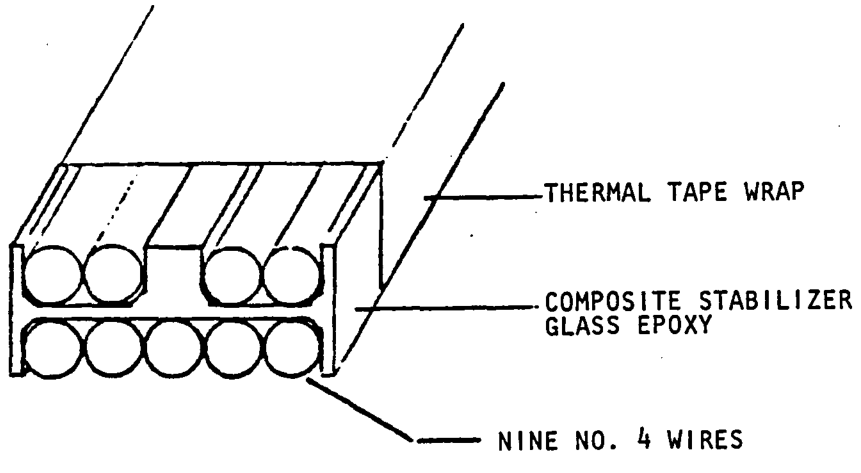


Figure 56. Utilities in Container Trays

4. In integrated ducts which of themselves form a distribution system which is attached to the platform structure (Figure 57).

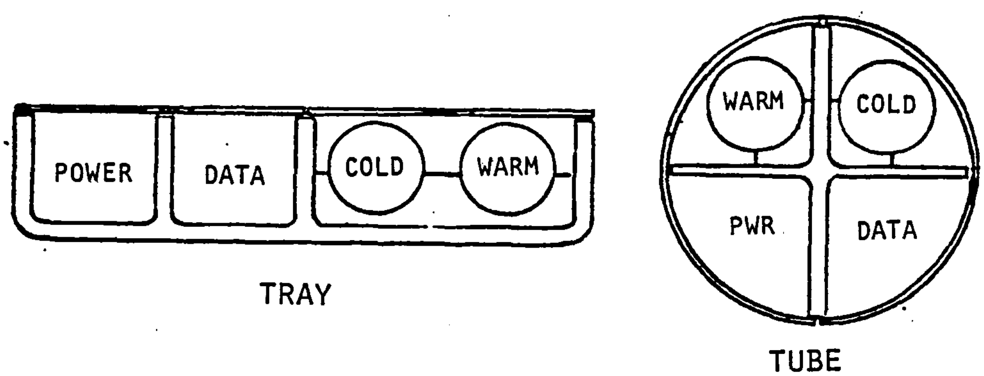


Figure 57. Utilities in Ducts

Characteristics of the different configurations are shown in Table 2. The total platform distribution can be made of any combination of different configurations.

Table 2. *Configuration Characteristics*

	TRANSPORT HANDLING	INSTALLATION	MAINTENANCE	WEIGHT	TEMP	SHIELDING	MOUNT STRESS	CONNECTIONS
SINGLE CABLES	EVA INDIVIDUALLY	SADDLES OR CLIPS ON STRUCTURE, EVA	EXCELLENT 1	MINIMAL 1	CABLE WRAP DEGRADES MAINT. 2	FUNCTION WRAP DEGRADES MAINT. 2	MINIMAL 1	SINGLE CONNECTORS ONLY
CABLE BUNDLES	EVA POSSIBLE RMS	SADDLES OR CLIPS ON STRUCTURE, EVA	POOR 4	MINIMAL 1	CABLE WRAP DEGRADES MAINT. 2	FUNCTION WRAP DEGRADES MAINT. 2	MINIMAL 1	PLATE
TRAYS	EVA, INDIVIDUALLY OR BY FUNCTION	INTO TRAY, EVA	VERY GOOD 2	MAX. 2	INHERENT IN TRAY 1	INHERENT IN TRAY 1	MINIMAL 1	SINGLE—POSSIBLY PLATE
DUCTS	RMS, PRE-INSTALLED	ATTACH FITTINGS, RMS/EVA	GOOD 3	MAX. 2	INHERENT IN DUCT 1	INHERENT IN DUCT 1	SPECIAL CONSIDERATIONS IN ATTACH FITTINGS 2	PLATE, INTEGRATED WITH DUCT
STRUCTURE INTEG.	NONE—PRE-INSTALLED	NONE	TBD	MINIMAL 1	TBD	TBD	MINIMAL	TBD

7.2.2 Interference/Cross-Coupling

Interference can be overcome either by physical separation or by shielding. Separation is especially convenient on platforms that have broad structural features such as the Model H (Section 5.3).

Shielding is especially convenient with the use of ductors or trays which can separate different utility lines by function. Shielding also separates the utilities from outside interference, or from interfering with outside functions. Ducts and trays are an ideal base for thermal protection from solar incidence (Section 7.3).

7.3 TEMPERATURE CONTROL

Trays and ducts afford an ideal base for temperature control using thermal control coatings. A utility duct was configured in the P-1 platform model development. Although revised in the model analysis, the effects of temperature control coatings are effectively illustrated.

The lay-on utility duct was configured in a rectangular shape, approximately 24×7 cm, of a composite structure and a thin aluminum set of covers. The composite matches that of the structural columns for attachment directly at the platform nodes .

The configuration is shaped for utility lines to be approximately in line with the end connectors for minimum line routing distortion and to maximize the space cooling effect of power dissipation to keep that load off the central cooling system.

On the J-box view, the Freon tubing connection outline is sized to match the manually operated disconnect coupling illustrated in NASA SP8119. Coaxial connections are sized at 1-5/8 times line diameter, typical of state-of-the-art coax connection housing. The TSP connections assume a MIL-STD-1669 size 12 connector capable of carrying ten or more No. 22 leads. The A/C connection assumes a MIL-C-5015 connector No. 18-11 with a capacity of five No. 12 leads.

The available MIL connectors for No. 4 wire—28-22 (three No. 4), 32-2 (three No. 4), and 32-17 (four No. 4)—are rather large in comparison to the remaining connections, so a 24-10 connector with seven No. 8 leads is assumed. This requires the substitution of three No. 8 wires for each No. 4 designated. The change is not detrimental.

Three No. 8 Wires	One No. 4 Wire
More bundle flexibility	
0.768 ohm/1000 m	0.919 ohm/1000 m
2.83 kg/m	0.233 kg/m
0.96 cm diameter	0.69 cm diameter
10.0 cm bend radius	7.0 cm bend radius

The utility duct has some size flexibility for minimal growth, periodic tiedowns, and thermal expansion (tube bellows and cable slack).

The composite structure is normally insulating in the direction normal to the fiber direction and this may be improved by surface coatings. The hot section (power wires) can be made isolated from the cold section (Freon lines).

The hot and cold sections are thermally stabilized by separate dissipation covers of thin aluminum sheet metal with thermal control material coatings; for example, Sheldahl G400900, 5-mil pressure-sensitive adhesive Al/teflon tape, α/ε ratio of 0.15.

The hot section is close to the ideal rectangular shape (L = 2 W) for maximum cooling (Figure 58).

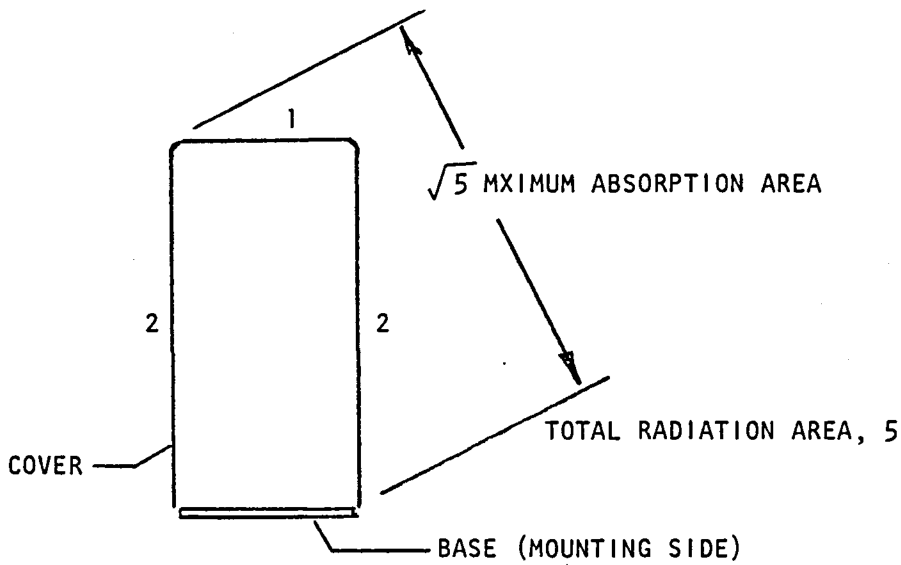


Figure 58. Ideal Rectangular Shape

Approximating the hot cover ideal temperature—

$$\varepsilon\sigma T^4 A_1 = \alpha\, 1353\ A + W$$

where $\varepsilon = 0.75$
$\alpha = 0.14$
$A_1 = 0.4\ m^2/\text{meter}$ $\qquad T = 3°C$
$A = 0.179\ m^2/\text{meter}$
$W = 65\ W/m$
and $\sigma = 5.67\ 10^{-8}$

Approximating the cold cover

$$\varepsilon\sigma T^4 = \alpha\, 1353$$

where $\varepsilon = 0.75$ $\qquad T = -15°C$
$\alpha = 0.14$
and $\sigma = 5.67\ 10^{-8}$

Even with special design parameter corrections, the hot chamber area should be in the range of room temperature and the Freon chambers should be considerably lower to minimize load on the thermal control system and power losses due to copper resistance.

Thermal expansion of the aluminum covers over the composite structure is about 6-1/2 mm per 38°C over the 5.5-m duct section. A relatively short slip allowance should permit the snap-on covers to expand differentially.

7.4 INTEGRATION OF J-BOXES

J-boxes are defined here as anomalies in the distribution runs which contain connections or branch junctions. They may also contain coupling devices, rotary joints, expansion or flexible sections, etc. (Figure 59).

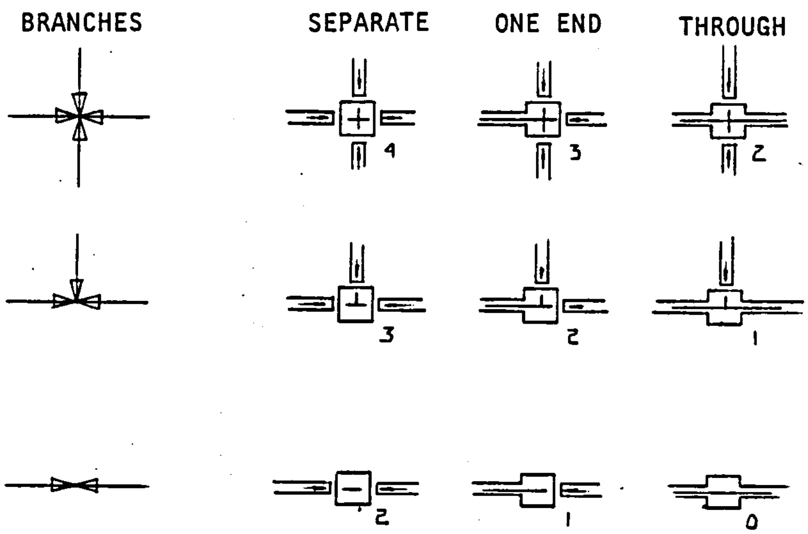


Figure 59. J-Box Integrations

The J-boxes could be separately installed to the structure, in which case the distribution system could be made modular. This might be desirable in situations where large quantities or identical items are to be integrated with other non-identical items (repetitive lines with variable J-boxes), but extra connections are required. Tradeoffs of stowage volumes, connection reliabilities, and other factors must be considered.

The J-boxes could be integrated with the line runs prior to installation, in which case fewer connections would be made (minimum of 25 percent), but stowage lengths may be excessive, handling and installation could be more difficult, and parts scheduling could be complicated. Total number of parts should be considered—small platform versus large platform.

7.5 THERMAL EXPANSION

Differential thermal expansion must be considered between the utilities lines, the platform structure, and the ducts (trays) if used. Assuming a fixed structure, the expansion differential must be designed into the utility lines, ducts, and trays. The expansion (contraction) feature can be located along the line runs or at the termination (end points).

Electric lines (power and data) have only one option—bends in the wires. Fluid lines have two options—bends in the tubing, or expansion couplings. Bends could be in rigid tubing or flexible hose. Couplings could take the form of bellows or swivels.

Trays and ducts could have the expansion capability either built in, as a slip joint, or incorporated into the mounting features.

The distribution hardware may be considered to consist of utility lines and mounting assemblies, which would likely be equivalent to J-Boxes (7.4).

Configurations which would accommodate a differential thermal expansion between the utilities and the platform structure are summarized with the following options.

Utility lines, ducts, trays, mounting assemblies, and platform structure are attached to each other as applicable: rigidly, flexibly, or not attached.

Figure 60 illustrates the accommodating configurations of lines or line bundles.

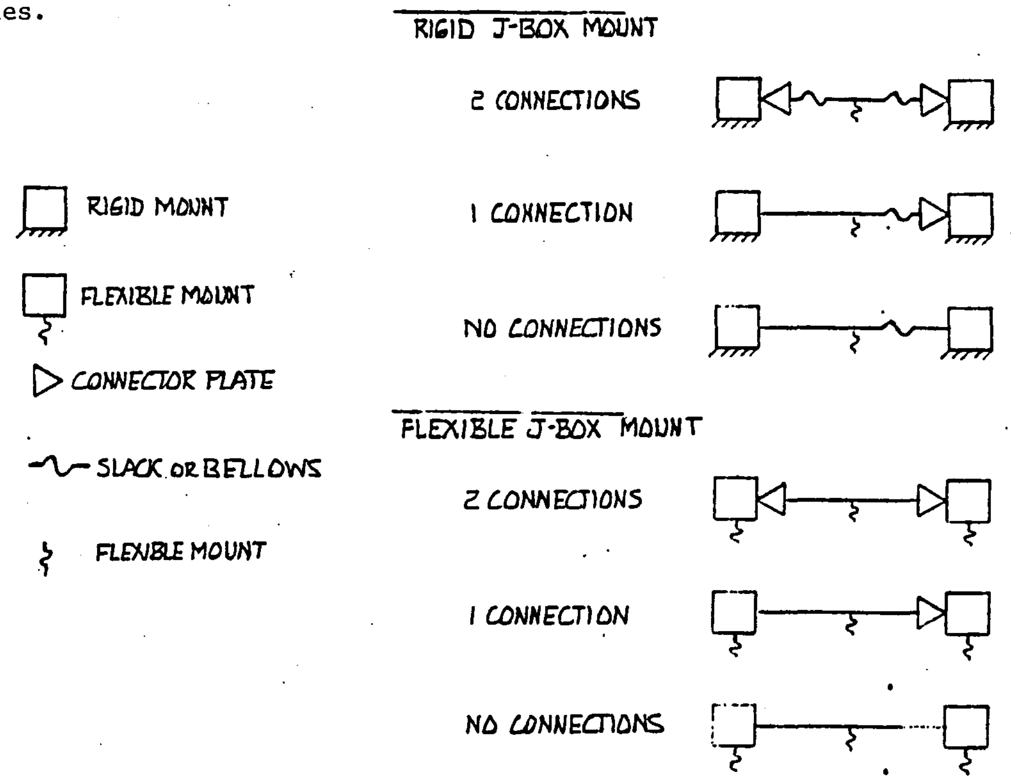


Figure 60. Lines or Line Bundles

Figure 61 illustrates the accommodating configurations of lines in ducts or trays.

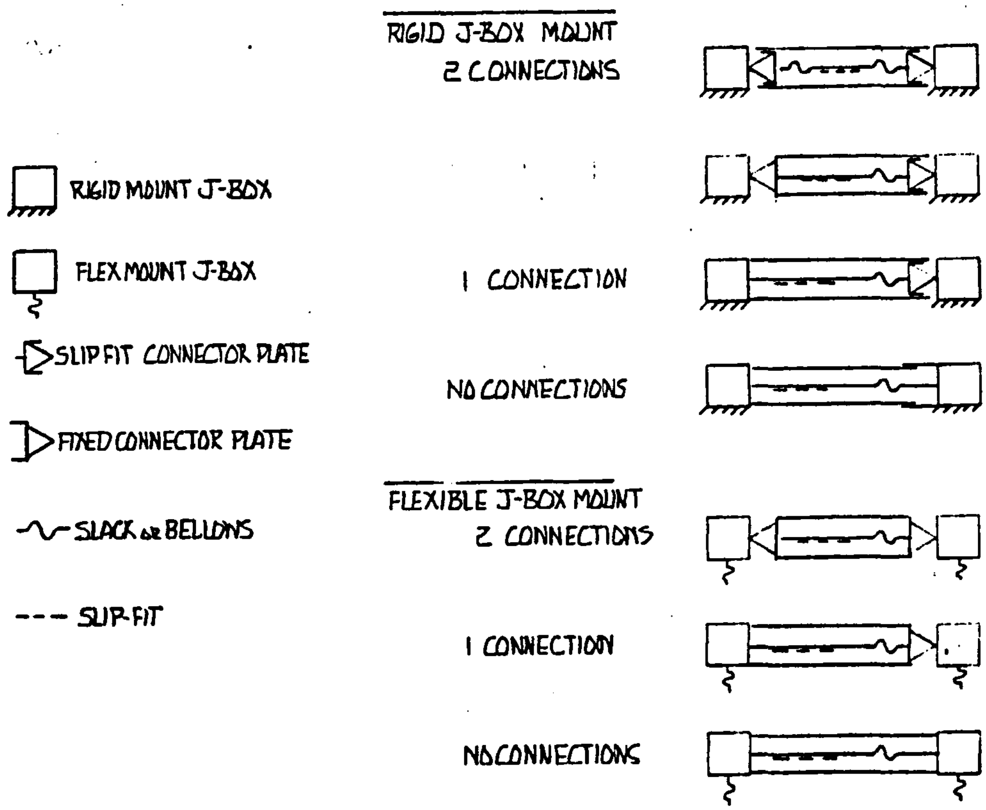


Figure 61. Ducts

7.6 MOUNTING AND ATTACHMENT

Attachment of utilities to prefabricated structures, such as sections of deployable platforms, would normally follow the same guidelines as for aircraft structures assembled at ground level.

Requirements for attaching in space are generally different. In space, the effects of environment drive the construction processes significantly. Lack of weight and atmosphere are factors affecting some processes, especially in-space fabrication. A more important factor in all construction activity is logistics. Energy, timelines, manpower, facility, forces, equipment and fixtures, access, and the interaction of the platform are the primary drivers that affect the mounting/attachment of utilities.

Mounting/attachment in space can take on two separate forms: continuous attachment where lines, bundles, conduit, etc., are continuously or repeatedly fixed to the platform structure; and discrete mounting where single items (J-boxes, connection plates, regulators, valves) and single points of lengthy items, such as ducts, are mounted to specified structural points on the platform.

An important requirement of attachments is that they be compatible with disassembly, because of the unique logistics limitations of space construction. Permanent installations may eventually prove to be of value in some applications but are not considered here.

Bolt attachments—large-scale or mass items such as J-boxes, ducts, etc.—can be attached with bolt-fasteners in many cases. Bolt fasteners may be of two different types—actively or passively engaged. An illustration of active engagement is shown in Figure 62 where an RMS, cherry picker, or EVA tool could engage and seat a screw-fastener to make the attachment of a mass item. The application could be as shown in Figure 63.

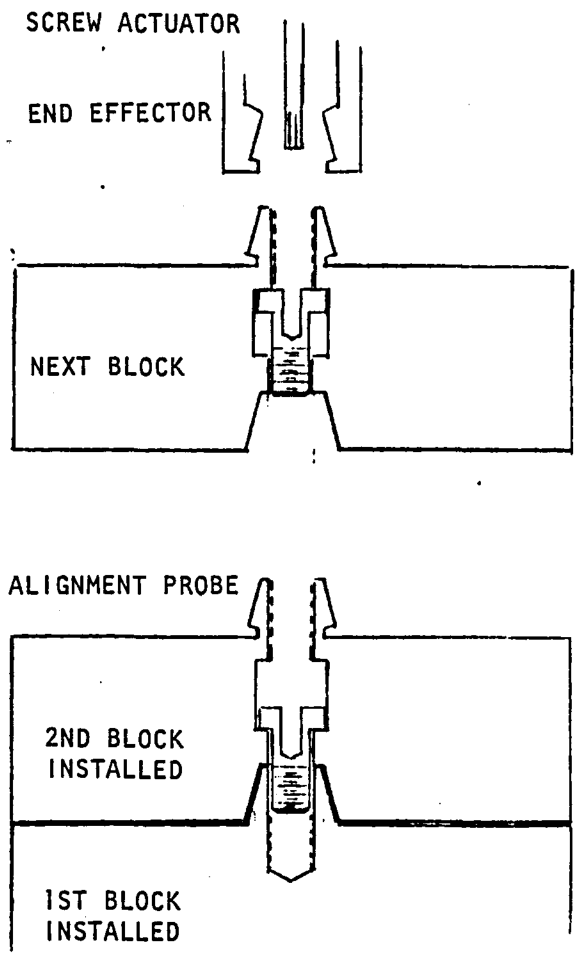


Figure 62. Bolt Attachment with Accessibility

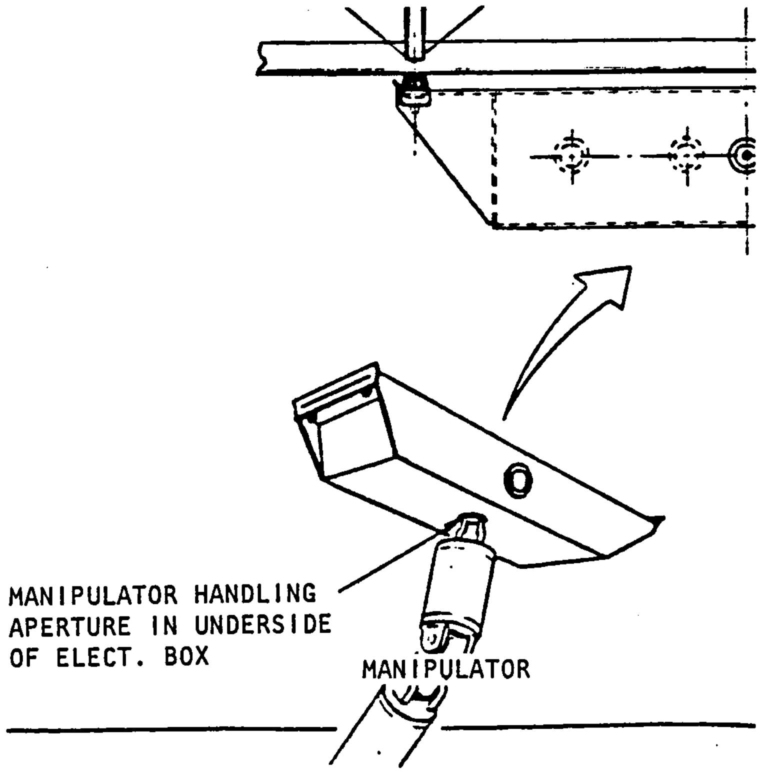


Figure 63. Application of Bolt Attachments

Where the item is inaccessible to an actuator, a self-activating bolt fastener as shown in Figure 64 could be used. A ball-lock pin, inserted into a recess, would trigger when the center pin reaches the bottom of the recess, would latch itself into place and release a spring device to hold the mass item in place on the structure.

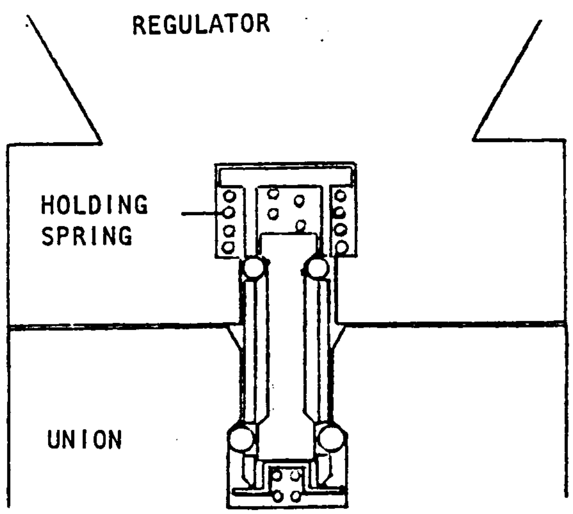


Figure 64. Inaccessible Attachment

Contact devices—A contact device, such as Velcro, is extremely flexible in its use in that it can be shaped, formed, and tailored to fit a wide range of applications. It is quite applicable to use in repetitive attachments, such as fastening long cable runs to increments along a lengthy structure. It has a drawback, however, in that it is entirely without any indexing feature and once having made an attachment with a slight misalignment, the removal and reattachment is rather difficult; attachment is by compression, but removal is by peel.

For a single attachment, some flexibility should be built into the configuration. In Figure 65, for example, showing a remote single attachment of a cable run to the center of a structural column, it might be desirable to permit rotation of the Velcro band, rotation of the sleeve about a normal axis, and a linear slide of the cable (tray) within the sleeve; these are to compensate for a misalignment that might result from the initial contact.

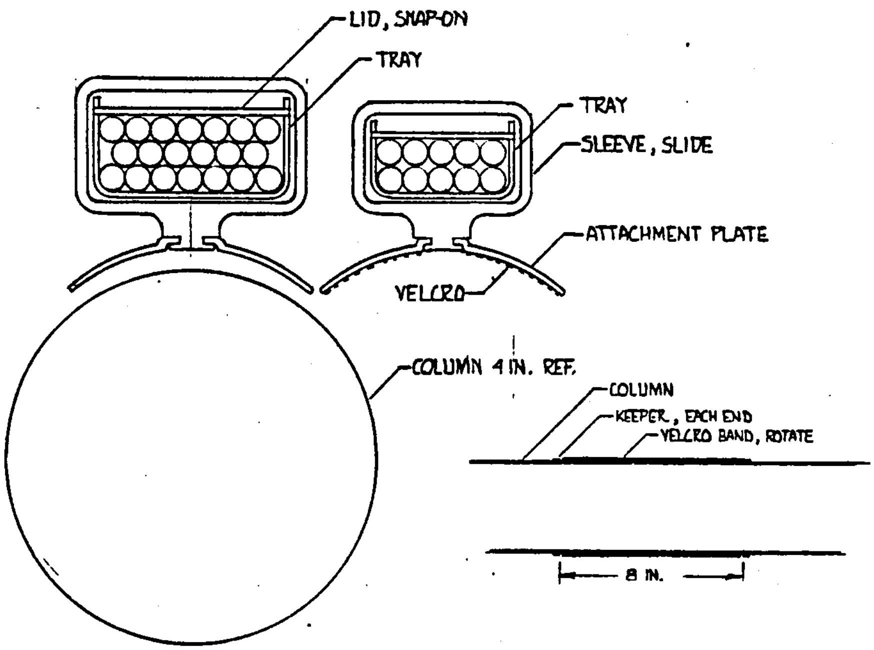


Figure 65. Velcro Cable Attachment

If the attachment device is made with some alignment feature to be effective before the Velcro contact is made, the flexibility stated might not be required.

If the attachment can be made with indexing tooling, Velcro may provide a very simple interface. Figure 66 illustrates a cable-laying assembly for a long space construction beam where the cable itself is attached to the cross members as shown in the sequence, Figure 67. A preinstalled cable clip, Figure 68, is attached by tooling which provide the indexing required.

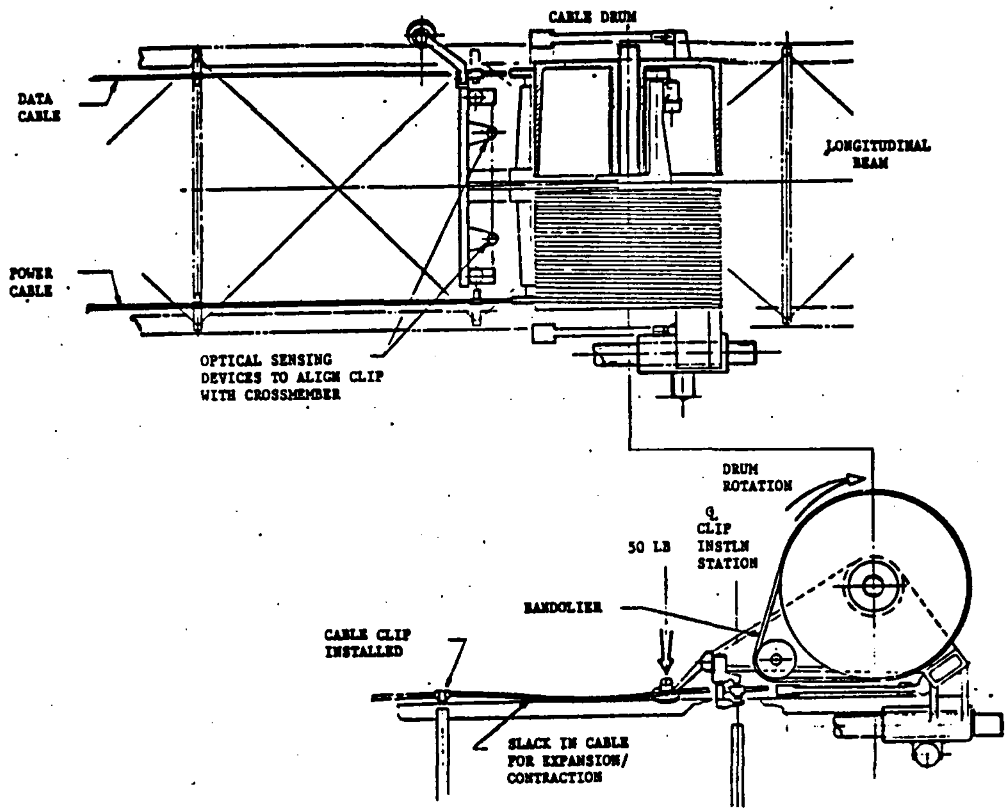


Figure 66. Cable-Laying Assembly— Long Space Construction Beam

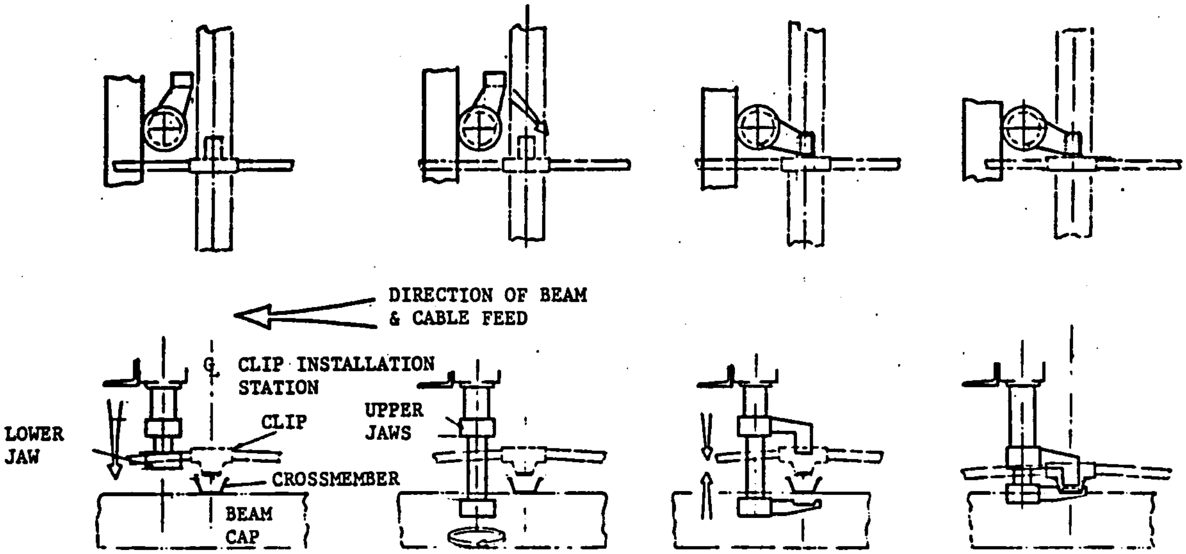


Figure 67. Index Tooling Sequence

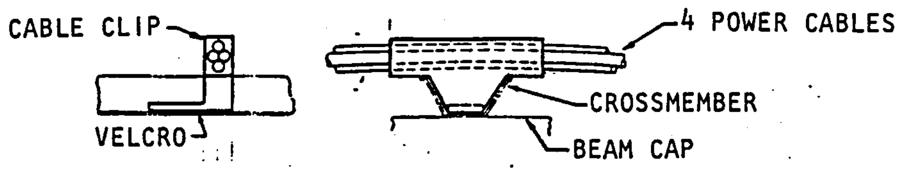


Figure 68. Index Cable Clip

Clamps—Larger cable bundles, trays, ducts, etc., could be installed to the structure over long runs by using clamps as an integral part of the utility run (see Figure 69). Figure 70 illustrates a clamp concept which could be installed remotely by the RMS. Grasping the sleeve would release the latch and allow installation or removal. Releasing the sleeve would permit the latch to lock the clamp fingers in place.

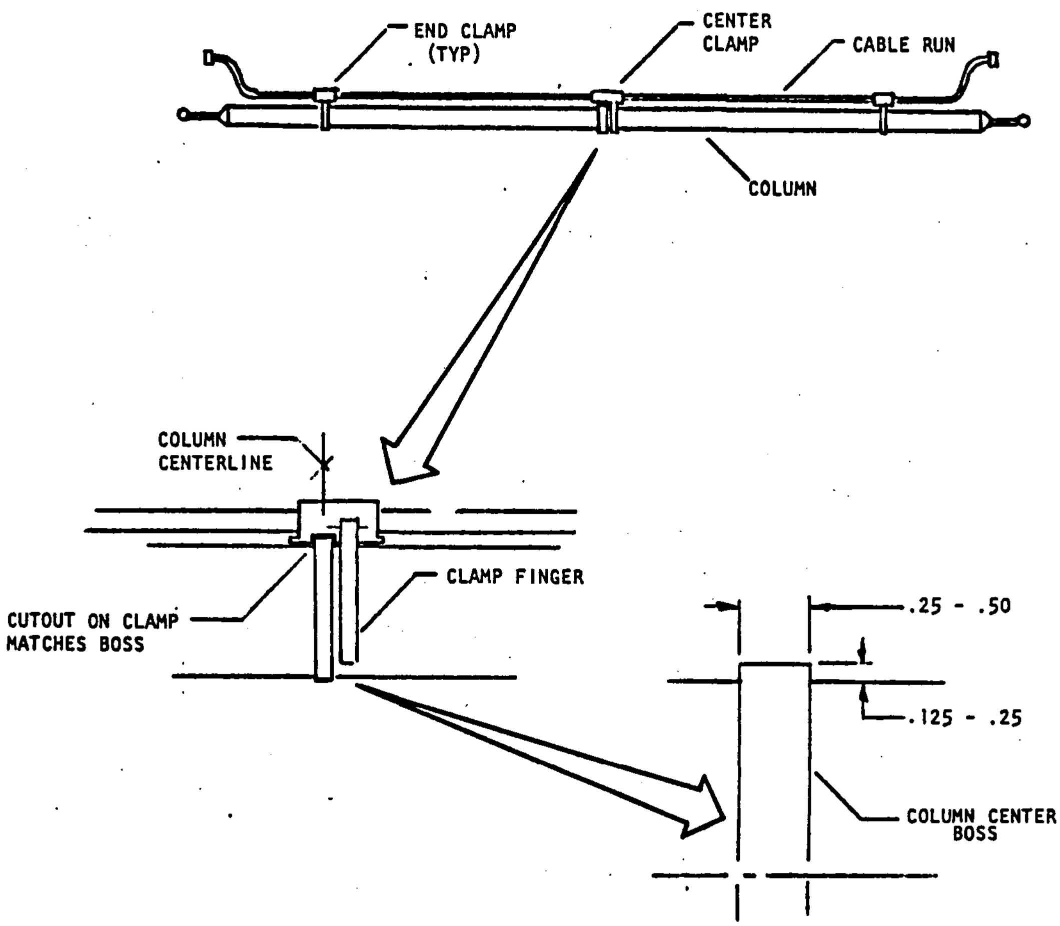


Figure 69. Axial Rigidizing of Cable Clamp Sleeve

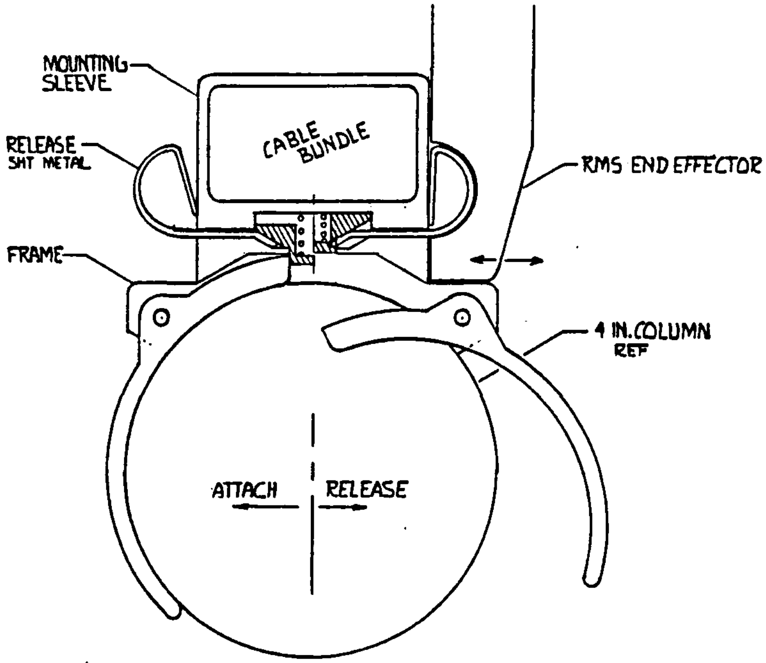


Figure 70. Remote Installation Clamp

A self-triggering latch version is shown in Figure 71. Clamp fingers are spring-loaded to clamp the structure when the structure is engaged. Release could be effected by inserting a tool between the release latch and the duct. This configuration would be more suitable to EVA installation.

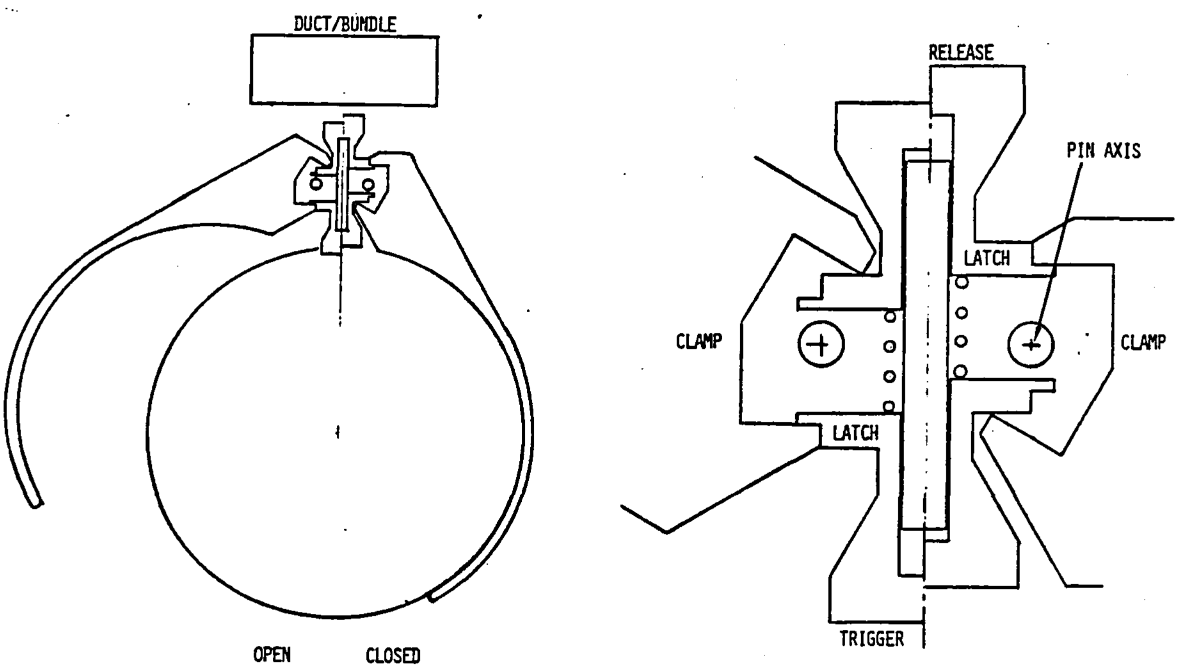


Figure 71. Self-Triggering Clamp

Clips—For single cables or small cable bundles, a clip as illustrated in Figure 72 would provide attachment. The clip could be preinstalled on the structure or on the cable with attachment made on the other item.

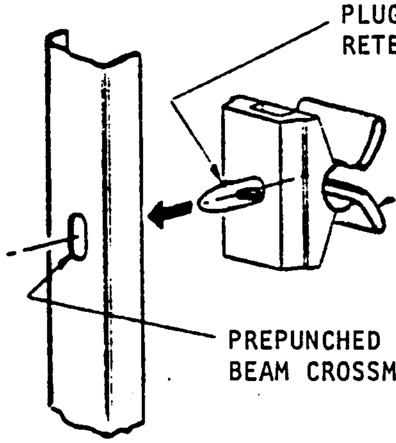


Figure 72. Clip

8.0 DEVELOPMENT REQUIREMENTS

In the study of the three baseline platforms, three separate component areas emerged as logical candidates for future development—utilities connections, end effectors for construction aids, and rotary couplings (joints). None of these are areas in which individual designs of acceptable hardware could not be developed, proofed, and made ready for space usage; but there is not a present state-of-the-art or standardized configuration which can be drawn upon for the various applications. This report does not recommend any particular design approach, but some suggestions of possible technical direction are presented.

8.1 CONNECTIONS

Electrical connectors typify the state-of-the-art connection components. The present selection of electrical connectors is basically from the MIL-STD inventory which was developed for ground installation requirements. It is obvious that the configurations are designed to withstand this environment which might include fairly rough logistical handling and the possibility of inadvertent dropping and kicking. Insertion is meant to be performed manually with considerable dexterity and with both feet on the floor. This is not the situation that would prevail during space assembly of distribution systems.

Ruggedness, however, is not the issue; some connectors may have to be more rugged to withstand handling by remote equipment. The issues are some combination of the following considerations:

- Insertion/removal by suited astronauts wearing very restrictive suits and gloves
- Insertion/removal by construction aids (i.e., RMS, cherry picker, fixture devices) which do not have the human sensory feedback
- Insertion/removal against a very light and possibly flimsy structure
- One-time mating with an extremely long-duration reliability

Requirements on connections, then, are that the insertion/removal be made easily with very light forces against the fixed half. The remoteness of the installation in some cases will demand some alignment forgiveness or some automatic realignment feature between the initial engagement and final insertion. Connections made by EVA must be simplistic in their manual interface.

To some extent, these requirements may be met—not by the connectors themselves, but by an appurtenance containing the connector or group of connectors. This is commonly done as with a connection plate incorporating grasping, alignment, pull-in, and verification features. For single connections, however, this technique constitutes an added complexity.

8.1.1 Electrical Connections

A technique for providing some measure of remote alignment is shown in Figure 73. This application is illustrated in Figure 74. This concept has undergone verification testing using both EVA and the RMS in simulated space environments.

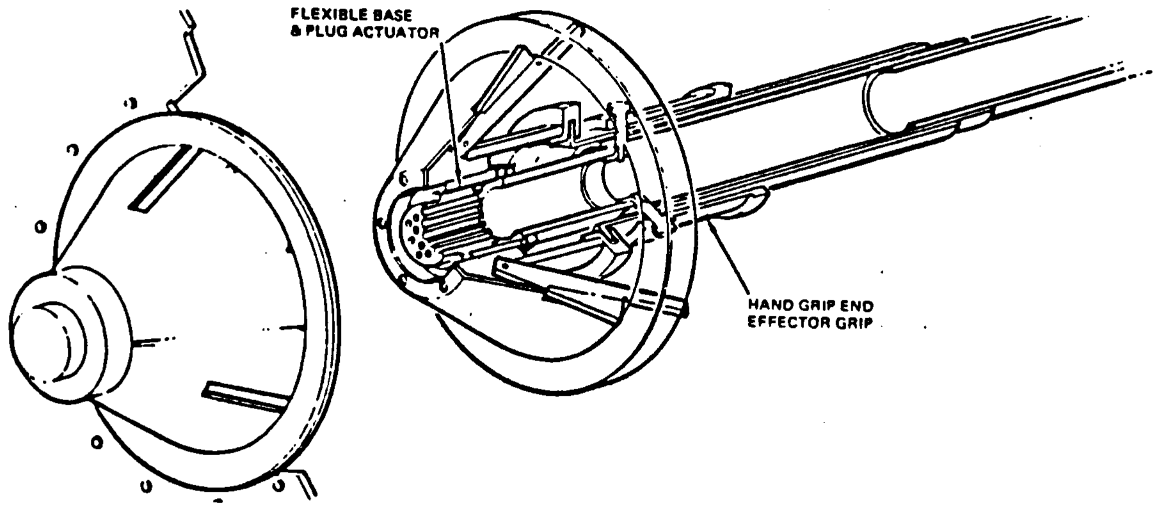


Figure 73. Remote Alignment Connector

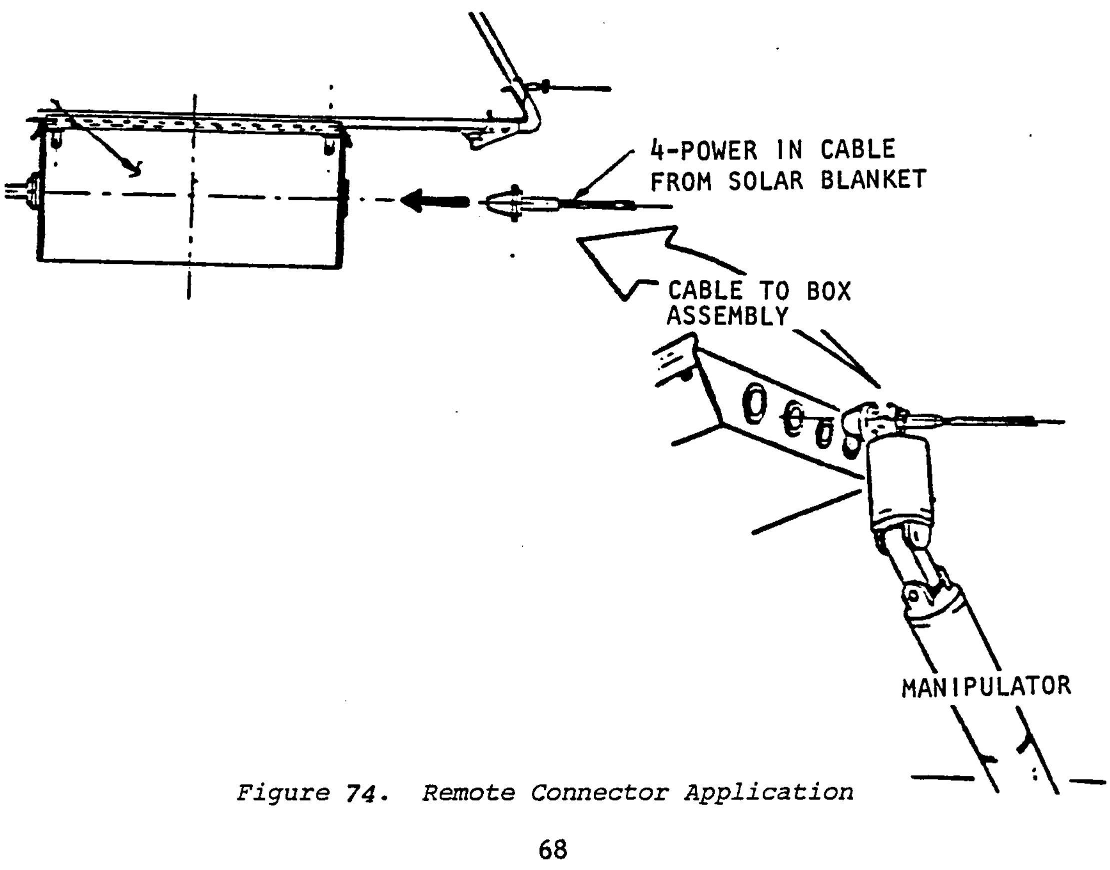


Figure 74. Remote Connector Application

The connector probe assembly incorporates a swivel feature in the cone-and-connector combination for forgiveness of misalignment.

A concept for a flat connector with no insertion is shown in Figure 75. The application might be used where connecting forces are prohibited or where axial insertion is prevented by the configuration, or where initial lateral engagement is the available option. Surface connection of three contacts in a flexible carrier is made by the compression force of a screw against a triangular pad acting on the carrier and two other carriers; in theory, like a series of milking stools. Each of nine contacts has an equal surface connection force. The concept is derived from the design of a printed circuit board connector by Hughes Aircraft Company.

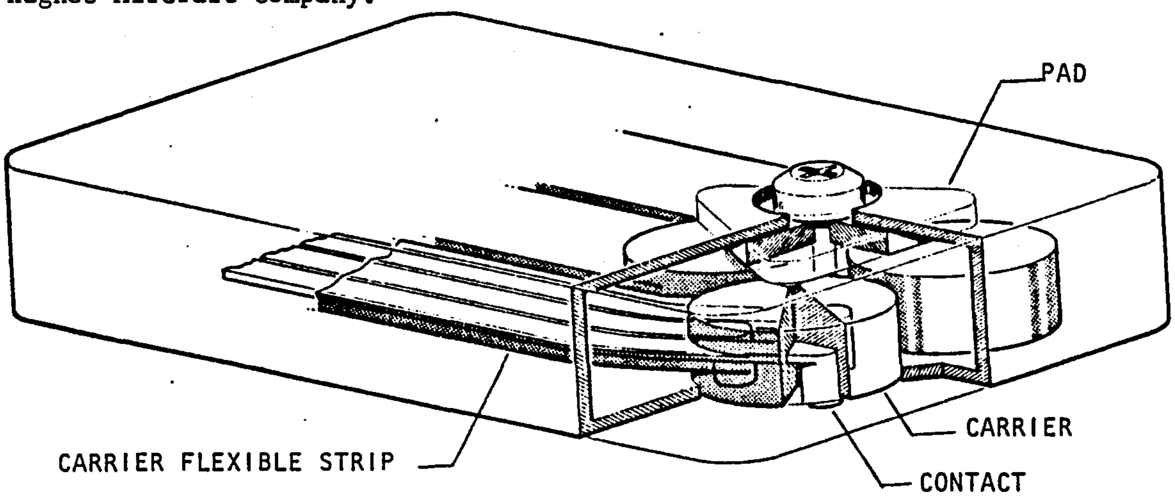


Figure 75. Flat Connector

Figure 76 shows a concept for a self-insertion feature of a connector to be operated by EVA in the environment shown in Figure 77. The actuation is specifically designed to relieve the operator from making the connection by force against relatively fragile structure such as a space fabricated beam. Pin sockets incorporate a low-force, high-reliability bristle connection developed by the Bendix Corporation.

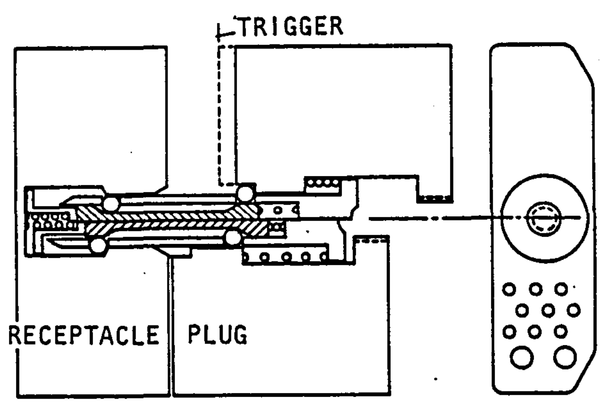


Figure 76. Self-Insertion Connector

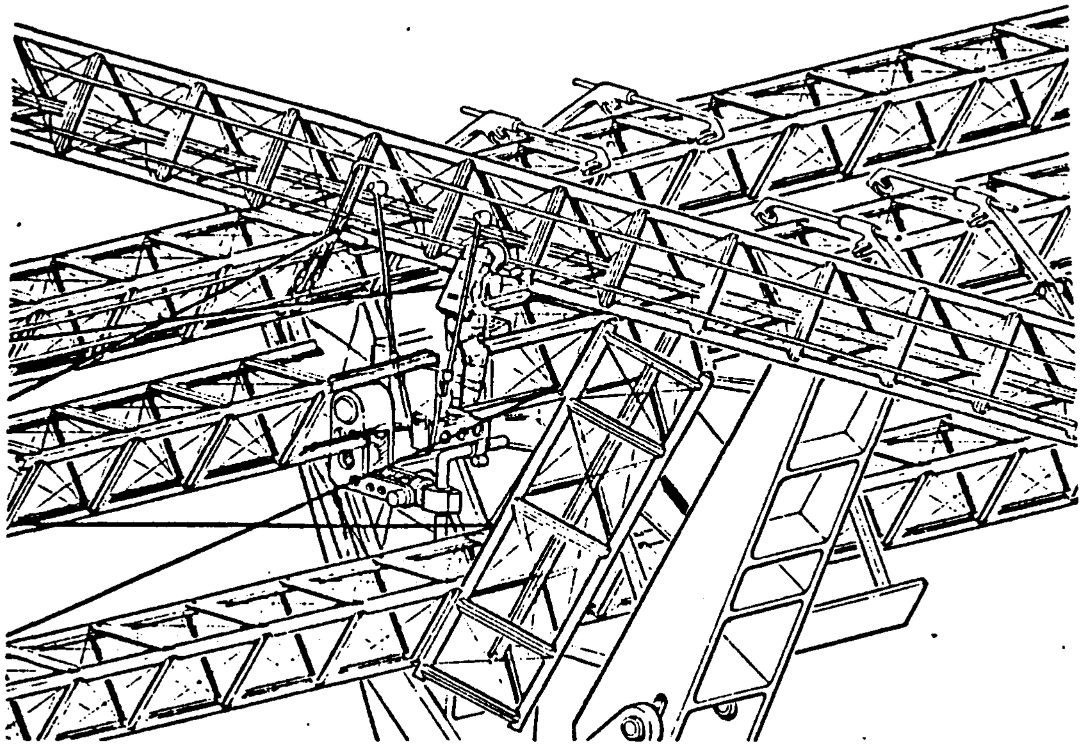


Figure 77. Operating Environment

8.1.2 Fluid Line Connections

Fluid line connections have the same general deficiencies as electrical connectors. The state of the art, again, is based on ground-installed equipment and does not conform to space installation requirements.

The configurations are basically covered in NASA SP-8119 and AIR 1047 (Reference 5).

Two specific areas require some development; the design configurations for insertion and latching do not lend themselves to manipulation by EVA nor by a remote manipulator. Tooling fixtures might be used, however, in a mechanized assembly simulation, but this is somewhat complex for small-scale platforms. Connection leak-check verifications, mandatory on ground-installed systems, suggest that similar verifications would be required in space. Bubble tests commonly used would be inappropriate. Tests in vacuum are not state of the art.

8.2 END EFFECTORS

In every study involving space assembly the use of an end effector for the RMS, cherry picker, or MMU is presumed to be able to manipulate assemblies and hardware items in the construction schedule. Except for the deployment of large module items, the standard NASA end effector (Reference 6) would be inappropriate. For that end effector, the module interface is specifically defined and equipment designs can be specified to conform.

For the many construction/assembly tasks, however, involving grasping and positioning of structural elements, insertion, and actuation of hardware items (including the installation and connection of utility distribution elements) there is no defined end effector and each study randomly defines the end effector for the hardware items under consideration.

A standard, or set of standard, end effectors should be defined by NASA for which the interface of developed elements and hardware could be specified. This definition is required unless each contractor is to require a special interface.

Some typical candidate configurations are shown in Figure 78 (Reference 7).

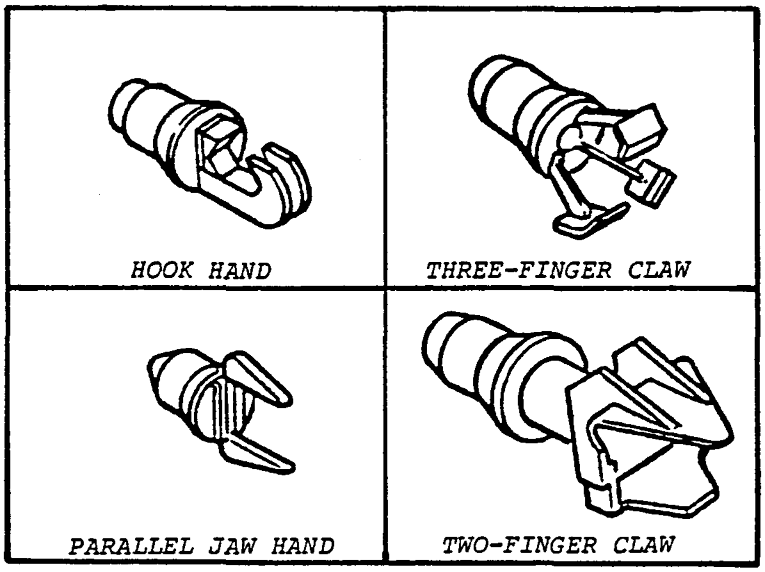


Figure 78. Candidate Configurations

Secondary functions would be a serious consideration. Figure 79 illustrates a conceivable configuration for providing an active installation drive.

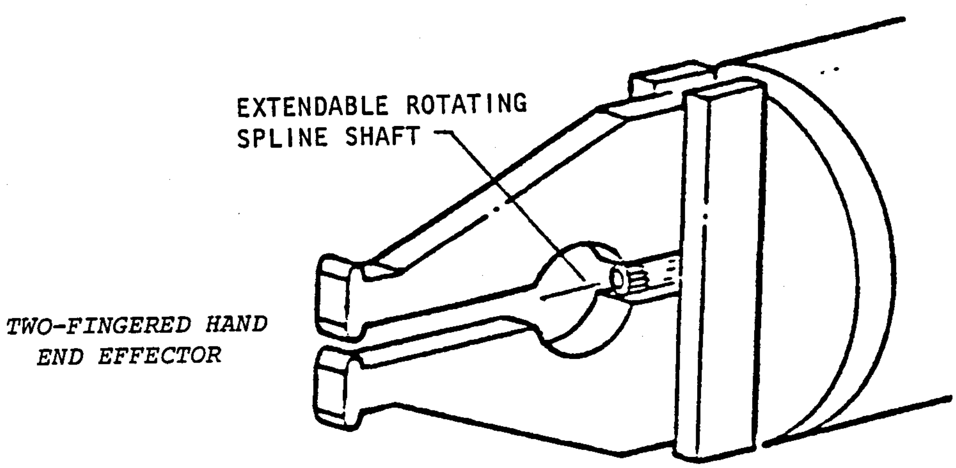


Figure 79. Active Installation Drive

8.3 ROTARY COUPLING

In both platforms, Model A/B and Model H, there is a requirement for a continuous rotary coupling (360 degrees) which cannot be met by flexible or wind-up conductor paths. State-of-the-art couplings would not suffice in two areas: (1) extremely high electrical path density as illustrated by the 462 TSP conductors on the A/B model, and (2) requirements for four continuous fluid rotary joint paths.

The electrical path density would probably be met, not be designs to implement that number of paths, but by alternate approaches leading to higher data rates per path. Coax rotary joints are available - however, not in the multi-channel configurations of the quantity that would be required - and fiber -optics rotary couplers are not presently available.

The fluid rotary joint problem is one of design and development rather than technology. Four-channel joints are presently not available, however, three-channel joint designs are available which might be extended to the additional channel.

A more serious problem is that of leakage. The continuously rotating joint must survive a long time period (perhaps 10 to 20 years) unattended, with a minimum finite reserve of fluid.

Through a dynamic O-ring seal, the minimum leakage is by permeating through the O-ring material. At a pressure of 200 psi, using an 8-cm-diameter O-ring, a low permeation rate (8×10^{-8}) Freon coolant permeation equates to the order of 0.1 liter per year (Reference 8). Leakage around the O-ring would be significantly greater.

Rotary joints are currently rated as "zero leakage" but this is in terms of ground applications where leak rates unmeasurable over short time periods are considered zero. There is not significant data at present on long-term effects of rotary seals.

The same problem is present with static seals, but not to the same degree. High compression forces can be applied to static O-rings, minimizing the bypass leakage, although permeability leakage is still present.

8.4 DEVELOPMENT SUMMARY

In the design approach to new development in all three areas, it would seem desirable - because of the unique space environment and logistics - that, in addition to extending the present configuration technologies, consideration should be given to innovative techniques for meeting the requirements. Explosive welding techniques, for example might be desirable for certain tubing connections, or dual-state memory metal could prove to be highly reliable for tubing or electrical connections, especially where disassembly is not required (Reference 9).

Table 3. Development Requirements

Construction	Performance	Prerequisite Data
	END EFFECTOR	
Compatible with rapid changeout on RMS—or on standard RMS end effector Jaw/grip interface to assembly parts Rotation drive secondary function	Grasp utilities duct interface for transportation Release utilities duct from orbiter bay stowage restraints Drive screw clamps for utilities duct installation	Duct interface design data Duct segment line mass and c.g.; RMS acceleration capability and control limits Installation closure force requirements Secondary drive, torque and displacement design limits Other studies (see NOTE below)
	ROTARY JOINT	
Power/data/fluid and structural integration Four-channel fluid lines Alternate to slip rings—possibly coax or fiber optics Alternate to present groove/O-ring dynamic seals	High-data-rate transfer with fewer channels Long-term rotation reliability—fluid leakage Continuous rotation	Maximum leakage allowance/fluid reservoir capacity Statistical maximum payload/pallet data rates Temperature extremes Flow, pressure limits
	CONNECTOR	
Alignment/orientation forgiveness for initial insertion Manual connection outline compatible with suited EVA interfaces RMS connection outline compatible with 8.2 end effector interface	Connect with very low insertion force Long-term connection reliability—electrical contact Long-term connection reliability—fluid leakage Multiple connection capability—power/data/fluid Disconnect capability	Maximum force limits Maximum leakage allowance/fluid reservoir capacity EVA compatibility simulation test data from MSFC NBS RMS compatibility simulation test data from JSC MDF

NOTE: Prerequisite for end effector development should include requirements derived from studies of other construction tasks, as well as those references in this report. The data consist of projected requirements and use factors related to interface sizes, interface shapes, grasping (internal/external), tactile requirements/feedback, end effector changeout schedules, and secondary operations (push/pull, rotation, operations verification). It is recommended that a single or category of end effectors be baselined using this data approach, rather than from single study data. Further utilities system studies can then be made to conform to a NASA standard end effector as they are now to the NASA standard RMS.

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APPENDIX A

NORMALIZED UTILITIES

(See Section 3.0)

APPENDIX A

In modeling the three baseline systems, a statistical allocation of loads is established simply to develop a model-size for developing the distribution concepts.

The power distribution system must be capable of supplying maximum pallet power to any pallet location but not to all locations simultaneously. Because the specific payloads and specific locations are not defined, the payload power and locations are arranged so that the distribution network is sized to supply a reasonable allocation of loads.

The total platform power is defined as the total number of platform pallet locations times the average power per pallet of all the listed payloads.

The maximum pallet power is defined as the maximum power per pallet of all the listed payloads.

The individual pallet powers are defined as decreasing in a geometric progression from the maximum.

For computation of distribution sizing, the maximum defined pallet is assigned to the farthest location from the source, etc., until the minimum pallet is at the nearest location. The distribution system derived from this arrangement appears to satisfy the worst case payload arrangement.

P-1 POWER SIZING

	Max	Min	Avg
KW per pallet	4.5	.07	1.75
Maximum Pallet	4.5 kw		
Total Platform	1.75 x 15 = 26.25		

Pallet #1	4500 W
2	3787
3	3187
4	2681
5	2256
6	1899
7	1598
8	1345
9	1131
10	952
11	801
12	674
13	567
14	477
15	402
TOTAL	26,257

P-A/B POWER SIZING

	Max	Min	Avg
KW per Pallet	7.4	.03	1.335
Maximum Pallet	7.4 kW		
Total Platform	1.335 x 16 = 21.36		

Pallet #1	7400 W
2	4840
3	3165
4	2070
5	1354
6	885
7	579
8	379
9	248
10	162
11	106
12	69
13	45
14	30
15	19
16	13
TOTAL	21,364

P-H POWER SIZING

	Max	Min	Avg
KW per Pallet	3	.025	.886
Maximum Pallet	3 kW		
Total Platform	.886 x 27 = 23.922 W		

Pallet #1	3000
2	2635
3	2315
4	2033
5	1786
6	1569
7	1378
8	1210
9	1063
10	934
11	820
12	720
13	633
14	556
15	488
16	429
17	377
18	331
19	291
20	255
21	224
22	197
23	173
24	152
25	133
26	117
27	103
TOTAL	23,922

APPENDIX B

WIRE TABLE

FROM SHUTTLE SPECIFICATIONS

(See Section 6.1)

CURRENT CARRYING CAPACITY & RESISTANCE FOR MB 0150-048 KAPTON WIRE

Gage		Current Amp		Orbiter 200°F Resistance/Ft. Ohms
0	(1) (2)	320.0	SINGLE CONDUCTOR	.000146
2	(1)	214.0		.000228
4	(1) (2)	173.0		.000354
6	(1) (2)	130.0		.000562
8	(1) (2)	90.0		.000894
10	(2)	45.0	BUNDLES	.00160
12		29.5		.00255
14		24.0		.00386
16		18.5		.00613
18		16.5		.00786
20		13.0		.01258
22	(2)	8.5		.02061
24	(2)	6.5		.03877
26	(2)	4.5		.06364

NOTE:

1. Resistance values shown are for a wire temperature of 200°F.
2. Per NASA Report LEC-1756 dated March 1974, these ratings are for a bundle of 35 wires with 7 wires carrying current at a wire temperature of 392°F except as noted (Note 4 & 5).
3. The current carrying capacity shown is for vacuum conditions and will be used for all areas of the Orbiter.

(1) 4. Per NASA Report LEC-1756 dated March 1974, these ratings are for a single conductor carrying current at a wire temperature of 392°F.

(2) 5. Tests were not performed on wire gages noted. The current carrying capacity was determined by extrapolation/interpolation.

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15. Supplementary Notes

Contract Monitor: John W. Goslee, NASA Langley Research Center

16. Abstract

A study was conducted to provide generic concepts for the installation of power data and thermal/fluid distribution lines on large space platforms. Connections with central utility subsystem modules and pallet interfaces were also considered. Three system concept study platforms were used as basepoints for the detail development.

The tradeoff of high voltage/low voltage power distribution and the impact of fiber optics as a data distribution mechanism were analyzed. Thermal expansion and temperature control of utility lines and ducts were considered.

Technology developments required for implementation of the generic distribution concepts were identified.

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