MAINTENANCE TECHNOLOGY FOR SPACE SYSTEMS

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INTRODUCTION

Early assessment of man's actual capability and utility in performing maintenance tasks in the hazardous environment of space is necessary as the results could significantly affect the space maintenance concepts and the role that man will play in maintaining future space systems.

The first manned American space program established that man can contribute significantly to the success of space missions with the proper design consideration in the system. This recognition has led to the establishment of experiments for the two manned American space program that will explore the ability and utility of man in maintaining his vehicle in a space environment.

This paper will attempt to define the technology that presently exists in the various disciplines with respect to their utilization for establishing design criteria to maintain vehicles in a space environment. The areas to be discussed are; joining techniques, maintenance operations, assembly techniques, electrical repairs, and utilization of abstract models.

Maintenance Objective

The objective of the space maintenance experimentation is to obtain the capability to maintain, assemble, and repair vehicles in a space environment. To accomplish this mission the following approach is being used.

1. Develop the tools and techniques to enable the accomplishment of maintenance on a vehicle in a space environment.

2. To develop the design criteria necessary for the fabrication of systems to be maintainable in a space environment.

3. To develop and utilize abstract models for the maintenance planning of space systems.

4. To design and fabricate the necessary test models that will enable verification and establishment of man's ability to perform repairs in the various disciplines of maintenance for space.

There is a definite need for an organized space maintenance program to bring together all of the work that has and is being done by both industry and the government in the area of space maintenance. Proper organization of the technology in the various disciplines (required to accomplish maintenance on a total system) would insure the design and fabrication of test models that could be utilized to effectively obtain design criteria to be used in designing future space systems for longer and more extended missions.

MAINTENANCE TECHNOLOGY

General: The exploration of the space frontier for effective utilization by man will require him to live in this new environment for long periods of time. Some of the common subsystems required to make up the environment man must take with him to survive in this new frontier are: structures, propulsion, electronics, environmental control system, power supply and fluid system. In order to operate a system containing these subsystems a detailed maintenance analysis of each subsystem must performed along with the necessary research to investigate the constraints placed on the orbital worker by space suits, weightlessaness, available tools, and phenomena such as micrometeorites and radiations.

There are certain tools, techniques, and concepts that can be established from a research point of view to accomplish maintenance on representative subsystems in space without designing to maintain a particular system. However, the research would probably prove worthless if no plan were formulated to implement the research into a practical maintenance program for maintaining vehicles in space. The following discussion will be on concepts, tools, and maintenance techniques and how they can be utilized to establish design criteria for future systems.

Joining Systems

Whether one is familiar with maintenance requirements or not, it is not hard to visualize the need to establish methods of joining materials in space. Some of the basic requirements of a joining technique for space would be; (a) must operate in a vacuum of 10^{-12} torrs, (b) must operate with materials over the temperature range of -150°F to +250°F, (c) must be capable of bonding to various types of materials used to fabricate space vehicles and (d) must be safe and capable of being accomplished with man in the loop both inside and outside of a space vehicle. There are four areas presently being explored for establishing techniques that can be utilized by man in a space environment to join materials or objects together. These are adhesives, soldering, brazing, welding and mechanical fasteners. The temperature range for the operation of these systems are shown in Figure 1.

Adhesives - The programs to date directed toward developing adhesives systems for the space environment have been concerned with bonding problems such as; astronauts to work sites, equipment to work site, etc. Basic requirements for this type of system are; short cure times (10 to 15 seconds), small power requirements (e.g. D-cell nickel cadmium range) for

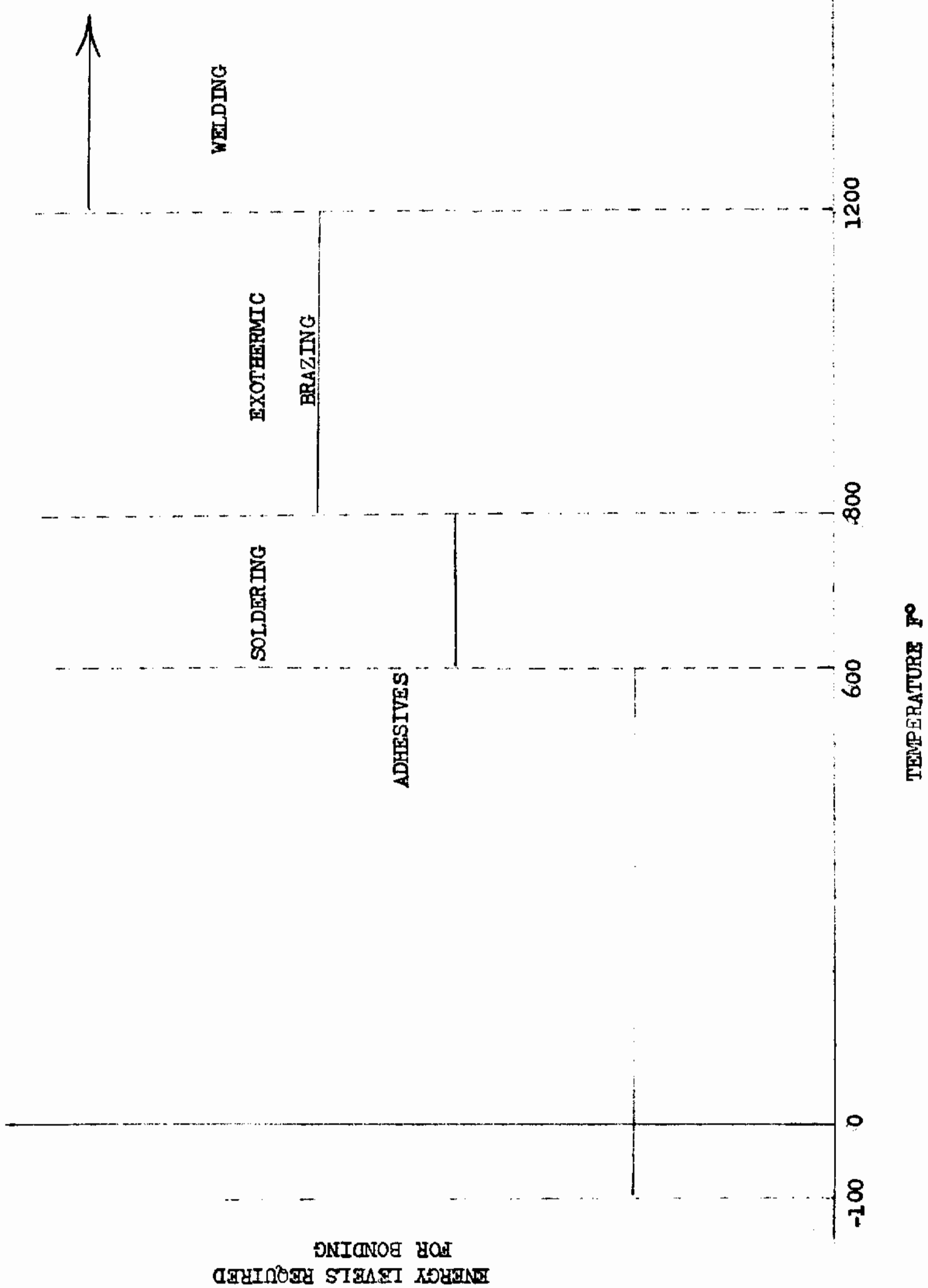

WELDING
EXOTHERMIC
BRAZING
SOLDERING
ADHESIVES
1200
800
600
0
-100
TEMPERATURE F°
ENERGY LEVELS REQUIRED FOR BONDING

Figure #1

ease of protability, be able to function in a dispenser mechanism for reusability, and strengths of at least 100 psi in tension and shear.

The initial program directed toward developing an adhesive system to satisfy the above requirement was performed by the Archer Daniels Midland Co. (ADM) under an Air Force Contract. The austerity of the program limited the scope to developing an adhesive pad that could be utilized by the Air Force to prove feasibility of the astronaut adhesive/mechanical bonding concept. The system accomplished this and also defined the problem areas that would have to be solved if off-the-shelf adhesives were to be modified for use in space (See Reference 1).

Based upon the problems defined in the ADM effort, two areas were defined for immediate work; (a) the encapsulation of an epoxy resin adhesive system, and (b) the development of a surface pre-heat pad utilizing an exothermic chemical reaction system (See Figure 2). Efforts in these areas are under contract for development by the Air Force. The adhesives systems being studied in these research programs are; epoxy resins systems, bot melt system, and thermal plastic systems. The application of this work for space structural adhesive system will be discussed at the end of the above efforts.

Adhesives are now available for bonding practically all solid materials (organic or inorganic) in the earth environment. Extending this technology for use in the space environment will require considerable study and definition of the joining problem to be accomplished. It is expected that as man becomes more active in the space role the advantages provided by adhesives system in the areas of; assembling structures, bonding objects to work site, electrical insulation, and electrical conductors will in the near future emphasize the importance of developing adhesives for use by man in the space environment.

Soldering

Soldering is one of the most common methods of joining electrical wires to terminals for all types of equipment in the earth environment. However, in considering the various techniques of joining electrical wires in space it probably commands the least amount of attention at this time. Some of the limitations of the soldering techniques justifying this are; (a) The requirement for alighment of the joint while the joint is being made, (b) the problem of pieces of the joining material floating out of control, and (c) the lack of analysis of performing the operation in an oxygen rich environment.

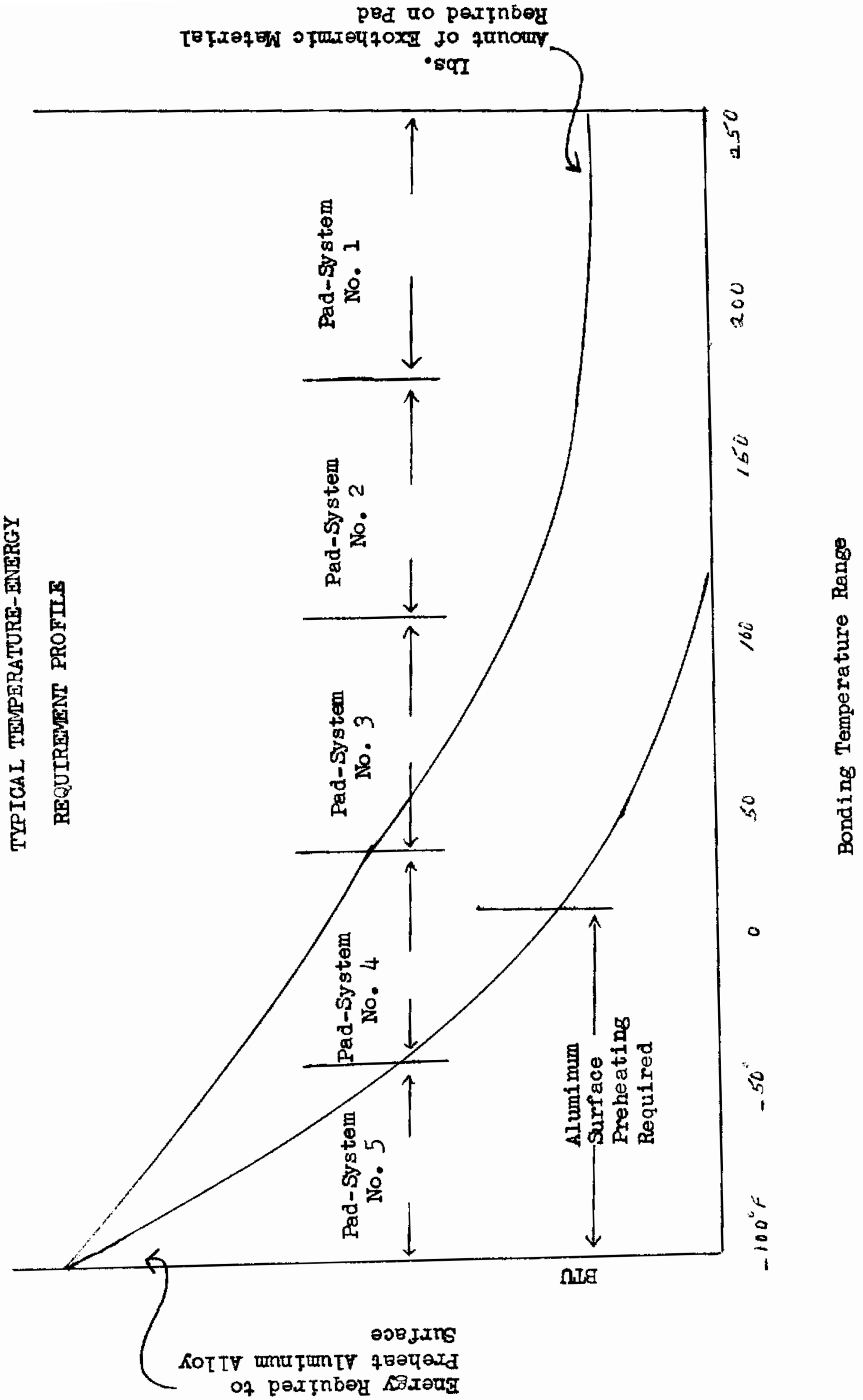
Brazing

Most of the work accomplished in the area of brazing as a technique for joining materials in space has been accomplished under an Air Force contract (Reference 2). The effort developed and brazed in a vacuum exothermically brazed joints of stainless steel and titanium alloy, capable of withstanding structural loads.

Exothermic chemical reaction was the heating concept developed that provided heat pulses to the base metal and braze alloy to accomplish the

FIGURE 2

TYPICAL TEMPERATURE-ENERGY REQUIREMENT PROFILE



joining of the materials. The concept provides the following advantages; (a) controlled heating times, (b) remote control capabilities, (c) module bonding units and (d) lightweight module bonding unit.

The work accomplished under the above effort has provided technology that could be explored now on an actual space test bed for application to joining problems in a space environment.

Welding

The exploration of welding techniques that can be utilized by man in a space environment has been limited to the electron beam technique (Reference 3). There has been considerable discussion on the advantages and disadvantages of various welding techniques (e.g. ultrasonic, friction, explosive, arc, and coldwelding) for space application, but the only welding technique where representative hardware has been designed for feasibility testing in space is the electron beam welding technique.

The Air Force has established the basic requirements for the design of an electron beam gun type welder that could be utilized by a suited astronaut in a space environment. This was accomplished for the purpose of establishing feasibility of welding joints in space. A physical model representing the concept has been fabricated for demonstration purposes. The actual development of operating hardware remains to be accomplished.

Welding techniques that take advantage of the space environment (e.g. friction welding, coldwelding) are definite candidates for future research along with explosive welding. It is the author's belief that in order to develop an effective welding technique for joining materials (with man in the loop) tests will have to be accomplished using a vehicle in space.

Mechanical Fasteners

The area of mechanical fasteners for utilization in space has not as yet experienced many changes or new innovation. No one to date has made a comprehensive analysis of the mechanical fastener area for the specific purpose of designing a fastener with the following factors as constraints; operation by a suited astronaut, space environment, structural loads and space assembly operations.

Fasteners such as Allen's Aeroscrew/Aeronut fastener technique exemplify a more efficient type of fastener but it was not designed for use by a suited astronaut in a space environment. Unique fasteners and rivet concepts are needed for the space assembly task that man will be required to accomplish during the next several decades of manned spaceflight.

Electrical Repairs

The magnitude of electrical equipment aboard space systems will require that man have the capability to accomplish electrical maintenance in space. This capability will consist of; detection, isolation, special tools, and positive control over the component parts. The philosophy of electrical maintenance for space will not be discussed in this paper, but rather the efforts directed toward establishing design requirement for tools to be used in electrical repairs.

One of the efforts being pursued at the present time by the Air Force is directed toward the development of a manual device for locating electrical arc-producing faults (Reference 4). The tool designed and fabricated under the above effort operates by sensing the radiation emitted by the sensing elements. The tool permits fault isolation by manual scanning techniques and detects signal levels as a function of probe location. The tool was designed to locate and isolate an RF disturbance within a two square inch area. The readout is visual and is located within the hand-held unit (total unit housed in two separate units).

An in-house study has been conducted by the Air Force to establish the requirements for the design of a wire joining tool that can be used by a suited astronaut. The function that such a tool should be able to accomplish are; wire wrap with built-in insulation capabilities, wire joining (e.g. fusion) with insulation capabilities and insulation of wires (e.g. epoxy coatings).

Fluid System Repairs

The research to date for maintaining fluid system suffers from a lack of definition as to what is really needed for maintaining fluid systems in space. Maintenance engineers have only to take a look at system such as; attitude control, propellant storage, equipment and station environmental control, space suit environmental control and electrical power (fuel cells) to realize the importance of being able to accomplish maintenance on systems containing fluids in space.

The approach being followed for fluid maintenance is to recommend simple experiments (using a space test bed to define the problem areas. These recommendations are based on detail analysis of fluid system repairs and the observation that there are many functions required to be accomplished in a fluid system maintenance task would be common to other requirements. Examples of this are; brazing a pipe coupling or brazing a structural patch, removing the shaft of an hydraulic actuator or removing the shaft of an electrical actuator, tightening a fluid line connector or tightening a structural fastener, etc.

The design, fabrication and testing of representative fluids tasks on simulators within the earth environment will provide valuable information concerning the repair technique for valves, pumps or similar assemblies without the loss of fluid. However, the data spectrum will not be complete for design criteria until end to end testing can be accomplished aboard a test vehicle in the actual space environment.

Tools

The utilization of motion simulators providing 6 degrees of freedom, and aircraft flying the Keplarian trajectory to provide approximately 30 seconds of zero gravity has provided invaluable information for the design of space tools. The maintenance concept that has evolved from studies accomplished on the above simulators has proven to highly effective in providing man with the capability to perform maintenance under weightless conditions.

The concept being pursued in the tools and techniques area for maintenance operations is to: (a) provide minimum reaction power tools with the necessary adapters to accomplish functions such as impacting, shearing, drilling, tapping, sawing, etc. (b) provide modified hand tools, (c) provide rigid and flexible work site attachment techniques for the astronaut, and (d) provide a special multi-high power (5-10 horsepower) tool for emergency tasks.

Power Tools - High output torque with low reaction was the basic requirement established for multipurpose power tools. The exploded drawing shown in Figure 3 illustrates the design of a multi-purpose minimum reaction electrical power tool. Operating with an unrestrained field and armature, this tool can produce a torque output of 15 to 50 ft. lb. with less than 0.0116 ft. lb. being transmitted back to the operator. The multipurpose tool can be used to perform the functions of a wrench, drill, thread tapper, and screwdriver.

The multi-purpose minimum reaction power tool, commonly denoted the "Space Power Tool (SPT)", consists of a counter rotating mechanism and the tool handle which stores the batteries. The only torque that can be transmitted back to the operator is that caused by the friction in the bearings which support the counter rotating mechanism in the tool handle. By using the frictional force inherent is a fastened object that resists other forces until it is overcome, a controlled internal restraint mechanism transfers the reaction torque to the object being fastened.

The natural characteristics of a fastener which permits this transfer of the reaction torque are illustrated by the semilinear curve in Figure 4. As a tightening torque is applied, the fastener will not rotate; no motion in the cw direction will occur, until the torque exceeds the ± A level. As the tool turns in the counterclockwise direction during the tightening process, it will by design not exceed the -A level; again by design, no torque will exceed the +A level as the tool turns clockwise.

Tested under weightless conditions at Wright-Patterson Air Force Base, the SPT demonstrated its capability to torque a fastener satisfactorily while a negligible force was transmitted back to the operator. The success of these tests led to another study to evaluate and define the relationship between the SPT and fastener types and to determine design criteria which would ensure that the torque delivered by future tools would not be appreciably transferred back to the operator. The SPT has the capability to accept adapters developed to perform other functions such as cutting, sawing, hammering, riveting, and hole punching.

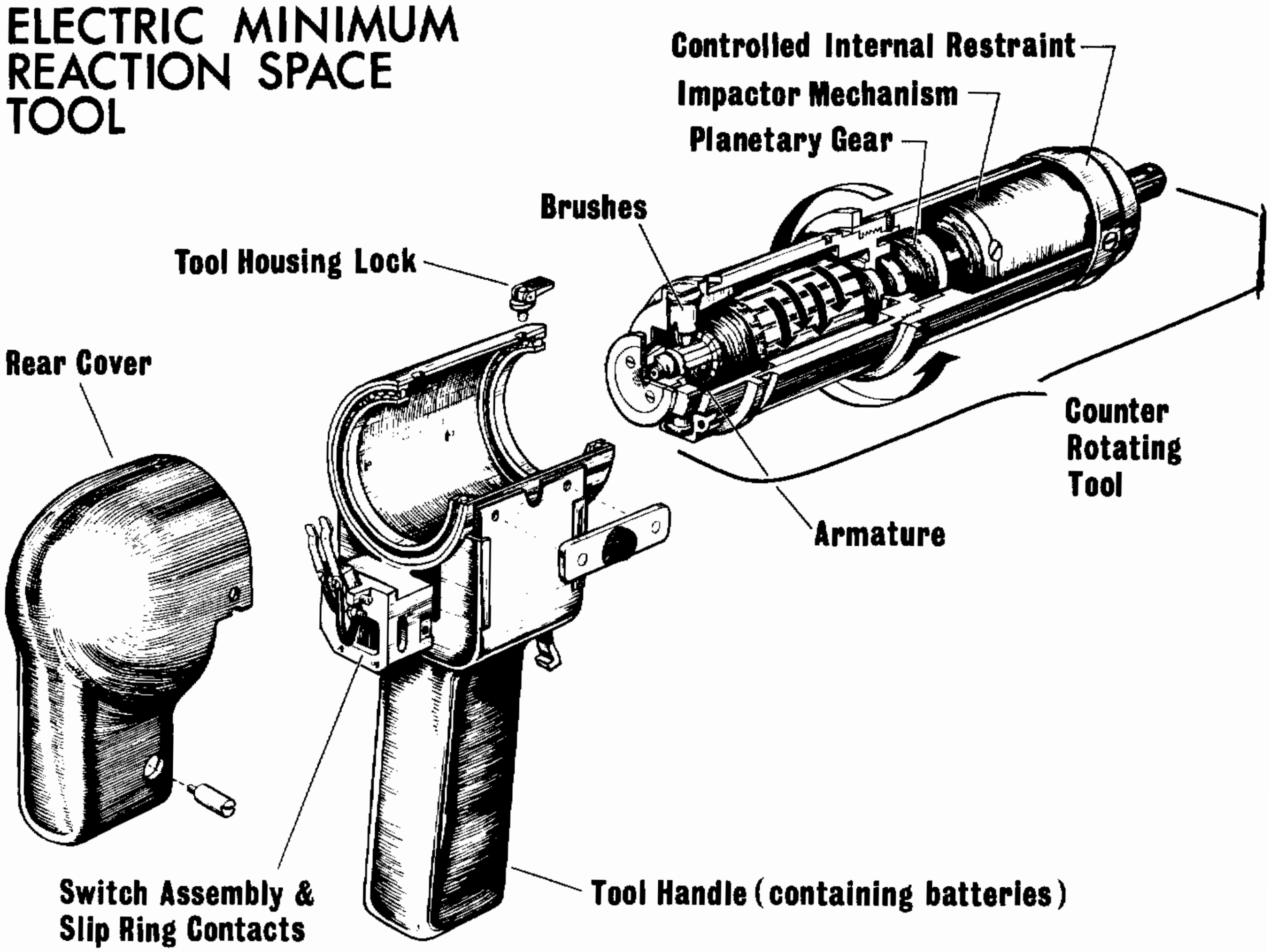


Figure 3

Minimum Reaction Power Tool

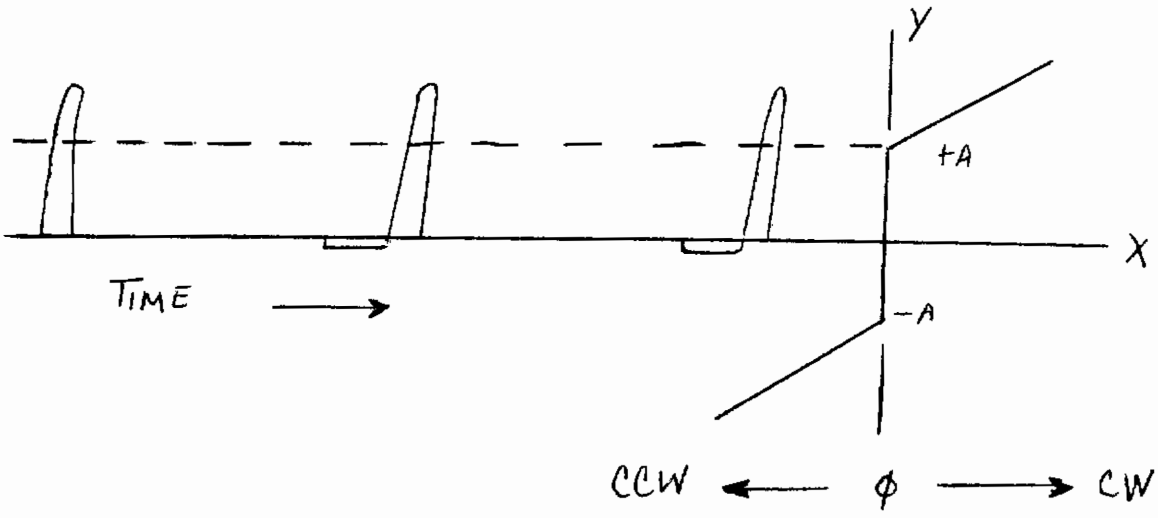


Figure 4

Natural Characteristic
Of A Fastener

Hand Tool - To obtain data relative to the magnitudes of torques and forces that a man could produce under weightless conditions, test subjects applied conventional tools to various tasks conducted during early tests in the simulated zero-g environments. Rather than being representative of work which could be performed in a weightless environment, the tests indicated the motions attendant with the work efforts which would prevent an astronaut from accomplishing useful work in space.

The Air Force has evaluated several unique tools developed by various companies to enable the in-house duplication of tasks performed by conventional tools in a normal earth environment. Many of these tools require special adapters at every bolt and a hand squeezing motion. Among the hand tools tested was a torque cancelling unit which uses two pins to transfer the torque to the structure and requires a squeezing motion to apply the torque. A summary of its evaluation is as follows:

The arrangement of the handles parallel to the plane of the work site or perpendicular to the axis of the fastener proved unsatisfactory because (a) the position required for the operator's hand was both inconvenient and tiring, (b) the particular squeezing action required was too arduous, and (c) the distance between the handles was excessive for the average hand. The use of pins to effect an attachment actually increases the complexity of the system since the removal of each nut would require drilling two holes for the pins; furthermore, the pin type of attachment is correcting only for pure torque does not allow for the application of other types of forces.

An in-house study involving operators using conventional tools strove to determine whether a man can use the friction characteristic inherent in a fastener to control his stability. This characteristic was discussed above illustrated in Figure 4. The study indicated that the use of the friction characteristic does facilitate an operator's maintenance of his position. However, to use both hands in performing a maintenance task on a spacecraft exterior, an astronaut would have to be rigidly attached to the exterior. This requires a versatile (ability to attach to a prepared or unprepared surface) attachment system borne by the astronaut.

Attachments to Couple Astronaut to the Spacecraft Exterior - Tests conducted at Wright-Patterson Air Force Base firmly evidenced that in - space maintenance man will need an attachment system to couple himself to the spacecraft exterior to effectively perform a maintenance task while weightless. This requirement prompted the investigation of techniques that would be useful in an attachment system. Such techniques included the use of mechanical connectors, toe holds, flexible lines, rigid rods, telescoping arms, unfurlable structures, magnets, and adhesives. Requirements for the prototype attachment system prescribed that the system (a) provide a stable platform, (b) be sufficiently rigid to prevent pendulum motion (c) be simple to operate, (d) be capable of becoming attached to a prepared or unprepared surface of the various types of metals incorporated in spacecraft exteriors, (e) operate on surfaces with temperatures ranging from -150° to +250°F, (f) have a bonding system capable of operating in a vacuum, (g) provide 100 psi in tension, compression, and shear, and (h) be lightweight.

Based on the above requirements, the designs selected for further investigation were a single knee attachment and a three-point rigid attachment system consisting of three components; (a) a tripod linkage formed by either telescoping or unfurlable rods, (b) a dispenser to contain several adhesive pads (the present unit holds three pads), and (c) an adhesive system to bond the tripod to the spacecraft. Figure 5 illustrates the coupling of the attachment system to a spacecraft exterior. The blowup in the lower right corner of Figure 5 depicts the basic configuration of dispenser mechanism. The functions of this mechanism are four fold: (a) storing the adhesive pads, (b) dispensing them one at a time to the spacecraft surface, (c) actuating the firing of a pyrofuze foil or exothermic material on the adhesive to melt the adhesive and applying a force to the pad to cause its adherence to the surface and (d) releasing the pads from the coupling device to permit the astronaut's leaving the work site. The prototype adhesive system consists of a hot-melt layer of adhesive whose contact side is covered by a pyrofuze foil with the other side attached to a foam which, in turn, is mounted to a backing disc.

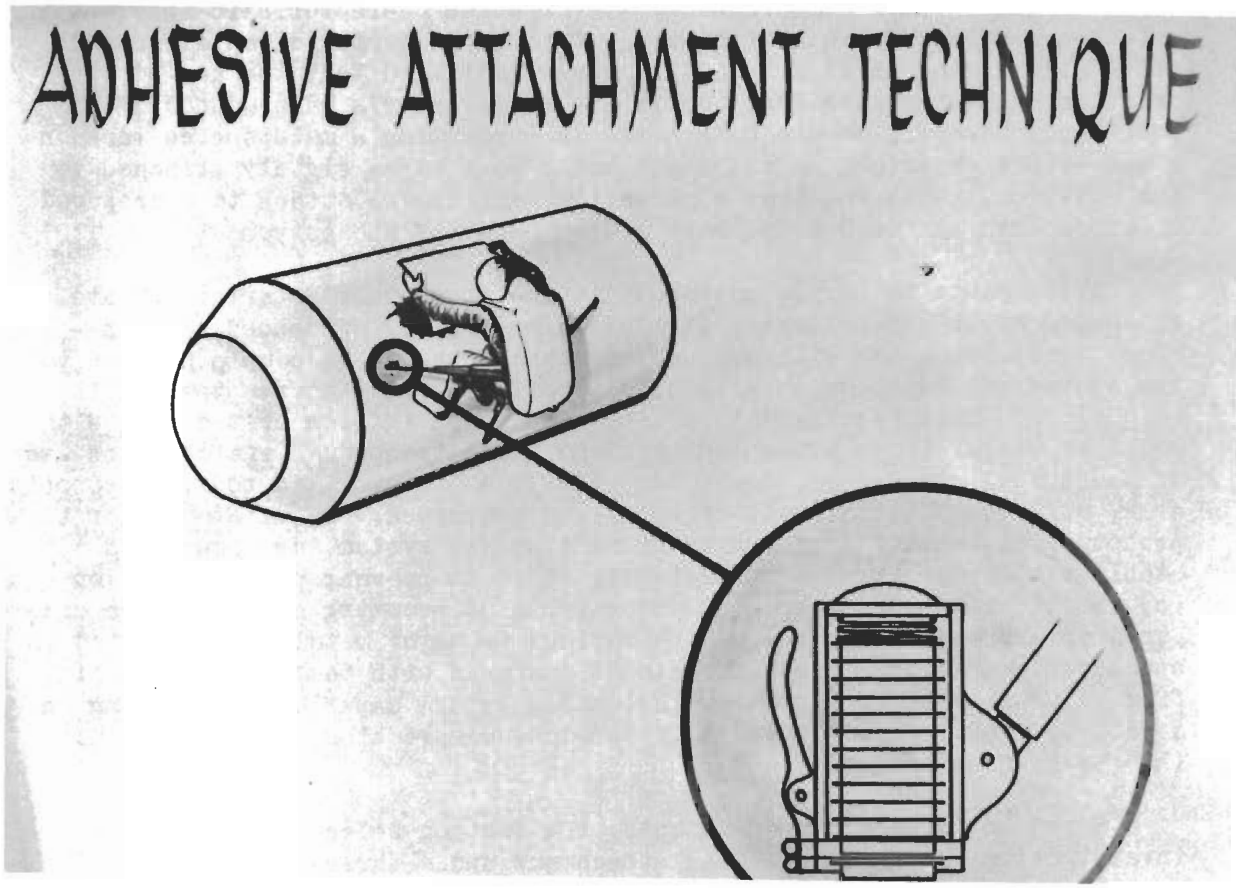


Figure 5

Adhesive Attachment Technique

Two braids at opposite sides of the adhesive pad connect the foil so that the adhesive may wet the surface as it melts. Upon solidifying, the adhesive forms a bond between the adhesive pad and the surface. The adhesive system used two types of adhesives, one for low-temperature (-150°F) and the other for high-temperature (+250°F) conditions. The former is a mixture of Versamid 100 and Versamid 940, their distribution by weight being 75 and 25 percent, respectively, and the latter is a mixture of Versalon 1112 and Versamid 100, their distribution by weight being 85 and 15 percent, respectively.

In-house tests of the prototype adhesive system indicated that the heat generated was insufficient to properly melt the adhesive. Much of the heat for melting was lost because of the heat-conduction properties of the bonding surfaces.

Because of the insufficient heating to effect adequate bonds with the adhesive pads (and other deficiencies such as those found in the foam backing) the Air Force is now considering the use of a pressure-sensitive encapsulated epoxy resin system to produce the bond or the use of an exothermic material to supply the required heat for a system using a thermal plastic system. Another potential modification to the attachment system is the incorporation of unfurlable arms, based on the concept of the carpenter's tape, to improve the tripod linkage.

Gyroscopic Stabilization for Space Maintenance Workers - The problem of stabilizing a space worker when he is applying forces required for maintenance tasks is easily accomplished by attaching the worker to the work site. However, in some cases, such as space station assembly, the attachment technique is not practical. Therefore, the worker must be stabilized by some other system. One such system is the AMU back pack. The problem here is that using the AMU to stabilize the worker while performing tasks requires a large fuel expenditure.

A suggested stabilization system would be a gyroscopic platform that could absorb the momentum, required for the worker to perform the task, by precession of the gyroscopic element and permitting the astronaut to remain stationary.

The major problem associated with this concept is the phenomenon known as "gyro lock." This phenomenon can be explained briefly as follows. When a torque is applied to the spin axis of a gyroscope, the gyroscope will resist this torque and precess in a plane that contains the torque vector orientation such that it is parallel to the torque vector. When this occurs the gyroscope is in the condition of "gyro lock" and loses all ability to resist the applied torque. In other words it can be said that a gyroscope will resist an applied torque as long as the torque vector and spin vector are not parallel.

Therefore, to develop a passive gyro stabilization system it is necessary to devise a scheme of coupling gyroscopic elements such that the lock condition can be avoided. To this end, several techniques have been evaluated with a small mock-up using inexpensive gyroscopes. The results of these have all been negative, however, additional concepts are being tested. It is possible that electromechanical concepts could be incorporated to achieve the desired characteristics.

Remote Maintenance Techniques - From the start of the nuclear age man has been concerned with performing maintenance in hazardous environments. The success of the development and utilization of remote manipulators in the nuclear area has given prominence to the possibility of integrating remote maintenance capabilities with man's capability for accomplishing certain types of maintenance in space.

It has been demonstrated on air bearing and aircraft simulators that man can operate a remote vehicle away from his mother ship. The next logical step is to design manipulators that can be attached to the remote unit which contains propulsion, stabilization, television, and power supply for determining the types of tasks that man can best accomplish with this type of system. The development of minimum reaction power tools over the past few years is expected to greatly reduce the weight of a man/machine system for maintenance.

<u>Summary</u>

Tool Repair Kits - The types of tools and equipment that represent the basic maintenance requirement for space are:

1. Tools, both hand and power, to perform a wide variety of required maintenance tasks.

2. Astronauts attachments single, two and three points depending on complexity of tasks.

3. Spare parts to replace failed items.

4. Repair kits for the purpose of effecting repairs not practical through normal component or blackbox replacement techniques. Included are: (a) leak repair kits for skin and radiators, (b) electrical malfunctions detection and repair tool for general wire joining kit, (c) fluid maintenance repair kits to effect repair of on-board fluid systems, (d) damage control kit to provide general material to effect emergency repairs (including a high power multi-purpose tool) of the station, (e) joining kit including: adhesives, brazing and welding capabilities, (f) development of Ancillary equipment to support crew maintenance operation, example of equipment required for work within the station, include, extension lights for viewing, vacuum mechanism for removal of filings from a pressurized cabin, etc. For work outside a maneuvering unit for attitude control and translation purposes will be required, (h) maintenance techniques and plans describing in detail the procedures and processes by which space maintenance operations will be performed.

Design Criteria

The purpose of this section is to present an approach for establishing design criteria for space systems.

Mock-Ups - The breaking down of a complete space system into the various subsystems for purposes of maintenance analysis enables the establishment of function common to all and the ones that are unique to a particular type of subsystem. The performance of subsystem analysis provides a guide for the design and fabrication of representative models (e.g. structural repair, joining experiment, fluids experiment, etc.) that can be used on earth simulators and space test beds to acquire comparative data. This data can then be used to establish design requirements for future systems that are to be maintained in space.

Tests - The acquisition of data to establish design criteria will have to be carefully planned in order to obtain data that can be realistically compared using the various types of simulation (6 degree of freedom, zero-g aircraft, space test bed). Each type of simulation has constraints that will have to be taken into consideration for purpose of selecting the type of data to collect for comparison. Some of these limitations are:

1. Air Bearing - Use of the 6-degree-of-freedom simulator to evaluate the torques and motions produced by man along under weightless conditions requires knowledge of the simulator effects. The motion of a rigid body with a fixed coordinate system through the center of its mass and moving with it can be expressed by using the Euler equations of motions. These expressions give a torque equation relating rotational motion, a force equation relating translational motion, and a direction cosine equation relating angular displacement. These equations along with a detailed analysis of their application to the 6-degree-of-freedom simulator are presented in another paper. (Reference 5)

The study of the applicability of the Euler equations to the data obtained from the 6-degree-of-freedom simulator demonstrated that the torque effects caused by the simulator cannot be mathematically calculated to permit their extraction from the total torque output to reveal the torque produced by man alone. Since the simulator system consists of not one but three rigid bodies, that is, the man with his back pack, the yaw ring, and the roll frame, the Euler equations would have to be applied to the coordinate systems for each of the bodies. But the use of three different coordinate systems would be of no avail since there is no transfer function to relate the systems. Still, as discussed in this study, the 6-degree-of-freedom simulator may be used to determine man's ability to perform maintenance tasks by measuring his motions up to the levels where he loses control to perform any further useful work. Another revelation pertinent to the use of the 6-degree-of-freedom simulator was the observation during tests in the zero-g aircraft that man's actions in a torque application comprised, for the most part, three motions in one plane; one was rotational, and the other two were translational. Should the 6-degree-of-freedom simulator be restricted to permit only these three degrees of freedom, the simulator could function as a single rigid body. This restriction would then allow the application of the Euler equations to torque measurements and the subsequent extraction of the simulator effects to yield the torque caused by man alone. Consequently, future test phases with the 6-degree-of-freedom simulator intend to study man's motions in the six-degree-of-freedom mode and to measure both man's motions and the torque delivered to a fastener in the 3- degree-of-freedom mode. The simulator will also be used to establish base line data with the constraints of the Euler equations removed and then correlated with data from the zero-g aircraft.

2. Water Simulation - The author believes this type of simulation will be valuable in learning how to construct large structures under simulated weightless conditions. The simulation of performing large structure assembly type tasks forces one to use water simulation. The size and gravity problems encountered using a 6-degree-of-freedom simulator and the zero-g aircraft will not enable the performance of these types of tasks. The problems that must be overcome to use water simulation (e.g. data is qualitative) for other types of tasks are many with practically no real advantages other than the one mentioned above.

Human Factors - The inclusion of man in the maintenance loop requires one to consider the following:

1. A preliminary evaluation of problems imposed on the man by the pressurized suit or hard shell enclosure, micrometeorite protection, heat exchange, time required by task, radiation protection, gravity conditions, safety conditions, warning devices, vision problem, communication, illumination, physiological comfort, mechanical requirements, and efficiency input/output.

2. Human performance evaluation of space requirements and manual dexterity capability and how these might be effected by protective equipment.

3. Training requirements for space maintenance tasks will involve time in simulators (6 degree of freedom and aircraft) and space chambers in preparation for the task to be performed.

The development of a truly flexible space suit is still considered to be the number one problem for the orbital worker to successfully carry out his maintenance mission.

<u>Computer Models for Maintenance</u>

The two types of computer models (physical and abstract) both have application in the area of maintenance planning for space. The following are possible application of an analog model for a space worker:

1. It is possible that a space worker can use the tool he is working to apply reaction forces for stability. The feasibility of this has been demonstrated for planar motion and is reported in "Manual Application of

Impulses While Tractionless." The problem is more complex for torques applied in a six degree of freedom environment. In this case, the reaction torques may induce rotation about other axes. An analog program could be used for investigation of this problem.

2. An analog model can be used to evaluate the effectiveness of applying short duration impulse forces for space maintenance. This type of force application may leave the worker relatively stable. Typical examples of this type of loading would be manually impacting a common wrench or using a hammer.

3. During extra vehicular assembly the space worker may have to perform some tasks when attachment is not possible or practical. Under these conditions the worker may be able to use an Astronaut Maneuvering Unit (AMU) for the stability as well as mobility. An analog could be used to determine if the required tasks can be performed with the assistance of the AMU.

4. In connection with the above application an analog model can be used to determine the fuel consumed when the AMU is used for stability while the worker is performing such tasks.

5. Also in the same light, an analog model can be used to determine if the AMU thrust levels are sufficient to stabilize the worker while performing maintenance tasks.

6. The use of minimum reaction tools require small stabilization forces. If the space worker is equipped with a battery of these tools the AMU could be used for stabilization with a minimum fuel consumption. An analog program could be used to evaluate the feasibility of this concept.

7. It is possible that an analog model can be used to simulate the use of simple short tethers. Such tethers can be used for providing the small stabilization forces required while working with minimum reaction tools.

8. An analog model can be used to study the mobility of a space worker by self-propulsion while confined in a spacecraft.

9. An analog model can also be used to evaluate the maneuverability of an astronaut with the AMU. A typical example would be the evaluation of various emergency procedures.

10. An analog model can be used as a prototype for a similar program for the AMU.

Abstract Model - Abstract models are predictive devices which may be utilized as; (a) an evaluation tool of either existant or proposed maintenance and support systems by simulating real world conditions, (b) a comparison device which will generate a relative evaluation of the predicted performance among competing concepts of a maintenance system,

(c) a design tool to formulate an optimum maintenance system through a trial and error or iterative procedure.

In order for computers to play an active role in the maintenance planning for space systems, it is important to keep their role in mind throughout the testing phase so that data can be logged for easy accessibility when the time comes for its use.

SUMMARY AND CONCLUSION

Summary

The objective of this paper has been to; (a) bring to the attention of those interested in space maintenance some of the things that have occurred over the past several years to enhance man's ability to accomplish maintenance in space and (b) present an approach to get from maintenance concept, to test hardware that can be utilized for obtaining design criteria required for the fabrication of maintainable vehicles for future space missions.

Conclusion

Man has progressed considerably in the past several years in his drive to obtain unique tools, maintenance devices and abstract models. All directed toward obtaining the technology that will enable him to design space maintainable systems. Considerable testing and evaluation of man-machine relationship in air bearing simulators and the KC-135 aircraft under zero-g conditions has been accomplished. However, none of this data establishes how effectively maintenance can be performed considering the combined effects of extended time in space, the space environment, and weightlessness. Until this is accomplished the design criteria necessary for obtaining the technology to design space maintainable systems can not be obtained. Tests to date have indicated that man can in general with the proper tools and techniques accomplish maintenance in the space environment.

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