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Analytical Study of Electrical Disconnect System for Use on Manned and Unmanned Missions

Prepared for:
National Aeronautics and Space Administration
George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama

MARTIN MARIETTA

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FINAL REPORT

ANALYTICAL STUDY OF ELECTRICAL DISCONNECT SYSTEM FOR USE ON MANNED AND UNMANNED MISSIONS

Contract NAS8-31971

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FOREWORD

This document presents the results of work performed by the Martin Marietta Corporation's Denver Division for the National Aeronautics and Space Administration, George C. Marshall Space Flight Center. This final report was prepared as partial fulfillment of Contract NAS8-31971, *Analytical Study of Electrical Disconnect System for Use on Manned and Unmanned Missions*. The NASA Contracting Officer's Representative was Mr. Wayne J. Shockley of the Electronics and Control Laboratory.

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ABBREVIATIONS

AC	Alternating Current
AFD	Aft Flight Deck
AMB	Ambient
BTU	British Thermal Unit
^{o}C	Degree Centigrade
cc	Cubic Centimeter
cm	Centimeter
D	Diameter
DC	Direct Current
defl	Deflection
displ	Displacement
EEE	Electrical, Electronic and Electromechanical
ET	External Tank
EVA	Extravehicular Activity
F	Force
FSS	Flight Support System
^{o}F	Degree Fahrenheit
ft	Foot
g	Acceleration of Gravity 9.8 m/sec^2 (32.2 ft/sec^2)
GSE	Ground Support Equipment
GSFC	Goddard Space Flight Center
H	Height
hr	Hour
Hz	Hertz
ID	Inside Diameter
IFM	Inflight Maintenance
in	Inch
IUS	Interim Upper Stage
IVA	Intravehicular Activity
JPL	Jet Propulsion Laboratory
^{o}K	Degree Kelvin
kg	Kilogram
lb	Pound
M	Meter
min	Minutes
ml	Milliliter
mm	Millimeter
MMC	Martin Marietta Corporation
no	Number
n	Newton
NASA	National Aeronautics and Space Administration
OEM	Original Equipment Manufacture
OD	Outside Diameter

ABBREVIATIONS (cont'd)

P	Pressure
phm	Parts/Hundred Million
psi	Pounds per Square Inch
psia	Pound per Square Inch Absolute
psig	Pounds per Square Inch Guage
rad	Radians
RCS	Reaction Control System
RH	Relative Humidity
RI	Rockwell International
RMS	Remote Manipulator System
RMU	Remote Maneuvering Unit
sec	Second
Sin	Sine
SRB	Solid Rocket Booster
SRU	Spacecraft Replaceable Unit
sta	Station
TBD	To Be Determined
TV	Television
V	Volume
v	Velocity
Wt	Weight

I. PROGRAM SUMMARY AND RESULTS

A. PROGRAM SUMMARY

The objective of this contract was to survey existing electrical connector availability, analyze, study, and establish an optimum connector design(s) for maintainable spacecraft substation interfaces. Application was for various "black boxes" and subassemblies required on various types of space flight missions such as experiment support on Spacelab Pallet, Sortie Pallet, and on both manned and unmanned spacecraft service and/or maintenance missions. Orbital assembly operations will be performed by manned extravehicular activity (EVA) or remote servicing methods. Either activity is dependent on the capability to make and break electrical connections in both a controlled environment and the environments of outer space where temperature extremes in a vacuum are of major importance.

The program to develop maintainable spacecraft substation optimum connector design(s) consisted of five tasks as follows:

Task 1 - Establish Functional, Operational, and Environmental Requirements - In this task, the functional, operational and environmental requirements were defined for the connector system to support the leading prototype candidate concepts.

Task 2 - Documentation Review and Survey of Available Existing Connector Designs - This task involved investigating connectors used in previous NASA programs to determine their technical suitability. This was accomplished by conducting a documentation review and surveying NASA contractor original equipment manufacturers and electrical connector suppliers who were listed as approved sources on various NASA-MSFC 40M series connector specifications.

Task 3 - Establish Optimum Connector Design(s) and Modification(s) - In this task, connector designs were generated or existing connector designs were modified to be compatible with the Task 1 requirements established. Separate designs were established for manipulator/EVA crewman and for a spacecraft replaceable unit (SRU).

Task 4 - Sketches to Illustrate the Mounting and Operation of the Recommended Connector(s) - In this task, the recommended designs were sketched to illustrate the mounting and operation. This involved two manipulator/EVA crewman connector sketch and one SRU connector sketch.

Task 5 - Design Evaluation to Determine Optimum Concepts - In this task, connector element concepts were evaluated and selected so that system concepts could be formulated. After formulation, the system concepts were compared and evaluated and the optimum concepts were selected.

The deliverable end products were an interim report, a final report, and sketches of the recommended systems.

B. PROGRAM RESULTS

1. *Requirements* - The following is a summary of the major functional and operational requirements:

- System - The disconnect system must connect/disconnect electrical connections in both a controlled environment and the environments of outer space. The connect/disconnect functions will be manually accomplished by manned EVA or remote servicing methods. The design goal of the system is to provide a low cost, simple, and reliable design. In addition, the design for remote manipulator systems and for manned EVA applications shall be similar with the exception of a possible hand tool for latch/delatch.

- Connector Contacts and Inserts - The connector for the system must meet the requirements of NASA-MSFC specifications 40M39580, 40M38277, and 40M39569 for only the following components of the connector:

  - Contacts per 40M39580;
  - Contact sealing per 40M39580;
  - Inserts per 40M39580;
  - Finishes;
  - Design and construction;
  - Insert arrangements;
  - Shell sizes;
  - Contact current carrying sizes per 40M39580.

- Latching Method - The connector latching method (if required) must be compatible with the end effector on the servicing mechanisms which allow rotation and lateral motions. Any rotational coupling technique must be less than 1.57 rad (90^{o}). Preferred coupling is axial, push-pull actuating mechanism. The latching method shall be mechanical and shall provide forces to lock the connector halves together when mated. On demating, the latching method must release and allow separation of the connector. The connector coupling lock mechanism shall be designed to accommodate remote operation as well as IVA hand and EVA suited glove operation.

- Mating and Unmating Mechanisms - Mechanisms shall be designed to minimize the force required to initially align and affix the mating connectors followed by the required coupling force. The reacting coupling forces shall be confined within the coupled connectors to the greatest extent possible. The connector system must withstand retract and extraction forces applied to the module translated by orbital servicing mechanisms and hand tools.

- Connector Housing - The connector housing shall be scoop-proof and explosion-proof by virtue of sealing the housing before electrical contact is made. Mounting means shall include a hermetic seal capability to the black box or subassembly.

- Materials - Tentatively conform to NASA-MSFC 40M39569 requirements until testing program defined in IIB1 verifies acceptability.

- Alignment Features - The connector system shall incorporate an alignment feature which allows angular and floating tolerances of the orbital servicing mechanisms to final mating of the plug/receptacle to within the tolerances for pins and sockets required in the 40M39580 specification. The use of auxiliary pilot/guide hardware and increased lead-in shall be considered. Locksmith keying polarization features of current 40M connectors shall be utilized.

- Voltage Levels - The disconnect system shall be designed for the following voltage levels:

  - 5 to 32V DC;

  - 115V AC, 60 Hz;

  - 115V AC, 400 Hz.

- Durability - The connector system shall withstand 500 cycles of connect/disconnect.

- Remote Connections Requirements - The connectors must allow mating/demating by remotely controlled equipment (orbiter servicer or manipulator arm). The remote connections can be classified as RMS or rack and panel applications and the requirements are as follows:

  a. RMS Applications:

  - Alignment tolerance (design connector to accommodate or eliminate) ± 3.81 cm (± 1.5 in.), $\pm 8.75 \times 10^{-2}$ rad ($\pm 5^{o}$).

  - Force to mate/demate - less than 6.81 kg (15 lbs) - any greater force requirement must be accommodated by latching mechanism on the end effector.

  - Provide alignment guides and pin protection as required (alignment guides may be located on the module/equipment).

  - Maximum cycle time - 300 sec (5 min.).

  b. Rack and Panel Applications:

  These applications are for connectors that interface with replaceable modules that have alignment rails and pins to achieve alignment tolerances of $\pm 1.02 \times 10^{-2}$ cm ($\pm$ .004 in.) floating and $\pm .57 \times 10^{-2}$ rad ($\pm$ 20 arc min.) angular minimum.

- Manned Operations Requirements - The requirements listed here are for connectors operated by an EVA crewman with the suit pressurized to 24.13×10^{3} N/m^{2} (3.5 psi). Mating/demating of the connectors shall be able to be accomplished utilizing the remote connections requirements within the following limits:

  - Maximum hand rotation required - less than 1.57 rad (90^{o});

  - Maximum grip strength required (without tool usage) - less than 15.89 kg (35 lbs);

  - Maximum torque required (without tool usage) - less than $.230 \times 10^{-3}$ m - kg (20 in.-lb.);

  - Design for one-hand operation;

  - Design to preclude damage to pressure suit;

  - Verify (by procedure) power removed prior to connect/disconnect;

- Design to protect pin contacts;

- Provide alignment and polarization cues as required;

- Minimum connector diameter - 1.59 cm (5/8-in.)

Manned operations of the disconnect system as an IVA exercise should conform to the same general requirements. Although force and torque capabilities in the pressurized environment are greater and design constraints in the absence of the need for an EVA glove are less severe, the same requirements should be utilized in disconnect system design.

2. *Documentation and Survey*

a. <u>Documentation Research and Review Summarization</u> - The documentation research and review activity disclosed that the MSFC 40M series connectors possess the preferred design features of current connector state of the art. These connectors have satisfactorily demonstrated their physical and performance capability in their previous use in the Skylab program and are included in the preferred parts lists of the current Space Shuttle program. The evolvement of connectors for use in manned and unmanned maintainable spacecraft warrants the strong consideration of the continued use of the 40M series connectors. Modifications may be required to facilitate the coupling operation of these connectors to alter the method of actuation and to reduce forces. The 40M series connectors also offer diversified contact sizes and insert arrangements which would cover most electrical circuit requirements for use in maintainable spacecraft applications. A heavy duty connector may be required for certain power applications; a space-compatible connector of this type is currently listed for Space Shuttle usage as a project-peculiar part.

The availability of single-cable coaxial connectors appears to be limited and, by virtue of their design characteristics--especially size and coupling features--would require extensive modification or redesign to enable their use in maintainable spacecraft applications. The only availability of multi-coaxial connectors are those limited arrangements included in the 40M39569 specification or as provided in the Air Lock/Microdot connector. Expansion may be required to facilitate additional coaxial requirements, if anticipated.

Rack-and-panel type connectors are not listed in previous or current NASA manned spacecraft project lists; inclusion of these parts are listed in scientific spacecraft parts lists but these afford no preferred design characteristics which would favor their utilization in manned or unmanned maintainable spacecraft applications.

b. NASA Contractor/Connector Supplier Survey - The survey involved visitation of two NASA contractor original equipment manufacturers (OEM)--Rockwell International Space Division (RI) and TRW--five (5) electrical connector suppliers who are currently listed as approved sources on various MSFC 40M series connector specifications--G&H Technology, ITT Cannon Electric, Deutsch Company, Bendix ECD, and Burndy Corporation--and one (1) supplier of the astronaut suit connector--Air Lock, Inc.

With a basic knowledge of manned and remote capability, the following predominant factors pertaining to the utilization of available connector designs were evolved.

- Connector Contacts and Inserts - The current available MSFC 40M series electrical contacts and connector inserts could probably be utilized in future circular connectors for maintainable spacecraft applications.

- Coupling Mechanisms - The current available rotational concepts (bayonet, threaded) for coupling/uncoupling of connectors should be modified to significantly reduce the coupling action to less than 1.57 rad (90°) or, more precisely, replaced with axial, push-pull actuating mechanism. Emphasis should be placed on reducing the applied coupling forces to overcome contact engagement and seal compression inherent forces by increasing the efficiency and mechanical advantages of actuating mechanisms.

  Mechanisms should be designed to minimize the force required to initially align and affix the mating connectors followed by the required coupling force. The reacting coupling forces should be confined within the coupled connectors to the greatest extent possible.

  The existing requirements of the MSFC 40M39580 specification demand strong consideration as viable requirements for maintainable spacecraft applications. Cetain modification of this connector's design features may be required to improve its operation and to adopt its use for unmanned applications.

- Alignment Features - The alignment features of current available connectors should be improved to facilitate their ability to be properly coupled. The use of auxiliary pilot/guide hardware and increased lead-ins should be considered. Locksmith keying polarization features of current connectors is preferred to prevent mismating of adjacent connectors.

* Miscellaneous Connector Features - Scoop-proof connector features for all contact sizes should be considered to afford adequate protection of pin contacts. The necessity for explosion-proofing would be contingent on system parameters including combustible atmospheres and procedural requirements for the disruption of active electrical circuits.

* Single Cable Coaxial Connectors - Use of single-cable coaxial connectors should be discouraged in that current available connectors are not deemed suitable for maintainable spacecraft application in terms of handling and actuation. Multi-coaxial applications should be more thoroughly investigated to determine the adequacy of current available configurations to meet performance (frequency, VSWR, impedance, etc) requirements.

* Rack and Panel Connectors - Modular type, rack and panel connectors should be regarded as a separable connector design than that of hookup, circular connectors due to their unique application. The rectangular connectors would appear to be most space-and-force efficient although the circular versions do offer the advantage of utilization of available inserts and contacts. The alignment features of the current available rack and panel connectors should be improved to facilitate their mateability in a more limited environment. More emphasis might be placed on the module racking and alignment provisions and tolerancing to minimize the need for extensive or elaborate connector alignment features.

3. *Optimum Designs* - Design concepts for electrical connectors were developed for three remote servicing applications as follows:

* Spacecraft replaceable modules serviced by manipulators;
* Suited crewman performing EVA tasks;
* Connectors mated/demated by manipulators independent of other servicing operations.

These system concepts were developed by first identifying major design elements and developing concepts for each element. Concepts were developed for the following elements:

* Alignment - Grossly aligning the plug half with receptacle half for both floating and angular tolerances.

* Latching - Latching the plug to the receptacle prior to inserting the pins into the sockets.

- Drive Mechanisms - Mating the pins into the sockets including fine alignment.

- Locking Devices - After final pin/socket mating, the firm lock-up of the plug to the receptacle.

- Polarization - Techniques to ensure mating compatible plugs into receptacles.

Advantages/disadvantages tables were prepared for each design element to aid in the concept evaluations. After evaluation of the design elements, the two top elements were combined into overall system concepts. It was determined that crewman EVA tasks and independent manipulator tasks should be the same design to eliminate hardware inventory and minimize hardware costs. Three concepts were developed for these applications:

- Yoke/pin alignment with linkage drive;

- Tapered cone alignment with linkage drive;

- Interlocking face flange alignment with cam drive.

An alternate connector approach tapered cone alignment with cam drive, was also developed which was a combination of the last two concepts above.

Spacecraft replaceable module concepts included utilizing a standard NASA 40M series without the locking ring for SRUs that have alignment tracks and pins that can achieve the final tolerances required for mating. For concepts that have only alignment tracks that cannot meet the final mating alignment tolerances, two concepts were developed to meet the final tolerances:

- Compression spring centered plug with gimbal receptacle.

- Flex-pivot centered plug with gimbal receptacle.

4. *Mounting and Operation Sketches* - The selected designs based upon the evaluation, were then sketched to show the mounting and operational features. Sketches were generated for the following:

- EVA suited crewman mating a plug/cable into a receptacle in the Orbiter payload bay.

- Manipulator mating a plug cable on a serviceable spacecraft without the aid of guide rails and alignment pins such as the Space Telescope.

- A replaceable module being positioned into a structure of a spacecraft and the mating sequence of its electrical connector. Also shown are two possible connector locations.

- A manipulator mating a plug into an alignment track without fine alignment pins.

These sketches can be found in Section VI, Figures VI-1 through VI-5.

5. *Evaluation* - A design evaluation was performed on all concepts to determine the optimum solution for each application. This evaluation was accomplished as follows:

- Consideration factors were established for each design element from the advantages/disadvantages tables. For the system concepts, design parameters were defined.

- Each consideration factor and design parameter were then evaluated to determine which were more important to the overall selection of the concept. These were then converted into a factor weight that was expressed as a percent of total value.

- This factor weight was then multiplied by a comparative rating assigned to each candidate concept. The totals were then compared with the highest value being the concept that best matches the system requirements.

Table I-1 summarizes the design elements selected. The system concepts selected are summarized in Table I-2.

A thermal analysis was prepared to investigate sensitivity to temperature extremes for connector alignment, pin/socket dimensional variations, and conductor current carrying capacity. In addition, a hardware simulation was accomplished to verify that a modified NASA 40M series specification connector without the locking sleeve could be successfully mated in conjunction with a spacecraft module replacement mechanism.

6. *Documentation Submittals* - Documentation submittals were prepared and submitted in accordance with the contract report requirements. The following is a brief description of each submittal:

Progress Reports - These reports summarized all work accomplished during each month. These reports were submitted as Martin Marietta No. MCR-76-377.

Table I-1 Selected Design Element Candidates

DESIGN ELEMENT	FUNCTION	SELECTED CANDIDATES
Alignment	Plug to Receptacle Alignment	• Cone and pivot • Tapered square shaped cone plug and receptacle • Interconnecting face flanges
Latching	Coupling of Two Connector Halves	• Yoke pivot with spring loaded latch • Interconnecting flange with spring-loaded ball detent
Drive Mechanism	Pin to Socket Insertion	• Mechanical linkage driving core side pins • Cam drive
Locking	Maintaining Pin-Socket Positions	• Overcenter link • Overcenter cam
Polarization	Pin/Socket Protection	• Pin/hole pattern • Tabs/notches pattern

Table I-2 System Concepts Selected

APPLICATION	SYSTEM CONCEPT	MOUNTING & OPERATION SKETCH FIGURE NO.
EVA Suited Crewman and Manipulator Without Guide Rails/Pins	Tapered cone alignment with linkage drive. Alternate: Tapered cone alignment with cam drive.	Figures VI-1, VI-2 and VI-3. Figures VI-4, VI-5 and VI-6.
Spacecraft Replaceable Module With Guide Rails and Pins	Standard NASA 40M specification connector or modified to eliminate the connecting ring.	Figure VI-7.
Spacecraft Replaceable Module With Only Gross Alignment	Flex pivot centered plug with gimbal receptacle.	Figure VI-8.

Interim Report - This report describes the functional requirements established for the Electrical Disconnect System and the results of the connector documentation review and survey. The report was submitted as Martin Marietta No. MCR-76-393.

Final Report - This report documents and summarizes the results of the entire contract work, including recommendations and conclusions. The report was submitted as Martin Marietta No. MCR-77-2.

II. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

1. Separate electrical connector designs are required for the following remote servicing applications:

   - spacecraft replaceable modules,
   - crewman EVA.

2. The connector design for crewman EVA applications is also compatible with the remote manipulator system for remote connection of electrical disconnects within the Shuttle payload bay or on a serviceable spacecraft,

3. Material compatibility for the environment extremes of 88.71°K (-300°F) to 372.04°K (210°F) is unknown and must first be tested prior to specifying insert materials.

4. The designs developed are compatible with the statement of work requirements for their intended applications.

5. The designs developed are applicable to terrestrial applications requiring remote handling due to hostile environments or inaccessible areas.

B. RECOMMENDATIONS

Remote servicing of spacecraft requires the mating and demating of electrical connectors. This program has developed concepts for various remote applications that should be developed in parallel with other remote servicing mechanisms and hardware. It is recommended that continued development be accomplished as follows:

1. *Perform Materials Testing* - Test criteria should be evolved to practically evaluate the adequacy of materials and mechanisms in selected space environments (i.e., temperature extreme of 88.71°K (-300°F) for male half being mated to 372.04°K (210°F) female half to determine the ability of connectors to properly function

and operate when coupled/uncoupled in these environments.

2. *Develop Manipulator/EVA Detail Prototype Design* - Prepare detail design drawings of the selected manipulator/EVA connector to a detail that can be fabricated. The design should allow for a standard insert to be compatible with the connector mechanism and provide for an interface with the connector shell.

3. *Fabricate Prototype Connector* - Fabricate manipulator/EVA connector in accordance with prototype design drawings.

4. *Perform Development Testing* - A test plan should be developed and testing should be conducted as follows:

   <u>Mode 1 - EVA Crewman</u> - Conduct neutral buoyancy tests with a suited test subject and an EVA connector with the inserts. The man-machine characteristics could be tested as the test subject mates/demates the connector in the simulated EVA environment.

   <u>Mode 2 - Manipulator</u> - Utilizing a manipulator connector, conduct mating/demating sequences, with a manipulator and task panel, to check compatibility and life of the connector.

   <u>Mode 3 - Spacecraft Replaceable Module Connector</u> - Perform removal/replacement of a SRU with a manipulator utilizing a modified NASA 40M series connector without the locking sleeve.

   <u>Mode 4 - Modified 40M Connector</u> - Utilizing a modified 40M connector and mounting it to a structure that allows for pitch, roll, and yaw movements, demonstrate mating/demating of the connector utilizing a manipulator system.

5. *Perform Environment Testing* - Perform a test program on the manipulator/EVA connector that includes additional life tests and a complete environmental test program per Shuttle MF0004-014 requirements to verify the mechanism portion of the connector.

III. TASK 1 - POTENTIAL APPLICATIONS AND REQUIREMENTS

A. PURPOSE AND SCOPE

This section presents the results of Task 1 of the contract effort. In Section B.1 potential applications of electrical disconnect systems for Shuttle-era spacecraft are discussed. The functional, operational, and environmental requirements for electrical disconnects for use on manned and unmanned missions are defined in Section B.2. The details which form the basis of this report were derived from available Shuttle Orbiter, Spacelab, and payload requirements documentation. The disconnect applications identified were derived from consideration of the philosophy of spacecraft refurbishment, servicing, or repair to increase lifetime and reduce costs.

B. POTENTIAL APPLICATIONS

Figure III-1 below summarizes the steps utilized to identify specific potential applications of electrical disconnect systems for this contract effort. It should be noted that each mission and payload type were examined against each possible task opportunity. The specific technique used to accomplish the identified task for a given payload was then identified (IVA, EVA, or remote).

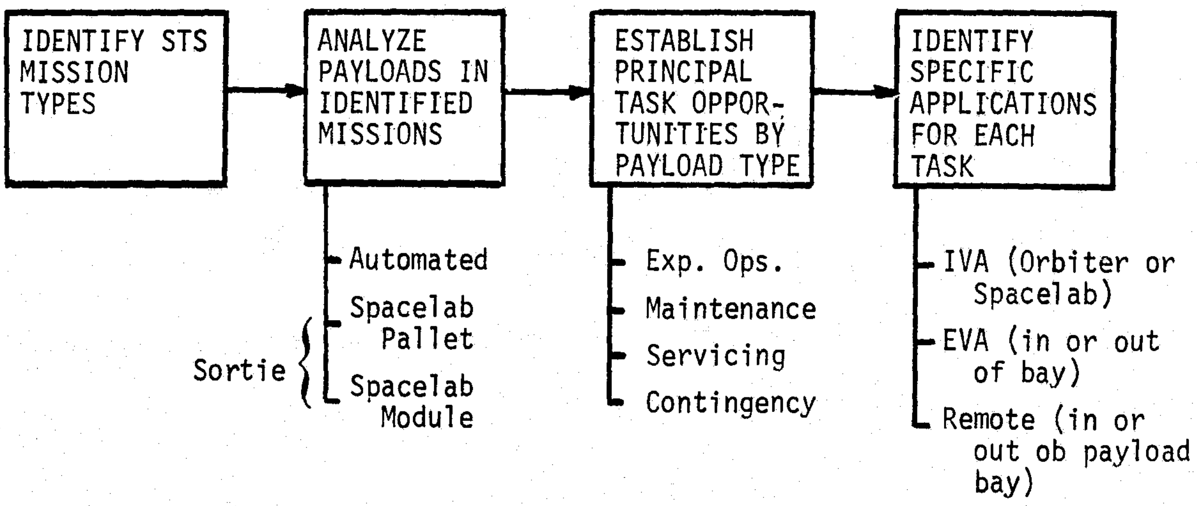

Figure III-1 Identification of Electrical Disconnect Applications (STS-Related)

1. *STS Missions and Payloads Analysis* - The Space Transportation System (STS) includes the Shuttle Orbiter with its cargo bay, which can carry payloads such as automated spacecraft, the Interim Upper Stage (with attached spacecraft), pallet-mounted experiments, or the pressurized Spacelab module. Mission models prepared by the NASA for the 1980's indicate that many combinations of paylaods make up the projected missions.

For the purposes of this study, mission configurations are not as important as the characteristics of the major paylaod types. Sortie payloads are those payloads which are carried into orbit in the Orbiter cargo bay, and which remain in the bay for the entire flight. The payloads or experiments are mounted on pallets and are controlled either from the ground, the Orbiter aft flight deck, or from the Spacelab pressurized module also mounted in the cargo bay. Thus, sortie payloads implicitly rule out the repositioning or reconfiguration of equipment during flight, and therefore, limit the requirement for electrical disconnects except in contingency modes.

Automated payloads are autonomous spacecraft which are carried into orbit in the cargo bay and either deployed directly or carried to operational orbit by an Interim Upper Stage (IUS). Such payloads--particularly if designed to be on-orbit maintainable (as opposed to expendable or ground-refurbishable)--may directly require the use of electrical disconnect systems for normal operations. Table III-1 shows a list of automated payloads which might require such systems.

2. *Principal Task Opportunities* - As shown in Figure III-1, the general tasks which might involve electrical disconnect systems can be categorized as experiment operations, maintenance, servicing, or contingency procedures. In general, nominal experiment operations (for any payload) do not include mating/demating of electrical connectors. (The only identified potential exceptions to this are two Life Sciences experiments which include instrumentation to be utilized both in the Orbiter AFD and in the pressurized Spacelab module.)

Pallet and module payloads are generally not designed for on-orbit servicing or maintenance. Particularly for early Shuttle missions, which will be of seven days duration, payloads should not require replenishment of supplies, subsystem changeout, or any similar activities. Only in the case of contingency operations may there be a requirement for electrical disconnect systems to be available in the Orbiter AFD, Spacelab module, or on the pallet.

For automated payloads, as Table III-1 shows, maintenance or servicing operations in orbit are anticipated. Of course, all such procedures would be performed in the space environment using either

Table III-1 Automated Payloads/On-Orbit Maintainable

Payload Number	Payload Model Code No.	Spacecraft Name
AS-01-A	AST-6	Space Telescope
AS-03-A	AST-1B	Cosmic Background Explorer
AS-05-A	AST-1C	Advanced Radio Astronomy Explorer
AS-07-A	AST-N1	3m Ambient Temperature IR Telescope
AS-11-A	AST-N2	1.5m IR Telescope
AS-13-A	AST-N3	UV Survey Telescope
AS-14-A	AST-N4	1m UV Optical Telescope
AS-16-A	AST-8	Large Radio Observatory Array
AS-17-A	AST-N5	30m IR Interferometer
HE-01-A	AST-9B	Large X-Ray Telescope Facility
HE-03-A	AST-5A	Extended X-Ray Survey
HE-05-A	AST-5D	High Latitude Cosmic Ray Survey
HE-07-A	PHY-1A	Small High Energy Satellite
HE-08-A	AST-5B	Large High Energy Observatory A
HE-09-A	AST-4	Large High Energy Observatory B
HE-10-A	AST-5C	Large High Energy Observatory C
HE-11-A	AST-9A	Large High Energy Observatory D
HE-12-A	PHY-5	Cosmic Ray Laboratory
SO-02-A	AST-7	Large Solar Observatory
SO-03-A	AST-3	Solar Maximum Mission
AP-01-A	PHY-1B	Upper Atmosphere Explorer
AP-02-A	PHY-1C	Explorer - Medium Altitude
AP-04-A	PHY-2A	Gravitational and Relativity Satellite - LEO
AP-05-A	PHY-3A	Environmental Perturbation Satellite - A
AP-07-A	PHY-3B	Environmental Perturbation Satellite - B
EO-08-A	EO-3	Earth Observatory Satellite
EO-09-A	EO-4	Synchronous Earth Observatory Satellite
EO-10-A	EO-5	Applications Explorer (Special Purpose Satellite)
EO-12-A	EO-6	TIROS
EO-56-A	NN/D-8	Environmental Monitoring Satellite
EO-57-A	NN/D-9	Foreign Synchronous Meteorological Satellite
EO-58-A	NN/D-10	Geosynchronous Operational Meteorological Satellite
EO-59-A	NN/D-12	Geosynchronous Earth Resources Satellite
EO-61-A	NN/D-11	Earth Resources Survey Operational Satellite
EO-62-A	NN/D-13	Foreign Synchronous Earth Observation Satellite
OP-02-A	EOP-5	Gravity Gradiometer
OP-04-A	EOP-7	GRAVSAT
OP-05-A	EOP-8	Vector Magnetometer Satellite
OP-51-A	NN/D-14	Global Earth and Ocean Monitoring System
LS-02-A	LS-1	Biomedical Experiment Scientific Satellite
CN-51-A	NN/D-1	INTELSAT
CN-52-A	NN/D-2A	DOMSAT A
CN-53-A	NN/D-2B	DOMSAT B
CN-54-A	NN/D-3	Disaster Warning Satellite
CN-55-A	NN/D-4	Traffic Management Satellite
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CN-59-A	NN/D-6	Communications R&D Prototype

remote systems or an EVA crewman. Present IUS ground rules specify that no recovery of the IUS (or its payload) will be performed; therefore, disconnect system requirements should be emphasized for low earth orbit spacecraft only (deliverable directly by Shuttle). Several techniques have been defined to perform such servicing/maintenance remotely, and these include a pivoting arm servicer, the Shuttle remote manipulator system (RMS), the flight support system (FSS), and the remote maneuvering unit (RMU). Specific EVA operations have also been defined for such payloads as the Space Telescope.

Contingency operations on automated payloads may also be possible, either remotely or EVA, but would primarily involve the same disconnect requirements as defined for planned servicing or maintenance.

Table III-2 summarizes specific task opportunities for each major payload type.

Table III-2 Disconnect System Task Opportunities by Payload Type

General Task	PAYLOAD TYPE			
	Automated	Pallet Only	Spacelab Module	Orbiter AFD
Experiment Ops			X (limited)	X (limited)
Maintenance	X			
Servicing	X			
Contingency	X	X	X	X

3. *Specific Applications/Technique* - The general tasks identified in paragraph IIIB2 above must in general be accomplished by either direct EVA techniques, remote EVA (manipulator systems), or by IVA in the Orbiter or Spacelab pressurized environments. Some of the activities related to automated payloads might be completed by any of the EVA techniques. Specific examples of each application can be cited.

Servicing of the Space Telescope, for example, will be performed by direct EVA in the subsystems or science instrument modules. The flight support system (FSS) is the intended servicer for such spacecraft as the Earth Observatory Satellite and the Solar Maximum Mission. The pivoting arm servicer might be utilized on the Large

High Energy Observatory. The remote manipulator system (Shuttle) can assist in the scheduled or contingency maintenance activities of the other systems, including EVA assistance. The remote maneuvering unit can perform activities outside the Orbiter payload bay at distances of up to 30 km from the Orbiter. The application of disconnect systems to IVA for Life Sciences experiments has already been noted.

All these general tasks may involve cable-to-cable, cable-to-equipment and equipment-to-equipment connections, with some restrictions based on operational requirements. Maintenance tasks performed remotely, for example, are essentially blind connections between modules. IVA requirements could include both cable-to-cable and cable-to-equipment applications.

Such considerations allow definition of the functional, operational and environmental limits within which electrical disconnect systems must perform. Detailed requirements in each of these areas were generated based on the anticipated potential applications.

C. REQUIREMENTS

The overall requirements which electrical disconnect systems must satisfy are largely defined by the tasks which they must perform. They must operate properly in space vacuum and in the Orbiter or Spacelab pressurized environment. They must allow operation (mate/demate) with bare hands (IVA), with pressurized EVA gloves, or remotely (blind connection).

The following paragraphs summarize the requirements for electrical disconnect systems in terms of functional, operational, and environmental criteria.

1. *Functional Requirements* - These requirements relate to the characteristics of the disconnect system, independent of the environments and conditions to which they may be subjected. These requirements are as follows:

- System - The disconnect system must connect/disconnect electrical connections in both a controlled environment and the environments of outer space. The connect/disconnect functions will be manually accomplished by manned EVA or remote servicing methods. The design goal of the system is to provide a low cost, simple, and reliable design. The system shall consider vibration and mechanical shock requirements coupled in both the hot and cold extremes.

- Connector Contacts and Inserts - The connector for the system must meet the requirements of NASA-MSFC specifications 40M39580, 40M38277 and 40M39569 for only the following components of the connector:

  - Contacts per 40M39580;
  - Contact sealing per 40M39580;
  - Inserts per 40M39580;
  - Finishes;
  - Design and construction;
  - Insert arrangements;
  - Shell sizes;
  - Contact current carrying sizes per 40M39580.

- Latching Method - The connector latching method (if required) must be compatible with the end effector on the servicing mechanisms which allow rotation and lateral motions. Any rotational coupling technique must be less than 1.57 rad (90°). Preferred coupling is axial, push-pull actuating mechanism. The latching method shall be mechanical and shall provide forces to lock the connector halves together when mated. On demating, the latching method must release and allow separation of the connector. The connector coupling lock mechanism shall be designed to accommodate remote operation as well as IVA hand and EVA suited glove operation.

- Mating and Unmating Mechanism - Mechanism shall be designed to minimize the force required to initially align and affix the mating connectors followed by the required coupling force. The reacting coupling forces shall be confined within the coupled connectors to the greatest extent possible. The connector system must withstand retract and extraction forces applied to the module translated by orbital servicing mechanisms and hand tools.

- Connector Housing - The connector housing shall be scoop-proof and explosion-proof by virtue of sealing the housing before electrical contact is made. Mounting means shall include a hermetic seal capability to the black box or subassembly.

- Materials - The materials to be utilized in the system shall tentatively conform to the requirements of the NASA-MSFC 40M39569. This tentative selection is valid until future testing data under the environmental extremes are available to verify adequacy of material during cycling connection/disconnection.

- Alignment Features - The connector system shall incorporate an alignment feature which allows angular and floating tolerances of the orbital servicing mechanisms to final mating of the plug/receptacle to within the tolerances for pins and sockets required in the 40M39580 specification. The use of auxiliary pilot/guide hardware and increased lead-ins shall be considered. Locksmith keying polarization features of current 40M connectors shall be utilized.

- Voltage Levels - The disconnect system shall be designed for the following voltage levels:

  - 5 to 32V DC;

  - 115V AC, 60 Hz;

  - 115V AC, 400 Hz.

- Durability - The connector system shall withstand 500 cycles of connect/disconnect.

2. *Operational Requirements* - Operational requirements relate to the actual techniques which will be utilized to connect and disconnect the electrical components. These techniques are separable into two major categories--remote (blind) connections and operations performed directly by a crewman.

a. Remote Connections - The connectors must allow mating/demating by remotely controlled equipment (Orbiter servicer or manipulator arm). The remote connections can be classified as RMS or rack and panel applications and the requirements are as follows:

- RMS Applications:

  Alignment Tolerance (design connector to accommodate or eliminate) ± 3.81 cm (± 1.5 in.), $\pm$ 8.75×10^{-2} rad ($\pm 5^{\circ}$).

  Force to Mate/Demate - less than 6.81 kg (15 lbs) - any greater force requirement must be accommodated by latching mechanism on the end effector.

  Provide alignment guides and pin protection as required (alignment guides may be located on the module/equipment.

  Maximum Cycle Time - 300 sec (5 min.).

- Rack and Panel Applications:

  Utilize existing MSFC specifications 40M38277 and 40M39569 less coupling sleeve.

b. Manned Operations - The requirements listed here are for connectors operated by an EVA crewman with the suit pressurized to 24.13 x 10^3 N/m^2 (3.5 psi). Mating/demating of the connectors will be accomplished utilizing the RMS application requirements within the following limits:

- Maximum hand rotation required - less than 1.57 rad (90°);
- Maximum grip strength required (without tool usage) - less than 15.89 kg (35 lbs);
- Maximum torque required (without tool usage) - less than .230 x 10^{-3} m-kg (20 in.-lb);
- Design for one-hand operation;
- Design to preclude damage to pressure suit;
- Verify (by procedure) power removed prior to connect/disconnect;
- Design to protect pin contacts;
- Provide alignment and polarization cues as required;
- Minimum connector diameter - 1.59 cm (5/8 in.).

Manned operations of the disconnect system as an IVA exercise should conform to the same general requirements. Although force and torque capabilities in the pressurized environment are greater, and design constraints in the absence of the need for an EVA glove are less severe, the same requirements should be utilized in disconnect system design.

3. *Environmental Requirements* - Electrical disconnect systems must operate in the pressurized Orbiter environment, the pressurized Spacelab module, the unpressurized payload bay, or completely external to the Orbiter vehicle. The disconnects must withstand launch and reentry environments in the above locations, and must allow connect/disconnect operations to be conducted during on-orbit periods. General requirements are described in the following paragraphs.

a. <u>Orbiter Pressurized Environment</u> - The following are applicable as design to environments.

- Pressure

  (1) Ground

  (a) Structural Leak Check - 2.07×10^5 N/m^2 (30.0 psia) max.

  (b) Operational Leak Check - 1.24×10^5 N/m^2 (18.0 psia) max.

  (c) Ambient - $.85 \times 10^5$ N/m^2 (12.36 psia) to 1.05×10^5 N/m^2 (15.23 psia).

  (d) O_2 Partial Pressure - $.22 \times 10^5$ N/m^2 $\pm$ $.017 \times 10^5$ N/m^2 (3.2 $\pm$ 0.25 psia).

  (2) Orbital Mission

  (a) Range - $.95 \times 10^5$ N/m^2 (13.7 psia) to 1.10×10^5 N/m^2 (16.0 psia).

  (b) Emergency - $.55 \times 10^5$ N/m^2 (8.0 psia) max, 9.9×10^3 sec (165 min.) max.

- Temperature

  (1) Ground

  (a) Atmospheric and Structural - 274.82°K (35°F) to 322.04°K (120°F).

  (2) Ferry Flight

  (a) Atmospheric and Structural - 249.82°K (-10°F) to 305.37°K (+90°F).

  (3) Orbital Flight

  (a) Atmospheric - 291.48°K (65°F) to 305.37°K (90°F).

  (b) Structural - 289.26°K (61°F) to 322.04°K (120°F).

- Humidity

  (1) Ground - 8 to 100% RH

(2) Orbital Mission - 85% RH maximum at 291.48°K (65°F) dry bulb; 17% RH minimum at 305.37°K (90°F) dry bulb.

- Lightning - refer to MF0004-002.

- Shock - All components shall be designed to withstand a 20g terminal sawtooth shock pulse of an 11 millisecond duration in each of three orthogonal axes (six directions).

- Acceleration - Ultimate steady-state acceleration from 0 to $\pm$5g's in each direction of each major axis.

- Structural Vibration - TBD.

b. Payload Bay - The following are applicable as design to environments:

- Pressure

  (1) Ground - .85 x 10^5 N/m^2 (12.36 psia) to 1.05 x 10^5 N/m^2 (15.23 psia).

  (2) Ferry Flight - .23 x 10^5 N/m^2 (3.28 psia) to 1.05 x 10^5 N/m^2 (15.23 psia).

  (3) Orbital Mission - 1.33 x 10^{-8} N/m^2 (1 x 10^{-10} torr) to 1.05 x 10^5 N/m^2 (15.23 psia).

  (4) Approach and Landing Test - .23 x 10^5 N/m^2 (3.28 psia) to .96 x 10^5 N/m^2 (13.9 psia).

- Temperature

  (1) Ground - 242.59°K (-23°F) to 338.71°K (150°F).

  (2) Ferry Flight - 219.26°K (-65°F) to 327.59°K (130°F)

  (3) Orbital Mission - 88.71°K (-300°F) to 372.04°K (210°F)

  (4) Approach and Landing Test - 233.15°K (-40°F) to 338.71°K (150°F)

- Solar Radiation - assume 18.1 x 10^9 J/m^2/sec (443.7 Btu/ft^3/hr).

- Shock - All components shall be designed to withstand a 20g terminal sawtooth shock pulse of an 11 millisecond duration in each of three orthogonal axes (six directions).

- Acceleration - see Table III-3 below.

Table III-3 Orbital Mission Crash Safety Load Factors

	g_x +Aft	g_y +Right	g_z +Up
Zone 1*	+20.0	$\pm$3.3	+10.0, -4.4
Zone 2**	+ 9.0 - 1.5	$\pm$1.5	+4.5, -2.0
Zone 3***	No crash load factor requirements		

Zone 1* (20g's)

(1) Flight deck (Sta. 439 to Sta. 576, above Z^o 419)

(2) Mid-deck (Sta. 387 to Sta. 576, Z^o 328 to Z^o 419)

Zone 2** (9g's)

(1) Forward RCS package

(2) Mid fuselage

(a) Equipment bay (below Z^o 330)

(b) Payload attachment

(c) Manipulator arm attachment

Zone 3*** (No requirement)

(1) All other areas of Orbiter Space

Load factor is equivalent to the total externally applied load on the component divided by the component weight, and carries the sign of the total externally applied load.

c. Spacelab Pressurized Module Environment - Environmental requirements for equipment contained in the Spacelab module are detailed in Section 5.0 of the *Spacelab Payload Accommodation Handbook*, Estec Reference No. SLP/2104.

IV. TASK 2 - DOCUMENTATION RESEARCH AND SURVEY

A. PURPOSE AND SCOPE

The purpose of this activity was to perform documentation research and review to investigate and to relate Martin Marietta experiences associated with those connectors used in previous NASA programs and to determine their technical suitability or design characteristics for possible consideration for use in manned and unmanned maintainable spacecraft connector applications.

B. DOCUMENTATION RESEARCH AND REVIEW

1. *Review of NASA Project Parts Lists* - This activity involved the review of selected project parts lists which prescribed preferred connectors for the past Skylab program and for the current Space Shuttle program. The Jet Propulsion Laboratory (JPL) and Goddard Space Flight Center (GSFC) parts lists for general space projects were also reviewed. Brief abstracts of this research follow.

- Skylab Program, *Preferred Electrical Parts List for Apollo Applications Program*, MSFC Document 85M02716, Revision C, dated 25 June 1972.

  This document lists the MSFC 40M39569 connector as the sole, preferred, miniature, circular connector. Listing of the MSFC radio frequency connectors are also included.

- Skylab Program, *Skylab Program, MMC Skylab Experiments EEE Parts List*, JSC Document MSC-00841, EL40-001, Revision 8, dated 15 May 1972.

  This document lists the MSFC 40M39569 miniature circular, the 40M39580 zero-g, and various project-peculiar Martin Marietta-use connectors, including the Air Lock/Microdot astronaut connector, for use on the various Skylab experiment, instrumentation, TV communication, and Multiple Docking Adaptor end items. The predominant-use 40M39569 and 40M39580 and Air Lock/Microdot connectors are considered to be the most technically viable candidates for use in manned and unmanned maintainable spacecraft applications. Other project-peculiar connectors were of specialized design and of limited application and would offer no significant design features which could be effectively adapted to meet the objectives of this study.

- Space Shuttle Program, *EEE Parts Selection and Application Guidelines for the Space Shuttle External Tanks and Solid Rocket Booster (ET and SRB)*, MSFC document 85M03936, Revision B, dated 15 February 1975.

  This document lists the MSFC 40M39569 miniature circular, the 40M39580 zero-g, and the 40M38277 high density circular connectors. These connectors are considered as those which currently possess the most favorable design characteristics or features best suited for possible use in manned and unmanned maintainable spacecraft applications.

- Space Shuttle Program, *Electrical, Electronic, and Electromechanical Orbiter Project Parts List*, Rockwell International (RI) document MF0004-400, Revision A, Sequence 03, dated April 1976.

  This document lists the MSFC 40M39569 miniature and 40M38277 high density circular connectors, and the RI project-peculiar ME414-0611 hermetic feedthrough, ME414-0235 straight plug, ME413-0234 wall-mount receptacle connectors, MC414-0343 TNC coaxial, and MC414-0344 HN coaxial connectors. Connector accessories for the multi-contact connectors are also listed including the short clamp nut, backshell with straight strain relief, and backshell with right-angle strain relief. The latest addendum also adds notation that the 40M connectors have not qualified to the Orbiter temperature (specifically, to 116.48^{o}K (-250^{o}F) and vibration requirements. This effort is in process at RI. The MSFC connectors are the preferred items used in current NASA projects for general cable hook-up applications. The ME414-0234 and -0235 connectors are of the MIL-C-5015, MS3450 type with crimp, removable contacts, threaded coupling design, and constructed with space-compatible materials. The RI project-peculiar connectors are listed with limited shell sizes and insert arrangements primarily for size 0, 4, and 8 contacts for power applications.

- General Space Applications, *Preferred Materials, Fasteners, Processes, and Packaging and Cabling Hardware*, Jet Propulsion Laboratory document JPL-STD-00009, Revision A, dated April 1976.

  This document lists specialized, custom connectors procured to JPL specification 20045/2-0 for the MIL-C-24308-type, subminiature "D" rectangular, rack-and-panel, solder contact type, and JPL specification 2245-0300 for the MIL-C-26482, MS3100-series, circular, solder contact type connectors. A limited-use, rectangular, rack-and-panel separation connector is also listed for specialized applications. These connectors are uniquely utilized in scientific spacecraft designs and possess no substantial features which would meet the basic design requirements for this study.

- General Space Applications, *GSFC Preferred Parts List*, GSFC document PPL-12, dated July 1972, with Notice 2, dated August 1973.

  This document lists GSFC specifications S-311-P-10 and S-311-P-4/5 for MIL-C-24308-type, subminiature "D" rectangular, rack-and-panel connectors of the solder and crimp contact types and containing quantities of 9, 15, 25, 37, and 50 contacts and the MIL-C-22557 miniature, screw-on, coaxial, radio frequency connectors for flight usage. Similar to JPL applications, these connectors are utilized in specialized applications and lack the necessary features required for maintainable spacecraft applications.

2. *Review of MSFC Connector Specifications* - This effort involved the review of each of the current MSFC 40M series specifications--40M38268, 40M38277, 40M38294, 40M38298, 40M39569, and 40M39580--to ascertain their technical suitability or adaptation for use in manned and unmanned maintainable spacecraft applications. Since these connectors, with the exception of the 40M38277, 40M38294, and 40M38298 connectors which were not available, performed satisfactorily in the Skylab program, their continued use in future projects, including the Space Shuttle program, warrants strong consideration. In that the newer 40M specifications are based essentially on the same material and performance requirements as their predecessors, and the conventional rotational bayonet-locking or threaded coupling mechanisms of these connectors may not be suitable for use in maintainable spacecraft, a new type or altered mechanism may be required. The 40M39580 mechanism, specifically designed for astronaut use, does offer features which merit consideration for use in maintainable spacecraft applications, notably one-hand, axial push-pull actuation with minimal force required for initial alignment and coupling followed by increasing forces for seal and contact engagement. The design and construction of the 40M series connectors affecting contact installation, insert, and seal/grommet characteristics are acknowledged to be of the latest technological state-of-the-art. The 40M series connector alignment and polarization features are consistent with current connector design; features affecting explosion- and scoop-proofing are lacking with the exception of the 40M39580 connector. The materials

associated with these connectors, having previous Skylab experience associated with earth and on-orbit controlled and space environments, would also warrant continued use for maintainable spacecraft applications. The electrical and performance characteristics of the 40M series connectors are listed in Table IV-1.

3. *Martin Marietta Related Experience* - Martin Marietta served as the principal contractor for the Multiple Docking Adapter and a number of Skylab experiments. In addition to the MSFC 40M39569 and 40M39580 predominant-use connectors, approximately 15 project-peculiar specification control drawings were prepared to specify the unique requirements for connectors utilized in special applications. These included the heavy duty, power, and multicoaxial feedthrough connectors used in the MDA penetrator to the microminiature, .127 cm (0.050 in.) centers, twist pin connectors used in various Skylab medical experiments.

The life-support umbilicals and TV communications system utilized the Air Lock/Microdot astronaut connector. Experience with these connectors showed their sensitivity to handling, particularly with the microminiature types. Fracture of plastic shells, bending of pin contacts, and connector damage caused during contact installation were the predominant problems encountered during fabrication. Also, difficulties were experienced in the proper termination and assembly of miniature and subminiature contacts used in the multicoaxial connectors.

Problems associated with the 40M39580 zero-g connector involved coupling mechanism hang-up resulting from inner-to-outer shell binding and linkage action. Some problems were also experienced with incorrect installation of the peripheral dynamic seal. Pin-to-socket contact engagement adequacy was also investigated under worst-case connector mating conditions.

With the exception of the Air Lock/Microdot connector where it was determined that the contact engagement integrity was dependent on the location of the Air Lock shell with respect to the panel thickness and its tolerancing, all other critical use connectors showed satisfactory electrical engagement in excess of .127 cm (0.050-in.).

It is known that the high density-type connectors utilizing size 22 contacts and those common to the MIL-C-38999 specification (i.e., 40M38277 and 40M39580) are typically rated as minimal engagement in their design. The engagement integrity of the multi-coaxial and the MIL-C-39012 single coaxial connectors is also rated as minimal in the calculated engagement of approximately .025 cm (0.010-in.) under worst-case conditions. Any modification or redesign of these

Table IV-1 NASA-MSFC 40M Specification Summary

Specification No.	Description	Classification	Styles	Shell Sizes	Contact Sizes	Shell Mtl.	Shell Finish	Oprn. Temp.	MECHANICAL REQUIREMENTS: Cpling. T.	MECHANICAL REQUIREMENTS: Durability	MECHANICAL REQUIREMENTS: Vibration	MECHAN… Vibrat…
MSFC 40M38268	Terminal Junction Assembly (See Remarks)											
MSFC 40M38277	Miniature, Circular, high density, low profile, bayonet cpling	Environmental(E), Hermetic (H)	Plug, St. Plug, Grd Plug, w/o cpl'g ring Recept, flg mtd Recept, jam nut Recept, solder Mtd Recept, thru Blkhd	8 thru 24	22D	Al Alloy Carb. steel St. steel	Nickel Tin Pass'vte	123.15°K to 473.15°K (-238°F to +392°F) (for E); 123.15°K to 423.15°K (-238°F to +302°F) (for H)	.0914 to .4343 m kg (8 to 38 in-lbs)	250 cycles	Sine: 10 to 55 Hz @ .325 DA, 55 to 2000 Hz @ 50 g, Pk Rand: 20 to 100 Hz @ 6 db/oct, 100 to 2000 Hz @ 1 g^2/Hz	Sine: … Rand: …
MSFC 40M38294	Miniature, Circular, cryogenic, Thd'd Cplng	Environmental(E), Hermetic (H) Non-Envirn'tl(I)	Plug, Int'nl Plug, Ext'nl Recept, feed thru Recept, weld MT	8 thru 18, 22, 24	20,16,12, 8 coax	Al alloy St. steel	Nickel Pass'vte	4.26°K to 473.15°K (-452°F to +392°F)	No Rqmt	200 cycles	Sine: 10 to 55 Hz @ .325 DA, 55 to 2000 Hz @ 50 g, Pk Rand: 20 to 100 Hz @ 6 db/oct, 100 to 2000 Hz @ 1 g^2/Hz	Sine: … Rand: …
MSFC 40M38298	Miniature, Circular, bayonet cpling, shell size 8	Environmental(E)	Plug, St Recept, Jam Nut	8 only	20	Al Alloy	Nickel	123.15°K to 473.15°K (-238°F to +392°F)	.0914 m kg (8 in-lbs)	500 cycles	Sine: 10 to 55 Hz @ .325 DA, 55 to 2000 Hz @ 50 g, Pk Rand: 20 to 100 Hz @ 6 db/oct, 100 to 2000 Hz @ 1 g^2/Hz	Sine: … Rand: …
MSFC 40M39569	Miniature, Circular, bayonet cplng	Environmental(E) Hermetic (H)	Plug, St. Plug, Grd Plug, w/o cpl'g ring Recept, flg mtd Recept, jam nut Recept, solder mtd Recept, thru blkhd	8 thru 24	20,16,12, 8 coax, 12 shld'd	Al alloy St. steel	Nickel Pass'vte	123.15°K to 473.15°K (-238°F to +392°F) (for E); 123.15°K to 423.15°K (-238°F to +302°F) (for H)	.0914 to .4343 m kg (8 to 38 in-lbs)	500 cycles	Sine: 10 to 55 Hz @ .325 DA 55 to 2000 Hz @ 50 g, Pk Rand: 20 to 100 Hz @ 6 db/oct, 100 to 2000 Hz @ 1 g^2/Hz	Sine: … Rand: …
MSFC 40M39580	Circular, astronaut-use, push-pull cplng mechanism	Environmental(E) Hermetic (H) Cryogenic (C)	Plug, St. Recept, flg mtd Recept, jam nut	15,17, 21,25	20,16, 12,22D	Al alloy St. steel	Chrome Pass'vte	208.15°K to 423.15°K (-85°F to +302°F) (for E) 302.59°K to 423.15°K (+85°F to +302°F) (for H); 20.37°K to 423.15°K (-423°F to +302°F) (for C)	3.37 to 6.67 N (12 to 24 oz) premate 17.82 to 53.46 N (4 to 12 lbs) cplng force	250 cycles	Sine: 10 to 55 Hz @ .325 DA, 55 to 2000 Hz @ 50g, Pk Rand: 20 to 100 Hz @ 6 db/oct, 100 to 2000 Hz @ 1 g^2/Hz	Sine: … Rand: …

FOLDOUT FRAME

MECHANICAL REQUIREMENTS		ELEC. REQ'MTS		MISC. REQ'MTS			
Vibration	Phys. Shock	Contact Rating	DWV	Moist. Resistance	Explo. ATM	Scoop Proof	Remarks
							Not a disconnect-type device· not applicable for this study
Sine: 10 to 55 Hz @ .325 DA, 55 to 2000 Hz @ 50 g, Pk Rand: 20 to 100 Hz @ 6 db/oct, 100 to 2000 Hz @ 1 g^2/Hz	1/2 sinewave, 75g, 11 ms	22D: 5 Amps	1300 vac @ seal 350 vac @ 70k ft 200 vac @ 110k ft	10 cycles, 90 to 98% RH, 10°C to 65°C	7% H, 93% O, Mated, Energized ckts	No	Space compatible mtls· 9 insert arr'mts avail w/ 6 to 128 contacts; keying via key rotation. Used on Space Shuttle.
Sine· 10 to 55 Hz @ .325 DA, 55 to 2000 Hz @ 50 g, Pk Rand: 20 to 100 Hz @ 6 db/oct. 100 to 2000 Hz @ 1 g^2/Hz	1/2 sinewave, 75g, 11 ms	20: 7.5A 16: 20A 12: 35A	1500/2300 vac @ Sea Level for Service I/II: 375/550 vac @ 70k Ft for I/II; 250 vac @ 110k ft for I & II: 200 vac @ 10^{-6} mm Hg for I & II	10 cycles, 90 to 98% RH, 10°C to 65°C	No Req'mt	No	Space compatible mtls· 13 insert arr'mts avail w/ 1 to 61 contacts: keying via key rotation. Used on Space Shuttle.
Sine: 10 to 55 Hz @ .325 DA, 55 to 2000 Hz @ 50 g, Pk Rand· 20 to 100 Hz @ 6 db/oct. 100 to 2000 Hz @ 1 g^2/Hz	1/2 sinewave, 75g, 11 ms	20: 7.5A	1500 vac @ Sea L. 250 vac @ 110k ft 200 vac @ 10^{-6} mm Hg	10 cycles, 90 to 98% RH, 10°C to 65°C	7% H, 93% O, Mated, Energized circuits	No	Mtls same as 40M39569· 3 insert arr'mts avail w/ 2 to 4 contacts, keying via key rotation
Sine: 10 to 55 Hz @ .325 DA 55 to 2000 Hz @ 50 g, Pk Rand· 20 to 100 Hz @ 6 db/oct, 100 to 2000 Hz @ 1 g^2/Hz	1/2 sinewave, 75g, 11 ms	20: 7.5A 16: 20A 12: 35A	1500/2300 vac @ Sea Level, for Service I/II; 375/550 vac @ 70k ft for I/II; 250 vac @ 110k ft for I & II; 200 vac @ 10^{-6} mm Mg for I & II	10 cycles, 90 to 98% RH, 10°C to 65°C	7% H, 93% O: mated· energized ckts	No	Space compatible mtls, 29 insert arr'mts avail w/ 3 to 61 contacts, incl coaxial. Keying via insert rotation. Used on Skylab, Space Shuttle
Sine: 10 to 55 Hz @ .325 DA, 55 to 2000 Hz @ 50g, Pk Rand· 20 to 100 Hz @ 6 db/oct, 100 to 2000 Hz @ 1 g^2/Hz	1/2 sinewave, 75g, 11 ms	22D: 5A 20: 7.5A 16: 13A 12: 23A	1300/1500/2300 vac @ Sea Level for Service M/I/II; 300/400/500 vac @ 50k ft; 200 vac @ 110k ft for M, I & II	10 cycles, 90 to 98% RH, 10°C to 65°C	7% H, 93% O: mated, energized ckts	Yes	Space compatible mtls· designed for one-hand oprn, astronaut-use. 12 insert arr'mts avail w/ 6 to 61 contacts Keying via roll pin & slot. Utilizes movable plug insert. Used on Skylab program

FOLDOUT FRAME 2

type connectors should include an assessment of contact engagement integrity to assure proper connector function.

A Martin Marietta connector study of single and redundant release systems associated with separation-type connectors was recently completed in March 1976 under contract to the U. S. Air Force. This study surveyed the current use separation mechanisms and presented factors which should be considered in the design of redundant release systems. The involvement of connector alignment, coupling, and release forces and retention reliability was also documented. The findings gained through this study would most likely have an influence on the design of coupling mechanisms for use in manned and unmanned maintainable spacecraft applications.

4. *Research of Miscellaneous Related Documents* - In addition to Martin Marietta previous experience on the Skylab Program, a search was conducted to verify the actual inflight experience reported for the three (3) manned Skylab missions. Telephone conversations with MSFC and JSC personnel indicated that no significant connector concerns or problems were encountered as reported by the Skylab crews. Martin Marietta participants at each of the oral crew debriefings reported no serious connector problems, nor were any anomalies presented including the specific address of the 40M39580 connector.

NASA Technical Memorandum, Report No. NASA TM X-64814, dated October 1974, entitled *MSFC Skylab Mission Report--Saturn Workshop*, was perused and confirmed that no major connector anomalies or difficulties were experienced by the crews. A damaged connector on the TV input station was the sole item discussed in this report and proved to be of no significant consequence. One comment suggested that improved markings on connector shells for visual alignment and locking indication be entertained as a future improvement.

NASA Technology Utilization Compilations, SP-5936 (01), (02), and (03) on the subjects of cables and connectors and SP-5908 (04) on hand tools were reviewed to obtain information which might be appropriate for this study. Of particular interest were those devices associated with the blind mating, alignment, non-arcing, and low-force coupling of connectors (SP-5936 (01), five items) and a one-hand operated connector coupling tool (SP-5908 (04)).

The Rome Air Development Center technical report, *Reliability Study (of) Circular Electrical Connectors*, Report No. RADC-TR-73-171, dated June 1973, was reviewed to afford an in-depth baseline of connector statistical reliability data which was gained from this comprehensive study. The conclusions of this study indicate that

".... the best reliability and overall performance will be obtained either from MIL-C-38999, Series I, or from MIL-C-83723." The design of the 40M38277 Series connectors resembles the MIL-C-38999, Series I, parts with the basic exception that the 40M connectors are not scoop-proof; however, the preferred contact retention and insert design features are the same. The insert design of the 40M39580 Series connectors are identical to those of MIL-C-38999 and 40M38277 (for the size 22 contact arrangements).

C. NASA CONTRACTOR ORIGINAL EQUIPMENT MANUFACTURERS SURVEY

The survey involved visitation of two NASA contractor original equipment manufacturers (OEM)--Rockwell International Space Division (RI) and TRW. Of the two OEMs visited, only RI has had previous experience associated with serviceable space flight connectors. These connectors were of the general types currently listed for use in the Space Shuttle Orbiter and the Shuttle External Tanks and Solid Rocket Booster preferred parts lists. RI also stated that they have had previous experience with the astronaut-use MSFC 40M39580 zero-g and Air Lock/Microdot connectors used on life support umbilical cables in the Skylab program. RI mentioned that various problems were encountered with previous-use connectors but none were considered to be of a major concern or catastrophic consequence and which were not satisfactorily resolved. A concern associated with the adequacy of contact engagement (pin height) and coupling mechanism actuation with the zero-g was reported and should be more thoroughly investigated for future use of this connector. TRW's expertise has been involved primarily with scientific satellites where nonserviceable, lightweight connectors have been exclusively utilized.

Both contractors indicated current participation in the Space Shuttle program. RI is the prime contractor for the Shuttle Orbiter and TRW is providing the Orbiter communications systems and a number of Shuttle payloads. Both OEMs indicated the preferred use of MSFC 40M39569 and 40M38277 connectors for the majority of the Shuttle applications. No explicit requirement currently exists to provide connectors suitable for on-orbit servicing. With the exception that RI is in current process of qualifying the 40M series connectors to a lower temperature capability 116.48^{o}K (-250^{o}F) than that currently specified 123.15^{o}K (-238^{o}F), all other requirements in the 40M specifications are deemed adequate for use in the Space Shuttle program. To date, no major connector application problems have been cited in conjunction with the Shuttle Orbiter or Shuttle communications systems. One contractor reported, however, that a continual concern exists relative to the tearing of wire-seal grommets during contact installation and especially with the MSFC 40M38277 high density connector and that this concern is being resolved by training of assembly personnel.

For future or anticipated NASA projects, both contractors felt that the current state-of-the-art for connectors would be satisfactory. This would indicate that the current connector materials and design characteristics for NASA space-use connectors would be adequate. Military specification versions would not, however, be suitable.

Specific address of factors affecting utilization of connectors for on-orbit manned (IVA, EVA) and unmanned (remote) space flight applications indicated that many uncertainties exist. One contractor reported that connectors anticipated to be used at the Shuttle Orbiter payload interface panels, payload operations stations, and prelaunch payload service panel have not been defined to date. This contractor is currently involved with the Space Shuttle System Payload Accommodations Study and expects that these connector requirements will soon be established. Until such time as more discrete connector maintainability/serviceability and performance requirements are evolved, no specific assurance could be established by the contractors as to the total adequacy of current available connectors. Both OEMs did agree that the available electrical contacts and connector inserts used in connectors listed for use in the Shuttle program would probably be satisfactory for anticipated maintainable spacecraft applications. One contractor did suggest that for weight and space savings, NASA should consider the incorporation of additional size 12, 16, and 20 electrical contacts in the MSFC 40M38277 specification. Both participants indicated that the present threaded and bayonet coupling features of current-use connectors would not be suitable for manned and unmanned spacecraft applications. In order to facilitate connector coupling/uncoupling in these applications, the present forces should be reduced most practically through the use of auxiliary or increased efficiency mechanisms. The use of in-line or axial actuating mechanisms would be preferred over the conventional rotating (bayonet or threaded) means for connector coupling. Innovations of the "zero insertion force" concept whereby connectors would be initially mated with no significant force and where secondary action is employed to effect contact engagement was favored by one contractor. Where force reductions cannot be practically reduced, particularly in large-size connectors, the use of coupling assist tools should be considered. It was also suggested that improved connector alignment features be developed to more positively assure proper engagement of connectors and especially for those remote applications where visibility is reduced or negated.

Coincident with these factors, one OEM felt that the alignment features of current NASA-use connectors would be manageable for maintainable spacecraft applications whereas the other participant indicated that additional mismatch tolerancing of the present alignment features or the possible use of secondary alignment devices be utilized to facilitate connector coupling. No strong opinions were voiced relative to the adequacy of current available connector polarization features with the exception that one contractor stated the current locksmith keying concept is preferred over the rotating insert method. A difference of opinion was expressed relative to the need for contact protection, or scoop-proofing. One contractor stated that scoop-proofing should be a mandatory requirement for all contact sizes whereas the other indicated that the present non-scoop MSFC 40M39569 and 40M38277 connectors would be suitable. Both OEMs indicated that explosion-proofing would not be necessarily a critical nor essential requirement for maintainable spacecraft applications. One contractor reported that their technical practices dictate that "live" circuits be deenergized whenever connectors are to be coupled or uncoupled.

Both contractors would subscribe to the use of the MSFC 40M38277, high-density, size 22 contact connector for maintainable spacecraft applications. As previously indicated, however, one contractor suggested the scoop-proof feature--and especially for size 22 electrical contacts--be incorporated in this connector. The contractors would also permit the use of hermetic seal connectors, as required, in spite of their susceptibility to damage of the annealed pin contacts. One contractor indicated their nonpreference of hermetic connectors was due primarily to the large increase of resistance or voltage drop with their use. One contractor stated the current connector cable accessories listed in the MSFC 40M series specifications would continue to be suitable; the other prefers not to use accessories but favors potting of connectors to provide strain relief and termination of shields. Both OEMs also stated reparability of connectors on-orbit would not be practical in that accessibility to component-installed receptacles or jacketed cable plugs would not be attainable. For contingency purposes, however, the current state-of-the-art construction characteristics of the MSFC 40M series connectors would permit their repair of discrete circuits.

Both contractors reported that the present single-cable coaxial and multi-coaxial connectors would not be suitable for use in maintainable spacecraft applications. Current NASA specifications for these connectors and contacts do not list impedance-control requirements, according to the participants, nor would the present products be totally suitable for S-band and higher frequencies. Also, single-cable coaxial connectors would require more manageable coupling mechanisms to facilitate their use but no practical suggestions were offered.

For modularization of maintainable spacecraft components as commonly designated space replaceable units (SRU), discussion centered on the use of rack-and-panel, blind mate connectors. Typically, these connectors would require alignment and coupling force capability through the facility of the module installation racking and securing support hardware. One participant stated that these type connectors are not preferred in their design of avionics systems in that the rack-and-panel connectors are more prone to contact damage and would require substantial strengthening of avionics enclosures to withstand the ensuing connector mating forces and to provide axial tolerancing to assure proper connector engagement which might otherwise be jeopardized due to deflection of panel interfaces. The other contractor suggested that modification of present connectors may be required to facilitate their use in maintainable spacecraft applications. Both OEMs believed that the alignment and mateability features of current available rack-and-panel connectors should be improved. These would include the expanded use of dowel-and-cone piloting and more ample shell lead-in chamfers. Both participants also believed that the MSFC 40M39569 and 40M38277, Style 6W, plug-less-coupling ring connectors might be made adaptable for use in rack-and-panel applications to favor the availability of a wide variety of space-proven inserts and contacts; however, this adaptation could amount to a significant or substantial effort.

D. NASA CONNECTOR SUPPLIER SURVEY

The survey involved the visitation of five electrical connector suppliers who are currently listed as approved sources on various MSFC 40M series connector specifications: G&H Technology; ITT Cannon Electric; Deutsch Company; Bendix ECD; and Burndy Corporation; and one supplier of the astronaut suit connector, Air Lock, Inc. With the exception of two suppliers--G&H Technology and Burndy--all other suppliers indicated they had manufactured products used on the past Apollo and Skylab programs. All suppliers except Burndy stated they are currently involved with the Space Shuttle program. With the exception of two suppliers, all others generally felt the current connector state-of-the-art, as typlified in the MSFC 40M series specifications, would be adequate for future or anticipated NASA projects in that the realm of space environment characteristics has now been essentially established. One of the excepting suppliers believes new requirements may be established at the onset of any future program such as the Shuttle requirements for the MSFC 40M38294 cryogenic connector or for the unique Orbiter-to-747 Transport interface connector. The other excepting supplier feels the adequacy of present state-of-the-art connector materials should be thoroughly investigated to establish their use in maintainable spacecraft applications. This concern relates to the functional capability of connectors which would be exercised (i.e., coupled/uncoupled) in the space environment and particularly at the extreme cold temperature 123.15°K to 116.48°K (-238°F to -250°F) where the elasticity of materials such as flexural elastomers may not function responsively to preserve or maintain the operational integrity of the connector. This supplier suggested new test criteria be evolved to require that, for on-orbit serviceability applications, connectors be coupled/uncoupled at the extremes of applicable space environments and, with special consideration of the Shuttle mission profile, the repeated cyclic requirement of the earth launch-on-orbit-earth return environments.

With specific address of connector maintainability in manned (IVA, EVA) and unmanned (remote) space flight applications, the MSFC 40M series circular connector suppliers felt the current 40M series electrical contacts and connector inserts would effectively satisfy those requirements affecting material suitability and quantified application demands for electrical circuitry. The current available rotational MSFC 40M series coupling mechanisms would not be suitable according to the 40M suppliers. One supplier felt their proprietary breech locking mechanism characterized by a 1.57 rad (90 degree) maximum rotation and a .253 x 10^{-3} m-kg (22 in.-lb) (maximum) torque would satisfy manned requirements. Other suppliers suggested that an axial, push-pull actuation would best suit both manned and unmanned applications. One supplier felt that the MSFC 40M39580 zero-g connector mechanism would warrant continued use for manned applications and could be modified, if required, to facilitate use with manipulator mechanisms. Another supplier disclosed that a competitive design to the zero-g connector was generated during the Skylab program for presentation to MSFC but was not pursued due to its timeliness. The details of this connector design were not revealed during this survey but would be available through MSFC. The air lock/microdot push-pull mechanism is of a frictional-fit design relating directly to the contact engagement and peripheral O-ring frictional forces. No mechanical advantage is offered with this coupling concept. The suppliers concurred that the present coupling forces should be reduced. These forces are essentially attributed to contact engagement/separation forces and environmental and interfacial seal compression. These forces could best be compensated for by providing more efficient coupling mechanisms to increase the mechanical advantage for the operator (man or mechanical manipulator).

The use of compression springs remains the principal source of stored energy to assist in the coupling/uncoupling activity where the increased mechanical advantage attained with helical ramping or screw threads may not be suitable for manned or unmanned applications. One supplier stated the coupling forces should be minimized at initial engagement and should gradually increase to effect the total coupling followed by force reduction to provide coupling assurance via "feel" as opposed to a constant, no-force variance effect. This concept is exemplified in the coupling action of the MSFC 40M39580 zero-g connector. It was also suggested that coupling/uncoupling forces and reactions be confined or contained at or within the connectors by squeezing actions of the hand or manipulator articulator as opposed to force transmission or reactance through the entire operator medium (human arm, body, or manipulator linkages, pivots/joints). Should force reductions not be practically attainable, then assisting power mechanisms or servicing tools may be required.

The suppliers were also of the opinion that probable connector access limitations would require that the alignment characteristics of the current MSFC 40M series connectors be modified, particularly for use with manipulators. More generous mismatch tolerancing should be provided by means of preengage connectors piloting through increased shell lead-in or funneling or by auxiliary guidance (i.e., dowel-and-cone) devices. The 40M suppliers confirmed that the current connector polarization characteristics were generally adequate--the locksmith keying concept was favored over the insert rotation design. The supplier of the MSFC 40M39580 zero-g connector acknowledged the previous problems associated with the roll-pin polarization device and suggested a coined/dimpled protrusion could be substituted in future products.

Most suppliers were not strongly opinionated as to the necessity for explosion-proofing of connectors. The predominant means of sealing off of interconnector insert void during engagement is with the use of peripheral O-rings or dynamic seals. Static discharging could be essentially suppressed through the grounding or contacting of engaging shells prior to contact engagement. Three suppliers stated that scoop-proofing features should be incorporated in space application connectors, especially for size 20 electrical contacts--and smaller, to preclude inadvertent damage during handling.

One supplier recognized the coupling/uncoupling sensitivity for the use of single-cable coaxial connectors in manned and unmanned spacecraft applications and suggested the coupling mechanisms be redesigned, including significant enlargement, to provide a more manageable means of handling and actuation. Another possible means of modification would be to incorporate the internal elements of the single-cable coaxial connector into a conventional circular connector housing. Those suppliers involved with multi-coaxial connectors felt the present product availability, including the MSFC 40M39569 size 8 coaxial and size 12 shielded configurations would be adequate for future, general applications. One supplier stated that a GSFC concern exists relative to, "... the cascading VSWR oscillation effects..." which can result in the generation of excessive temperatures which could disintegrate the cable-to-contact termination and is tentatively attributed to the contact componentry/configuration and axial fit dimensional tolerances.

When queried as to the merits of the "zero insertion force" connector concepts for manned and unmanned spacecraft applications, no prevalent opinions were expressed with the exception that one supplier felt a "zero" initial mating force followed by a secondary actuation to engage the contacts (i.e., the MSFC 40M39580 zero-g connector concept) would be an approach to satisfy the minimal involvement to engage connectors and to confine the contact engagement forces within the coupled connectors.

In the address of rack-and-panel connectors for modularized SRU applications, three of four suppliers offering comments on this subject felt the current available rack-and-panel connectors would generally be suitable. The remaining supplier suggested that the alignment capability of the present connectors would not be adequate and that a new product featuring increased alignment capability and tighter dimensional product tolerancing--including tighter control of mounting provisions--is required. In effect, three suppliers recognized the alignment features of the present connectors should be improved by increasing shell lead-in or by use of auxiliary guide hardware to permit their use. One supplier suggested more emphasis on chassis guide provisions and the use of module guide pins would facilitate the continuing use of available rack-and-panel connectors. The possible use of fiber optics to ascertain proper connector alignment on a remote hasis was also suggested. The suppliers generally agreed that the alignment features of existing connectors should be improved to the extent that maximum connector mismatch can be tolerated and the connectors physically engaged with minimal frictional forces and with resulting contact engagement within the allowable axial tolerances.

Three of four suppliers stated the MSFC 40M39569 and 40M38277, Style 6W, plugless coupling ring connectors would not be ideally suited for rack-and-panel applications in that these connectors possess no self-contained alignment features whereas the remaining commentor suggested that these might be used only if critical adapter fixtures were evolved to permit "ganging" or multiple use of these connectors and would control their lateral and axial positioning to compensate for their lack of self-contained alignment. One supplier suggested the consideration of their circular, rack-and-panel connector for modularized SRU applications. This product is currently designed for an alignment mismatch of $\pm$.157 cm ($\pm$.062 in.) and could be modified to increase this allowance. It possesses a spring-loaded frontal protrusion feature which assures proper axial engagement. Current MSFC 40M series insets could be installed in this product. This connector, however, does require additional force during mating to reposition the spring-loaded connector.

It was disclosed by three suppliers that they were currently in process of responding to a GSFC quotation for rectangular, rack-and-panel connectors for Multimission Modular Spacecraft. The essential requirements for this connector-type include a $\pm$.030 cm/.174 rad ($\pm$.012 in./$\pm$10 degree) alignment mismatch, a mixed quantity of up to 160 various size power and coaxial contacts, friction-fit coupling, float-mounted plate, and blind mate capability. One supplier suggested an existing product would satisfy most of the GSFC requirements, whereas another proposed that a totally new concept should be evolved.

V. TASK 3 - CONNECTOR SYSTEM DESIGNS

A. PURPOSE AND SCOPE

The objective of this task was to formulate connector system designs to be compatible with the established requirements. This included manipulator/EVA crewman operated systems and spacecraft replaceable unit systems.

B. SYSTEM DESIGN ELEMENTS CONCEPTS

After reviewing the functional and environmental requirements, Task 1, several key system design elements became evident. These were:

- Floating and angularity alignment;
- Latching of the two connector halves;
- Drive mechanism for pin-to-socket insertion;
- Polarization;
- Effects of thermal extremes (This includes items such as pin/socket interfacing, mate/demate alignment, operation of locking devices, effect on insert material and sealing.);
- Shell design (This includes areas of sealing, scoop-proofing, vibration and mechanical shock.).

Concepts were generated for each of the system design elements along with operation and descriptions, advantages, and disadvantages. These are summarized in Tables V-1 thru V-5. Each of these element concepts were evaluated as discussed in paragraph VII.B, and the leading candidates were combined into system concepts.

C. MANIPULATOR/EVA SYSTEM CONCEPTS

The manipulator/EVA system concepts are for those applications where either a suited crewman on an EVA operation or a manipulator with an integrated end effector requires mating/demating a connector umbilical system. For minimum spares and hardware inventory, the concepts were developed for compatibility with either the EVA crewman or the manipulator system.

These connector system candidates were formulated from the top element concepts and in accordance with the requirements specified in paragraph III.C. A brief summary description of each candidate is provided in the following:

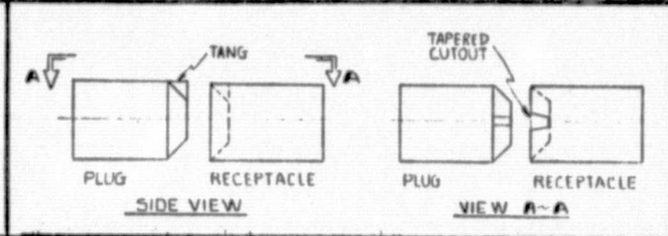
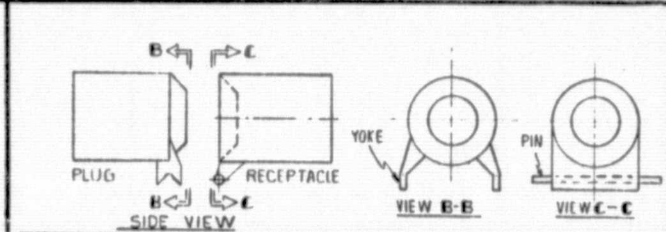
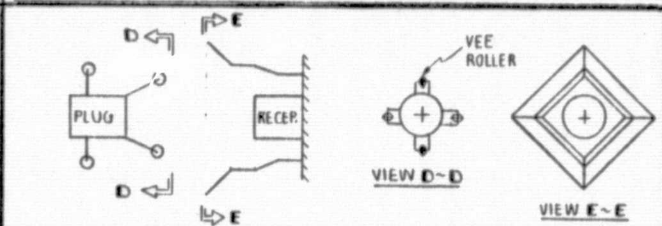
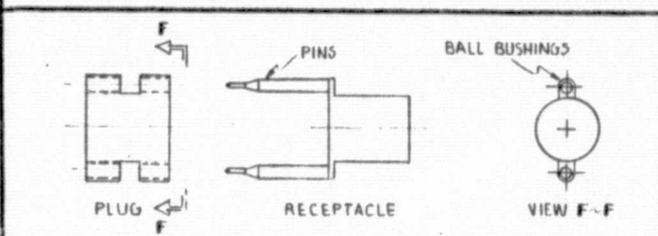
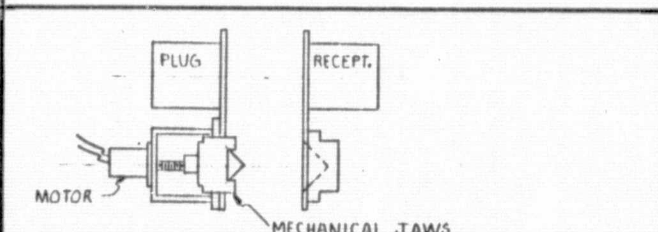
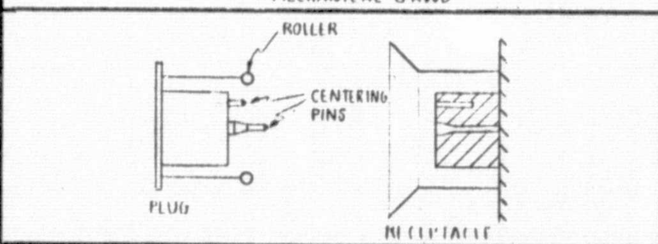
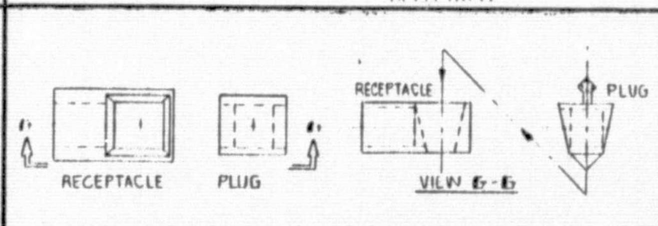
Concept 1 - This concept as shown in Figure V-1 consists of a receptacle and plug that uses a pivot pin and cone arrangement for gross and fine alignment, mechanical linkage for the drive mechanism, a spring-loaded catch for connector half latching, overcenter link for locking, and pin/notch pattern for polarization.

The receptacle is designed to allow the installation of a standard socket insert. A concentric recess around the insert provides for the fine alignment when the plug shell slips into this cavity. This surface is also the sealing surface for the explosion proofing seal. External to this recess and at the separation cone are the polarization slots that match pins on the plug assembly. At the base of the separation plane, two pivot pins and slide plates are located. The spacing between the plates is 7.62 cm (3-in.). A recessed cone surface is provided at the separation plane that is concentric with the center core. A slanted index slide plate intersects the front portion of the receptacle and spans a distance of 10.16 cm (4-in.) from top to bottom. This plate is used to guide the yoke portion of the plug onto the pivot pins. A square shaped attachment flange is also machined onto the receptacle housing.

The plug half of the connector contains a movable center core that contains a standard pin insert. Side drive pins in the center core protrude through slots in the plug housing. These pins are attached to a drive linkage with spring-loaded position locks. A pivoting handle configured for both EVA crewman and an RMS end effector attaches to the drive links. On top of the plug body is the location of the spring-loaded coupling latch. The latch assembly extends past its pivot to the side of the housing where the leg of the handle can contact it and push the latch to the open position when demating is desired. The front portion of the plug has a protruding cone section that matches the inverted cone surface of the receptacle. The lower front surface of the plug contains two protruding yoke arms that pick up the swivel pins on the receptacle.

The sequence of mating these two connector halves is shown in Figure V-2 and described as follows. First, the plug is oriented in a tilted back position so that the protruding yoke arms are well in front of the

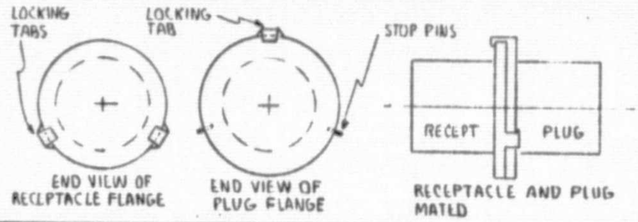
Table V-1 Alignment Concepts Advantages/Disadvantages

CONCEPT	ILLUSTRATION	OPERATION AND DESCRIPTION
CONE AND TANG		THE MALE/FEMALE CONE PROVIDES THE AXIAL ALIGNMENT AND THE TANG/NOTCH PROVIDES THE CLOCKING ALIGNMENT. AS THE TWO PARTS ARE BROUGHT TOGETHER THE TANG IS CENTERED IN THE TAPERED CUTOUT UNTIL THE CONES ARE MATED AND THE ALIGNMENT COMPLETED.
CONE AND PIVOT		THE MALE/FEMALE CONE PROVIDES THE AXIAL ALIGNMENT AND THE YOKE/PIN PROVIDES THE CLOCKING ALIGNMENT. THE YOKE ON THE PLUG CONTACTS THE PIN ON THE RECEPTACLE AND THEN THE PLUG PIVOTS AROUND THE PIN ALLOWING THE CONES TO MATE AND ALIGNMENT IS COMPLETED.
VEE ROLLERS IN TAPERED CONE		THE FOUR CORNERED RECEPTACLE CONE AND THE PLUG WITH MATCHING VEE-ROLLERS PROVIDES AXIAL AND CLOCKING ALIGNMENT. THE CONE IS TAPERED TO COMPENSATE FOR THE ALLOWABLE MISALIGNMENT AND AS THE TWO HALVES ARE BROUGHT TOGETHER THE MISALIGNMENT IS REDUCED TO A FEW THOUSANDTHS OF AN INCH.
BALL BUSHINGS WITH SHARP NOSE PINS		BALL BUSHINGS ON THE SIDE OF THE PLUG MATCH WITH THE PROTRUDING PINS ON THE RECEPTACLE TO PROVIDE AXIAL AND CLOCKING ALIGNMENT. THE DIAMETER OF THE BALL BUSHINGS IS LARGER THAN THE EXPECTED MISALIGNMENT AND AS THE SHARP NOSE TAPERED PINS ENTER THE BUSHINGS, THE MISALIGNMENT IS REDUCED TO ALLOW MATING OF CONNECTOR HALVES.
CONE W/ ELECTRO-MECHANICAL FLANGE CLAMPS		THE MALE/FEMALE CONE PROVIDES THE AXIAL ALIGNMENT AND THE MECHANICAL JAWS AND SQUARE FLANGE PROVIDE THE CLOCKING ALIGNMENT. AS THE TWO PARTS ARE BROUGHT TOGETHER, THE JAWS ARE ACTUATED WHICH CLAMP AND ALIGN BOTH PARTS TOGETHER. THE PLUG AND RECEPTACLE ARE ADJACENT AND PARALLEL TO THE ALIGNMENT MECHANISM.
CENTER PIN AND ROLLERS IN TAPERED CONE		ROLLERS AND CONE PROVIDE A GROSS ALIGNMENT AND CENTERING PINS PROVIDE FINE AXIAL AND CLOCKING ALIGNMENT. AS THE TWO HALVES ARE BROUGHT TOGETHER THE ROLLERS CONTACT THE TAPERED CONE AND FUNNEL THE ALIGNMENT PINS TO THEIR RESPECTIVE BUSHINGS WHERE FINE ALIGNMENT IS MADE TO ALLOW CONNECTOR MATING.
TAPERED SQUARE SHAPED CONE PLUG AND RECEPTACLE		THE PLUG ASSEMBLY IS SQUARE SHAPED AND TAPERED TO A POINT AND THE RECEPTACLE IS A MATCHING TAPERED RECESS THAT PROVIDES AXIAL AND CLOCKING ALIGNMENT. THE RECEPTACLE RECESS IS SIZED TO COMPENSATE FOR THE EXPECTED MISALIGNMENT. THE CENTERLINE OF THE CONNECTOR IS PERPENDICULAR TO THE ALIGNMENT CONE AXIS.

FOLDOUT FRAME 1

DESCRIPTION	ADVANTAGES	DISADVANTAGES	*SELECTED CONCEPT
ROVIDES THE AXIAL /NOTCH PROVIDES THE S THE TWO PARTS ARE TANG IS CENTERED IN IL THE CONES ARE MATED LETED.	1. ALIGNMENT TECHNIQUE IS CONCENTRIC WITH CONNECTOR. 2. RELATIVELY COMPACT IN SIZE. 3. STANDARD CONNECTOR INSERT CAN BE USED. 4. TANG/NOTCH CAN BE USED FOR POLARIZATION. 5. REQUIRES MINIMUM ALIGNMENT FORCE.	1. SIZE IS PROPORTIONATE TO ALLOWABLE MISALIGNMENT.	
ROVIDES THE AXIAL /PIN PROVIDES THE HE YOKE ON THE PLUG E RECEPTACLE AND THEN THE PIN ALLOWING ALIGNMENT IS COM-	1. ALIGNMENT TECHNIQUE IS CONCENTRIC WITH CONNECTOR. 2. STANDARD CONNECTOR INSERT CAN BE USED. 3. REQUIRES MINIMUM ALIGNMENT FORCE.	1. REQUIRES AXIAL AND PIVOT MOTION (OTHER CONCEPTS USE AXIAL AND ROLL MOTION).	*
PTACLE CONE AND THE S -ROLLERS PROVIDES GNMENT. THE CONE IS FOR THE ALLOWABLE E TWO HALVES ARE ISALIGNMENT IS RE- DTHS OF AN INCH.	1. ALIGNMENT TECHNIQUE IS CONCENTRIC WITH CONNECTOR. 2. STANDARD CONNECTOR INSERT CAN BE USED. 3. REQUIRES MINIMUM ALIGNMENT FORCE. 4. IDEAL FOR LARGE MISALIGNMENTS.	1. REQUIRES ACCURATE MACHINING AND TOLERANCING DURING FABRICATION. 2. RELATIVELY LARGE ENVELOPE VOLUME.	
CH E IDE OF THE PLUG MATCH NS ON THE RECEPTACLE ERLOCKING ALIGNMENT. LL BUSHINGS IS LARGER S. IGNMENT AND AS THE NG ENTER THE BUSHINGS, DUCED TO ALLOW MATING	1. ALIGNMENT TECHNIQUE IS CONCENTRIC WITH CONNECTOR. 2. STANDARD CONNECTOR INSERT CAN BE USED. 3. REQUIRES MINIMUM ALIGNMENT FORCE.	1. REQUIRES ACCURATE MACHINING AND TOLERANCING DURING FABRICATION. 2. RELATIVELY LARGE ENVELOPE VOLUME.	
AROVIDES THE AXIAL THANICAL JAWS AND SQUARE ARCKING ALIGNMENT. AS THE TOGETHER, THE JAWS ARE -ND ALIGN BOTH PARTS -D RECEPTACLE ARE AD- THE ALIGNMENT MECH-	1. STANDARD CONNECTOR INSERT CAN BE USED. 2. REQUIRES MINIMUM ALIGNMENT FORCE.	1. ALIGNMENT TECHNIQUE IS NOT CONCENTRIC WITH CONNECTOR. 2. ELECTRICAL POWER REQUIREMENT. 3. REQUIRES ACCURATE MACHINING & TOLERANCING DURING FABRICATION. 4. RELATIVELY LARGE ENVELOPE VOLUME.	
T DE A GROSS ALIGNMENT E IDE FINE AXIAL AND S THE TWO HALVES ARE S LLERS CONTACT THE THE ALIGNMENT PINS NGHINGS WHERE FINE LOW CONNECTOR MATING.	1. ALIGNMENT TECHNIQUE IS CONCENTRIC WITH CONNECTOR. 2. REQUIRES MINIMUM ALIGNMENT FORCE. 3. HIGH ACCURACY. 4. IDEAL FOR LARGE MISALIGNMENTS.	1. REQUIRES ACCURATE MACHINING AND TOLERANCING DURING FABRICATION. 2. RELATIVELY LARGE ENVELOPE VOLUME. 3. CONNECTOR INSERT MUST BE MODIFIED.	
A UARE SHAPED AND AL THE RECEPTACLE IS A E- THAT PROVIDES AXIAL TE THE RECEPTACLE RE- SATE FOR THE EXPECTED ERLINE OF THE CON- TO THE ALIGNMENT	1. RELATIVELY COMPACT IN SIZE. 2. STANDARD CONNECTOR INSERT CAN BE USED. 3. REQUIRES MINIMUM ALIGNMENT FORCE.	1. ALIGNMENT TECHNIQUE IS NOT CONCENTRIC WITH CONNECTOR. 2. REQUIRES ACCURATE MACHINING AND TOLERANCING DURING FABRICATION.	*

Table V-1 (continued)

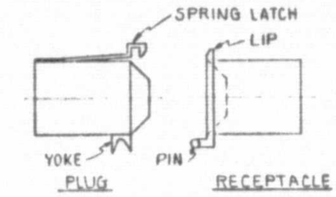
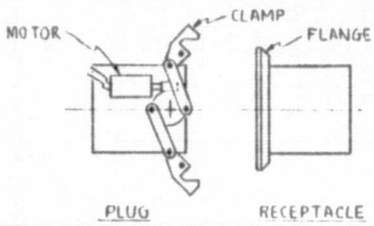
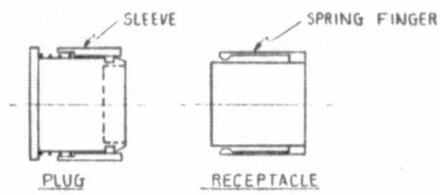
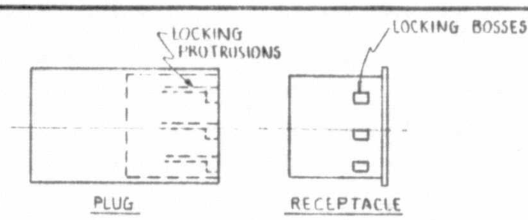
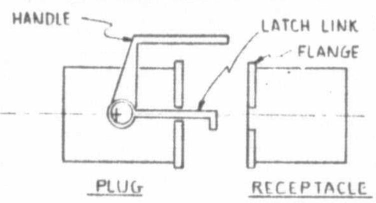
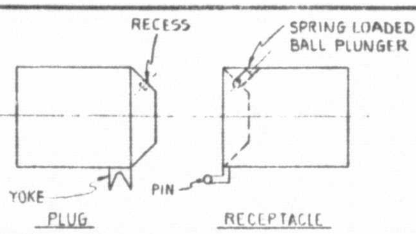
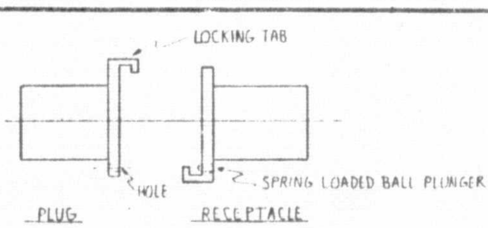
CONCEPT	ILLUSTRATION	OPERATION AND DESCRIPTION
INTER-CONNECT-ING FACE FLANGES		ALIGNMENT IN THIS CONCEPT INVOLVES TR LATING THE PLUG HALF OF THE CONNECTOR WARD THE TOP HALF OF THE RECEPTACLE F UNTIL THEY TOUCH. AT THIS TIME A DOW FORCE IS APPLIED TO THE PLUG WHICH AL THE LOCKING TABS TO CENTER THE FLANGE RETAIN THEM AXIALLY. THE STOP PINS O PLUG PROVIDE PROPER CLOCKING ALIGNMEN

FOLDOUT FRAME

N AND DESCRIPTION	ADVANTAGES	DISADVANTAGES	*SELECTED CONCEPT
CONCEPT INVOLVES TRANS- ALF OF THE CONNECTOR TO- OF THE RECEPTACLE FLANGE AT THIS TIME A DOWNWARD TO THE PLUG WHICH ALLOWS TO CENTER THE FLANGES AND LY. THE STOP PINS ON THE ER CLOCKING ALIGNMENT.	1. ALIGNMENT TECHNIQUE IS CONCENTRIC WITH CONNECTOR. 2. RELATIVELY COMPACT IN SIZE. 3. STANDARD CONNECTOR INSERT CAN BE USED. 4. REQUIRES MINIMUM ALIGNMENT FORCE.	1. REQUIRES ACCURATE MACHINING AND TOLERANCING DURING FABRICATION.	*

FOLDOUT FRAME 2

Table V-2 Latching Concepts Advantages/Disadvantages

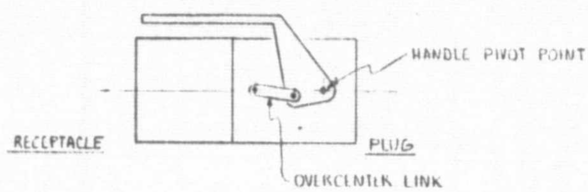
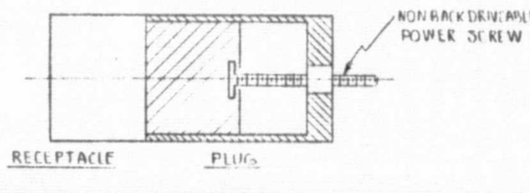
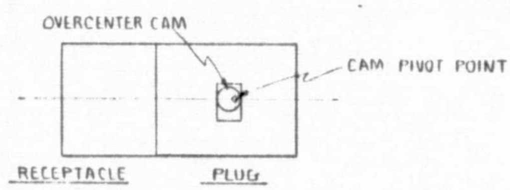
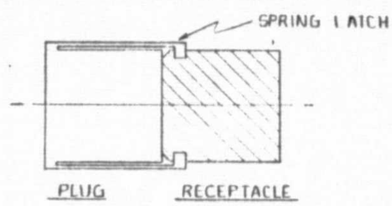
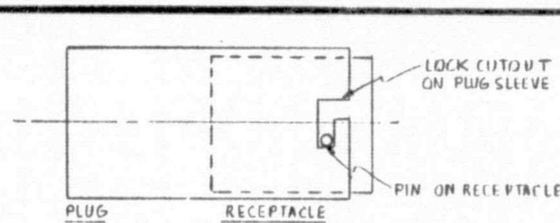
CONCEPT	ILLUSTRATION	OPERATION AND DESCRIPTION
YOKE PIVOT WITH SPRING LOADED LATCH		THIS CONCEPT USES A YOKE AT THE BASE OF T PLUG AND A LEAF SPRING CATCH AT THE TOP F LATCHING TO THE RECEPTACLE. THE PLUG RO- TATES AROUND THE PIN UNTIL THE SPRING LAT RIDES OVER THE RECEPTACLE LIP AND FIRMLY LATCHES BOTH HALVES OF THE CONNECTOR TO- GETHER.
ELECTRO-MECHANI-CAL FLANGE CLAMP		CLAMP PAWLS ON THE PLUG GRASP THE FLANGE THE RECEPTACLE FOR THE LATCH TECHNIQUE IN THIS CONCEPT. AFTER THE TWO HALVES ARE BROUGHT TOGETHER THE MOTOR DRIVEN CLAMPS ACTIVATED WHICH POSITIONS AND SECURELY HOLDS THE FLANGE OF THE RECEPTACLE AGAINS THE FACE OF THE PLUG.
SPRING FINGERS WITH OVER-LAPPING SLEEVE		SPRING FINGERS ON THE RECEPTACLE RIDE UP RAMP ON THE FORWARD END OF THE PLUG AND P BACK THE SPRING LOADED SLEEVE. WHEN THE SLEEVE IS RETRACTED SUFFICIENTLY THE FING FALL INTO THE RECESS THEREBY ALLOWING THE SLEEVE TO OVERLAP THE FINGERS AND POSITIV COUPLING BOTH HALVES OF THE CONNECTOR TO- GETHER.
BAYONET ROTA-TIONAL ATTACH-MENT		THE PLUG OUTER HOUSING OVERLAPS THE RECEP ACLE AND RECESSES IN THE PLUG SLEEVE MATC THE TABS ON THE RECEPTACLE. AS THE TWO PARTS ARE BROUGHT TOGETHER THE TABS SLIDE THROUGH THE RECESSES UNTIL THE UNITS BOTT OUT AND THEN A TWIST MOTION LOCKS THE CON NECTOR HALVES TOGETHER.
MECHAN-ICAL LINKAGE		THIS CONCEPT USES A CLAMP LINK THAT IS OP ATED BY A HANDLE DRIVING A CAM PIVOT MECH ANISM. THE CLAMP LINK ON THE PLUG PICKS A FLANGE ON THE RECEPTACLE. AFTER THE T PARTS ARE BROUGHT TOGETHER THE CAM IS RO- TATED AND THE CLAMP LINK PULLS AGAINST TH FLANGE LATCHING THE CONNECTOR HALVES TO- GETHER.
YOKE PIVOT WITH SPRING LOADED BALL-DETENT		A YOKE/PIN AT THE BASE AND A BALL/DETENT THE TOP PROVIDE THE LATCH TECHNIQUE IN TH CONCEPT. THE PLUG ROTATES AROUND THE PIN ON THE RECEPTACLE UNTIL THE SPRING LOADED BALL PLUNGER SNAPS INTO THE RECESS ON THE PLUG AND SECURELY HOLDS BOTH HALVES OF TH CONNECTOR TOGETHER.
INTER-CONNECT-ING FLANGE W/SPRING LOADED BALL-DETENT		THIS CONCEPT CONSISTS OF LOCKING TABS ON BOTH THE RECEPTACLE AND PLUG THAT HOLDS T TWO HALVES TOGETHER AXIALLY WHEN MATED. THE TABS ARE ARRANGED TO PROVIDE LATERAL RESTRAINT AND SPRING LOADED BALL PLUNGERS HOLD THE HALVES TOGETHER VERTICALLY.

FOLDOUT FRAME 1

ND DESCRIPTION	ADVANTAGES	DISADVANTAGES	*SELECTED CONCEPT
YOKE AT THE BASE OF THE NG CATCH AT THE TOP FOR PTACLE. THE PLUG RO- UNTIL THE SPRING LATCH TACLE LIP AND FIRMLY OF THE CONNECTOR TO-	1. POSITIVE LOCKING FEATURE. 2. RELATIVELY LOW INSTALLATION FORCE. 3. RELATIVELY COMPACT IN SIZE.	1. LOW AXIAL CLAMPING FORCE. 2. PIVOT MOTION MAY BE HARD TO CONTROL REMOTELY. 3. PRECISION MACHINING AND TOLERANCING REQUIRED FOR PROPER OPERATION.	*
LUG GRASP THE FLANGE ON HE LATCH TECHNIQUE IN THE TWO HALVES ARE MOTOR DRIVEN CLAMPS ARE TIONS AND SECURELY THE RECEPTACLE AGAINST .	1. POSITIVE LOCKING FEATURE. 2. HIGH AXIAL CLAMPING FORCE. 3. RELATIVELY LOW INSTALLATION FORCE.	1. ELECTRICAL POWER REQUIRED. 2. PRECISION MACHINING AND TOLERANCING REQUIRED FOR PROPER OPERATION.	
E RECEPTACLE RIDE UP THE END OF THE PLUG AND PUSH ED SLEEVE. WHEN THE SUFFICIENTLY THE FINGERS THEREBY ALLOWING THE E FINGERS AND POSITIVELY OF THE CONNECTOR TO-	1. POSITIVE LOCKING FEATURE. 2. RELATIVELY COMPACT IN SIZE.	1. LOW AXIAL CLAMPING FORCE. 2. RELATIVELY HIGH INSTALLATION FORCE. 3. PRECISION MACHINING AND TOLERANCING REQUIRED FOR PROPER OPERATION.	
NG OVERLAPS THE RECEPT- THE PLUG SLEEVE MATCH PTACLE. AS THE TWO GETHER THE TABS SLIDE UNTIL THE UNITS BOTTOM MOTION LOCKS THE CON- ER.	1. POSITIVE LOCKING FEATURE. 2. HIGH AXIAL CLAMPING FORCE.	1. RELATIVELY HIGH INSTALLATION. 2. DIFFICULT TO FEEL WHEN UNIT IS COMPLETELY LOCKED. 3. PRECISION MACHINING AND TOLERANCING REQUIRED FOR PROPER OPERATION.	
CLAMP LINK THAT IS OPER- VING A CAM PIVOT MECH- NK ON THE PLUG PICKS UP PTACLE. AFTER THE TWO GETHER THE CAM IS RO- LINK PULLS AGAINST THE CONNECTOR HALVES TO-	1. POSITIVE LOCKING FEATURE. 2. HIGH AXIAL CLAMPING FORCE.	1. RELATIVELY HIGH INSTALLATION FORCE. 2. HANDLE MOTION MAY BE HARD TO CONTROL REMOTELY.	
SE AND A BALL/DETENT AT LATCH TECHNIQUE IN THIS OTATES AROUND THE PIN TIL THE SPRING LOADED NTO THE RECESS ON THE LDS BOTH HALVES OF THE	1. RELATIVELY LOW INSTALLATION FORCE. 2. RELATIVELY COMPACT IN SIZE.	1. NOT A POSITIVE LOCKING FEATURE. 2. LOW AXIAL CLAMPING FORCE. 3. PIVOT MOTION MAY BE HARD TO CONTROL REMOTELY. 4. PRECISION MACHINING & TOLERANC'G REQD FOR PROPER OPERATION.	
IS OF LOCKING TABS ON AND PLUG THAT HOLDS THE AXIALLY WHEN MATED. D TO PROVIDE LATERAL LOADED BALL PLUNGERS ETHER VERTICALLY.	1. HIGH AXIAL RETENTION CAPABILITY. 2. RELATIVELY LOW INSTALLATION FORCE. 3. RELATIVELY COMPACT IN SIZE.	1. NOT A POSITIVE LOCKING FEATURE. 2. PRECISION MACHINING & TOLERANCING REQUIRED. 3. TWO MOTIONS REQUIRED FOR MATING.	*

FOLDOUT FRAME 2

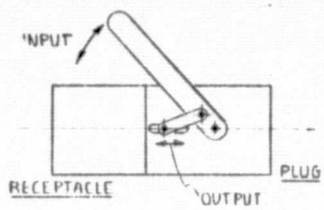
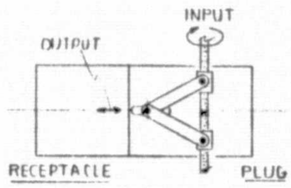
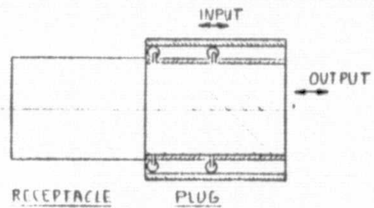
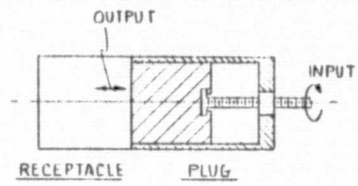
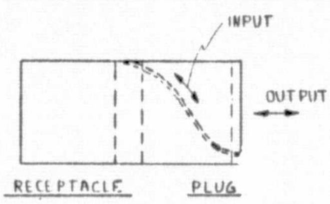
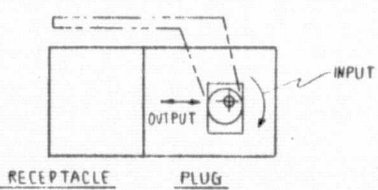
Table V-3 Locking Concepts Advantages/Disadvantages

CONCEPT	ILLUSTRATION	OPERATION AND DESCRIPTION
OVER-CENTER LINK		THIS CONCEPT USES A LINK THAT IS ATTACHED TO A DRIVE PIN AND A PIVOTING HANDLE. THE HANDLE PIVOT POINT AND DRIVE PIN ARE INLIN AND WHEN THE LINK SWIVEL POINT ON THE HAND PASSES OVERCENTER THE PLUG IS COMPLETELY I SERTED AND LOCKED IN THAT POSITION.
NONBACK-DRIVE-ABLE POWER SCREW		THIS CONCEPT USES A POWER SCREW TURNING IN NUT ATTACHED TO THE PLUG HOUSING. THE SCR IS TURNED UNTIL THE PLUG BOTTOMS OUT AGAIN THE RECEPTACLE AND THE PINS ARE COMPLETELY INSERTED IN THE SOCKETS. THE THREAD LEAD THE SCREW AND FRICTION IN THE NUT PREVENTS THE SCREW FROM BACKDRIVING THEREBY PROVIDI A LOCKED CONDITION.
OVER-CENTER CAM		THIS CONCEPT USES AN ECCENTRIC CAM TO DRIV THE PLUG INTO THE RECEPTACLE. WHEN THE PI ARE COMPLETELY INSERTED INTO THE SOCKETS, THE HIGH POINT OF THE CAM SWINGS OVERCENTE THIS LOCKS IN THE PLUG/RECEPTACLE POSITION
SPRING LOADED LATCH		IN THIS CONCEPT THE PLUG IS INSERTED INTO THE RECEPTACLE UNTIL THE PINS ARE COMPLETE MATED WITH THE SOCKETS. AT THIS TIME, WIT PROPER SIZING OF MECHANICAL ELEMENTS, THE LEAF SPRING LATCHES SNAP INTO THE GROOVE O THE RECEPTACLE AND LOCKS IN THE PLUG/RE-CEPTACLE POSITION.
BAYONET LATCH		IN THIS CONCEPT THE PLUG IS INSERTED INTO THE RECEPTACLE UNTIL THE PINS ARE COMPLETE MATED WITH THE SOCKETS. AT THIS TIME THE PLUG OUTER SLEEVE HAS OVERLAPPED THE LOCK PIN ON THE RECEPTACLE AND ROTATION OF THE PLUG SLEEVE LOCKS THE PLUG TO THE RECEPTAC

FOLDOUT FRAME 1

...ND DESCRIPTION	ADVANTAGES	DISADVANTAGES	*SELECTED CONCEPT
...LINK THAT IS ATTACHED ...PIVOTING HANDLE. THE ...ND DRIVE PIN ARE INLINE ...IVEL POINT ON THE HANDLE ...E PLUG IS COMPLETELY IN- ... THAT POSITION.	1. POSITIVE LOCKING FEATURE. 2. RELATIVELY HIGH LOCKING FORCE. 3. COMPACT IN SIZE.	1. PRECISION MACHINING AND TOLERANCING REQUIRED FOR PROPER OPERATION. 2. PIVOT MOTION OF HANDLE MAY BE HARD TO CONTROL REMOTELY.	*
...POWER SCREW TURNING IN A ...PLUG HOUSING. THE SCREW ...PLUG BOTTOMS OUT AGAINST ...HE PINS ARE COMPLETELY ...ETS. THE THREAD LEAD OF ...ON IN THE NUT PREVENTS ...RIVING THEREBY PROVIDING	1. POSITIVE LOCKING FEATURE. 2. RELATIVELY HIGH LOCKING FORCE. 3. RELATIVELY SIMPLE APPROACH.	1. RELATIVELY LARGE IN SIZE. 2. FULLY LOCKED CONDITION CANNOT BE OBSERVED. 3. ELECTRICAL POWER REQUIRED.	
... ECCENTRIC CAM TO DRIVE ...ECEPTACLE. WHEN THE PINS ...RTED INTO THE SOCKETS, ...HE CAM SWINGS OVERCENTER. ...LUG/RECEPTACLE POSITION.	1. POSITIVE LOCKING FEATURE. 2. RELATIVELY HIGH LOCKING FORCE. 3. COMPACT IN SIZE. 4. RELATIVELY SIMPLE APPROACH.	1. PIVOT MOTION OF HANDLE MAY BE HARD TO CONTROL REMOTELY.	*
... PLUG IS INSERTED INTO ... THE PINS ARE COMPLETELY ...ETS. AT THIS TIME, WITH ...CHANICAL ELEMENTS, THE ... SNAP INTO THE GROOVE ON ...LOCKS IN THE PLUG/RE-	1. POSITIVE LOCKING FEATURE. 2. COMPACT IN SIZE.	1. RELATIVELY LOW LOCKING FORCE. 2. PRECISION MACHINING AND TOLERANCING REQUIRED FOR PROPER OPERATION.	
... PLUG IS INSERTED INTO ...L THE PINS ARE COMPLETELY ...ETS. AT THIS TIME THE ...AS OVERLAPPED THE LOCK ...LE AND ROTATION OF THE ...HE PLUG TO THE RECEPTACLE.	1. POSITIVE LOCKING FEATURE. 2. COMPACT IN SIZE.	1. RELATIVELY LOW LOCKING FORCE. 2. PRECISION MACHINING AND TOLERANCING REQUIRED FOR PROPER OPERATION.	

Table V-4 Drive Mechanism Concepts Advantages/Disadvantages

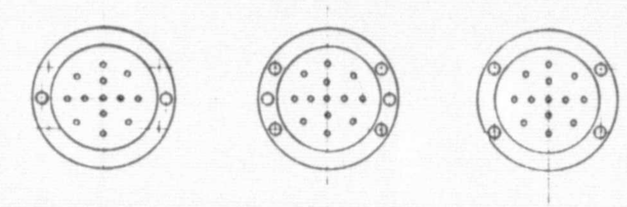
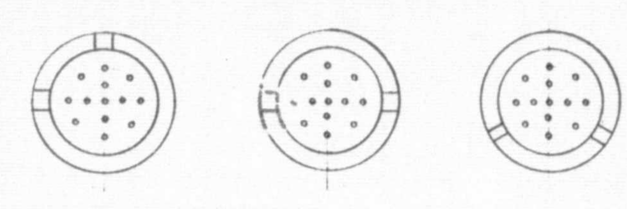
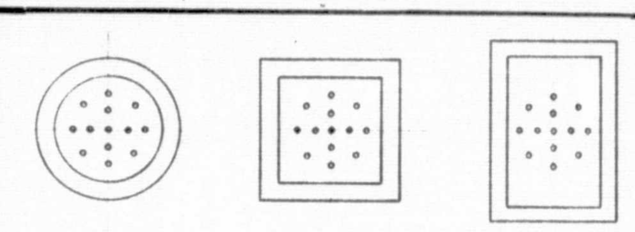
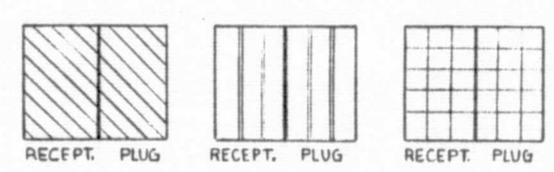
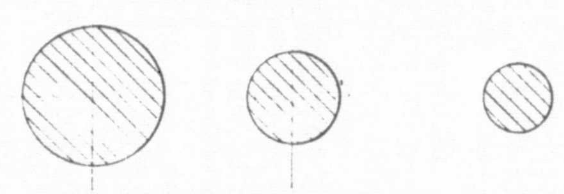
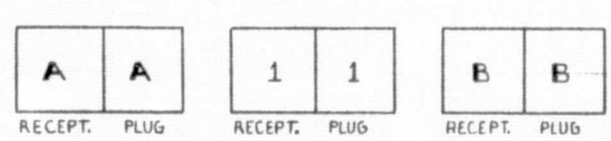
CONCEPT	ILLUSTRATION	OPERATION AND DESCRIPTION
MECHANICAL LINKAGE DRIVING CORE SIDE PINS		THIS CONCEPT UTILIZES A PIVOTING HANDLE W A LINK PUSHING ON SIDE PINS ATTACHED TO T CENTER CORE. AS THE HANDLE IS ROTATED, LINK PUSHES (PULLS) ON THE SIDE PINS THER PROVIDING TRANSLATIONAL MOTION TO THE CEN CORE WHICH IS SUPPORTED IN A MANNER TO AL ONLY LINEAR MOTION.
POWER SCREW DRIVING CORE SIDE PINS		A SUPPORTED ROTATING POWER SCREW WITH RH LH THREADS MOVES LINKS THAT ARE ATTACHED NUTS ON THE SCREW AND TO SIDE PINS ATTACH TO THE CENTER CORE. AS THE LINKS MOVE AP THEY DRAW THE SIDE PINS BACK IN A TRANSLA TIONAL MOTION AND VICE VERSA. THE CENTER CORE IS SUPPORTED TO ALLOW ONLY LINEAR MOTION.
OUTER SLEEVE DRIVING CONCENTRIC INNER CORE		IN THIS CONCEPT THE CENTER CORE IS ATTACH TO THE ROLLERS WHICH RIDE BETWEEN A FIXED INNER HOUSING AND A MOVABLE OUTER SLEEVE. AS THE OUTER SLEEVE IS PUSHED OR PULLED, ROLLERS AND INNER CORE MOVE AT A REDUCED RATE IN THE SAME DIRECTION.
DIRECT DRIVE WITH BALL SCREW		A BALL-SCREW WITH A SWIVEL END IS ATTACHE TO THE CENTER PLUG CORE AND THE BALL-NUT ATTACHED TO THE BACK SURFACE OF THE PLUG HOUSING. ROTATING THE SCREW PRODUCES TRA LATIONAL MOTION TO THE CENTER CORE WHICH SUPPORTED TO ALLOW ONLY LINEAR MOTION.
HELIX (ROTATIONAL MOTION TO LINEAR TRANSLATION)		IN THIS CONCEPT THE RECEPTACLE HOUSING EX TENDS OVER THE PLUG AND IN THE PLUG AREA HELICAL GROOVE IS MACHINED. THE PLUG BOD HAS A PIN THAT PICKS UP THE GROOVE AND WH THE PLUG BODY IS ROTATED, A TRANSLATIONAL MOTION IS ALSO PRODUCED.
CAM DRIVE		A CAM WITH ITS PIVOT POINT ATTACHED TO TH PLUG HOUSING AND THE ECCENTRIC PART IN A SLOT ON THE MOVABLE INNER CORE IS ROTATED WITH AN EXTERNAL HANDLE. HANDLE MOTION PRODUCES A TRANSLATIONAL MOTION OF THE CE TER CORE WHICH IS SUPPORTED TO ALLOW ONLY LINEAR MOTION.

FOLDOUT FRAME

ND DESCRIPTION	ADVANTAGES	DISADVANTAGES	*SELECTED CONCEPT
S A PIVOTING HANDLE WITH E PINS ATTACHED TO THE HANDLE IS ROTATED, THE N THE SIDE PINS THEREBY AL MOTION TO THE CENTER ED IN A MANNER TO ALLOW	1. HIGH MECHANICAL ADVANTAGE. 2. CAN ACCOMMODATE LONG STROKES. 3. RELATIVELY COMPACT IN SIZE. 4. RELATIVELY SIMPLE APPROACH. 5. BALANCED LOADING.	1. ACTUATING MOTION MAY BE DIFFICULT IN A REMOTE CONTROL MODE.	*
POWER SCREW WITH RH AND S THAT ARE ATTACHED TO TO SIDE PINS ATTACHED AS THE LINKS MOVE APART NS BACK IN A TRANSLA- E VERSA. THE CENTER LLOW ONLY LINEAR	1. HIGH MECHANICAL ADVANTAGE. 2. CAN ACCOMMODATE LONG STROKES. 3. BALANCED LOADING.	1. REQUIRES ELECTRICAL DRIVE MOTOR. 2. DESIGN MAY CAUSE UNIT TO BE RELATIVELY LARGE. 3. REQUIRES ACCURATE MACHINING AND TOLERANCING DURING FABRICATION.	
ENTER CORE IS ATTACHED RIDE BETWEEN A FIXED VABLE OUTER SLEEVE. S PUSHED OR PULLED, THE E MOVE AT A REDUCED CTION.	1. DESIREABLE MOTION FOR REMOTE CONTROL. 2. BALANCED LOADING.	1. LOW MECHANICAL ADVANTAGE. 2. DESIGN MAY CAUSE UNIT TO BE RELATIVELY LARGE. 3. REQUIRES ACCURATE MACHINING AND TOLERANCING DURING FABRICATION.	
WIVEL END IS ATTACHED E AND THE BALL-NUT IS URFACE OF THE PLUG E SCREW PRODUCES TRANS- E CENTER CORE WHICH IS Y LINEAR MOTION.	1. HIGH MECHANICAL ADVANTAGE. 2. RELATIVELY SIMPLE APPROACH.	1. LIMITED STROKE LENGTH. 2. REQUIRES ELECTRICAL DRIVE MOTOR. 3. DESIGN MAY CAUSE UNIT TO BE RELATIVELY LARGE. 4. OFF-CENTER LOADING IF CABLE IS INLINE WITH CONNECTOR.	
CEPTACLE HOUSING EX- D IN THE PLUG AREA A INED. THE PLUG BODY P THE GROOVE AND WHEN ED, A TRANSLATIONAL D.	1. CAN ACCOMMODATE LONG STROKES. 2. RELATIVELY COMPACT IN SIZE.	1. LOW MECHANICAL ADVANTAGE. 2. REQUIRES ACCURATE MACHINING AND TOLERANCING DURING FABRICATION.	
OINT ATTACHED TO THE CCENTRIC PART IN A NER CORE IS ROTATED E. HANDLE MOTION AL MOTION OF THE CEN- ORTED TO ALLOW ONLY	1. HIGH MECHANICAL ADVANTAGE. 2. RELATIVELY COMPACT IN SIZE. 3. RELATIVELY SIMPLE APPROACH. 4. BALANCED LOADING.	1. LIMITED STROKE LENGTH. 2. ACTUATING MOTION MAY BE DIFFICULT IN A REMOTE CONTROL MODE.	*

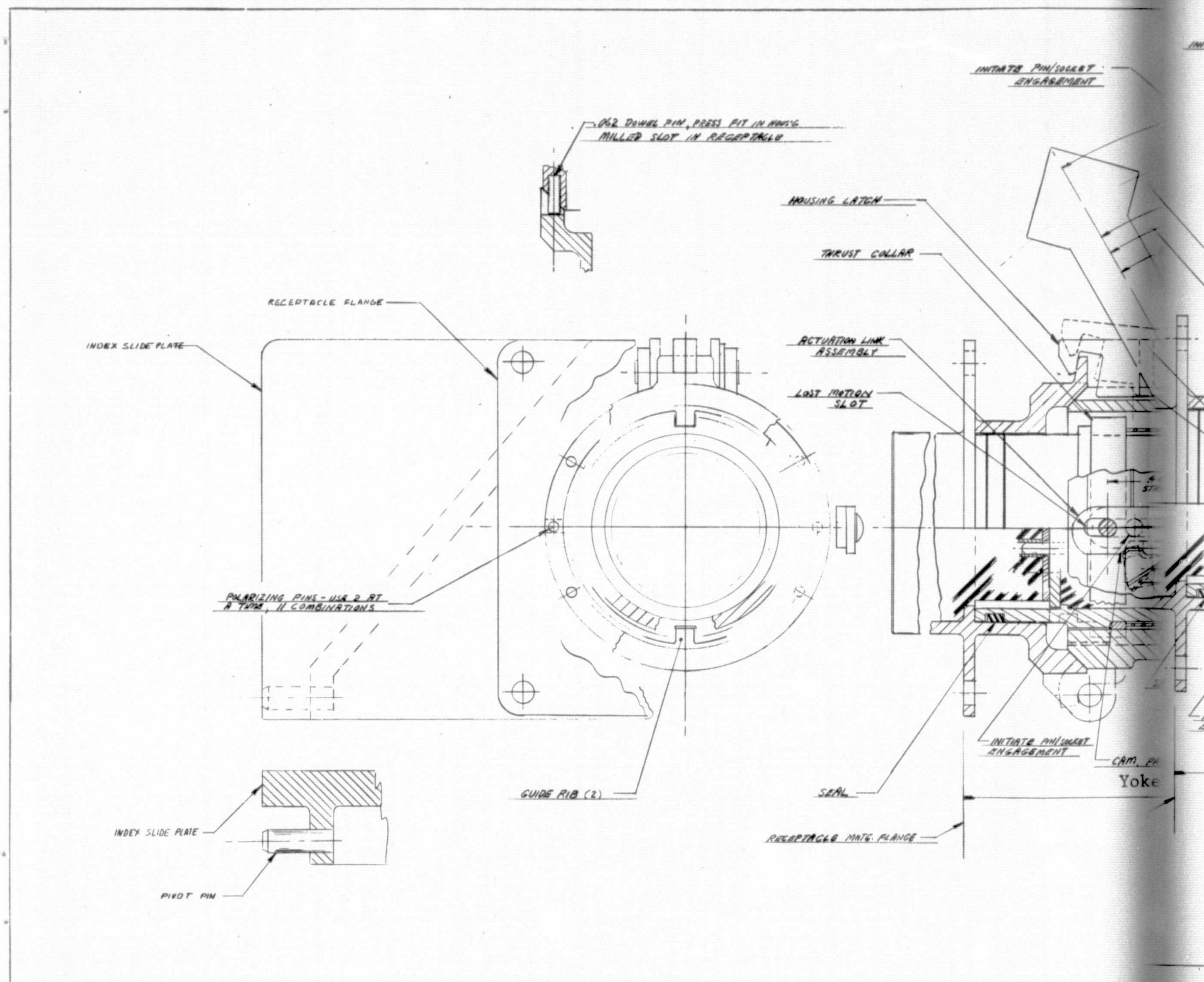
FOLDOUT FRAME 2

Table V-5 Polarization Concepts Advantages/Disadvantages

CONCEPT	ILLUSTRATION	OPERATION AND DESCRIPTION
PIN/ HOLE PATTERN		PINS AND MATCHING BUSHINGS AROUND THE PERIPHERAL MATING SURFACE OF THE CONNECTOR HALVES PROVIDE THE POLARIZATION TECHNIQUE IN THIS CONCEPT. THE NUMBER OF PINS AND LOCATIONS CAN BE VARIED TO PROVIDE SEVERAL POLARIZATION COMBINATIONS.
TABS/ NOTCHES PATTERN		THIS CONCEPT USES NOTCHES AND MATCHING TABS AT THE MATING SURFACE FOR POLARIZATION CONTROL. LOCATION, NUMBER OF TABS AND WIDTH OF TABS CAN BE VARIED TO PROVIDE NUMEROUS POLARIZATION COMBINATIONS.
HOUSING SHAPES		THIS CONCEPT USES DIFFERENT SHAPES FOR ADJACENT CONNECTORS FOR POLARIZATION. THE VARIOUS SHAPES PROVIDE A VISUAL INDICATION AS TO PROPER MATING CONNECTOR HALVES.
COLOR CODING		MATING HALVES OF A PARTICULAR CONNECTOR WILL BE OF THE SAME COLOR IN THIS CONCEPT. INTERACTION OF DIFFERENT CONNECTORS IS PREVENTED BY VISUALLY SELECTING MATING PARTS THAT MATCH IN COLOR.
HOUSING SIZES		THIS CONCEPT USES DIFFERENT CONNECTOR HOUSING SIZES TO VISUALLY SELECT MATING CONNECTOR HALVES.
LETTER/ NUMERICAL CODING		THIS CONCEPT USES LETTERS AND/OR NUMBERS TO IDENTIFY THE MATING HALVES OF A CONNECTOR.

FOLDOUT FRAME 1

...ND DESCRIPTION	ADVANTAGES	DISADVANTAGES	*SELECTED CONCEPT
...SHINGS AROUND THE ...RFACE OF THE CONNECTOR ...OLARIZATION TECHNIQUE ...E NUMBER OF PINS AND ...IED TO PROVIDE SEVERAL ...TIONS.	1. PHYSICALLY PREVENTS INTERCHANGING OF CONNECTOR HALVES. 2. RELATIVELY COMPACT. 3. STANDARD INSERT CAN BE USED. 4. LARGE NUMBER OF COMBINATIONS AVAILABLE FOR A GIVEN CONNECTOR SIZE.	1. VISUAL INDICATION FOR CONNECTOR HALF SELECTION IS NOT NECESSARILY OBVIOUS.	*
...TCHES AND MATCHING ...URFACE FOR POLARIZATION ...NUMBER OF TABS AND WID- ...RIED TO PROVIDE NUMEROUS ...TIONS.	1. PHYSICALLY PREVENTS INTERCHANGING OF CONNECTOR HALVES. 2. RELATIVELY COMPACT. 3. STANDARD INSERT CAN BE USED. 4. LARGE NUMBER OF COMBINATIONS AVAILABLE FOR A GIVEN CONNECTOR SIZE.	1. VISUAL INDICATION FOR CONNECTOR HALF SELECTION IS NOT NECESSARILY OBVIOUS.	*
...IFFERENT SHAPES FOR ... FOR POLARIZATION. ...ROVIDE A VISUAL IN- ...ER MATING CONNECTOR	1. PHYSICALLY PREVENTS INTERCHANGING OF CONNECTOR HALVES. 2. STANDARD INSERT CAN BE USED. 3. GOOD VISUAL SELECTION CAPABILITY.	1. OVERALL CONNECTOR ENVELOPE MAY BE UNNECESSARILY LARGE. 2. POSSIBLE COMBINATIONS ARE SOMEWHAT LIMITED.	
...PARTICULAR CONNECTOR ... COLOR IN THIS CONCEPT. ...ERENT CONNECTORS IS ...LY SELECTING MATING ... COLOR.	1. RELATIVELY COMPACT. 2. STANDARD INSERT CAN BE USED. 3. SEVERAL COLORS CAN BE UTILIZED FOR A GIVEN CONNECTOR SIZE. 4. GOOD VISUAL SELECTION CAPABILITY.	1. DOES NOT PHYSICALLY PREVENT INTERCHANGING OF CONNECTOR HALVES.	
...IFFERENT CONNECTOR ...SUALLY SELECT MATING	1. STANDARD INSERT CAN BE USED. 2. SEVERAL INCREMENTAL INCREASES IN SIZE IS POSSIBLE. 3. RELATIVELY GOOD VISUAL SELECTION CAPABILITY.	1. OVERALL CONNECTOR ENVELOPE MAY BE UNNECESSARILY LARGE. 2. DOES NOT PHYSICALLY PREVENT ACCIDENTAL INSERTION OF SMALL PLUG INTO LARGE RECEPTACLE RESULTING IN POSSIBLE DAMAGE.	
...ETTERS AND/OR NUMBERS ...ING HALVES OF A	1. STANDARD INSERT CAN BE USED. 2. LARGE NUMBER OF COMBINATIONS AVAILABLE FOR A GIVEN CONNECTOR SIZE. 3. RELATIVELY COMPACT. 4. GOOD VISUAL SELECTION CAPABILITY.	1. DOES NOT PHYSICALLY PREVENT INTERCHANGING OF CONNECTOR HALVES.	



FOLDOUT FRAME

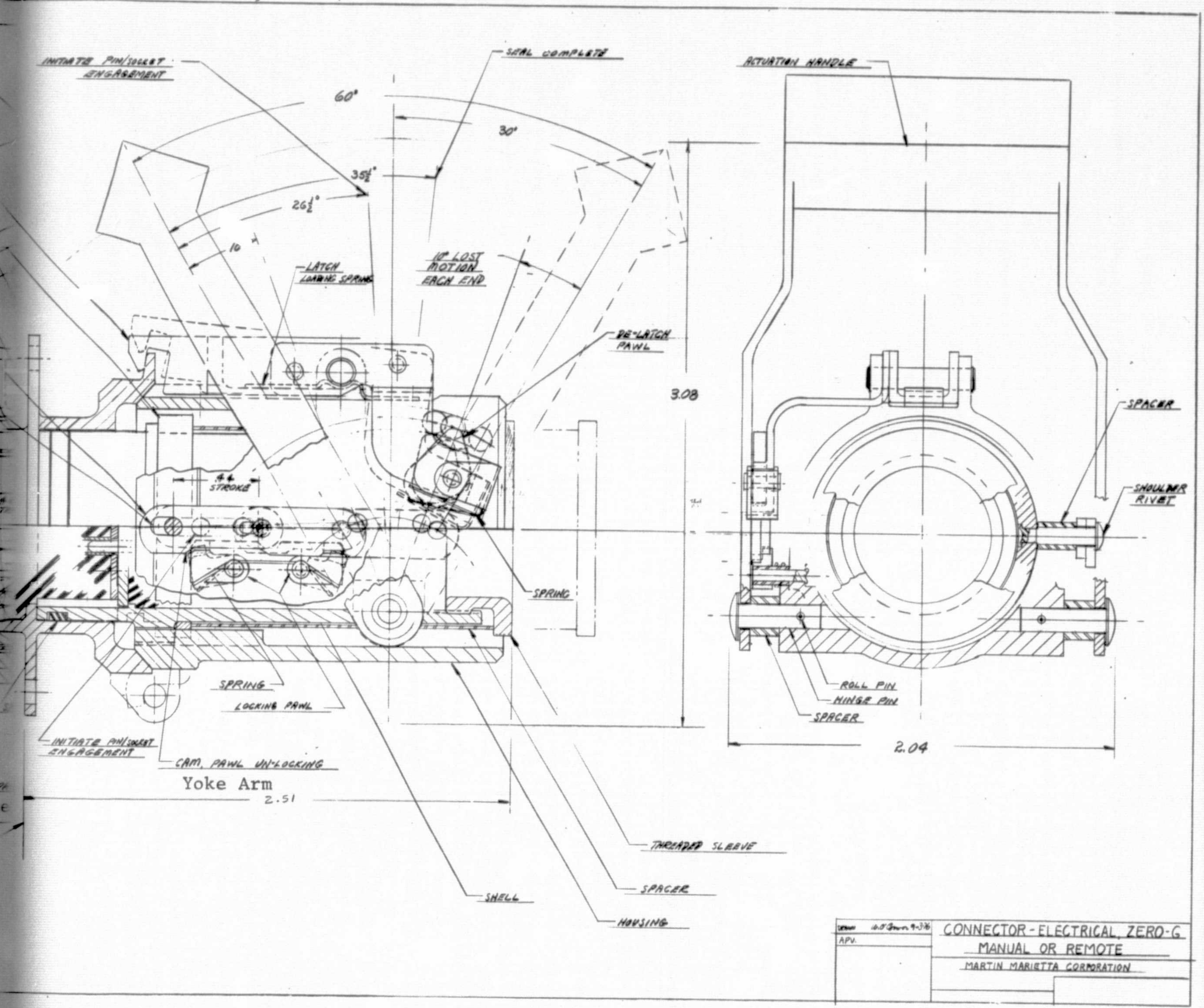


Figure V-1 Manipulator/EVA System Concept No. 1

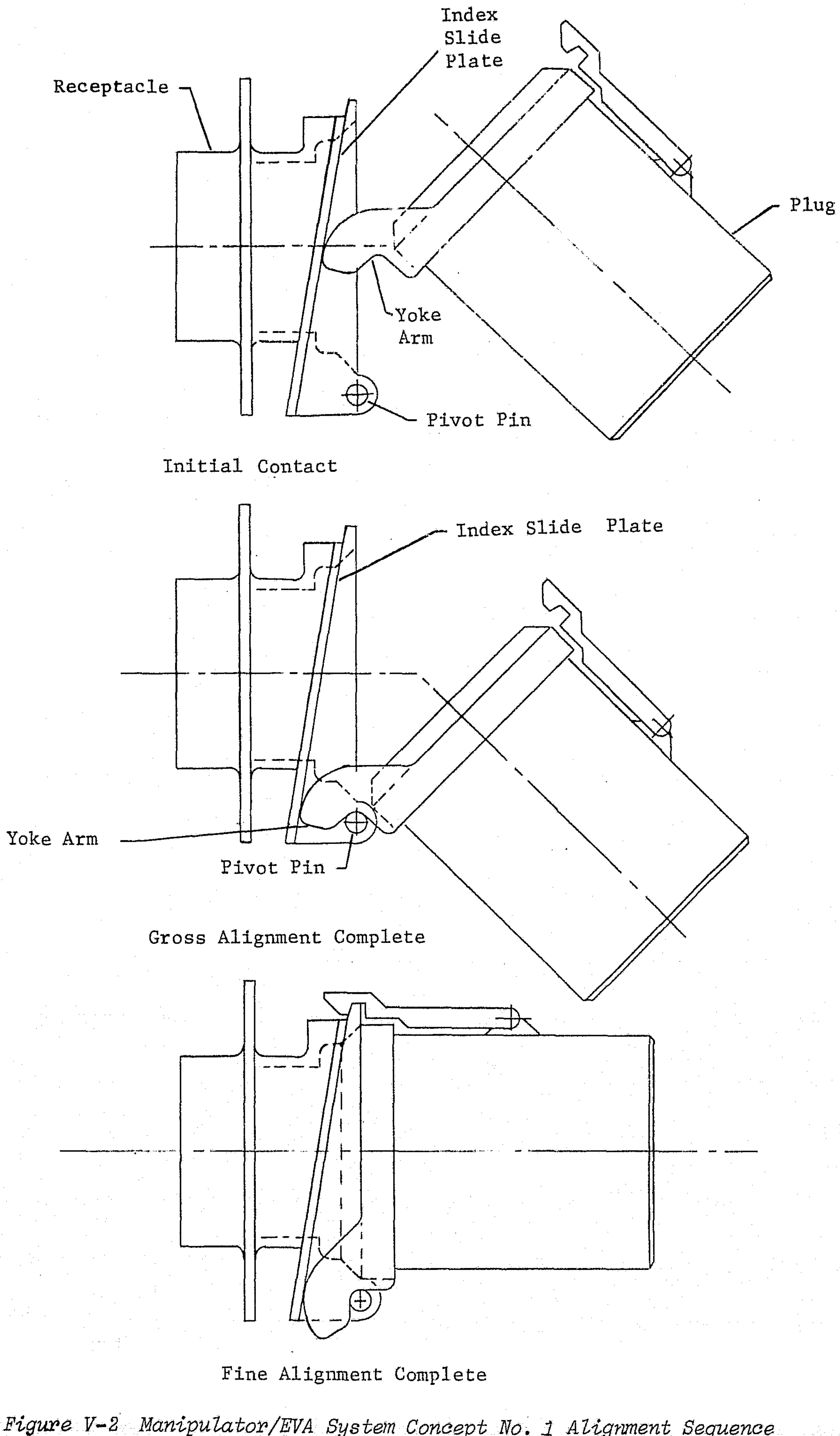


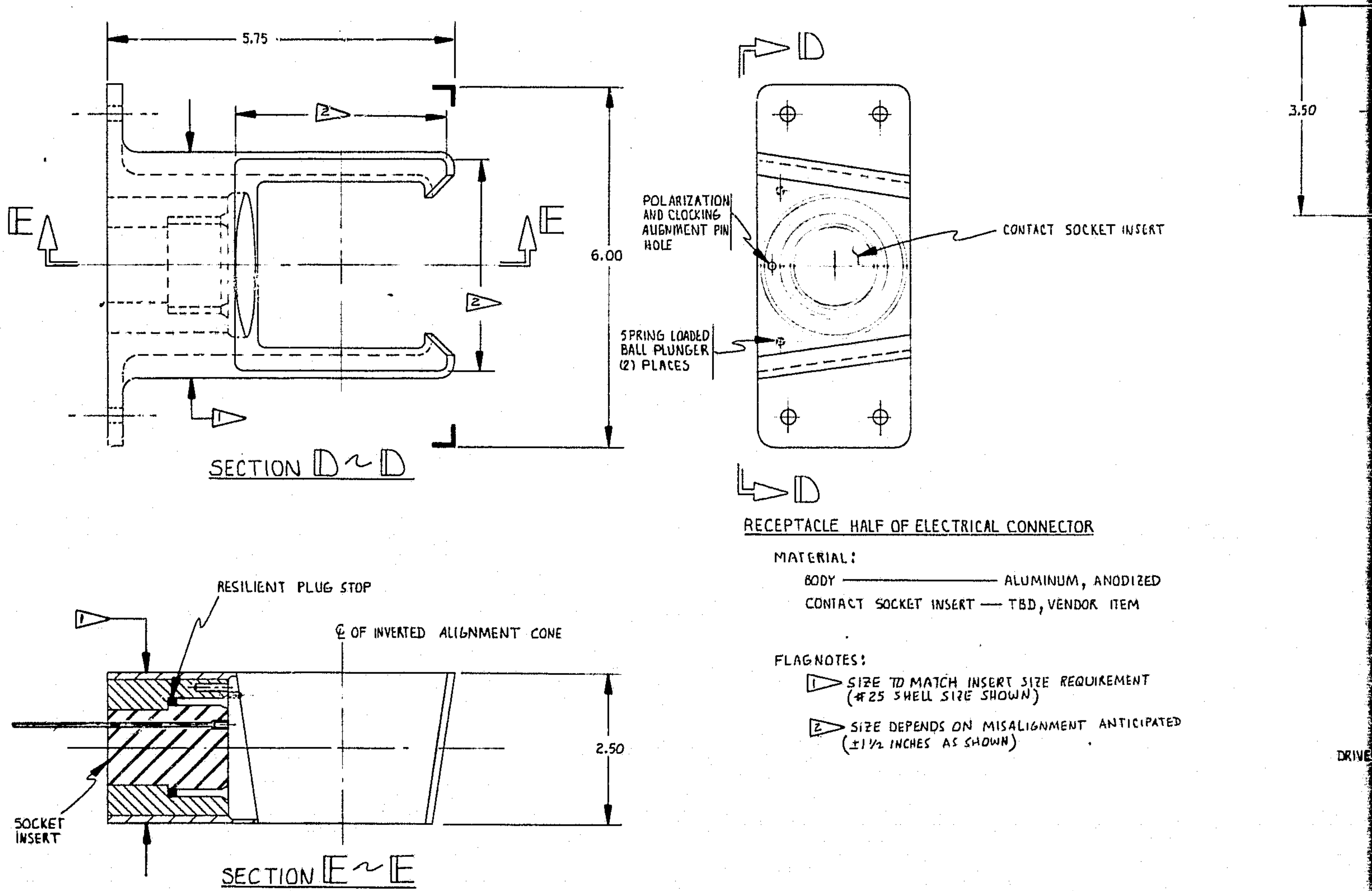
Figure V-2 Manipulator/EVA System Concept No. 1 Alignment Sequence plug body. Then the plug is moved towards the receptacle until the yoke arms contact the slanted guide plate on the receptacle. Further forward motion slides the yoke arms down the guide and around the radius of the receptacle housing. The yoke arms continue down the plate until they contact the pivot pins to complete the gross alignment. At this point further forward motion swivels the plug around the pivot pins and funnels the plug into the inverted cone and the spring-loaded latch holds the coupled position of the two halves to complete the fine alignment. Additional forward motion of the handle actuates the drive links and pushes the pins into the sockets of the receptacle. As the links reach the overcenter position, the pins are completely inserted into the sockets. All motions of the handle require a manipulator with back driveable joints when operated remotely.

Concept 2 - This concept, as shown in Figure V-3, consists of a receptacle and plug that utilize the tapered cone method for alignment, mechanical linkage for the drive mechanism, interlocking sleeve/housing for latching, overcenter link for locking, and pin/hole pattern for polarization.

The receptacle consists of a mounting flange followed by a section that houses a standard socket insert. Surrounding the insert is a close toleranced gap that receives the sleeve of the plug insert. The area around the gap has drilled holes for polarization and docking alignment. The housing extends past the insert and incorporates a tapered square shaped recess for plug-to-receptacle alignment.

The plug assembly consists of a tapered square shaped cone with a side extension that houses the sliding pin insert. On top of the plug assembly is the handle that is attached and actuates the sliding inner core through a series of links. At the handle swivel point, a pair of spring-loaded ball plungers retain the handle in the disconnected position and prevent premature actuation due to translating and rotating of connector/cabling prior to mating. The retaining force on the ball plungers is greater than the drag force of the cabling but less than that of the manipulator.

The sequence of mating the connector halves is accomplished by initially positioning the plug half above the receptacle by hand or remotely within ± 3.81 cm (± 1.5 in.) floating and $\pm 8.75 \times 10^{-2}$ rad ($\pm 5^{\circ}$) angular. The plug is then moved downward into the receptacle. The tapered sides and square shape provide the gross axial and docking alignment. As the plug bottoms out, a couple of spring loaded ball plungers in the receptacle pick up detents in the plug and provide a slight retention force to hold the plug/receptacle position. The handle is



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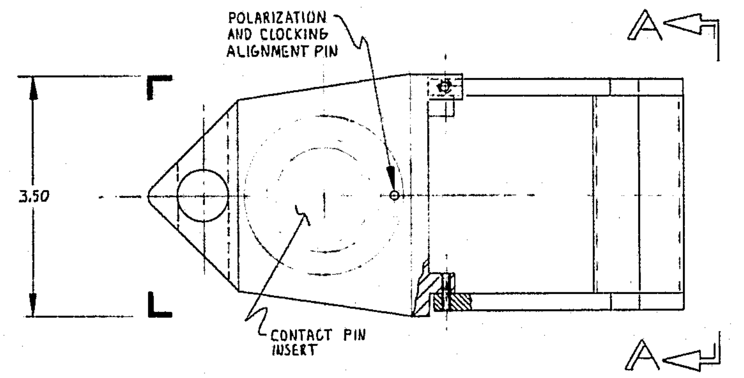
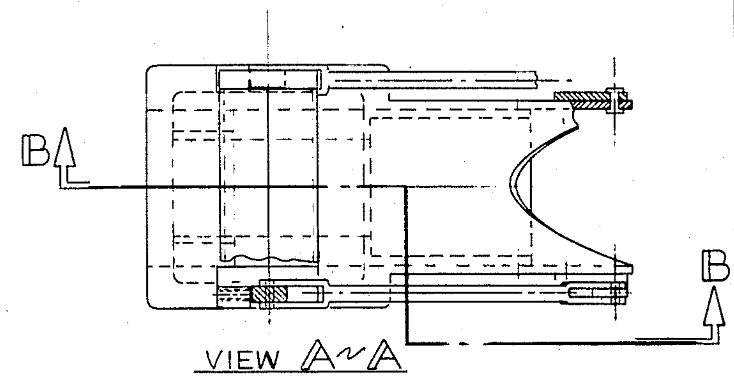




PLUG HALF OF ELECTRICAL CONNECTOR

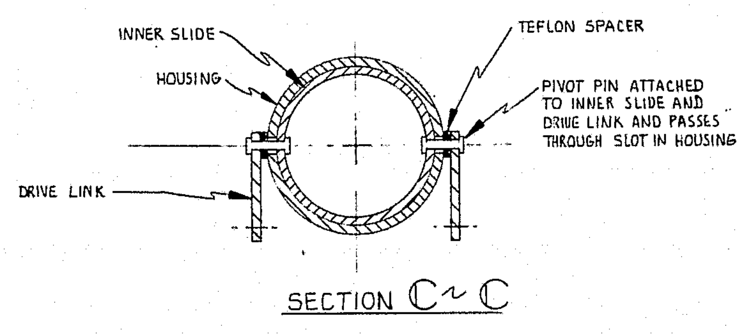
MATERIAL:

- BODY — ALUMINUM, ANODIZED
- LINKAGE — STAINLESS STEEL
- CONTACT PIN INSERT — TBD, VENDOR ITEM

NOTE: BODY SIZE DEPENDS ON MISALIGNMENT AND INSERT REQUIREMENTS

TABLE I.

HANDLE LENGTH	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5
MECH. ADVANTAGE	2.0:1	2.4:1	2.8:1	3.3:1	3.7:1	4.1:1	4.5:1	4.9:1	5.3:1	5.7:1	6.1:1



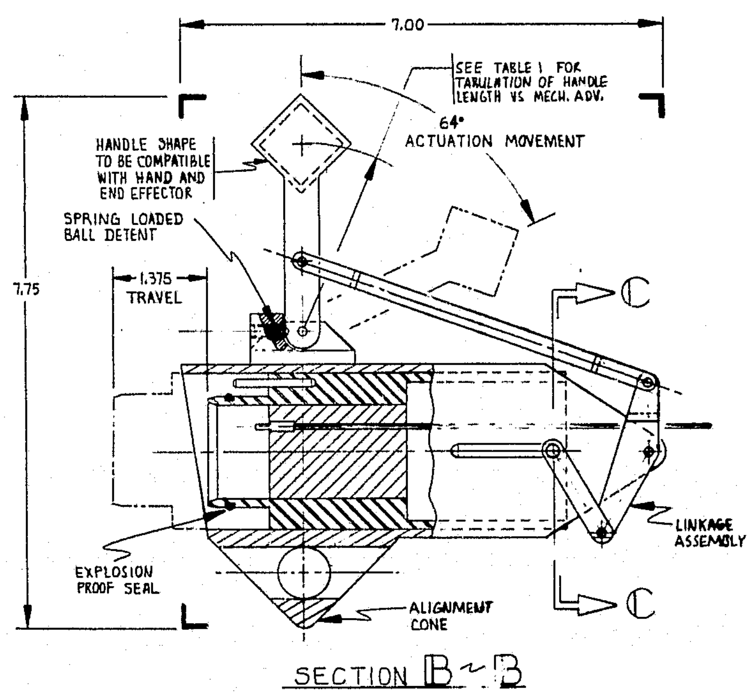


Figure V-3 Manipulator/EVA System Concept No. 2

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then rotated axially in line with the cabling by either the manipulator or by an EVA crewman. After .385 rad (22^{o}) rotation, the sleeve of the plug overlaps the socket insert and provides the fine axial alignment. When rotated to .665 rad (38^{o}), the explosion-proof seal has engaged and the dowel pins have picked up the bushings in the receptacle for fine docking alignment. At 1.12 rad (64^{o}), the pins of the plug are completely inserted into the sockets of the receptacle. All motions of the handle require a manipulator with back driveable joints.

Concept 3 - This concept as shown in Figure V-4 consists of a receptacle and plug that uses an interlocking flange for alignment, a rotating cam and pivoting yoke for the drive mechanism, flange tabs and overlapping sleeves for latching, overcenter cam for locking, and pin/hole pattern for polarization.

The receptacle is bored through the center for the adaptation of a standard socket insert. A closely machined recess around the insert provides a slip fit with the protruding sleeve of the plug insert for alignment. Also in this recess a seal is retained for explosion-proofing. Outside of the recess ring is the area where the polarization holes are located. The receptacle flange has two locking tabs at the base 2.1 rad (120^{o}) apart. The gap between the tab and the flange is equivalent to the flange thickness of the plug. Behind the tabs are spring-loaded ball plungers that help to temporarily retain the flange positions when coupled. The receptacle has a machined mounting flange towards the aft end.

The plug half of the connector is machined to accept standard pin inserts. This inner core slides axially in the plug housing. The forward end of this slide member extends past the insert by .95 cm (3/8 in.). This portion slides over the receptacle insert for the fine alignment. Also located in the front of the slide member is the polarization pins. The sliding center core is driven by a yoke spring pivoting around a ball end at its base and driven at the top by a cam type driven actuator. A handle suitable for both EVA crewman and a remote manipulator device is attached to the cam driver. The flange of the plug assembly contains a tab at the top that overlaps the receptacle flange and provides the axial retention means during connector half coupling. The lower portion of the plug flange contains stop pins that index against the edge of the receptacle flange tabs for docking alignment. Also in this area are the holes which pick up the ball plungers in the receptacle.

The sequence of mating the two connector halves is shown in the figure. The plug assembly is brought forward until contact is made between the flanges of the connector halves. At this time the axial alignment is within ± 3.81 cm (± 1.5 in.) and 8.75×10^{-2} rad (5^{o}) in angularity. The plug is then moved in a downward motion. The radius of the plug flange is centered as it passes between the receptacle flange tabs until the upper tab becomes seated, the ball plungers pick up the opposing flange recesses, and the stop pins rest on their respective tabs. Now the connector halves are grossly aligned and coupled. To mate the electrical contacts the handle is rotated. The first few degrees of rotation engage the plug sleeve and receptacle insert which provides the fine alignment. Further rotation of the handle starts the insertion of pins into the sockets. As the handle rotates 1.58 rad (90^{o}) the high point of the cam driver passes top dead center deflecting the spring yoke driver and locking the pins in the fully inserted position. All motions of the handle require a manipulator with back driveable joints.

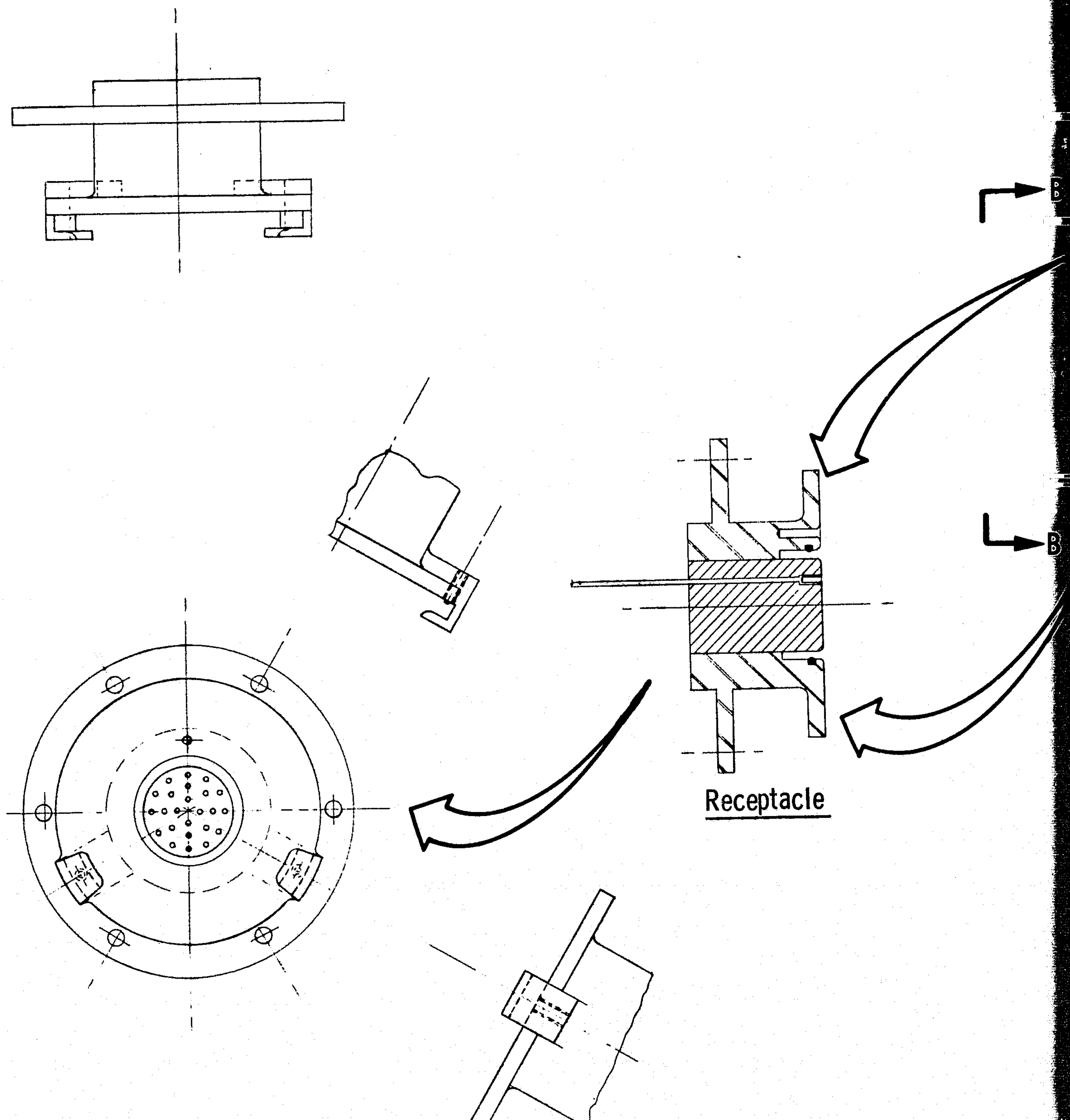
D. SPACECRAFT REPLACEABLE MODULE SYSTEM CONCEPTS

The spacecraft replaceable module system concept is for those applications where modules are interfaced with a spacecraft structure by means of a manipulator with an integrated end effector. These serviceable modules are mounted on a latch/delatch mechanism that has alignment guides and pins that match the spacecraft structure guide rails and female alignment receptacles to accomplish fine alignment tolerances. The tolerances that can be obtained are compatible with the alignment tolerances necessary to mate/demate existing NASA 40M series specification connectors; i.e., $\pm 1.02 \times 10^{-2}$ cm ($\pm .004$ in.) floating and $\pm .57 \times 10^{-2}$ rad (± 20 arc min) angular.

The system concept is a modified NASA 40M series specification that has the coupling ring removed. The module latch/delatch mechanism provides the necessary alignment and coupling force to mate/demate the connector halves. Mounting brackets are necessary to attach each half to their respective structures. These mounting brackets are peculiar to each structural application. The mounting and locations are shown in Section VI.

E. GROSS ALIGNMENT MODULE SYSTEM CONCEPTS

The gross alignment module system concepts are for those applications where modules are interfaced with a spacecraft structure



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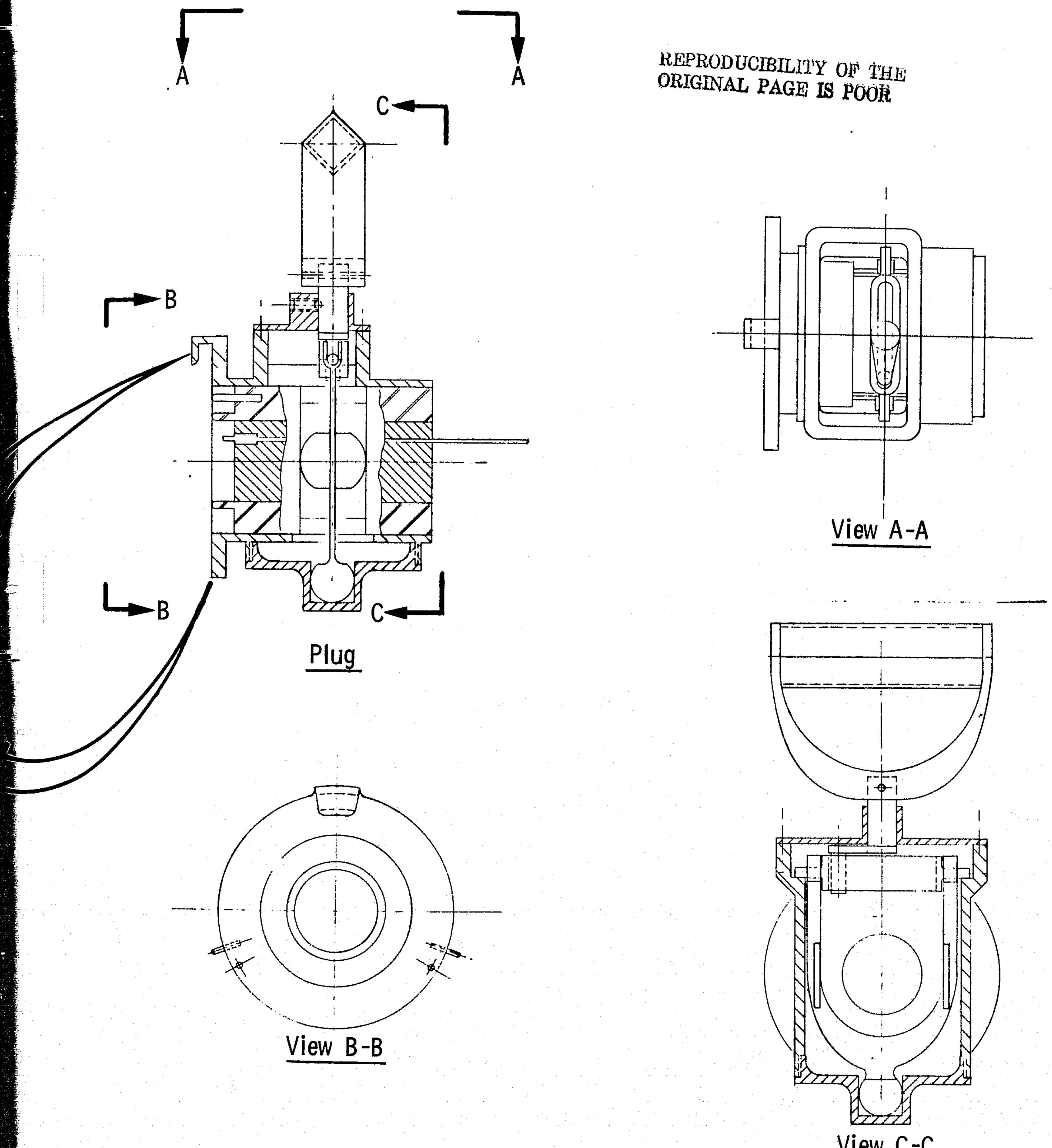
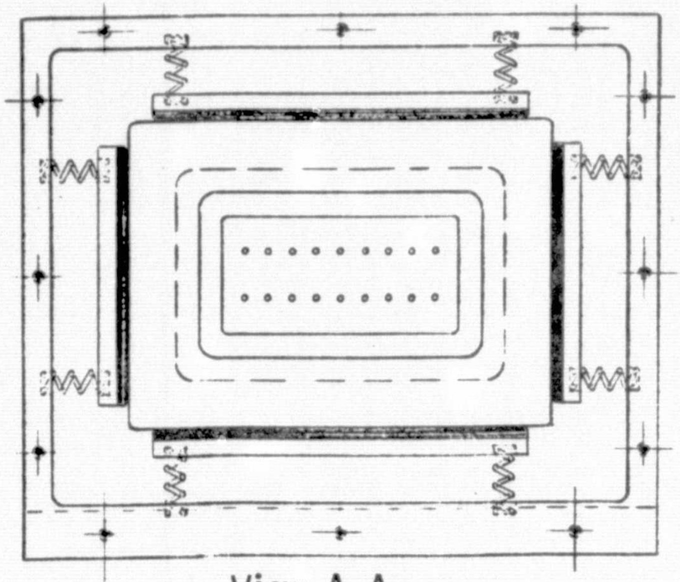


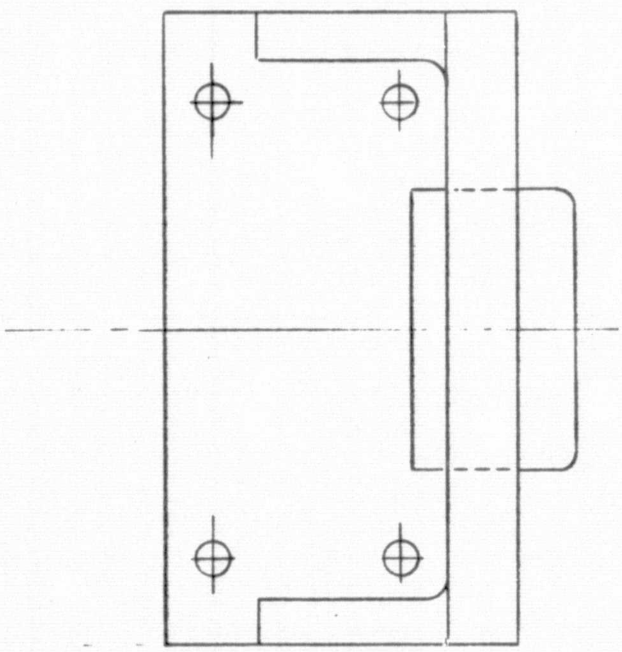
Figure V-4 Manipulator/EVA Crewman Concept Three that are not designed for fine alignment tolerances as in paragraph D. These modules are placed into a spacecraft rack by means of a manipulator system. The spacecraft module racking provides alignment to within $\pm.64$ cm ($\pm.25$ in.) and $\pm 8.75 \times 10^{-2}$ rad (5^{o}) angularity.

Two concepts for these "black box" type connectors are shown in Figures V-5 and V-6. Both concepts compensate for horizontal and vertical misalignments of $\pm.64$ cm (± 0.25 in.) and $\pm 8.75 \times 10^{-2}$ rad ($\pm 5^{o}$) angularity. Both concepts also use a tapered cone on the receptacle for centering. The receptacles are designed to compensate for roll, pitch, and yaw angularity misalignments with a swivel joint gimbal arrangement. The swivel joint used is the Bendix type flex pivots that provide a spring action for returning to the nominal position when connector halves are disengaged. The receptacles are mounted on a stationary structure.

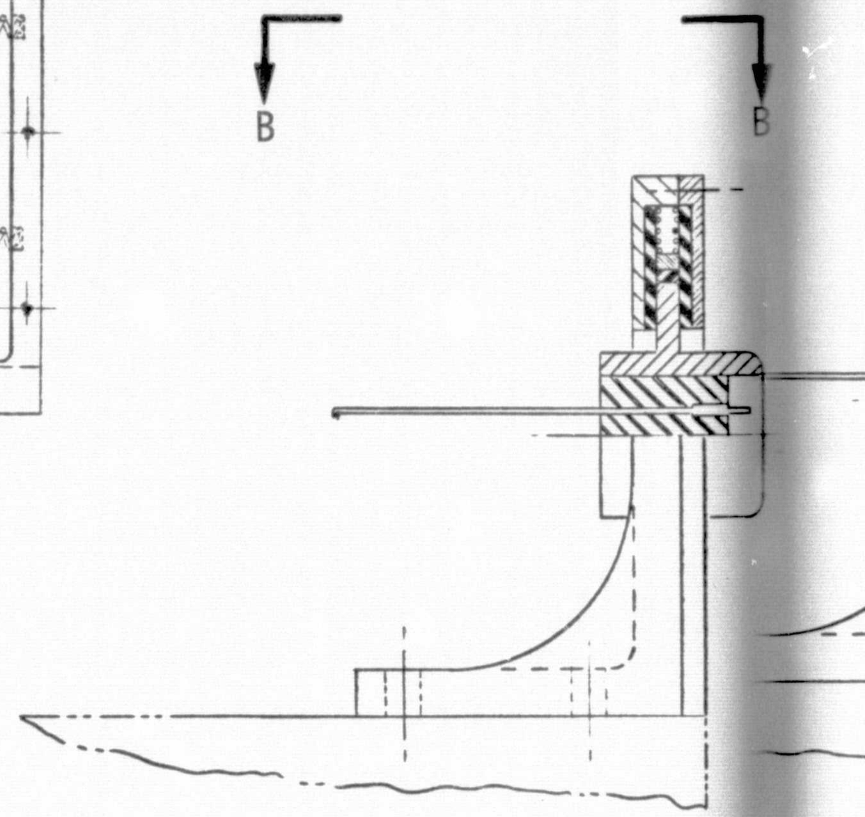
The plugs are mounted on replaceable modules that have their own alignment and drive mechanisms. The difference between the two concepts shown is in the method of compensating for the horizontal and vertical misalignments. The concept shown in Figure V-5 has the plug insert supported in a housing with eight centering springs. The springs are compressed as offset motions required for mating are made. As the connector halves are demated, the springs return the plug to a nominal center position. The concept in Figure V-6 uses the Bendix flex pivots in two sets of four-bar linkage arrangements to compensate for the required misalignments. As in concept SRU 1, a return to a neutral position is maintained during disengagement.



View A-A



View B-B



Plug (Mounted on Spacecraft Replaceable

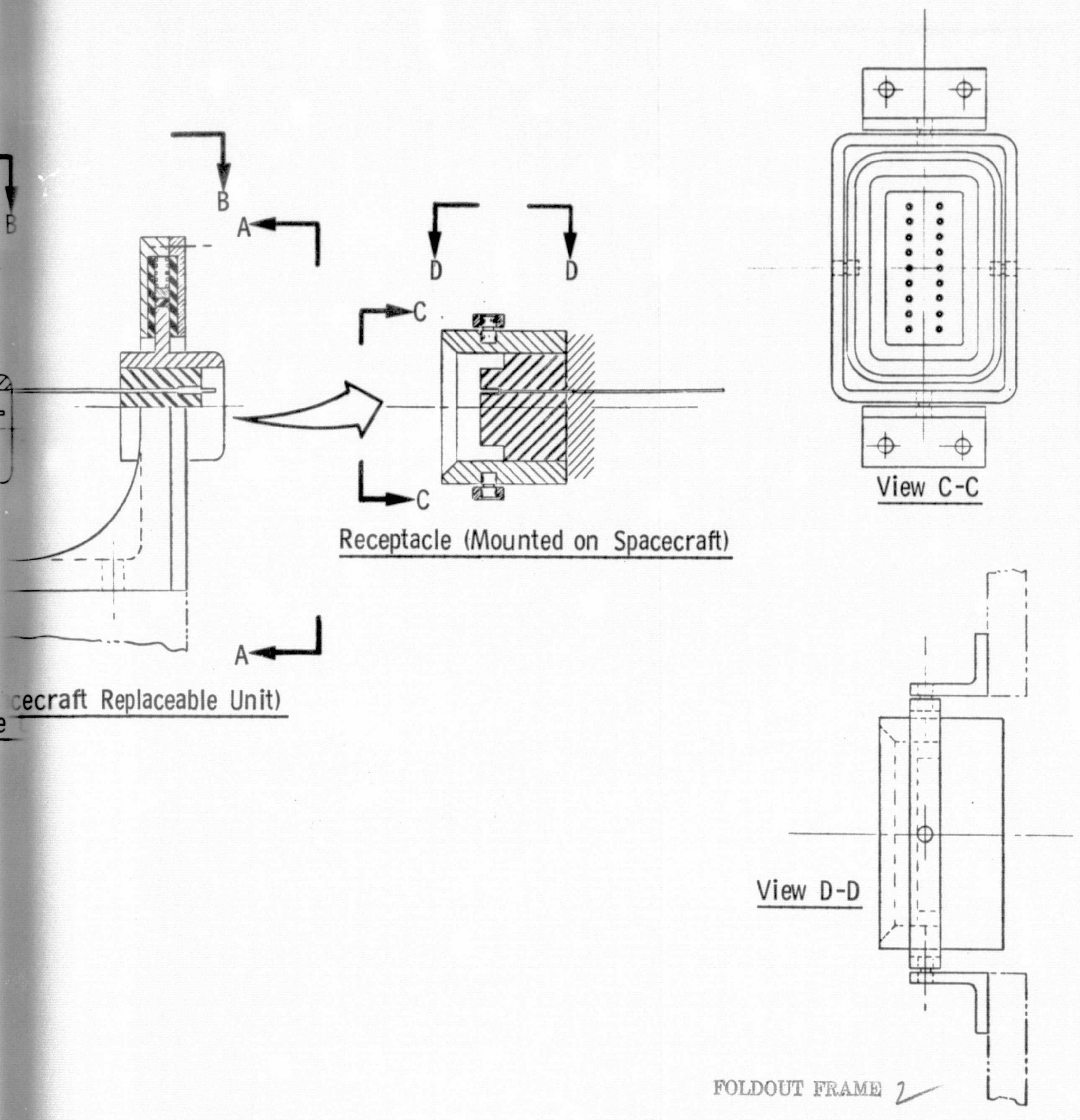


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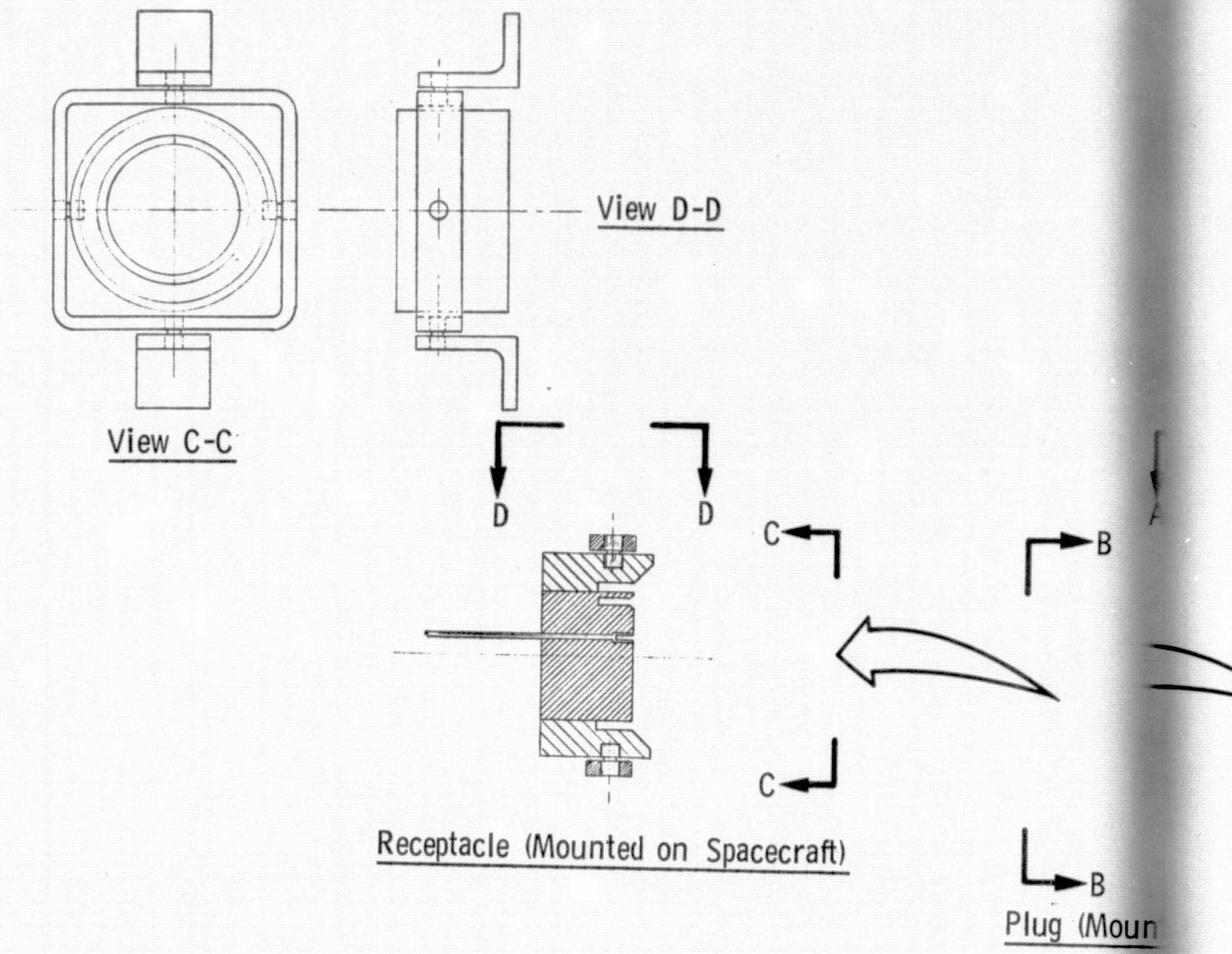
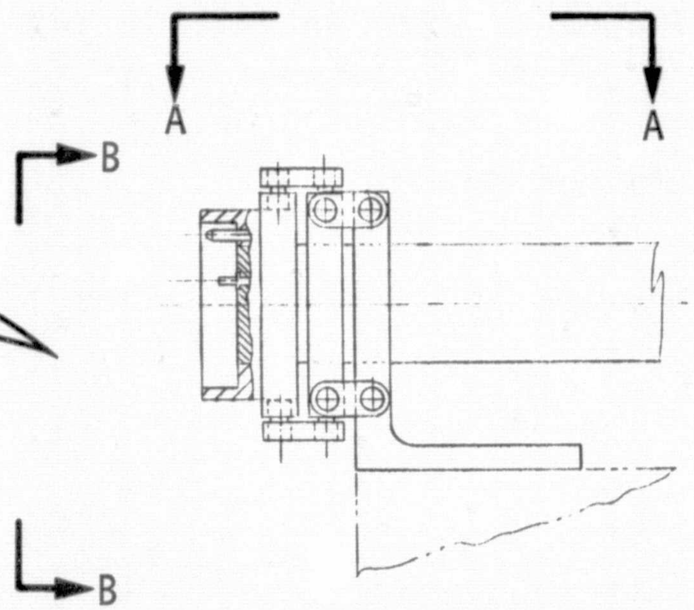
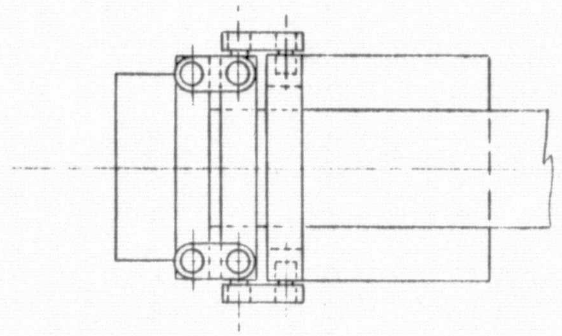
Figure V-5 Gross Alignment Module System Concept 1

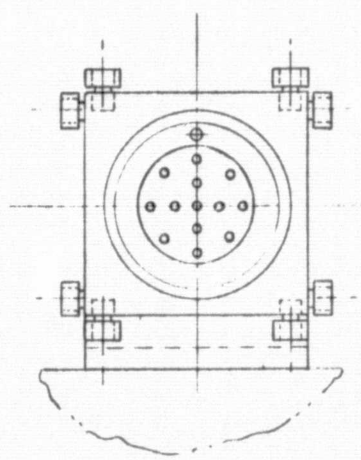

View D-D
View C-C
D
D
C
C
B
B
Receptacle (Mounted on Spacecraft)
Plug (Moun



Plug (Mounted on Spacecraft Replaceable Unit)



View A-A



View B-B

Figure V-6 Gross Alignment Module System Concept 2

VI. TASK 4 - MOUNTING AND OPERATION SKETCHES

A. PURPOSE AND SCOPE

This section presents the mounting and operation sketches of the system concepts selected during the design evaluation as discussed in paragraph VII. Four systems concepts are presented for the following applications:

- EVA suited crewman;
- Manipulator mating a plug similar to the EVA suited crewman;
- Spacecraft serviceable module with fine alignment;
- Spacecraft module in a serviceable rack without fine alignment.

B. EVA SUITED CREWMAN MATING SEQUENCE

The manipulator/EVA crewman electrical disconnect system mounting and operation sketch is shown in Figure VI-1. This sequence sketch is of a suited EVA crewman mating an electrical plug disconnect and cable system to a wall mounted receptacle in the Orbiter payload bay. A work platform is necessary to provide crewman stability and a hand rail provides the crewman with a bond restraint to counteract required torques and forces.

The receptacle ball can either be mounted on the wall, as shown in Figure VI-1a, or in a recessed structure. As the crewman attempts to position the plug half above the receptacle (see b), the design allows a forward force/pull without actuating the locking mechanism and inadvertently exposing the electrical contacts that could be damaged. The initial positioning of the plug can be within ± 3.81 cm (± 1.5 in.) prior to moving the plug in a downward plane toward the receptacle. Again, the handle design allows this movement without actuating the mechanical linkage.

As the plug is moved in a downward plane, the shape of the cone of the plug and the tapered sides and square shape of the receptacle structure provide the gross axial and docking alignment (see c). As the plug bottoms out, a couple of spring-loaded ball plungers in the receptacle matches detents in the plug to provide a slight retention force to hold the plug/receptacle position. The handle is then rotated axially in line with the cabling to engage the plug pins into the receptacle sockets (see Figure VI-1d). This movement causes the plug cabling to move forward on a sleeve at the back of the plug housing. The pins are locked into the sockets when the handle is in the position as shown in Figure VI-1e.

Figure VI-2 is a cross-section showing the mating sequence of the pins into their sockets as the handle is rotated. After .385 rad (22^{o}) rotation, the sleeve of the plug overlaps the socket insert and provides the fine axial alignment of $\pm 1.02 \times 10^{-2}$ cm ($\pm$.004 in.). When the handle is rotated to .665 rad (38^{o}), the explosion-proof seal has engaged and the dowel pins have picked up the brushings in the receptacle for the final angularity alignment of $\pm .58 \times 10^{-2}$ rad ($\pm$20 arc min.). At 1.12 rad (64^{o}), the pins of the plug are completely inserted into the sockets of the receptacle. With the complete rotation to 1.12 rad (64^{o}), the pins are locked into the sockets by means of an over-the-center linkage system as shown in Figure VI-1e.

C. MANIPULATOR MATING SEQUENCE

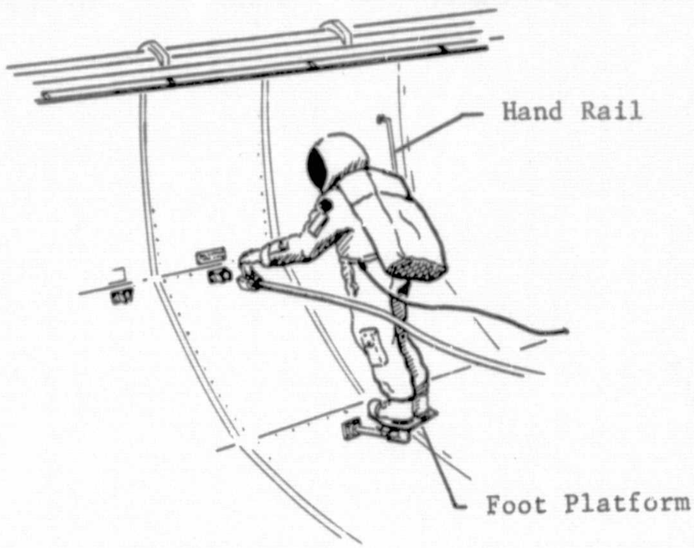
The manipulator/EVA electrical disconnect system mounting and operation sketch is shown in Figure VI-3. The mating sequence is similar to the EVA crewman mating sequence discussed in paragraph VI.B. The manipulators' characteristics are compatible with the movements and initial alignments necessary to mate the plug half with the receptacle half.

The end effector jaws attach to the handle in the same manner as an EVA crewman. The joints of the manipulator must be back driveable to compensate for the handle position during rotation through the 1.12 rad (64^{o}). This allows the manipulator to be continuously clamped to the handle for the complete coupling cycle. The design of the end effector is a simple four-jaw over-the-center mechanism that is being developed under contract NAS8-30820 for servicing spacecraft replaceable modules.

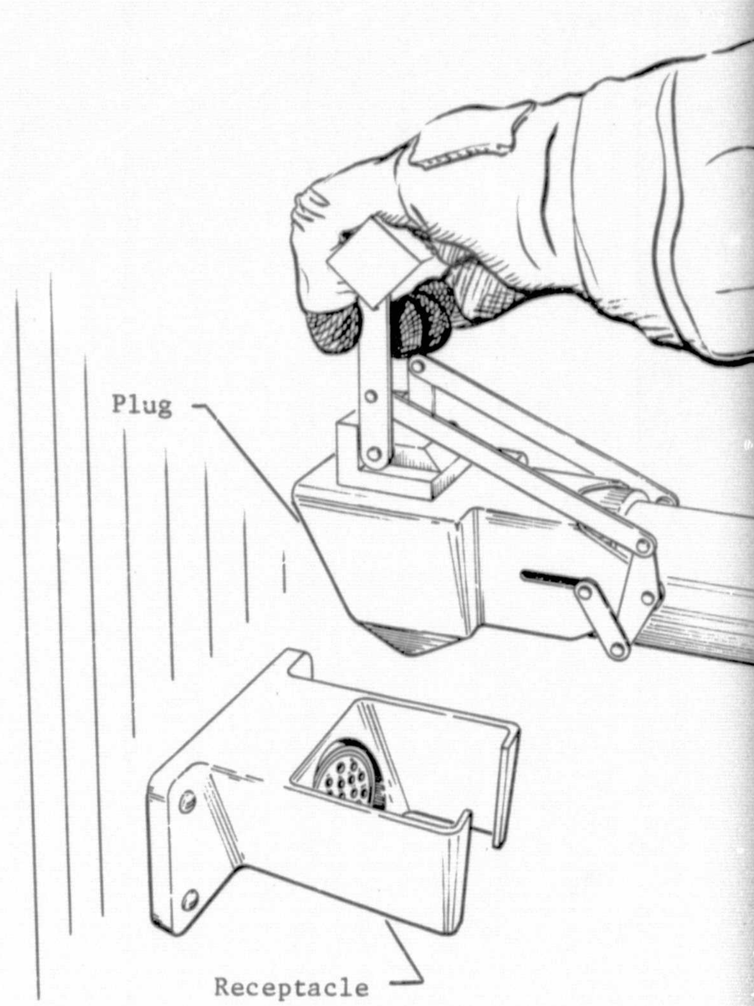
The manipulator mating sequence would include the following steps:

- Grasp handle of plug half;

- Position plug half over receptacle to within $\pm$3.81 cm ($\pm$1.5 in.);

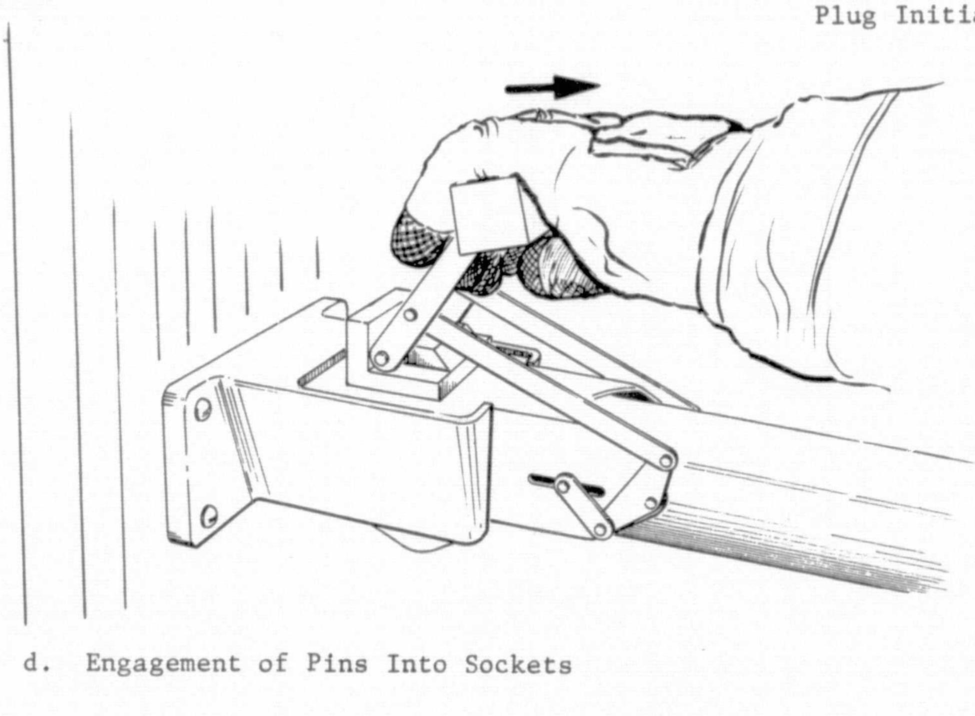


a. Crewman Work Platform
Provides Stability
and Force Aids



b. Initial Position Requires Locating
Plug Initially Above Receptacle

es Loc
ceptac



d. Engagement of Pins Into Sockets

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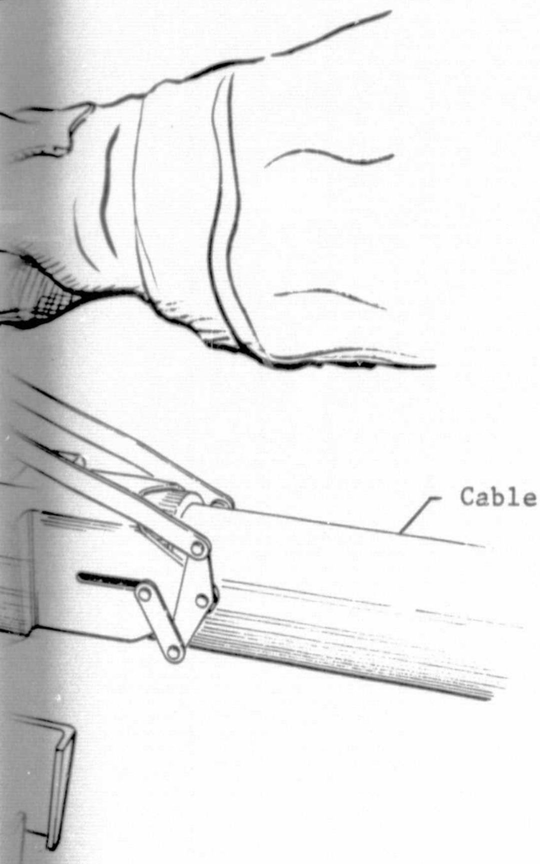
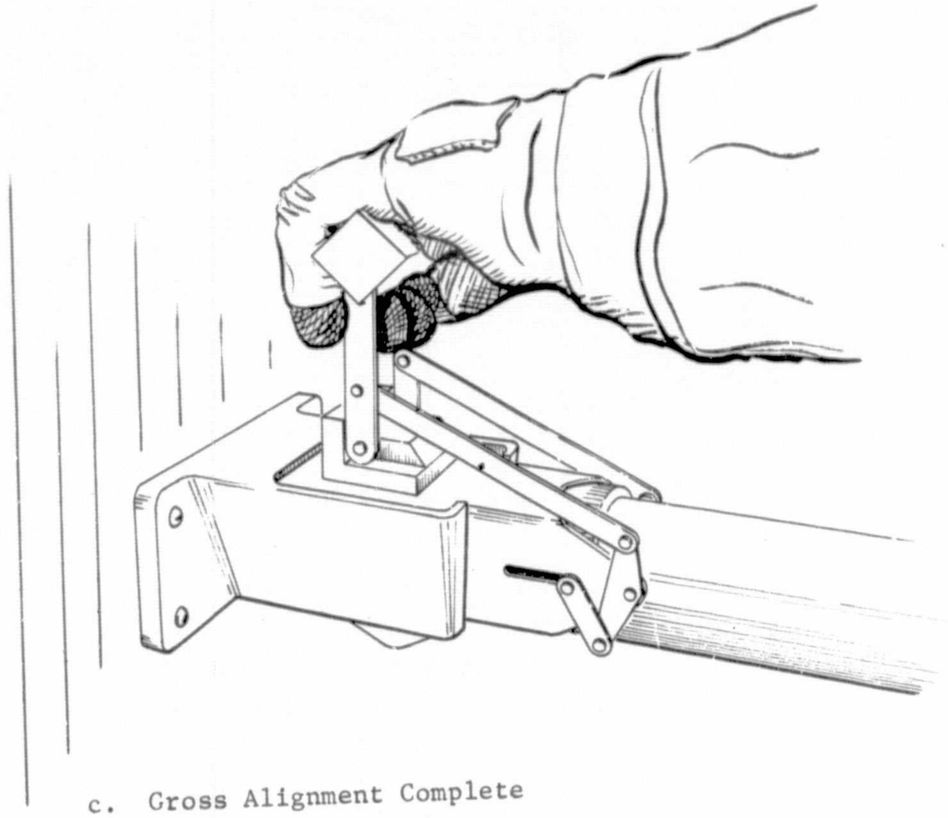
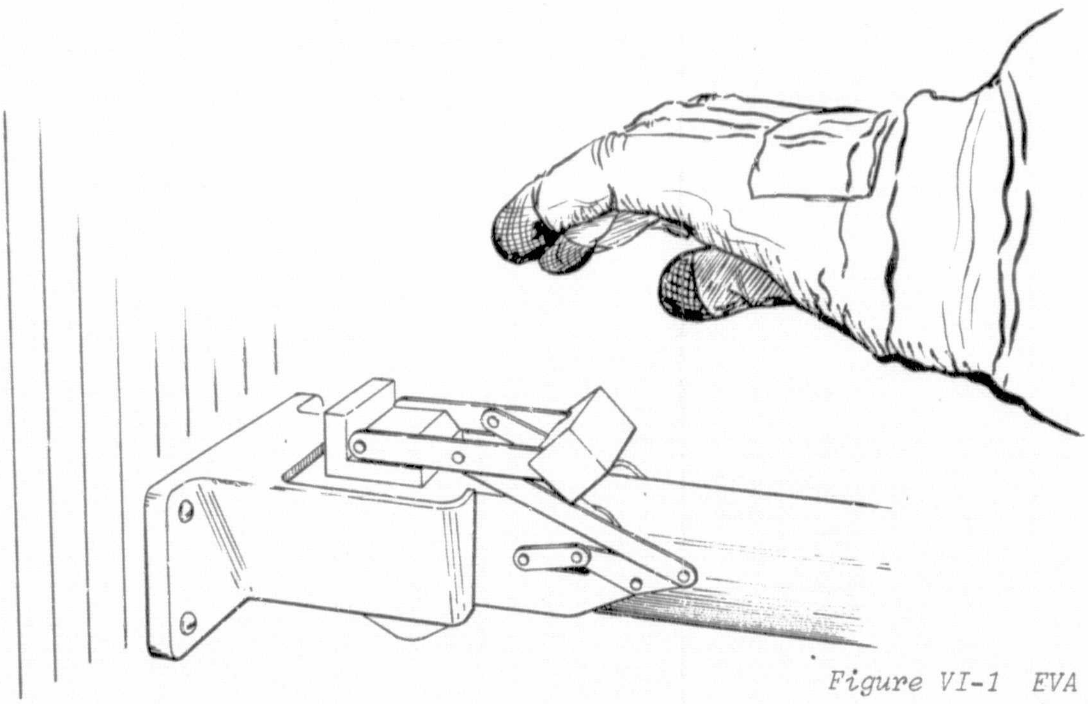




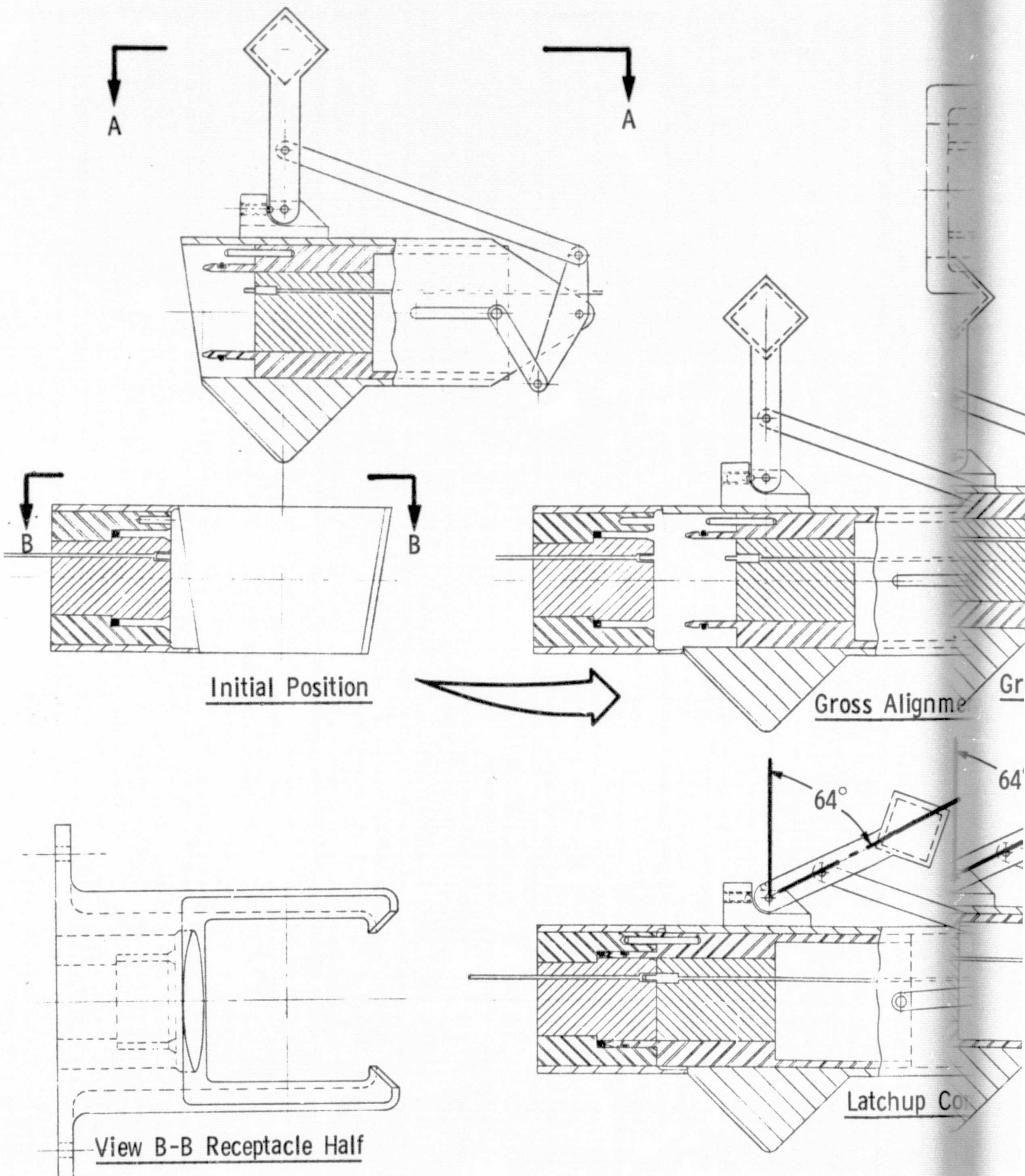
c. Gross Alignment Complete

es Locating
eceptacle



e. Mated and Locked Connector

Figure VI-1 EVA Electrical Connector System Mounting and Operation Sketch



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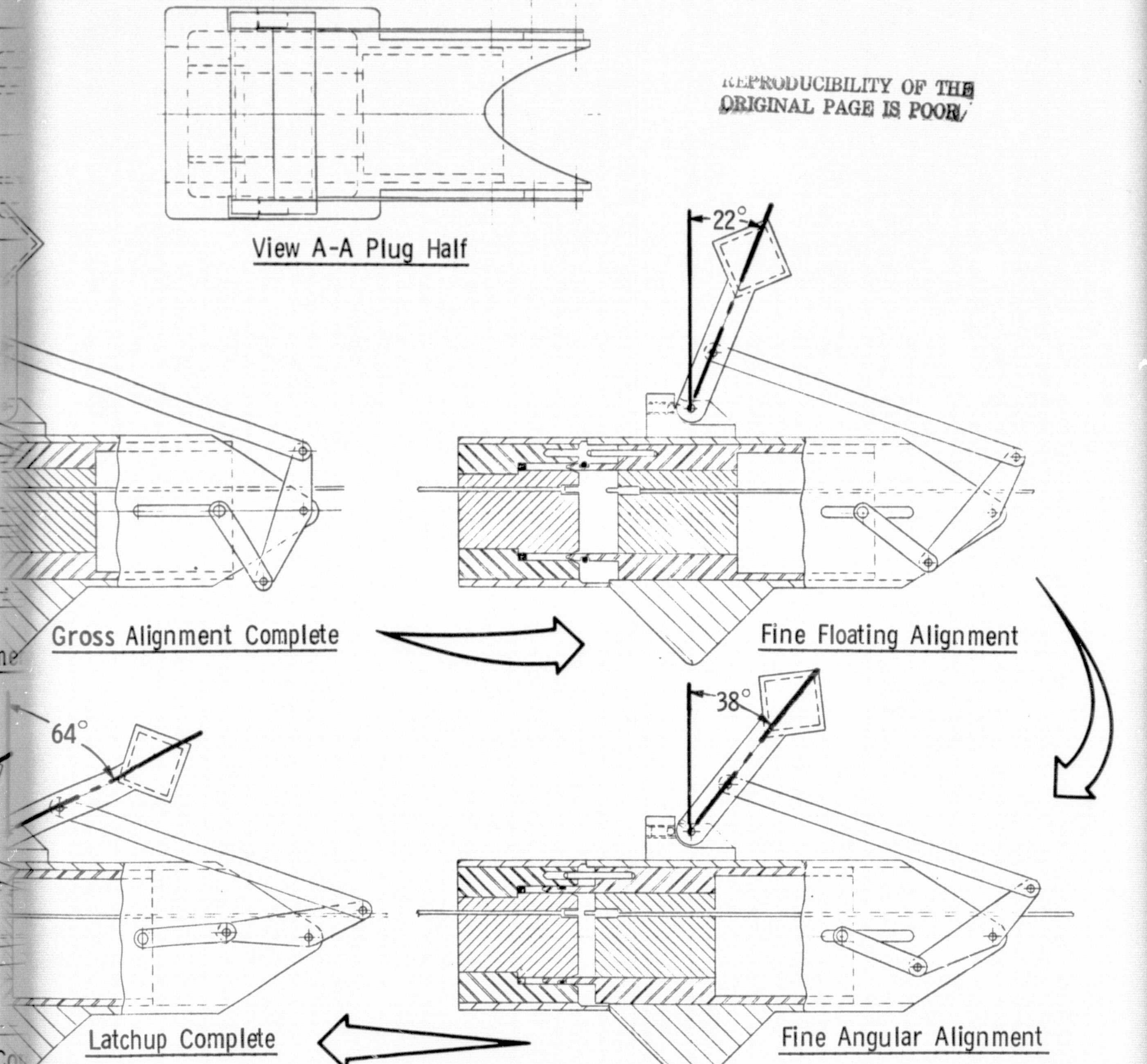
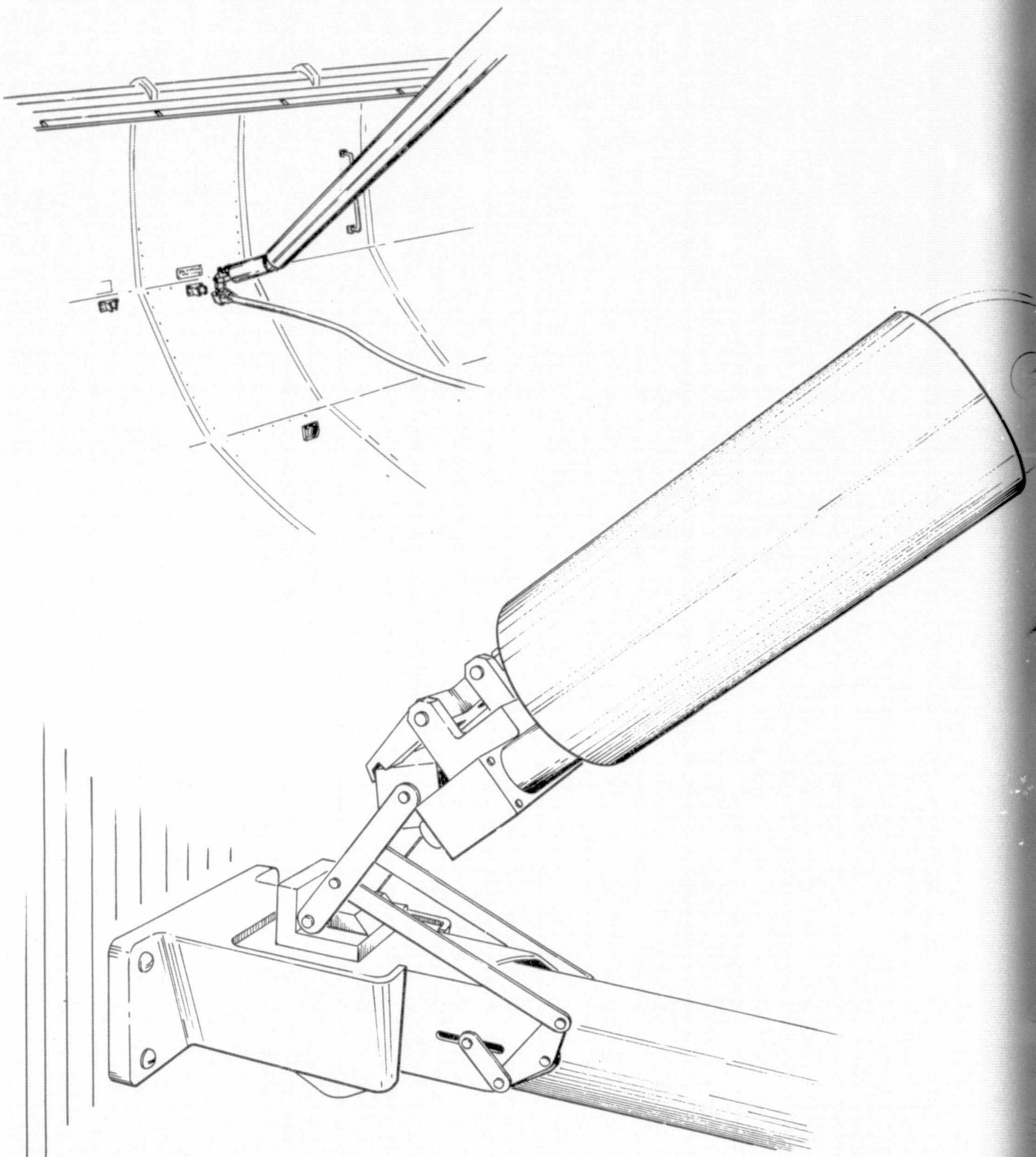


Figure VI-2 Manipulator/EVA Crewman Concept Two



Manipulator Mating

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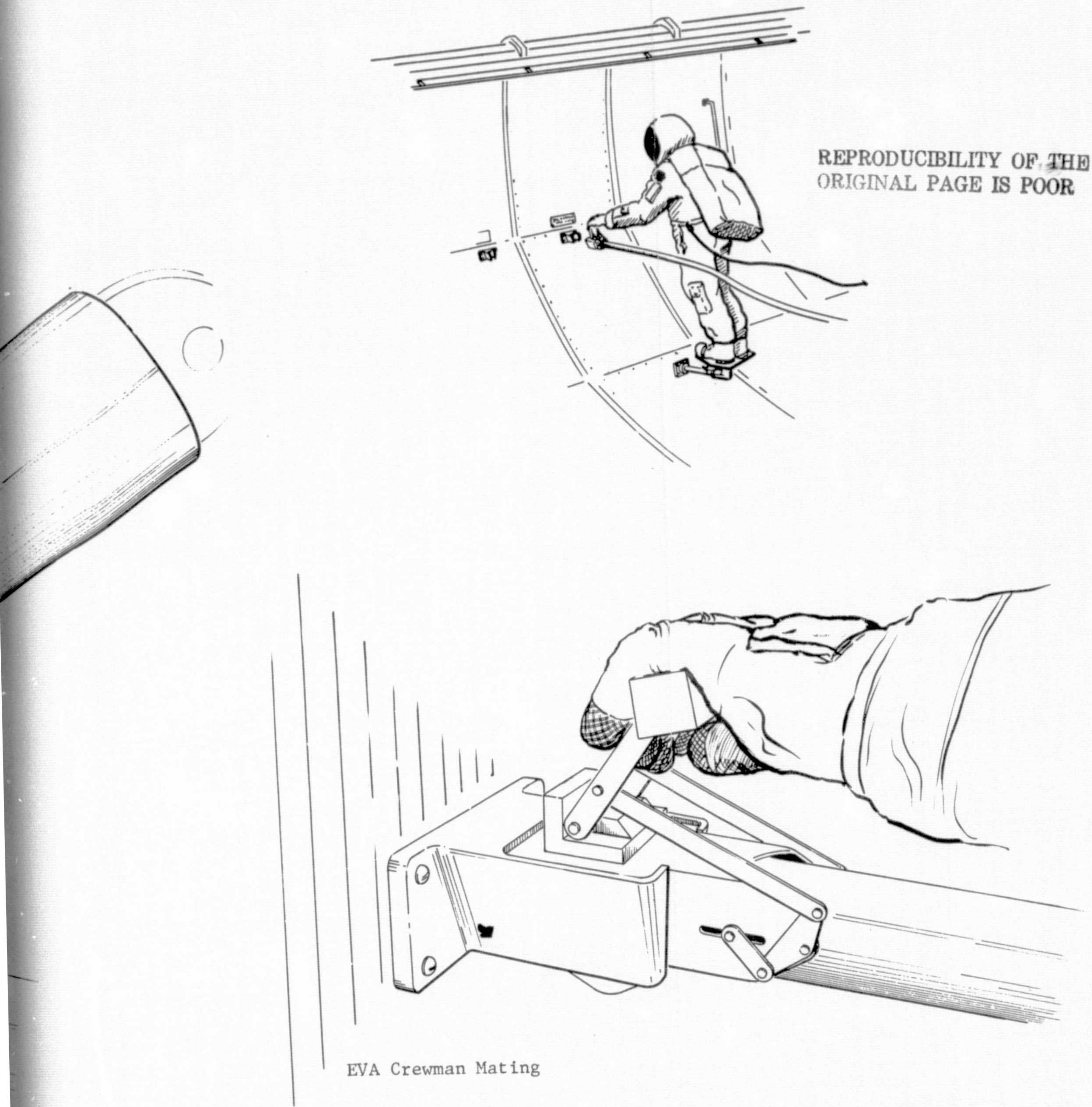


EVA Crewman Mating

Figure VI-3 Manipulator Electrical Connector System Mounting and Operation Sketch

- Move downward in verticle plane to intersect receptacle and complete gross alignment;
- Move handle back 1.12 rad (64^{o}) in a plane parallel to the cable;
- Release handle.

TV cameras and visual cues would be required to observe relative positions between the end effector and the connector.

D. ALTERNATE CONCEPT FOR EVA/MANIPULATOR MATING SEQUENCE

This approach as shown in Figure VI-4 is a combination of concepts 2 and 3 and consists of a receptacle and plug that utilizes the tapered cone method for alignment, a pivoting mechanical linkage for the drive mechanism, interlocking sleeve/housing for latching, overcenter cam for locking, and pin/hole pattern for polarization.

The receptacle consists of a mounting flange followed by a section that houses a standard socket insert. Surrounding the insert is a close toleranced gap that receives the sleeve of the plug insert. The area around the gap has drilled holes for polarization and docking alignment. The housing extends past the insert and incorporates a tapered square shaped recess for plug-to-receptacle alignment.

The plug assembly consists of a tapered square shaped cone that matches the recess in the receptacle and incorporates a sliding inner core that is machined to accept a standard pin insert. This inner core slides axially in the plug housing. The forward end of this slide member extends past the insert by .95 cm (3/8 inch). This portion slides over the receptacle insert for the fine alignment. Also located in the front of the slide member is the polarization pins. The sliding center core is driven by a yoke spring pivoting around a ball end at its base and driven at the top by a cam type driven actuator. A handle suitable for both EVA crewman and a remote manipulator device is attached to the cam driver. A ball plunger located at the base of the handle shaft picks a detent in the fully retracted position. The retaining force on the ball plunger is greater than the drag force of the cabling but less than that of the manipulator.

The sequence of mating the connector halves is accomplished by initially positioning the plug half above the receptacle by hand

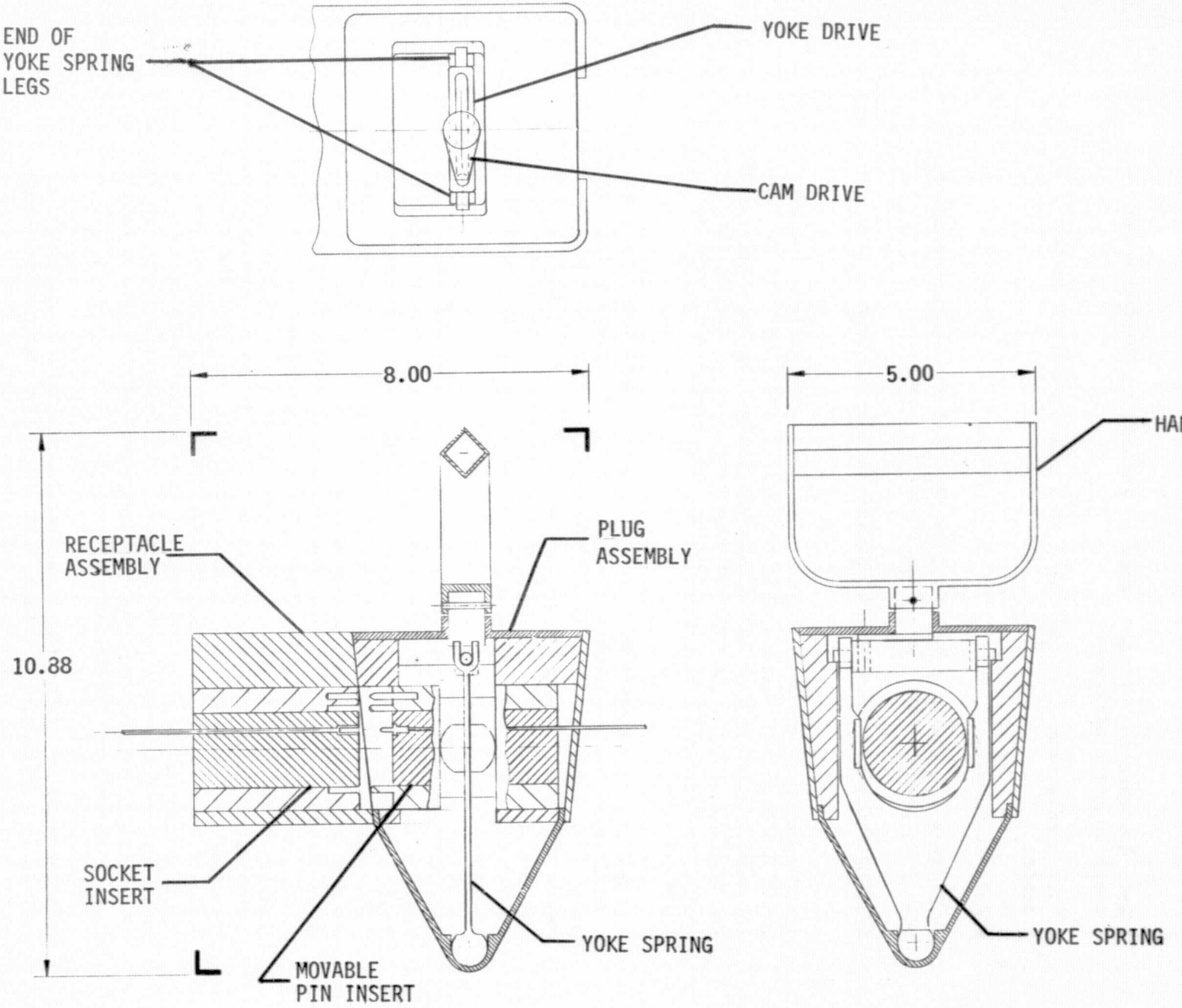


Figure VI-4 Alternate Connector Approach or remotely within $\pm$ 3.81 cm ($\pm$ 1.5 inches) floating and $\pm$ 8.75 x 10^{-2} rad ($\pm$ 5 degrees) angular. The plug is then moved downward into the receptacle. The tapered sides and square shape provide the gross axial and docking alignment. As the plug bottoms out, a couple of spring loaded ball plungers in the receptacle pick up detents in the plug and provides a slight retention force to hold the plug/receptacle position. To mate the electrical contacts the handle is rotated. The first few degrees of rotation engages the plug sleeve and receptacle insert which provides the fine alignment. Further rotation of the handle starts the insertion of pins into the sockets. As the handle rotates 1.58 rad (90 degrees) the high point of the cam driver passes top dead center deflecting the spring yoke driver and locking the pins in the fully inserted position. All motions of the handle requires a manipulator with backdriveable joints.

The manipulator/EVA crewman electrical disconnect system mounting and operation sketch is shown in Figure VI-5. This sequence sketch is of a suited EVA crewman mating an electrical plug disconnect and cable system to a wall mounted receptacle in the Orbiter payload bay. The receptacle ball can either be mounted on the wall, as shown in Figure VI-5a, or in a recessed structure. A work platform is necessary to provide crewman stability and a hand rail provides the crewman with a bond restraint to counteract required torques and forces.

The manipulator/EVA electrical disconnect system mounting and operation sketch is shown in Figure VI-6. The end effector jaws attach to the handle in the same manner as an EVA crewman. The joints of the manipulator must be back driveable to compensate for the handle position during rotation. This allows the manipulator to be continuously clamped to the handle for the complete coupling cycle. The design of the end effector is a simple four-jaw over-the-center mechanism that is being developed under contract NAS8-30820 for servicing spacecraft replaceable modules.

E. SPACECRAFT REPLACEABLE MODULE MATING SEQUENCE

The spacecraft serviceable module electrical disconnect system utilizes a standard NASA 40M series specification connector without the locking sleeve. As can be observed in Figure VI-7a, the manipulator system is utilized to remove or replace a module in a spacecraft structure that incorporates fine alignment racks and tapered pins.

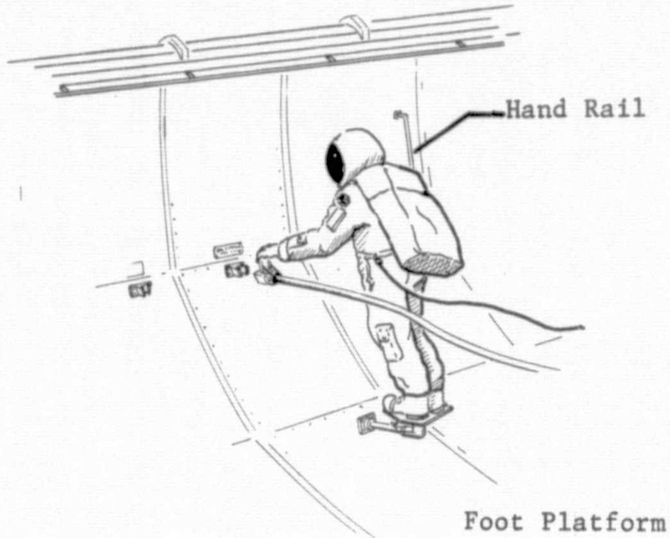
In Figures b and c, two potential locations for mounting the plug and receptacle are shown. In the front mounting location, the plug is mounted to the module by means of a bracket near the tapered alignment pin with the receptacle on the spacecraft structure near the alignment pin receptacle. The rear mounting location has the plug mounted on the latch/delatch mechanism near the rear tapered alignment pin with the receptacle mounted on the rack structure near the alignment pin receptacle (see Figure VI-7d). The module is mounted on the latch/delatch mechanism and the front mounting location allows the module to be assembled with the electrical plug at the manufacturer's facility. The rear mounting location would require the plug to be firmly mounted to the latch/delatch mechanism at the time of the module attachment. The advantage of the rear mount location is that the receptacle is recessed for possible environmental protection and does not require interfacing with the spacecraft outer structure and skin.

As the module is placed into the spacecraft rack, tapered rails allow the latch/delatch mechanism's tapered pins to engage the alignment receptacle as shown in Figure VI-7e. The tapered alignment pin provides the necessary floating and angular alignment tolerances to allow the connector plug pins to successfully mate the receptacle sockets (see Figure VI-7f). The latch/delatch mechanism provides the required force for mating/demating and the final lockup.

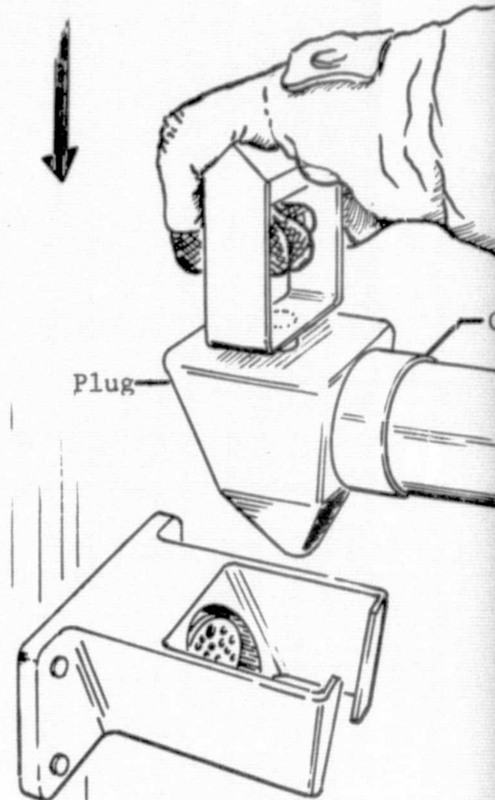
F. MODULE MATING INTO RACK SEQUENCE

The electrical disconnect system utilized for module mating into a rack utilizes a standard NASA 40M series specification connector without the locking sleeve. The connector is mounted in a bracket system consisting of a bar linkage system as described under paragraph V.E.

The difference between the SRU system described under VI.D (see Figure VI-8b) and this system is that no latch/delatch mechanism is required and the module is mounted on a structural base with rollers that mate with a structural rack (see Figure VI-8c). The module is replaced/removed either by a manipulator as shown in Figure VI-8a or by a suited EVA crewman. In either case the module is initially aligned within $\pm$ .64 cm ($\pm$ 1/4 in.) floating and $\pm$ .088 rad ($\pm$ 5°) angularity due to the rollers interfacing with the structural racks.

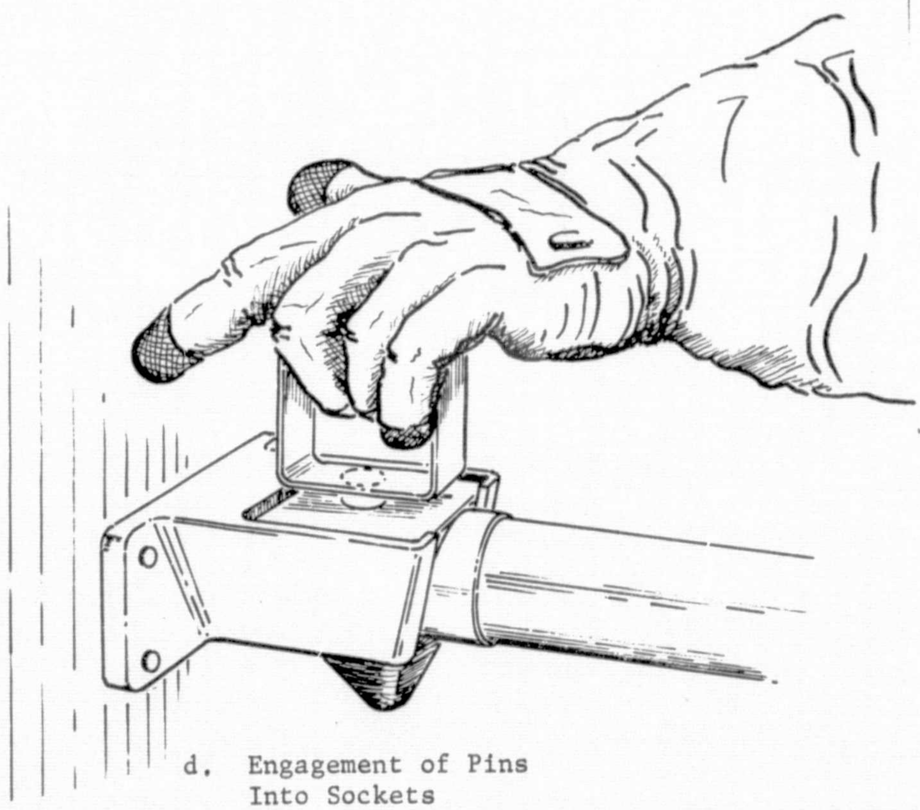


a. Crewman Work Platform
Provides Stability and
Force Aids



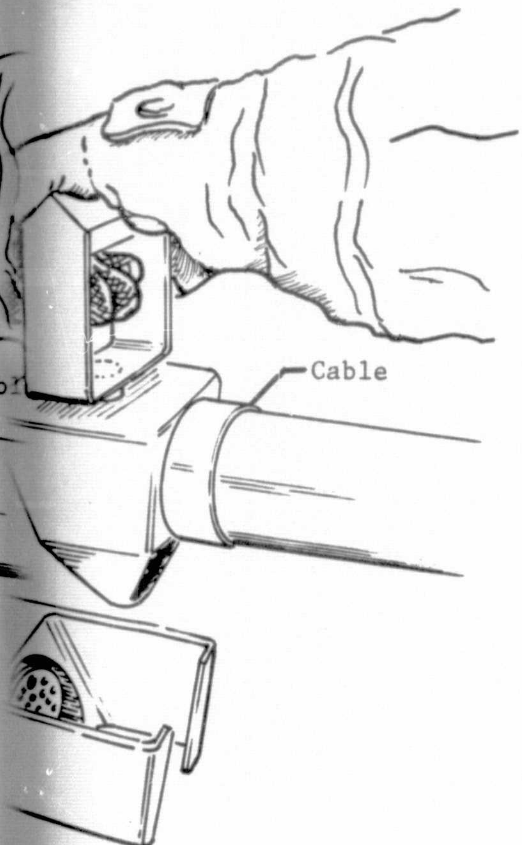
b. Initial Position Requires
Locating Plug Initially
Above Receptacle

l Posit
ng Plug
Recepta



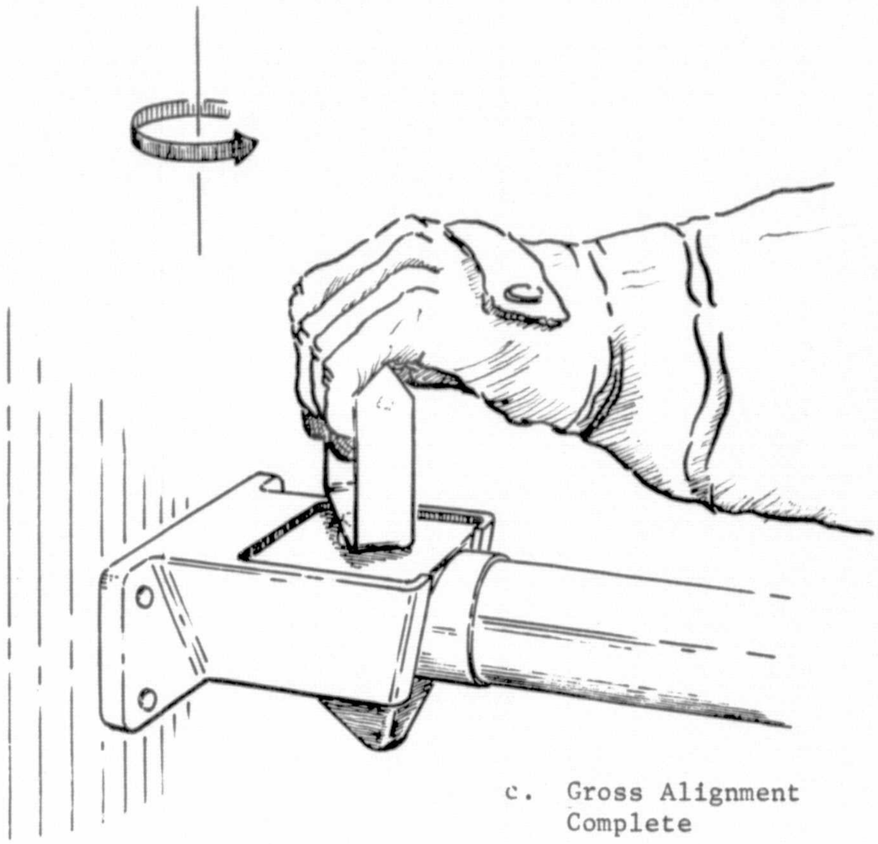
d. Engagement of Pins
Into Sockets

FOLDOUT FRAME

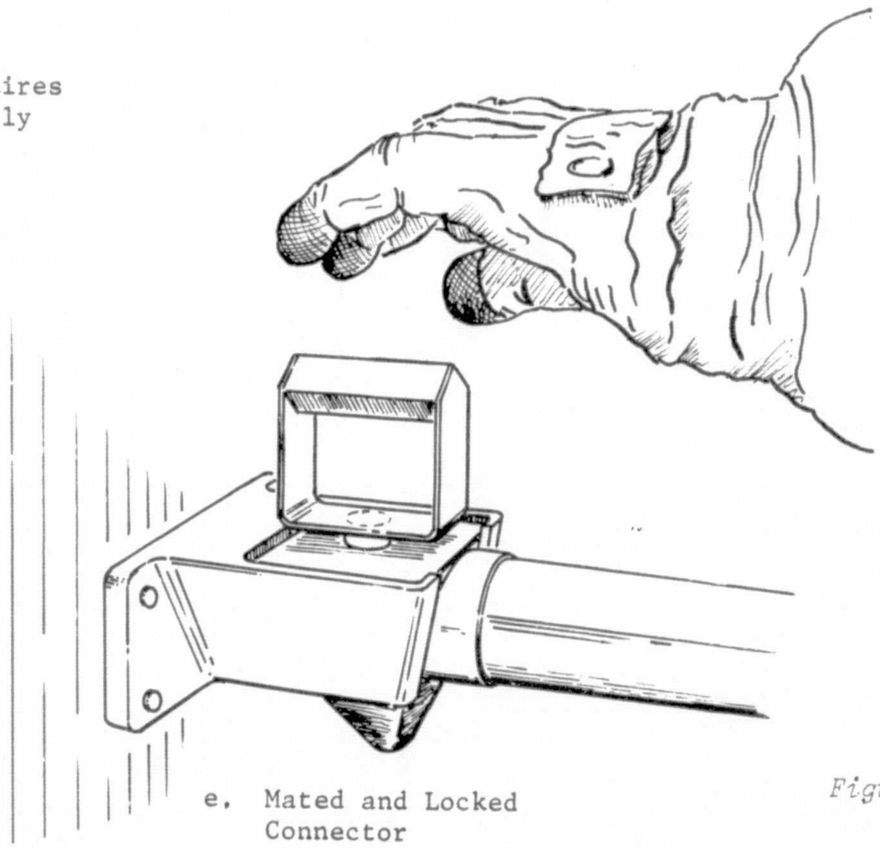


ptacle

l Position Requires
ng Plug Initially
Receptacle

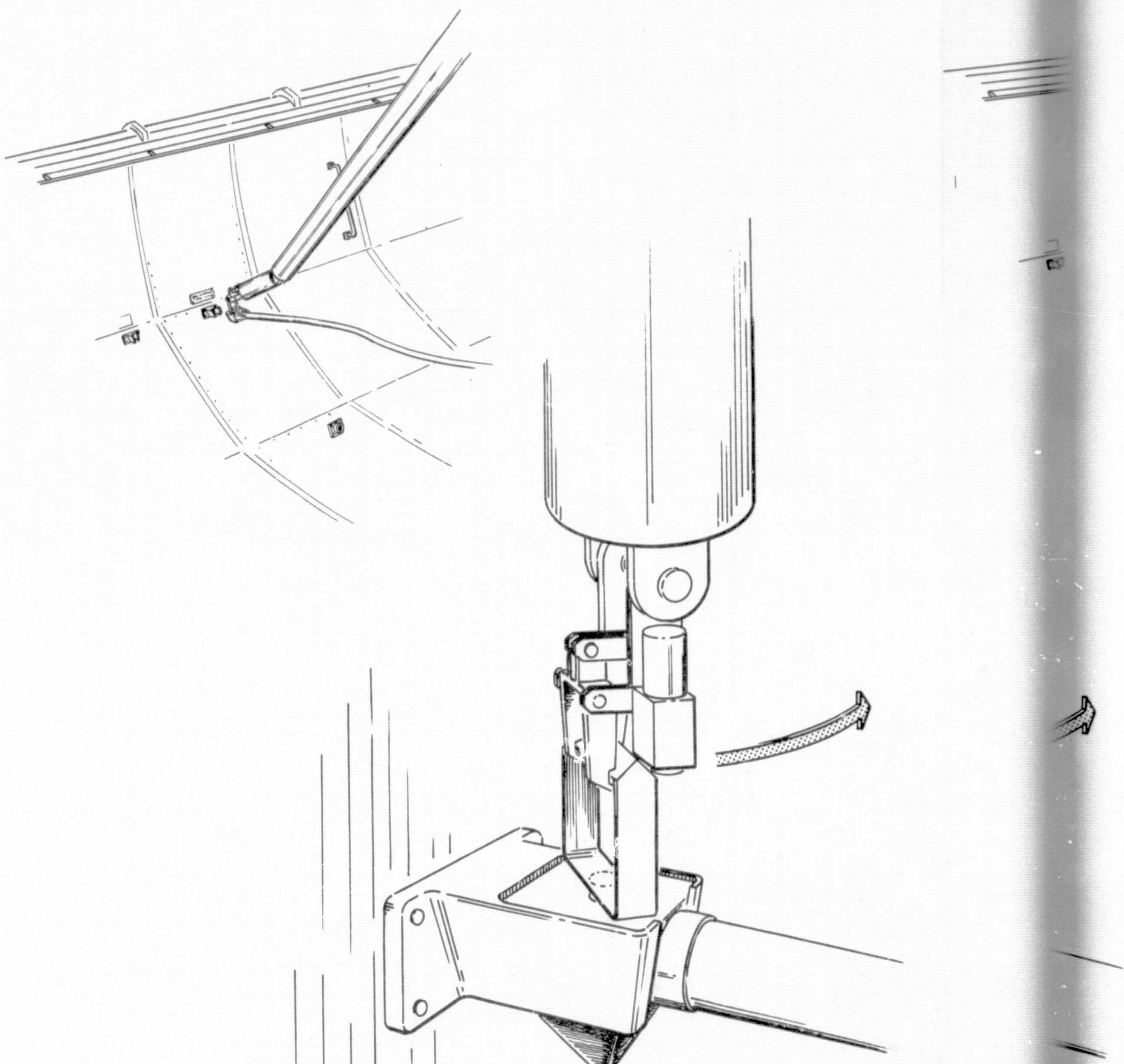


c. Gross Alignment
Complete



e. Mated and Locked
Connector

Figure VI-5 EVA Electrical Connector System Mounting and Operation Sketch - Alternate Concept



Manipulator Mating

FOLDOUT FRAME

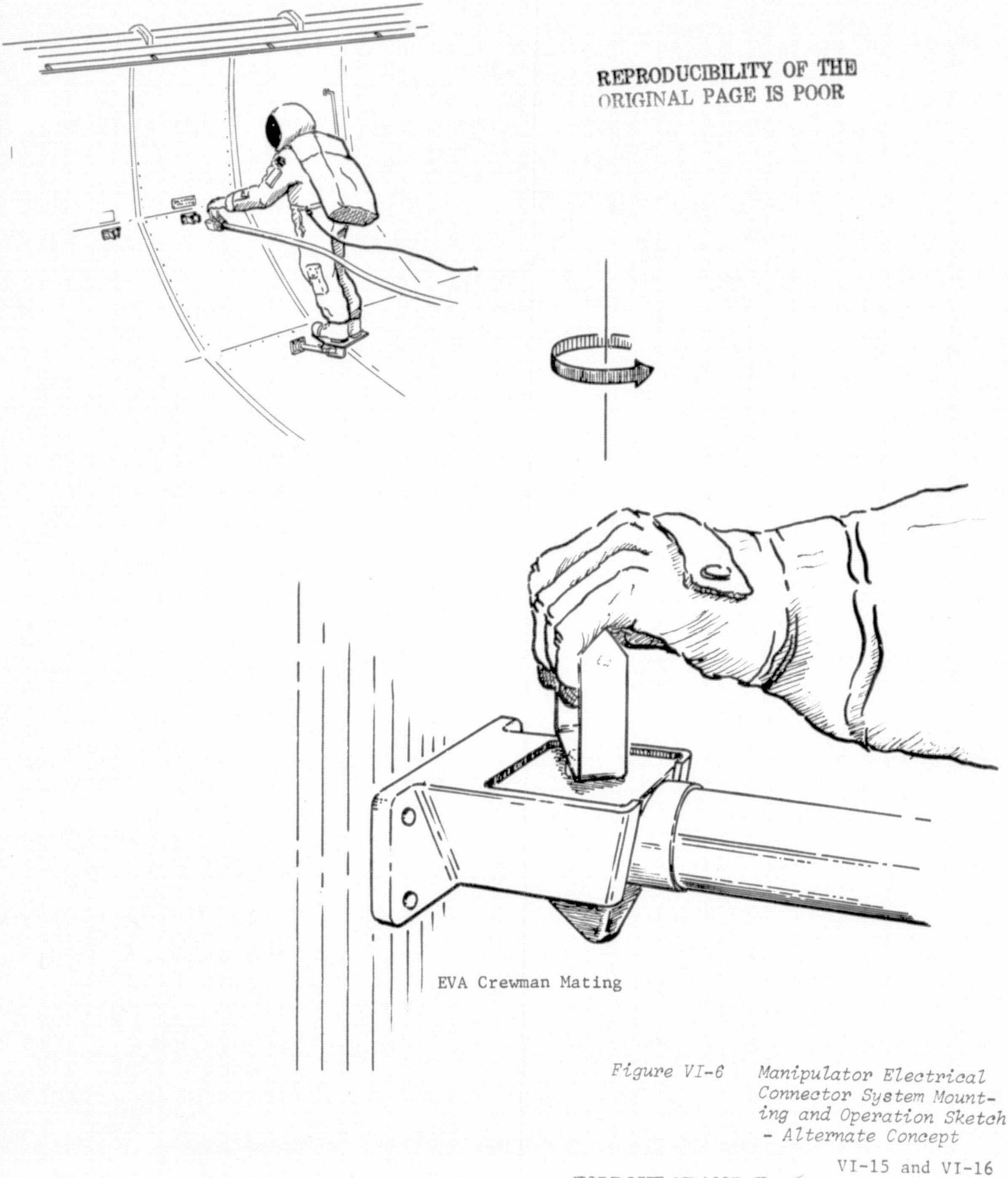
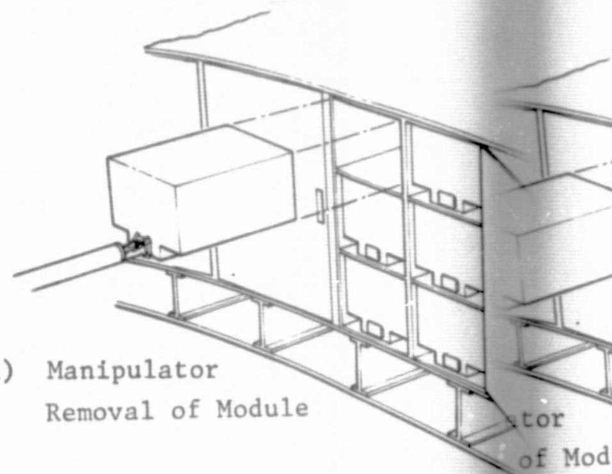
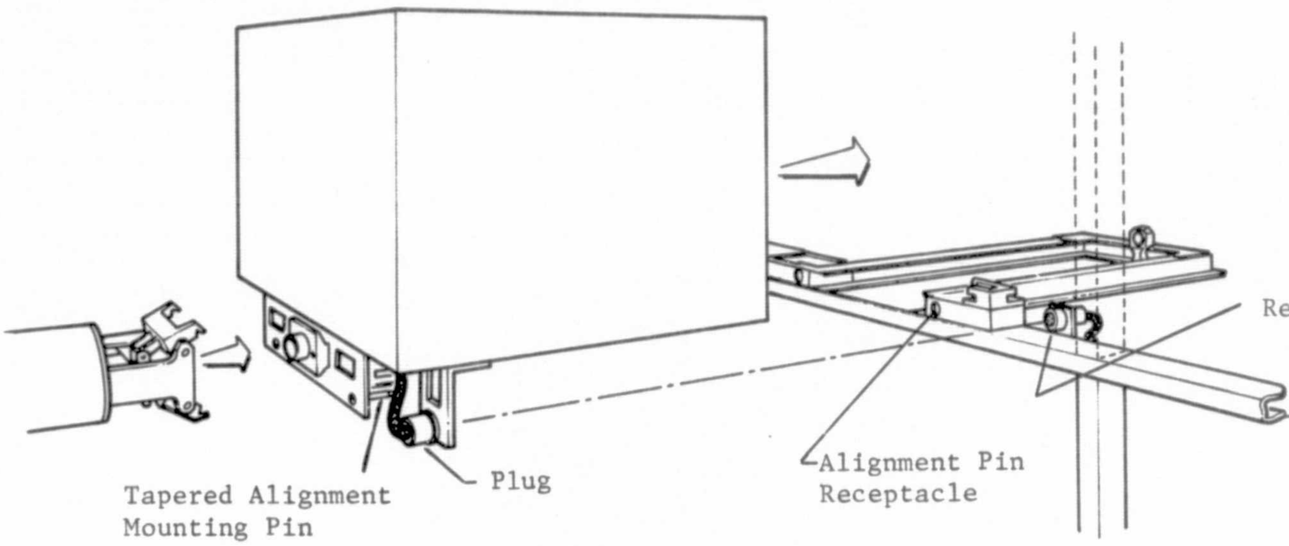


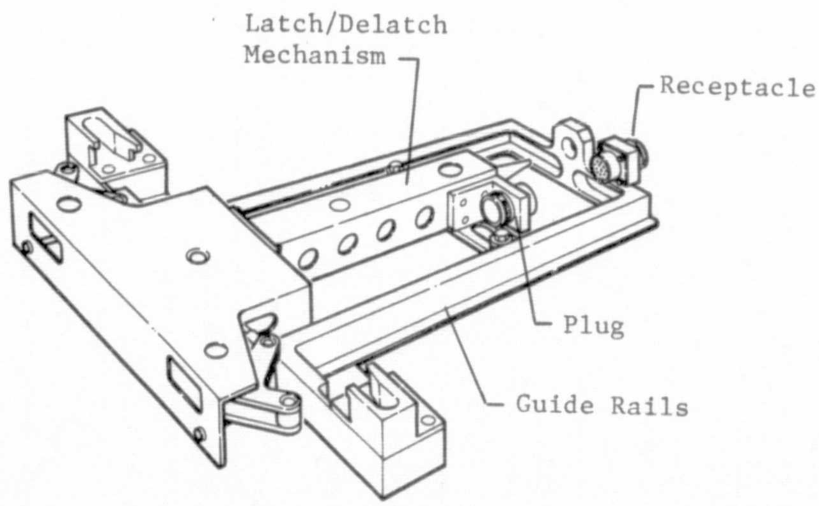
Figure VI-6 Manipulator Electrical Connector System Mounting and Operation Sketch - Alternate Concept



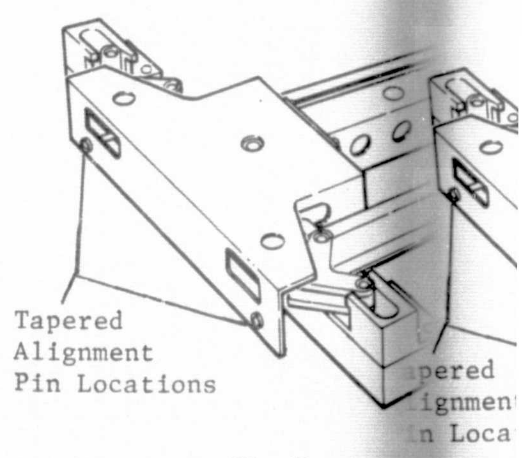
a) Manipulator
Removal of Module



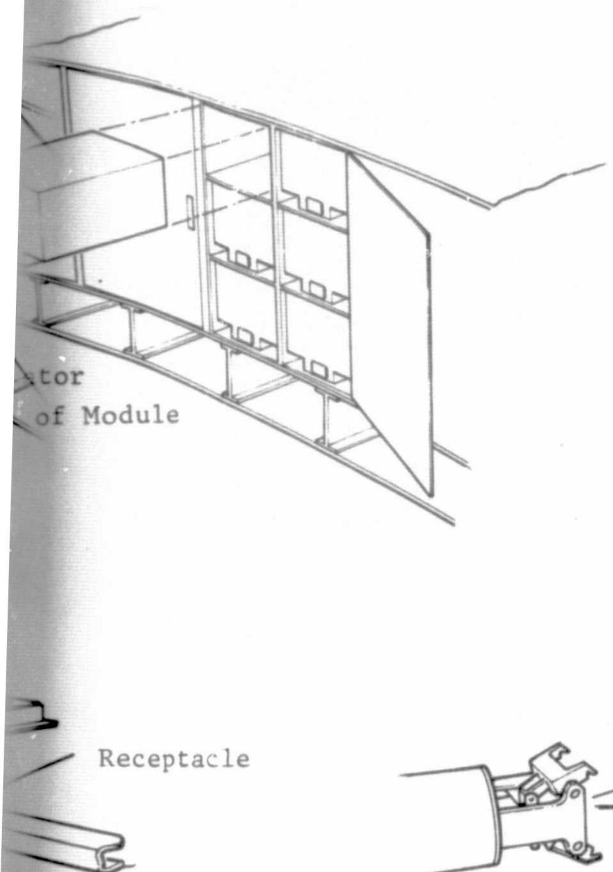
b. Front Mounting Location

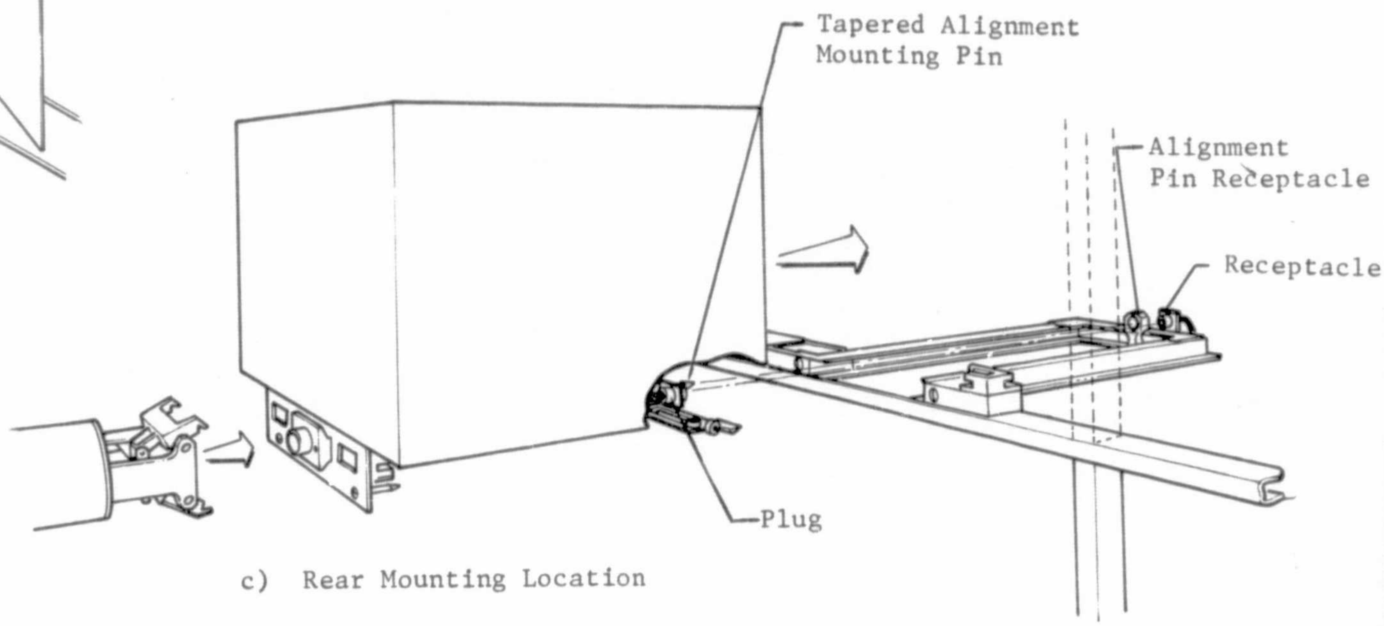


d) Latch/Delatch Mechanism
Entering Tapered Rail Rack

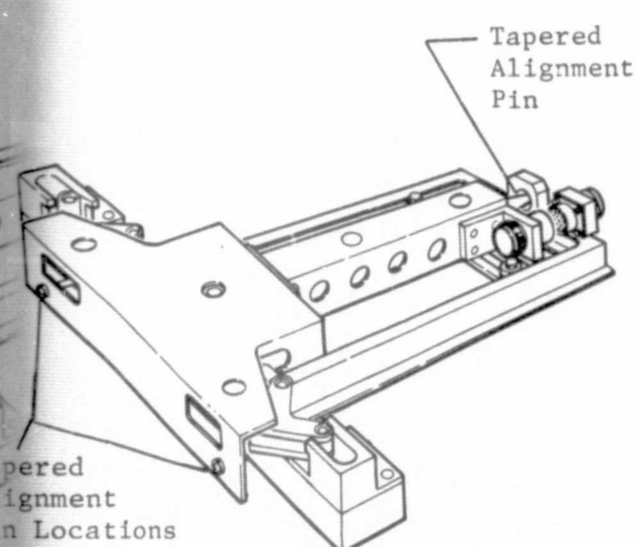


e) Alignment Pin Engageme

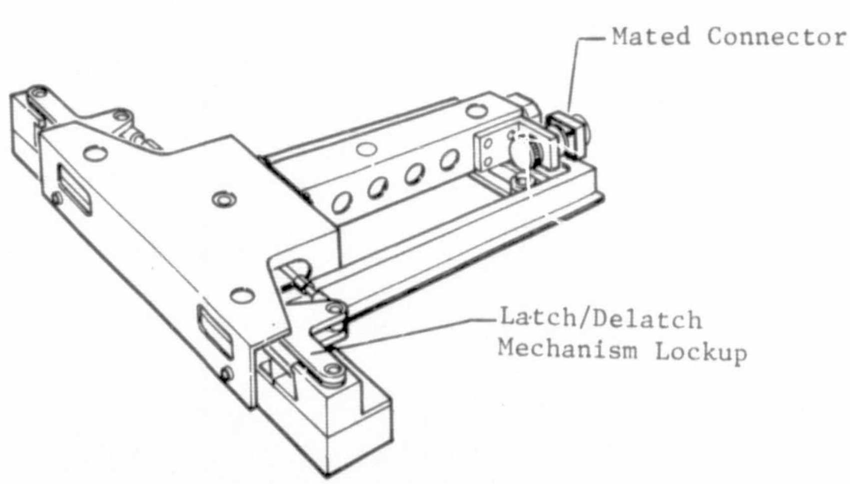




c) Rear Mounting Location

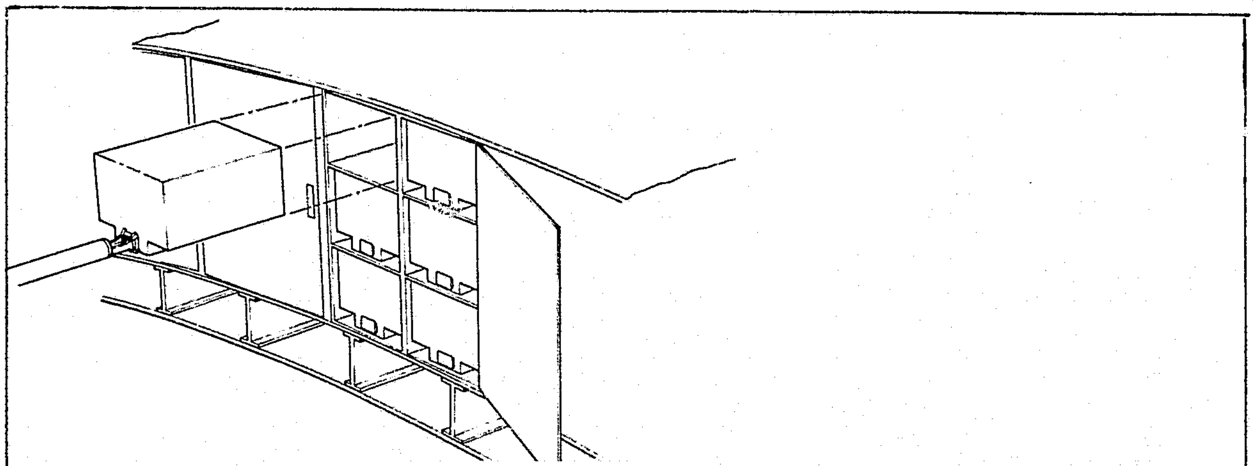


Alignment Pin Engagement

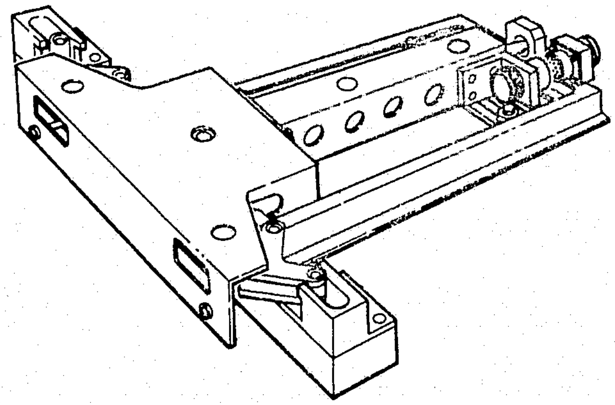


f) Connector Final Mated
Position and Lockup

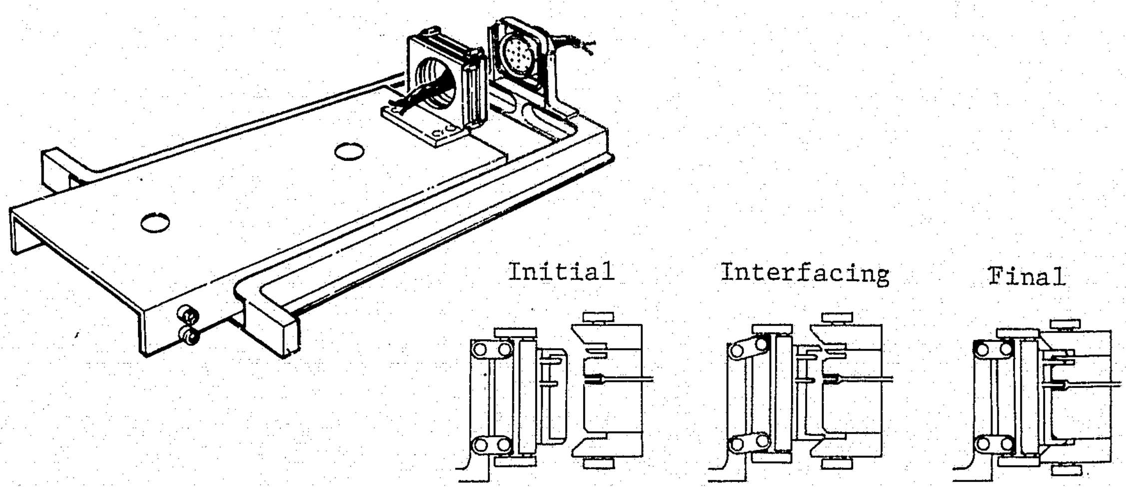
Figure VI-7 SRU Module Mating Sequence



a) Manipulator Removal of Module



b) SRU System Mating Concept



c) Gross Alignment Module Mating Sequence

Figure VI-8 Gross Alignment Module System Concept 2 Mating

As can be seen in the connector sequence series of Figure VI-8c, the plug approaches the receptacle and the square shaped plug shell intercepts the square shaped tapered receptacle shell. The bar linkage allows angular floating and alignment. Further movement allows the tapered pin in the plug half to intercept the receptacle half for final floating alignment prior to the pins entering their sockets. The module latching technique is utilized to lock the rear mounted connector.

VII. TASK 5 - DESIGN EVALUATION AND SELECTION

A. PURPOSE AND SCOPE

The objective of this task was to perform a design evaluation on the candidates to select the optimum concepts. This effort included the element concept evaluations, the system concept selection, and a hardware simulation.

B. SYSTEM DESIGN ELEMENTS SELECTION

The system design elements were evaluated as follows:

1. Consideration factors were established from the advantages/disadvantages tables for each design element (see Table V-1 for alignment concepts).

2. The factor weight was determined by comparing each factor individually against every other factor. The factor considered least important is assigned a value of zero (see Table VII-1). The factor weight is determined by adding the values assigned to each factor and then expressing them as a percent of the total values.

3. A comparative numerical rating was assigned to each element candidate as follows:

Superior	41 to 50
Above Average	31 to 40
Acceptable	21 to 30
Below Average	11 to 20
Marginal	1 to 10
Unacceptable	Reject Candidate

   The comparative rating is multiplied by the factor weight (see Table VII-6). The totals of the weighted values for each candidate were compared with the highest value indicating the candidate that best fulfills the system requirements.

Tables VII-1 thru VII-5 are the results of the factor weight comparisons. Tables VII-6 thru VII-10 are the results of the concept tradeoff

Table VII-1 Factor Weight Comparison for Alignment Concepts

CONSIDERATION FACTORS	FACTOR NO.														TOTAL	FACTOR WT.
Manipulator Motions	F-1	0	0	0	0	1	1	0							2	.07
Vol/Wt. Envelope	F-2	1		1	1	1	1	1	1						7	.25
STD Inserts	F-3		1	0		1	1	1	1	0					5	.18
Fab Complexity	F-4			1	0	0		0	1	1	0				3	.11
Aux. Power Req.	F-5				1	0	0	1		1	1	0			4	.14
Alignment Force Req.	F-6					0	0	0	0	0		1	0		1	.04
Wear	F-7						0	0	0	0	0	0		0	0	.00
Reliability	F-8							1	0	1	1	1	1	1	6	.21
															28	1.0

Table VII-2 Factor Weight Comparison for Latching Concepts

CONSIDERATION FACTORS	FACTOR NO.														TOTAL	FACTOR WT.
Positive Locking Feature	F-1	0	0	0	0	1	0	0							1	.04
Clamping Force	F-2	1		1	0	1	1	1	0						5	.18
Installation Force	F-3		1	0		0	0	1	1	0					3	.11
Vol/Wt Envelope	F-4			1	1	1		1	1	1	1				7	.25
Fab Complexity	F-5				1	0	1	0		1	1	0			4	.14
Aux. Power Required	F-6					0	0	0	0	0		0	0		0	.00
Manipulator Actions	F-7						1	0	0	0	0	1		0	2	.07
Reliability	F-8							1	1	1	0	1	1	1	6	.21
															28	1.00

Table VII-3 Factor Weight Comparison for Drive Mechanisms

CONSIDERATION FACTORS	FACTOR NO.														TOTAL	FACTOR WT.
Mechanical Adv.	F-1	0	0	0	0	1	0	0							1	.04
Vol/Wt. Envelope	F-2	1		1	1	1	1	1	1						7	.25
Fab Complexity	F-3		1	0		1	0	1	0	0					3	.11
Aux. Power Required	F-4			1	0	0		0	1	0	0				2	.07
Scoop Proof Capability (Stroke)	F-5				1	0	1	1		1	1	0			5	.18
Balanced Loading	F-6					0	0	0	0	0		0	0		0	.00
Manipulator Motion	F-7						1	0	1	1	0	1		0	4	.14
Drive Force	F-8							1	0	1	1	1	1	1	6	.21
															28	1.0

Table VII-4 Factor Weight Comparison for Locking Concepts

CONSIDERATION FACTORS	FACTOR NO.												TOTAL	FACTOR WT.
Positive Locking	F-1	0	0	1	0	0	0						1	.05
Locking Force Cap.	F-2	1		0	1	1	1	0					4	.18
Vol/Wt. Envelope	F-3		1	1		1	1	1	1				6	.29
Aux. Power Source	F-4			0	0	0		0	0	0			0	.00
Fab Complexity	F-5				1	0	0	1		0	0		2	.10
Manipulator Motions	F-6					1	0	0	1	1		0	3	.15
Req. Mating Force	F-7						1	1	0	1	1	1	5	.23
													21	1.0

Table VII-5 Factor Weight Comparison for Polarization Concepts

CONSIDERATION FACTORS	FACTOR NO.										TOTAL	FACTOR WT.
Positive Prevention of Interchange.	F-1	0	1	1	1	1					4	.27
Vol/Wt. Envelope	F-2	1		1	1	1	1				5	.33
Fab Complexity	F-3		0	0		1	0	0			1	.07
Visual Indication	F-4			0	0	0		0	0		0	.00
Reliability	F-5				0	0	1	1		1	3	.20
Logistics Complexity	F-6					0	0	1	1	0	2	.13
											15	1.0

Table VII-6 Alignment Concepts Tradeoff Comparison

			CONE & TANG		CONE & PIVOT		V ROLLERS TAPERED CONE		BUSHINGS/ NOSE PINS		CONE/ELECTRO MECH.		PIN/TAPER CONE		RECT. CONE & RECPT.		INTERLOCK. FLANGE	
CONSIDERATION FACTORS	FACTOR IDENT.	FACTOR WT.	COMPAR RATING	WEIGH VL	COMPAR RATING	WEIGH VL	COMPAR RATING	WEIGH VL	COMPAR RATING	WEIGH VL	COMPAR RATING	WEIGH VL	COMPAR RATING	WEIGH VL	COMPAR RATING	WEIGH VL	COMPAR RATING	WEIGH VL
Manipulator Motions	F-1	.07	35	2.45	45	3.15	40	2.8	25	1.75	40	2.8	45	3.15	45	3.15	35	2.45
Vol/Wt. Envelope	F-2	.25	45	11.25	40	10.0	15	3.75	25	6.25	11	2.75	25	6.25	40	10.0	45	11.25
STD Inserts	F-3	.18	50	9.00	50	9.00	50	9.00	50	9.00	50	9.00	20	3.6	50	9.00	50	9.00
Fab Complexity	F-4	.11	35	3.85	45	4.95	20	2.2	25	2.75	30	3.3	25	2.75	30	3.3	35	3.85
Alignment Force Req.	F-5	.14	50	7.00	50	7.00	50	7.00	50	7.00	10	1.4	50	7.00	50	7.00	50	7.00
Reliability	F-6	.21	40	8.4	45	9.45	35	7.35	30	6.30	30	6.3	35	7.35	45	9.45	45	9.45
		TOTALS		43.35		45.35		33.10		33.85		27.15		30.70		43.50		44.6
		Rank		4		1										3		2

Table VII-7 Latching Concepts Tradeoff Comparison

CONSIDERATION FACTORS	FACTOR IDENT.	FACTOR WT.	YOKE PIVOT/ SPRING		ELECTRO-MECH.		SPRING FING/ SLEEVE		BAYONET ROT. ATTACH.		MECH. LINK.		YOKE PIVOT/ BALL DET.		FLANG/ BALL DET.	
			COMPAR RATING	WEIGH VL	COMPAR RATING	WEIGH VL	COMPAR RATING	WEIGH VL	COMPAR RATING	WEIGH VL	COMPAR RATING	WEIGH VL	COMPAR RATING	WEIGH VL	COMPAR RATING	WEIGH VL
Positive Locking Feature	F-1	.04	35	1.40	50	2.00	40	1.60	40	1.60	35	1.40	15	.60	15	.60
Clamping Force	F-2	.18	20	3.60	50	9.00	25	4.50	45	8.10	40	7.20	15	2.70	15	2.70
Installation Force	F-3	.11	40	4.40	45	4.95	25	2.75	25	2.75	30	3.30	40	4.40	40	4.40
Vol/Wt. Envelope	F-4	.25	45	11.25	30	7.50	35	8.75	40	10.00	40	10.00	40	10.00	50	12.50
Fab Complexity	F-5	.14	40	5.60	40	5.60	25	3.50	25	3.50	30	4.20	40	5.60	40	5.60
Aux. Power Req.	F-6	.00	50	.00	20	.00	50	.00	50	.00	50	.00	50	.00	50	.00
Manipulator Actions	F-7	.07	50	3.50	30	2.10	45	3.15	20	1.40	45	3.15	45	3.15	50	3.50
Reliability	F-8	.21	40	8.40	25	5.25	30	6.30	25	5.25	35	7.35	40	8.40	40	8.40
		TOTALS		38.15		36.40		30.55		32.60		36.60		34.85		37.70
		RANK		1		4						3				2

Table VII-8 Drive Mechanisms Tradeoff Comparisons

CONSIDERATION FACTORS	FACTOR IDENT.	FACTOR WT.	MECH. LINK		POWER SCREW		SLEEVE/CONC. INNER CORE		DIRECT DRIVE/ BALL SCR.		HELIX		CAM DRIVE	
			COMPAR RATING	WEIGH VL	COMPAR RATING	WEIGH VL	COMPAR RATING	WEIGH VL	COMPAR RATING	WEIGH VL	COMPAR RATING	WEIGH VL	COMPAR RATING	WEIGH VL
Mech. Adv.	F-1	.04	50	2.0	50	2.0	15	.60	40	1.6	20	.80	50	2.00
Vol/Wt. Envelope	F-2	.25	40	10.0	30	7.5	40	10.00	30	7.5	45	11.25	40	10.00
Fab Complexity	F-3	.11	40	4.4	40	4.4	25	2.75	35	3.85	20	2.20	45	4.95
Aux. Power	F-4	.07	50	3.5	20	1.4	50	3.5	20	1.4	50	3.5	50	3.5
Scoop Proof Stroke	F-5	.18	50	9.0	50	9.0	40	7.20	15	2.7	40	7.2	30	5.4
Balanced Loading	F-6	.00	50	0.0	50	0.0	50	0.0	20	0.0	40	0.0	50	0.0
Manipulator Motion	F-7	.14	50	7.0	25	3.5	50	7.0	15	2.1	25	3.5	50	7.0
Drive Force	F-8	.21	45	9.45	40	8.4	20	4.2	35	7.35	25	5.25	45	9.45
		TOTALS		45.35		36.20		35.25		26.50		33.70		42.30
		RANK		1		3								2

Table VII-9 Locking Concepts Tradeoff Comparison

CONSIDERATION FACTORS	FACTOR IDENT.	FACTOR WT.	OVERCENTER LINK		POWER SCREEN		OVERCENTER CAM		SPR. LOADED LATCH		BAYONET LATCH	
			COMPAR RATING	WEIGH VL	COMPAR RATING	WEIGH VL	COMPAR RATING	WEIGH VL	COMPAR RATING	WEIGH VL	COMPAR RATING	WEIGH VL
Positive Locking	F-1	.05	50	2.5	50	2.5	45	2.25	50	2.5	50	2.5
Locking Force Cap.	F-2	.18	50	9.0	50	9.0	50	9.0	10	1.8	25	4.5
Vol/Wt. Envelope	F-3	.29	45	13.05	25	7.25	45	13.05	40	11.6	40	11.6
Aux. Power Source	F-4	.00	50	0.0	15	0.0	50	0.0	50	0.0	50	0.0
Fab Complexity	F-5	.10	40	4.0	25	2.5	30	3.0	20	2.0	25	2.5
Manipulator Motions	F-6	.15	45	6.75	25	3.75	25	3.75	20	3.00	25	3.75
Req. Mating Force	F-7	.23	40	9.2	40	9.2	40	9.2	15	3.45	25	5.75
	TOTALS			44.50		34.20		40.25		24.35		30.60
	RANK			1		3		2				

Table VII-10 Polarization Concepts Tradeoff Comparison

CONSIDERATION FACTORS	FACTOR IDENT.	FACTOR WT.	PIN/HOLE PATTERN		TAB/NOTCHES PATTERN		HOUSING SHAPES		COLOR CODING		HOUSING SIZE		LETTER/ NUMER. COD.	
			COMPAR RATING	WEIGH VL	COMPAR RATING	WEIGH VL	COMPAR RATING	WEIGH VL	COMPAR RATING	WEIGH. VL	COMPAR RATING	WEIGH VL	COMPAR RATING	WEIGH VL
Positive Prevention of Interchang.	F-1	.27	50	13.50	50	13.50	50	13.50	0	0	5	1.35	0	0
Vol/Wt. Envelope	F-2	.33	45	14.85	45	14.85	25	8.25	45	14.85	25	8.25	45	14.85
Fab Complexity	F-3	.07	25	1.8	25	1.8	20	1.4	45	3.2	20	1.4	45	3.15
Visual Indication	F-4	0	--		--		--		--		--		--	
Reliability	F-5	.20	40	8.0	40	8.0	45	9.0	25	5.0	5	1.0	25	5.0
Logistics Complexity	F-6	.13	40	5.2	40	5.2	25	3.25	40	5.2	10	1.3	40	5.2
		TOTALS		43.35		43.35		35.40		28.25		13.30		28.20
		RANK		1		1		2						

comparisons and the rank order of the candidates. Table VII-11 is a summary of the selected design element candidates.

C. SYSTEM CONCEPTS SELECTION

The consideration factors for the system candidates included the following:

- end effector design motions;
- item complexity/parts count;
- forces required to mate/demate;
- weight estimate;
- commonality between applications;
- operability in environments;
- alignment tolerances;
- volume/size;
- manufacturing tolerance buildup;
- manufacturing feasibility;
- manufacturing cost estimates; and
- compatibility of design with various inserts.

Table VII-12 is a comparison of these design parameters for all the manipulator/EVA applications. Table VII-13 is a comparison for the gross alignment module applications.

The candidates were selected utilizing the same procedure as described for the element concepts. Tables VII-14 and VII-15 are the factor weight comparisons and the results of the concept comparisons for manipulator/EVA applications. Table VII-16 are the results of the factor weight comparison and concept tradeoff comparisons including the rank order of the candidates for the gross alignment module applications.

Table VII-11 Selected Design Element Candidates

DESIGN ELEMENT	FUNCTION	SELECTED CANDIDATES
Alignment	Plug to Receptacle Alignment	• Cone and Pivot
		• Tapered Square Shaped Cone Plug and Receptacle
		• Interconnecting Face Flanges
Latching	Coupling of Two Connector Halves	• Yoke Pivot With Spring Loaded Latch
		• Interconnecting Flange With Spring-Loaded Ball Detent
Drive Mechanism	Pin to Socket Insertion	• Mechanical Linkage Driving Core Side Pins
		• Cam Drive
Locking	Maintaining Pin-Socket Positions	• Overcenter Link
		• Overcenter Cam
Polarization	Pin/Socket Protection	• Pin/Hole Pattern
		• Tabs/Notches Pattern

Table VII-12 Comparison of Concepts Design Parameters

CONCEPT	END EFFECTOR DESIGN MOTIONS	ITEM COMPLEXITY/ PARTS COUNT	FORCES REQUIRED FOR MATE/DEMATE
#1 YOKE/ PIN ALIGNMENT WITH LINKAGE DRIVE	MATE: 1. TILT ORIENTATION OF PLUG. 2. FORWARD MOTION FOR CENTER'G 3. FORWARD MOTION FOR PIN SOCKET ENGAGEMENT. DEMATE: 1. PULL BACK MOTION. NOTE: THE POSSIBILITY OF PREMATURE PLUG INSERT MOVEMENT EXISTS SINCE THE DRIVING OF THE PLUG INSERT AND PLUG CENTERING REQUIRE THE SAME MOTION.	23 MAJOR PARTS RELATIVELY HIGH COMPLEXITY	BESIDES THE PLUG INSERTION INTO TH RECEPTACLE RESISTANCE FORCE, THE O OTHER FORCES TO OVERCOME IS THAT O SLIDING FRICTION OF INTERNAL SLIDI SLEEVE WITHIN THE HOUSING, AND TH FORCE REQUIRED TO PUSH ASIDE THE S LOADED COUPLING LATCH. THESE TWO CES ARE NEGLIGIBLE. AS DRAWN A 5: MECH. ADV. EXISTS.
#2 TAPERED CONE ALIGNMENT WITH LINKAGE DRIVE	MATE: 1. PLUG ORIENTATION. 2. DOWNWARD MOTION FOR CENTERING. 3. SIDE MOTION FOR PIN SOCKET ENGAGEMENT. DEMATE: 1. SIDE MOTION. 2. UPWARD MOTION.	14 MAJOR PARTS RELATIVELY MODERATE COMPLEXITY	THE ONLY OTHER FORCES TO OVERCOME THAT OF THE INSERTS IS SLIDING FR AND DEPRESSING OF SPRING LOADED B DETENT WHICH IS NEGLIGIBLE. THE SHOWS A MECHANICAL ADVANTAGE OF 3 VALUE CAN BE VARIED BY CHANGING T OF THE HANDLE.
#3 INTERLOCKING FACE FLANGE ALIGNMENT WITH CAM DRIVE	MATE: 1. PLUG ORIENTATION. 2. FORWARD MOTION. 3. DOWNWARD MOTION. 4. 90° CLOCKWISE ROLL. DEMATE: 1. 90° COUNTERCLOCKWISE ROLL. 2. UPWARD MOTION. 3. PULL BACK MOTION.	11 MAJOR PARTS RELATIVELY HIGH COMPLEXITY	AS IN THE OTHER CONCEPTS THE ONLY FORCES TO OVERCOME BESIDES THAT O INSERTS IS SLIDING FRICTION AND D OF SPRING LOADED BALL DETENTS WHI NEGLIGIBLE. THIS CONCEPT USES A TION FOR DRIVING THE PINS INTO TH AND THE TORQUE IS HIGHEST AT THE ACTUATION AND DROPS TO ZERO AS TH POINT PASSES TOP DEAD CENTER.

FOLDOUT FRAME 1

ED FOR MATE/DEMATE	WEIGHT ESTIMATE	COMMONALITY BETWEEN "BLACK BOX" AND EVA CREWMAN TYPE CONNECTIONS	OPERABILITY IN ENVIRONMENTS
LUG INSERTION INTO THE SISTANCE FORCE, THE ONLY TO OVERCOME IS THAT OF ION OF INTERNAL SLIDING THE HOUSING, AND THE D TO PUSH ASIDE THE SPRING NG LATCH. THESE TWO FOR- GIBLE. AS DRAWN A 5:1 ISTS.	.77 kg (1.7 POUNDS)	COMMON ELEMENTS BETWEEN "BLACK BOX" AND CREWMAN TYPE CONNECTORS INCLUDE PIN AND SOCKET INSERTS, FINE ALIGNMENT TECHNIQUE AND POLARIZATION METHODS. THE DIFFERENCES ARE IN GROSS ALIGNMENT COMPENSATION TECHNIQUES, DRIVING AND LOCKING METHODS.	THERMAL EXPANSION DUE TO TEMPERATURE VARIATION HAS NO AFFECT ON ALIGNMENT AND COUPLING. CURRENT CARRYING CAPACITY OF CONDUCTORS AT DIFFERENT TEMPERATURES IS SOMEWHAT PREDICTABLE AND CONTACT SIZES CAN BE SELECTED ACCORDINGLY.
R FORCES TO OVERCOME BESIDES NSERTS IS SLIDING FRICTION G OF SPRING LOADED BALL IS NEGLIGIBLE. THE DESIGN NICAL ADVANTAGE OF 3:1. THIS VARIED BY CHANGING THE LENGTH .	1.13 kg (2.5 POUNDS)	SAME AS CONCEPT #1.	SAME AS CONCEPT #1.
ER CONCEPTS THE ONLY OTHER RCOME BESIDES THAT OF THE IDING FRICTION AND DEPRESSING DED BALL DETENTS WHICH IS THIS CONCEPT USES A CAM ROTA- ING THE PINS INTO THE SOCKETS AND E IS HIGHEST AT THE INITIAL DROPS TO ZERO AS THE CAM HIGH TOP DEAD CENTER.	1.04 kg (2.3 POUNDS)	SAME AS CONCEPT #1.	SAME AS CONCEPT #1.

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Table VII-12 Comparison of Concepts Design Parameters (continued)

CONCEPT	ALIGNMENT TOLERANCES	VOLUME/SIZE	MANUFACTURING TOLERANCE BUILD
#1 YOKE/ PIN ALIGNMENT WITH LINKAGE DRIVE	COMPENSATES FOR MISALIGNMENTS UP TO 3.81 cm ($\pm$ 1.5 INCHES) IN THE HORIZONTAL AND VERTICAL DIRECTIONS AND .09 RAD (5^{o}) IN ANGULARITY.	ENVELOPES: PLUG - 8.26x7.62x6.35 (3.25x3x2.50 INCHES) RECEPTACLE - 8.89x5.72x2.54 CM (3.50x2.25x1 INCH) MATED - 8.89x7.62x7.62 CM (3.50x3x3 INCHES)	NUMEROUS CLOSE TOLERANCE INTE PARTS (LINKS, SPRING LOADED PAWLS AND PIVOT ASSEMBLIES.) TOLERANCE MACHINING ON BODY SLIDING SLEEVE.
#2 TAPERED CONE ALIGNMENT WITH LINKAGE DRIVE	COMPENSATES FOR MISALIGNMENTS UP TO 3.81 CM ($\pm$ 1.5 INCHES) IN THE HORIZONTAL AND VERTICAL DIRECTIONS AND .09 RAD (5^{o}) IN ANGULARITY.	ENVELOPES: PLUG - 8.89x19.69x17.78 CM (3.50x7.75x7 INCHES) RECEPTACLE - 15.24x6.35x14.61 CM (6x2.50x5.75 INCHES) MATED - 15.24x12.70x25.40 CM (6x5x10 INCHES)	SEVERAL CLOSE TOLERANCE PARTS INCLUDE THE VALVE BODIES, LI INTERNAL SLIDING SLEEVE.
#3 INTERLOCKING FACE FLANGE ALIGNMENT WITH CAM DRIVE	COMPENSATES FOR MISALIGNMENTS UP TO 3.81 CM ($\pm$ 1.5 INCHES) IN THE HORIZONTAL AND VERTICAL DIRECTIONS AND .09 RAD (5^{o}) IN ANGULARITY	ENVELOPES: PLUG - 10.16x21.59x10.46 CM (4x8.5x4.12 INCHES) RECEPTACLE - 12.70x12.70x6.35 CM (5x5x2.50 INCHES) MATED - 12.70x12.70x14.61 CM (5x5x5.75 INCHES)	A FEW CLOSE TOLERANCE PARTS THE INTERNAL SLIDING SLEEVE, SPRING AND OTHER DRIVE COMPO

...URING TOLERANCE BUILDUP	MANUFACTURING FEASIBILITY	MANUFACTURING COST ESTIMATES	COMPATIBILITY OF LATCHING AND ALIGNMENT MECHANISMS WITH VARIOUS SIZE INSERTS
... CLOSE TOLERANCE INTERACTING LINKS, SPRING LOADED LOCKING ...ND PIVOT ASSEMBLIES.) CLOSE ...CE MACHINING ON BODY UNITS AND ... SLEEVE.	STANDARD MACHINE SHOP EQUIPMENT AND PRACTICES IS REQUIRED.	FABRICATION AND ASSEMBLY 550 HOURS	ALIGNMENT TOLERANCES IS THE DRIVER FOR CONNECTOR HOUSING SIZE. NO ENVELOPE CHANGE FOR INSERTS UP TO NO. 24 SIZE.
...CLOSE TOLERANCE PARTS. THESE ... THE VALVE BODIES, LINKS AND ... SLIDING SLEEVE.	STANDARD MACHINE SHOP EQUIPMENT AND PRACTICES IS REQUIRED.	FABRICATION AND ASSEMBLY 500 HOURS	SAME AS CONCEPT #1.
...LOSE TOLERANCE PARTS SUCH AS ...ERNAL SLIDING SLEEVE, YOKE AND OTHER DRIVE COMPONENTS.	STANDARD MACHINE SHOP EQUIPMENT AND PRACTICES IS REQUIRED.	FABRICATION AND ASSEMBLY 450 HOURS	SAME AS CONCEPT #1.

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Table VII-13 Gross Alignment Module Mounting System Trade Study

CONCEPT	ALIGNMENT METHOD	ITEM COMPLEXITY/ PARTS COUNT	FORCES REQUIRED FOR MATE/DEMATE	WEIGHT ESTIMATE
#1 COMPRESSION SPRING CENTERED PLUG WITH GIMBAL RECEPTACLE	TAPERED INERTED RECTANGULAR CONE ON RECEPTACLE WITH A TWO AXIS GIMBAL SYSTEM. PLUG IS OF A FLOATING TYPE CENTERED WITH COMPRESSION SPRINGS IN THE X-Y PLANE. THE PLUG COMPENSATES FOR HORIZONTAL, VERTICAL AND ROLL MISALIGNMENTS. THE RECEPTACLE COMPENSATES FOR PITCH AND YAW MISALIGNMENTS.	RECEPTACLE: 9 MAJOR PARTS, LOW COMPLEXITY PLUG: 22 MAJOR PARTS, MODERATE COMPLEXITY	THE FORCES APPLIED TO A SERVICEABLE MODULE DURING REPLACEMENT MUST BE GREATER THAN THE ACCUMULATIVE RESISTIVE FORCE OF PINS BEING INSERTED INTO SOCKETS. THE SIZE LOADS DURING ALIGNMENT ARE NEGLIGIBLE.	1.25 k[illegible] POUNDS
#2 FLEX PIVOT CENTERED PLUG WITH GIMBAL RECEPTACLE	TAPERED INVERTED CONE ON THE RECEPTACLE WITH A CLOCKING ALIGNMENT PIN AND A TWO AXIS GIMBAL SYSTEM. PLUG IS MOUNTED ON A PAIR OF 4-BAR LINKAGE PLATES WITH FLEX PIVOTS. THE PLUG COMPENSATES FOR HORIZONTAL, VERTICAL AND ROLL MISALIGNMENTS. THE RECEPTACLE COMPENSATES FOR PITCH AND YAW MISALIGNMENTS.	RECEPTACLE: 9 MAJOR PARTS, LOW COMPLEXITY PLUG: 27 MAJOR PARTS, LOW COMPLEXITY	THE FORCES APPLIED TO A SERVICEABLE MODULE DURING REPLACEMENT MUST BE GREATER THAN THE ACCUMULATIVE RESISTIVE FORCE OF PINS BEING INSERTED INTO SOCKETS. THE SIDE LOADS DURING ALIGNMENT ARE NEGLIGIBLE.	.57 kg POUNDS

CONCEPT	ALIGNMENT TOLERANCES	VOLUME/SIZE	MANUFACTURING TOLERAN	MANU
#1 COMPRESSION SPRING CENTERED PLUG WITH GIMBAL RECEPTACLE	COMPENSATES FOR MISALIGNMENTS UP TO $\pm$ 6.35 MM ($\pm$ .25 INCHES) IN THE HORIZONTAL AND VERTICAL DIRECTIONS AND .09 RADIANS IN ANGULARITY.	ENVELOPES: PLUG - 11.43x14.61x17.15 CM (4.5x5.75x6.75 INCHES) RECEPTACLE - 5.08x7.62x16.51 CM (2x3x6.50 INCHES) MATED -15.24x14.61x17.15 CM (6x5.75x6.75 INCHES)	CLOSE TOLERANCE PARTS FOR PLUG FLOATING MEC CRITICAL SPACING ON [illegible]) ON RECEPTACLE.	CLOS FOR CRIT ON F
#2 FLEX PIVOT CENTERED PLUG WITH GIMBAL RECEPTACLE	COMPENSATES FOR MISALIGNMENTS UP TO $\pm$ 6.35 MM ($\pm$ .25 INCHES) IN THE HORIZONTAL AND VERTICAL DIRECTIONS AND .09 RADIANS (5^{o}) IN ANGULARITY.	ENVELOPES: PLUG - 10.16x8.26x7.32 CM (4x3.25x2.88 INCHES) RECEPTACLE - 4.45x8.26x13.67 CM (1.75x3.25x5.38 INCHES) MATED -15.24x14.61x17.15 CM (6x5.75x6.75 INCHES)	CRITICAL SPACING ON P ON PLUG AND RECEPTACL ES)	CRIT ON F

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...UIRED FOR ...A...E	WEIGHT ESTIMATE	COMMONALITY BETWEEN "BLACK BOX" AND EVA CREWMAN TYPE CONNECTIONS	OPERABILITY IN ENVIRONMENTS
k... APPLIED TO ...DSBLE MODULE ...PLACEMENT MUST ...R THAN THE AC- ...E RESISTIVE ...PINS BEING IN- ...TO SOCKETS. THE ...S DURING ALIGN- ...NEGLIGIBLE.	1.25 kg (2.75 POUNDS)	COMMON ELEMENTS BETWEEN "BLACK BOX" AND CREWMAN TYPE CONNECTORS INCLUDE PIN AND SOCKET INSERTS, FINE ALIGNMENT TECHNIQUE AND POLARIZATION METHODS. THE DIFFERENCES ARE IN GROSS ALIGNMENT COMPENSATION TECHNIQUES, DRIVING AND LOCKING METHODS.	THERMAL EXPANSION DUE TO TEMPERATURE VARIATION HAS NO AFFECT ON ALIGNMENT AND MATING. CURRENT CARRYING CAPACITY OF CONDUCTORS AT DIFFERENT TEMPERATURES IS SOMEWHAT PREDICTABLE AND CONTACT SIZES CAN BE SELECTED ACCORDINGLY.
kg APPLIED TO A ...DSE MODULE DURING ...NT MUST BE GREATER ...ACCUMULATIVE RE- ...RCE OF PINS ...RTED INTO SOC- ...E SIDE LOADS ...IGNMENT ARE NEG-	.57 kg (1.25 POUNDS)	COMMON ELEMENTS BETWEEN "BLACK BOX" AND CREWMAN TYPE CONNECTORS INCLUDE PIN AND SOCKET INSERTS, FINE ALIGNMENT TECHNIQUE AND POLARIZATION METHODS. THE DIFFERENCES ARE IN GROSS ALIGNMENT COMPENSATION TECHNIQUES, DRIVING AND LOCKING METHODS.	THERMAL EXPANSION DUE TO TEMPERATURE VARIATION HAS NO AFFECT ON ALIGNMENT AND MATING. CURRENT CARRYING CAPACITY OF CONDUCTORS AT DIFFERENT TEMPERATURES IS SOMEWHAT PREDICTABLE AND CONTACT SIZES CAN BE SELECTED ACCORDINGLY.

...AN...	MANUFACTURING TOLERANCE BUILD-UP	MANUFACTURING FEASIBILITY	MANUFACTURING COST ESTIMATES	COMPATIBILITY OF DESIGN WITH VARIOUS SIZE INSERTS
...TS ...ECH ...B)	CLOSE TOLERANCE PARTS REQUIRED FOR PLUG FLOATING MECHANISM. CRITICAL SPACING ON PIVOT POINTS ON RECEPTACLE.	STANDARD MACHINE SHOP EQUIPMENT AND PRACTICES ARE REQUIRED.	FABRICATION AND ASSEMBLY - 240 HOURS	NO ENVELOPE CHANGE FOR INSERTS UP TO SHELL SIZE NO. 24.
...P ...ACL... ...ES)	CRITICAL SPACING ON PIVOT POINTS ON PLUG AND RECEPTACLE.	STANDARD MACHINE SHOP EQUIPMENT AND PRACTICES ARE REQUIRED.	FABRICATION AND ASSEMBLY - 160 HOURS	NO ENVELOPE CHANGE FOR INSERTS UP TO SHELL SIZE NO. 24.

Table VII-14 Factor Weight Comparison for Manipulator/EVA Applications

Consideration Factors	Factor No.																Total	Factor Weight
Item Complexity	F-1	1	1	1	0	1	1										5	.24
Forces Required to Mate	F-2	0		0	1	0	0	1									2	.10
Weight Estimate	F-3		0	1		1	0	0	1								3	.14
Volume/Size	F-4			0	0	0		0	0	0							0	.00
Mfg. Tolerance Buildup	F-5				1	1	1	1		1	1						6	.29
Mfg. Cost	F-6					0	1	1	1	0		1					4	.19
Manipulator Motions	F-7						0	0	0	1	0	0					1	.05
																	21	

Table VII-15 Manipulator/EVA Applications Tradeoff Comparison

Consideration Factors	Factor Ident.	Factor Weight	#1 Yoke/Pin		#2 Tapered Cone		#3 Interlocking Flng	
			Compar Rating	Weigh VL	Compar Rating	Weigh VL	Compar Rating	Weigh VL
Item Complexity	F-1	.24	15	3.60	35	8.40	25	6.00
*Forces for Mating	F-2	.10	45	4.50	40	4.00	40	4.00
Weight Estimate	F-3	.14	35	4.90	20	2.80	25	3.50
Volume/Size	F-4	.00	45	0.00	20	0.00	25	0.00
Mfg. Tolerance Buildup	F-5	.29	15	4.35	40	11.60	30	8.70
Mfg. Cost	F-6	.19	30	5.70	35	6.65	40	7.60
*Manipulator Motions	F-7	.05	20	1.00	35	1.75	25	1.25
*Within Acceptable Limits								
	Totals			24.05		35.20		31.05
	Rank			3		1		2

Table VII-16 Gross Alignment Module Factor Weight Comparison and Tradeoff Comparisons

Consideration Factors	Factor Number								Total	Factor Weight	Concept With Springs		Concept With Flex Pivots	
											Compar Rating	Weight Value	Compar Rating	Weight Value
Item Complexity	F-1	1	1	0	0				2	.2	25	5.0	45	9.0
Weight Estimate	F-2	0		1	0	0			1	.1	20	2.0	45	4.5
Volume/Size	F-3		0	0		0	0		0	0	15	0	40	0
Mfg. Tolerance Buildup	F-4			1	1	1		1	4	.4	35	14.0	45	18.0
Mfg. Cost	F-5				1	1	1	0	3	.3	30	9.0	40	12.0
									TOTAL			30		43.5

D. THERMAL INVESTIGATION

Areas investigated analytically for effects of thermal variations in a vacuum include, (1) alignment of connector halves, (2) dimensional variations of pin/socket configurations, and (3) current carrying capacity of conductors.

1. *Connector Alignment* - The alignment technique recommended for coupling the connector halves is a protruding concentric cone on the plug mating with an inverted concentric cone on the receptacle. This method is insensitive to thermal variations (plug/receptacle at opposite thermal extremes) and maintains axial alignment. The only variable is the separation distance of the plug and receptacle insert which is of an insignificant amount.

2. *Pin/Socket Dimensional Variations* - Several cases were examined with pins and sockets at opposite thermal extremes. For all cases, the temperature extremes were from a low of 88.71°K (-300°F) to a high of 372.04°K (210°F). The pin and socket material was assumed to be copper with a coefficient of thermal expansion of 17.64 x 10^{-6} m/m/°K (9.8 x 10^{-6} in/in/°F). For worst case analysis the socket diameter is assumed to be 2.54 mm (.100 inches) and the pin diameter is 2.41 mm (.095 inches) at a room temperature of 294.26°K (70°F).

Case 1 - Assume the socket is at 88.71°K (-300°F) and the pin is at 372.049 (+210°F). Determine interference, if any, between pin and socket.

Socket   Socket Diameter $= .100 - (300 + 70)\ (9.8 \times 10^{-6})\ (.100)\ (25.4)$

$= 2.53$ mm (.0996 in.)

Pin Diameter $= .095 + (140)(9.8 \times 10^{-6})(.095)(25.4)$

$= 2.42$ mm (.0951 in.)

Conclusion: difference between socket and pin diameters at room temperature is .13 mm (.005 inches) and the difference at the thermal extremes is .11 mm (.0045 inches) which is a negligible change.

Case 2 - Assume the pin and socket temperatures are reversed in Case 1 and determine effects.

Socket Diameter = $.100 + (140)\ (9.8 \times 10^{-6})\ (.100)\ (25.4)$

$= 2.54$ mm (.10013 in.)

Pin Diameter = $.095 - (300 + 70)\ (9.8 \times 10^{-6})\ (.095)\ (25.4)$

$= 2.4$ mm (.09464 in.)

Conclusion: Difference between socket and pin diameters at room temperature is .13 mm (.005 inches) and the difference at the thermal extremes is .14 mm (.0055 inches) which is a negligible change.

Case 3 - Determine the thermal effects on contact spacing on a relatively large connector (shell size #25). Assume that the expansion rate is that of aluminum which is 23.4 x 10^{-6} m/m/°K (13 x 10^{-6} in/in/°F) for a pin spacing of (.962 inches) at 294.26°K (70°F). Also, assume the receptacle is at 88.71°K (-300°F) and that the plug is at 372.04°K (+210°F).

Receptacle Spacing = $.962 - (300 + 70)\ (13 \times 10^{-6})\ (.962)\ (25.4)$

$= 24.32$ mm (.95737 in.)

Plug Spacing = $.962 + (140)(13 \times 10^{-6})\ (.962)\ (25.4)$

$= 24.48$ mm (.96375 in.)

Difference = .16 (.00638 in.)

Conclusion: Difference between socket and pin is normally .1/.13 mm (.004/.005 inches), therefore the .15 mm (.006 in.) change would cause up to .05 mm (.002 inches) interference on the outer pins.

3. *Conductor Current Carrying Capacity* - As the temperature of a conductor is lowered the current carrying capacity is increased. Table VII-17 is taken from military specification MIL-W-5088F and illustrates how conductors in free air (capable of heat exchange with the air) have a higher current rating than wires in a conduit or bundle. The values shown in the table are ratings for 20°C ambient. A new chart would have to be developed with temperatures approaching 100°C and the wires isolated in a vacuum. Since the

Table VII-17 Current Rating of Wires

Conductor Material	Wire Size	Continuous Duty Current (Amperes)					
		3/Single Wire in Free Air			3/Wires in Conduit or Bundles		
		105°C	150°C	200°C	105°C	150°C	200°C
Copper or Copper Alloy	1/2/26				3	4	5
	2/24				4	5	6
	22	14	17	20	6	7	8
	20	19	24	28	8	10	12
	18	26	32	36	11	13	15
	16	29	37	44	12	15	18
	14	40	50	60	17	21	25
	12	51	65	77	21	27	32
	10	68	86	101	28	36	42
	8	92	115	135	38	48	56
	6	125	155	185	52	64	77
	4	170	215	250	71	89	104
	2	235	290	350	98	120	145
	1	270	330	400	112	137	166
	1/0	320	390	460	133	162	191
	2/0	370	460	550	154	191	228
	3/0	440	540	640	183	224	266
	4/0	515	640	760	214	266	315
Aluminum	8	60			36		
	6	83			50		
	4	108			66		
	2	152			82		
	1	174			105		
	1/0	202			123		
	2/0	235			145		
	3/0	266			162		
	4/0	303			190		

1/ The use of this wire size requires procuring activity approval.
2/ Not to be used as a single wire.
3/ Rating is for 20°C ambient.

Notes: 1. Ratings are for copper conductors size 4/0 through size 22 and copper alloy for size 24 through size 26.
2. Temperature columns shown represent the wire construction ratings.

vacuum in outer space does not provide an atmosphere for heat transfer and since the conduit or bundle also tends to thermally isolate the conductor, the values listed in the 105°C column for bundles can be used for preliminary correlation between current and wire size.

E. HARDWARE SIMULATION

Contract NAS8-30820 is currently being performed by MMC and is developing mechanism concepts to remove and replace SRU modules. A prototype module latch mechanism was fabricated as part of that contract. This mechanism was utilized to demonstrate the feasibility to remotely mate a connector plug into its receptacle.

Figure VII-1 shows the installation of the MIL C-83723-20 plug on the NAS8-30820 prototype module latch mechanism. The MIL-C-83723-20 receptacle is mounted on a simulated spacecraft structure assembly containing gross quide rails that interface with rollers attached to the module latch mechanism. A tapered fine alignment pin on the module latch mechanism interfaces with a fine alignment female bushing mounted on the spacecraft frame. The end effector mechanism shown in Figure VII-2 interfaced with the module latch mechanism and was cycled a minimum of 50 times (mate/demate). The MIL-C-83723-20 connector (modified by removing the lock sleeve normally utilized for manual mating) was successfully mated on each cycle without failures.

In summary, this hardware simulation demonstrated that a standard 40M review connector can be utilized in a SRU application utilizing a module latch mechanism similar to the NAS8-30820 concept by removing the connector locking sleeve.

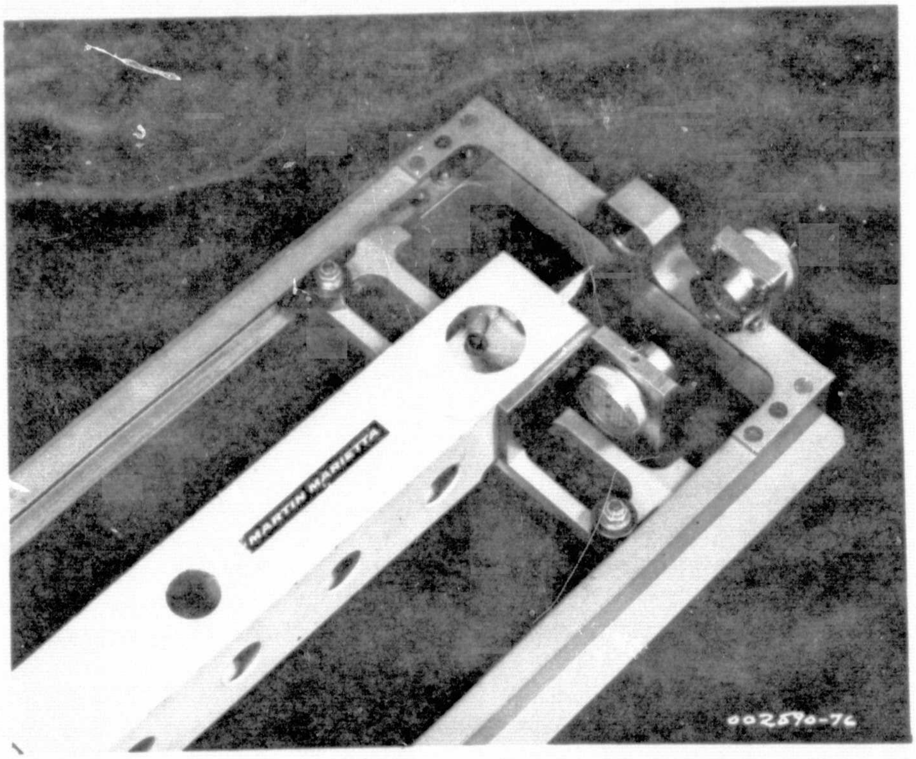

Figure VII-1 MIL-C-83723 Connector Mounted to NAS8-30820 Module Latch Mechanism

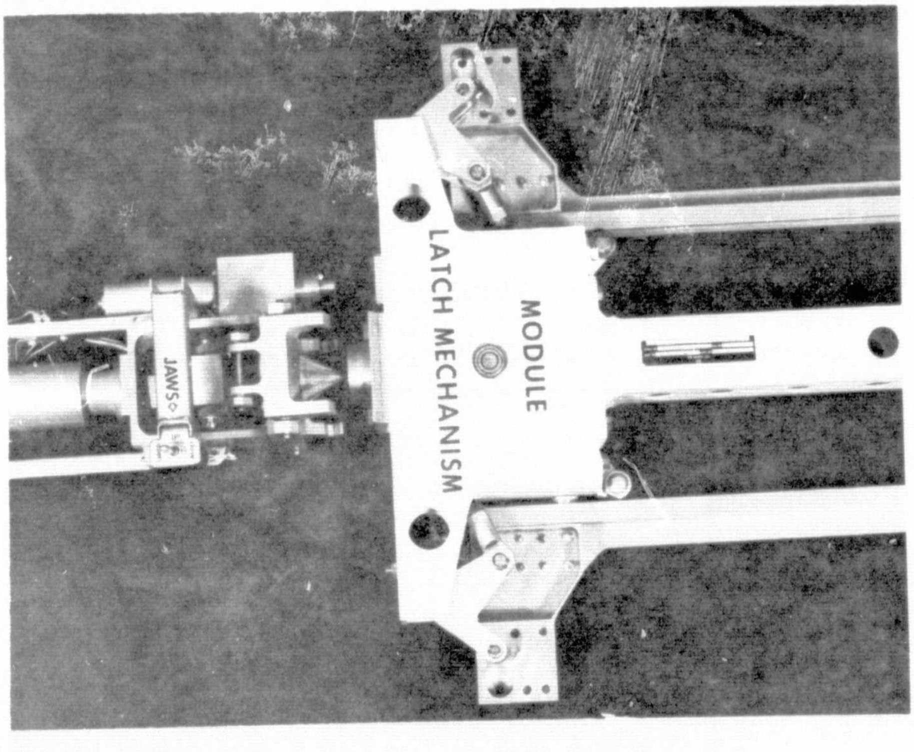

Figure VII-2 NAS8-30820 End Effector and Module Latch Mechanisms