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MAINTAINABILITY/SUPPORT REQUIREMENTS FOR SPACE PROGRAMS

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16. Abstract The identification of maintainability/support requirements for long duration space operations is extremely difficult because (1) we have scanty information concerning long duration operations, (2) some of the programs for which concepts and approaches must be developed are the second or third generation beyond our present state of the art, and (3) because at present we are not able to perform our space operations design and planning tasks from the same comfortable basis of complete familiarity with man, equipment, and environment as for on-earth operations. We have presented, therefore, an approach for identification and development of maintainability/support requirements that permits progression from state-of-the-art techniques and equipment to future requirements through use of standard engineering procedures. This approach includes an analysis of future program requirements to identify probable support requirements with an inductive reasoning approach to bootstrapping them from state-of-the-art techniques and equipment, since the identification alone of a support requirement is not enough. We also must show how to achieve the objectives, because this is also a part of the requirement picture.

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TECHNICAL MEMORANDUM X-53855

MAINTAINABILITY/SUPPORT REQUIREMENTS FOR SPACE PROGRAMS

SUMMARY

The identification of maintainability/support requirements for long duration space operations is extremely difficult because (1) we have scanty information concerning long duration operations, (2) some of the programs for which concepts and approaches must be developed are the second or third generation beyond our present state of the art, and (3) because at present we are not able to perform our space operations design and planning tasks from the same comfortable basis of complete familiarity with man, equipment, and environment as for on-earth operations. We have presented, therefore, an approach for identification and development of maintainability/support requirements that permits progression from state-of-the-art techniques and equipment to future requirements through use of standard engineering procedures. This approach includes an analysis of future program requirements to identify probable support requirements with an inductive reasoning approach to bootstrapping them from state-of-the-art techniques and equipment, since the identification alone of a support requirement is not enough. We also must show how to achieve the objectives, because this is also a part of the requirement picture.

INTRODUCTION

Long duration (3 to 5 years) manned space missions will require not only concept and operations planning, hardware development and construction, and operational crew training, but in addition careful support planning and support crew training will be required to achieve mission objectives. Manned space operations to date have only required a hardware operating life of from 3 to 5 weeks instead of future expected life requirements of from 3 to 5 years, and components and assemblies we are now using have been designed for our present requirements.

We have no hope that the life of every part to be assembled into mission hardware can be upgraded by a factor of 50 before it is needed. However, even if this were possible, we can have no assurance that every part would function for its designed life; so we must provide an in-space support capability for fault isolation and replacement of components that fail. Such planning can be accomplished by analyzing mission requirements and by developing a method for defining the maintainability/support requirements for space programs.

The support of space missions can be divided according to where such operations are to be performed into two general categories: (A) in-space support operations; and (B) ground support for the mission, including (1) pre-launch and launch support for space vehicles, (2) delivery of resupply into space by shuttle vehicles, and (3) data ground support for space support operations via the communications link. The conditions and requirements for the ground support operations are well known from previous space operations; however, the conditions and requirements for in-space operations must be largely conjectural, based upon the scanty repair experiences of astronauts, the data from Chet May and other aquanauts in extended habitat operations such as the Ben Franklin, and our best engineering estimates.

However, the basic approaches to program support apply to both the ground and the in-space support efforts, just as they apply to any other support effort. Ralph Thompson [1] stated the basic approach we must follow when developing space requirements in his description of the support program for the Gamma Goat vehicle: "It is necessary to 'design for support' rather than 'support the design.'" The basic requirement for support of space programs is "design for support," taking into account all the special conditions of space, intravehicular (IVA) and extravehicular (EVA) operations, the capability of the man, the available tools and equipment for space activities, and the available storage on the space vehicle for spares, repair equipment, and support data. The development of a support program for space is thus just a little different than the development of a support program for an automobile or for a military weapon system such as a fighter plane.

NASA SPACE PROGRAMS

The space programs that require in-space support and for which support requirements must be developed include (1) those which are firm, (2) those which are under study contract, and (3) those which are purely in the idea stage and for which there are no approvals. It should be noted that the programs are progressively more complex in nature and more ambitious in their technical objectives. Also, they are progressively more demanding upon the operations and service crews and upon the support equipment. However, support experiments in one program will prepare for the needs of the future program requirements, so we are really bootstrapping our support capability. It is only imperative that careful planning identify all possible requirements for each program and the the logical knowledge and technique sequence be established to provide needed capability to prevent failure of future programs. Support requirements are needed for the programs shown in Table 1.

TABLE 1. SPACE PROGRAMS

Program	Approvals	Space Life	Expected Operational Period
Apollo Applications Saturn Workshop I Apollo Telescope Mount Other Experiments	Firm Program	Missions – 28/56 days	Early 1970's
Space Station/Base	Study Contract	10 yrs	Late 1970's
Lunar Rover	Firm Program	----	Early 1970's
Dual Mode Lunar Rover	Study Contract	----	Mid 1970's
Low Cost Space Vehicle	Proposed Program	----	Late 1970's
Space Shuttle	Proposed Program	----	Mid 1970's
Nuclear Stage Study	Study Contract	----	Late 1970-1980
Outer Planet Exploration	Study Contract	----	Late 1970's
Lunar Shelter	NASA Study	----	----
Lunar Flyer	NASA Study	----	----
Manned Mars Operation	NASA Study	----	----

MAINTAINABILITY/SUPPORT FUNCTIONS

The development of maintainability/support requirements for long life space missions necessitates a thorough understanding of the functions of maintainability and support, their interrelationships, and how they contribute to the life of mission hardware. It is necessary to define each function; to relate them to the program phases of in-space operations and ground support (prelaunch and launch, resupply, and ground advice to space support operations via the communications link), and to establish the parameters for their integration for the various program phases and operations, both on the ground and in space. It is also necessary to relate the support functions to the schedule phases of the space program so that the requirements, when developed, can be implemented in a timely manner. It is particularly important that the maintainability and support functions be blocked out during the early concept phase and progressively developed and integrated into the planning for hardware, operations, training, and procedure development. This progressive implementation enables us to develop techniques far in advance of state of the art by a stepwise process and will ensure that there are across-the-board considerations of the requirements to ensure mission life objectives at the lowest possible cost.

The maintainability/support functions that we consider in establishing the requirements for space programs are listed in Table 2. These functions, which provide direct inputs to design, and those that must be closely responsive to design changes are indicated. Also indicated are those functions that are of a service nature with limited responsiveness to design changes.

Support Function Phasing

As a prelude to our discussion of support requirements development, we should look at a classical schedule for a space program with the support functions related to the preliminary concept, the main effort, and the continuing effort. It should be noted that these functions start during the early conceptual phases of the program and continue to the end, with varying levels of involvment during the different program phases, as shown in Table 3.

Mission Requirements for Maintainability/Support

There is no logic in the development of requirements for maintainability/support of space programs. There is only the hard work of integrating what we know of man and equipment capability with each program objective. As described in Reference 2, approximately 1200 proposed scientific and technical experiments were identified and examined for potential EVA requirements. These were reduced to 16 separate experiments that were representative of scientific and technical experiments likely to be performed in the

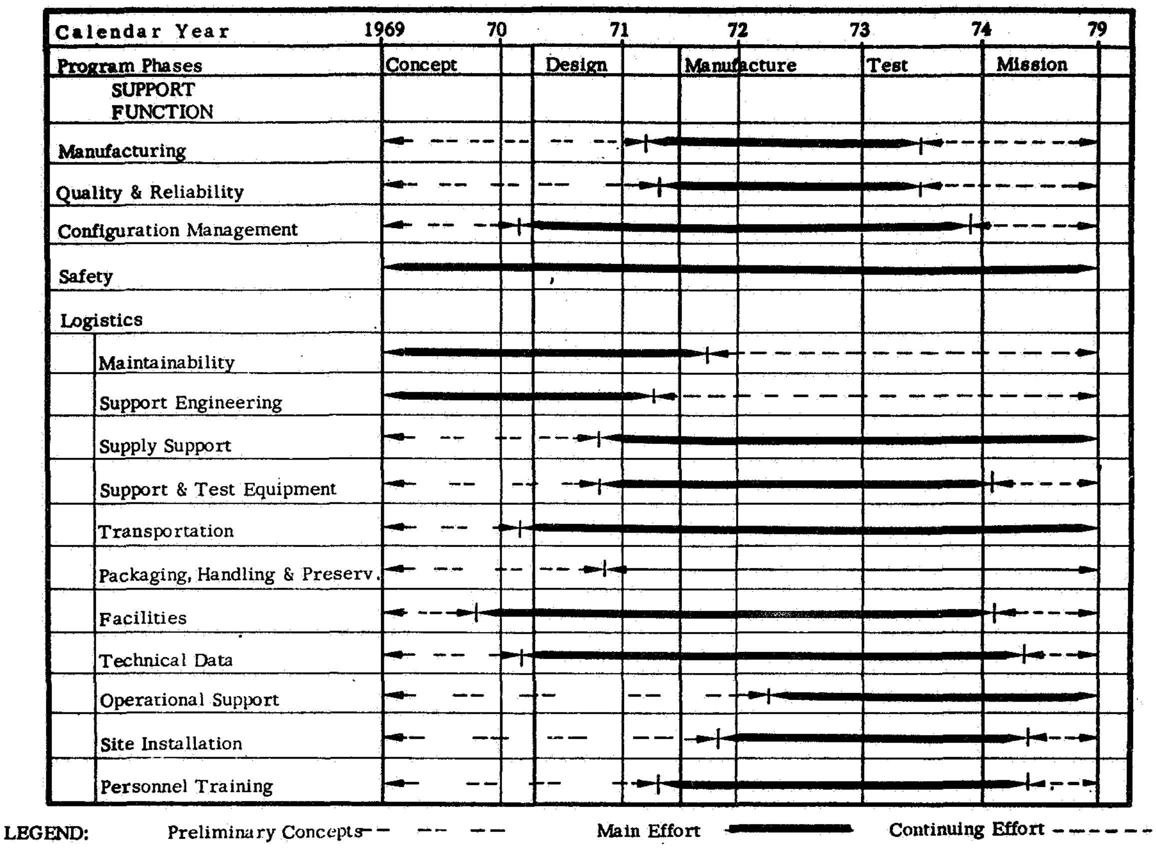
TABLE 2. ENGINEERING SUPPORT DESIGN RELATIONSHIPS

ENGINEERING SUPPORT FUNCTION	DIRECT INPUTS TO DESIGN	DESIGN RESPONSIVE	SERVICE NATURE
Manufacturing Support		x	
Quality & Reliability		x	
Configuration Management		x	
Safety		x	
Logistics		-	
Maintainability	x		
Support Engineering	x		
Supply Support		x	
Support & Test Equipment		x	
Transportation		x	
Packaging, Handling, and Preservation		x	
Facilities		x	
Technical Support Data			x
Operational Support			x
Site Installation and Support			x
Support Personnel & Training			x

early to mid-1970 time period. Each of the 16 experiments was subjected to a further, indepth analysis regarding EVA requirements. As a result, over 90 percent of the EVA requirements could be met by only 22 discrete EVA task functions, either singly or in combination. This analysis demonstrated that we did have the supporting research technology/advanced research technology (SRT/ART) capability required for the early 1970 time period. Reference 2 lists the experiments and identifies the EVA procedural requirements, specific EVA tasks, and the supporting EVA hardware. The same approach in developing maintainability/support requirements for any space program must be utilized. This sort of careful analysis and the orderly progression from known to unknown permit us to develop the majority of support requirements in a timely manner. Then the ones we do not foresee will not overwhelm us when they must be dealt with on a crash basis.

To assist in developing specific maintainability/support requirements for any space program, typical types of requirements have been grouped under the support functions they must apply to. These can be expanded into the specific requirements in the same manner as demonstrated in Reference 2.

TABLE 3. SUPPORT FUNCTION SCHEDULING



Manufacturing Support. The manufacturing support function should provide for the development of a manufacturing plan that is tied to resupply requirements for hardware components. This plan must be tied to the shelf life of critical components so they are not produced until needed. All must be integrated into the manufacturing plan so hardware can be produced when needed at minimum cost.

Quality Assurance. A quality assurance function should develop a parts management system for the production of hardware and for the preservation of its manned rating both on the ground and in space.

Reliability. The reliability function must develop a reliability approach that is compatible with long life space programs and that makes full use of previously proven hardware.

Safety. The safety group should perform the following functions:

1. Develop safety standards for spares management.

2. Develop safety standards for on-ground and in-space operations support.

3. Develop special safety requirements for operations involving especially hazardous equipment such as nuclear stages or devices.

Maintainability. The maintainability function is responsible for the following:

1. Development of a design/support philosophy that offers the greatest potential for long life systems.

2. Development of a design system that requires minimum expenditure for maintainability test programs.

3. Provision of the greatest response to contingencies.

4. Reduction of extensive redesign for human engineering reasons by early considerations.

5. Incorporation of safety requirements into design.

Support Engineering. The support engineering function provides the basis for all program support implementation. The program operations analysis and the support concept are the bases for the support analysis that develops requirements for spares, facilities, GSE, tools and test equipment, training, technical support data, and operations support (fault isolation and maintenance activities).

Supply/Resupply. The requirements for the supply/resupply group are as follows:

1. To establish need for onboard spares, with resupply according to plan.

2. To provide for emergency resupply based upon usage.

3. To establish special requirements for man rated and limited life items.

<u>Support Tools and Test Equipment.</u> The equipment support group should perform these functions:

1. Develop lists of all ground and in-space tools and equipment.

2. Develop those tools and test equipment not available.

3. Prove the tools and test equipment under simulated or in-space conditions.

<u>Transportation and Transportability.</u> The transportation function should provide the following requirements:

1. Develop ground and in-space requirements for personnel and equipment transport.

2. Develop transport plans responsive to emergency requirements.

3. Develop transport equipment as required.

<u>Technical Support Data.</u> The data support group should perform these functions:

1. Provide onboard data for service-repair operations.

2. Provide a fast response communications link from the ground for the in-space display of technical data, including drawings, instructions, etc.

3. Provide a quick response fault reporting system.

<u>Operational Support.</u> The operational support function should provide the following:

1. Identification of all ground and in-space operational support activities.

2. An analysis of each activity from the standpoints of maintainability, tools and test equipment requirements, and support data requirements.

3. Identification of those activities that have not been performed or that we do not presently have the capability to perform.

4. Development of the capability through simulation or actual mission operations to meet program requirements.

Training. The training functions are as follows:

1. Define training requirements in terms of courses and people.

2. Develop training aids and training programs.

3. Train required personnel.

TEST PLANNING FOR OPERATIONAL SUPPORT

The operational support test plan must be a completely integrated effort that considers the objectives of the space program, its schedule, the program hardware, and our capability to operate within the space environment. The requirements for operational support of the program must be synthesized, and from these a complete test plan must be developed. The plan must utilize input data from all program functions to identify requirements for tests. These must be analyzed to determine which tests must be performed in space and which can be performed in simulators on the ground. The time relation of the tests must also be considered in terms of interchangeability and the state of the art.

From these test requirements and the analysis, a comprehensive test plan is developed to provide a basis for support to all program functions. The test requirements must be identified, taking into account (1) state-of-the-art capabilities that can be applied to plans for tests and the development of testing techniques; (2) those requirements for which the capabilities can be expected to be developed by normal capability progression by the need date; and (3) those requirements that appear to be so far in advance of the state of the art that extraordinary prior study will be required before the tests can be performed.

Table 4 shows tests that are being planned for the early 1970's Saturn Workshop. The tests are grouped according to the type of objective. These typical requirements for space tests can be studied on the ground before space study and include equipment and technique testing in simulated space facilities.

TABLE 4. SATURN WORKSHOP SUPPORT REQUIREMENTS

OBJECTIVE	TEST REQUIREMENT
In-Space Verification	1. Analyzer for electron-beam welds 2. Analyzer for tube joint welds 3. Analyzer for bonded structures 4. Ultra sonic analyzer for torqued fasteners
In-Space Instrumentation	1. Temperature-vibration monitor for electronic component
Space Support Equipment	1. On-board machine shop 2. Leak detector 3. Portable flowmeter for mass flow rates 4. Fluid maintenance system 5. EVA manipulator and techniques 6. EVA space crane and techniques
In-Space Repair Techniques	1. Leak test techniques 2. Soldering under zero "g" conditions 3. Fluid systems repair techniques and kit 4. Structural repair techniques and kit 5. Small parts repair and handling techniques 6. Exothermic and electron beam welding techniques 7. Minor machining techniques 8. Wire joining techniques 9. Emergency repair techniques
In-Space Operational Techniques	1. Mechanical and adhesive bonding techniques for EVA 2. EVA transfer of liquid cargo 3. EVA recovery of free objects

Another kind of requirement for in-space testing is to develop a procedure for each operational support task, including the service and repair of all parts of the basic space vehicle and its accompanying modules, experiments, and satellites. Each task must be carefully analyzed, a stepwise procedure developed, and the procedure tested in a zero-gravity simulator to verify that it can be performed under actual space conditions.

To test Saturn Workshop operational requirements, NASA has immersed a full-scale mockup of the Workshop in a large tank of water (neutral buoyancy simulator). Zero-g conditions are simulated by establishing neutral buoyancy for the test personnel, the tools and operational equipment, and the parts of the structure to be manipulated. The data collected during these tests have been used by designers in developing the details of the equipment to be flown. The validity of the tests has been verified by astronauts who have performed similar tests under space conditions. They report that the "feel" of the underwater tests is not exactly like that in space zero-g, but the man-machine problems that have been established correspond to problems actually experienced in space flight. For instance, Astronaut Borman recently stated that the simple act of throwing an electrical switch is a problem unless there is an adjacent handhold. Without it, instead of the switch lever, the astronaut's body moves. So, until designers can "think" in terms of space requirements, all support operations, tools, and equipment will need to be tested under simulated space conditions.

Test Philosophy Considerations

For long life systems, serious consideration must be given as to whether we should continue our "tried and true" approach to malfunction prevention through periodic test and maintenance. Many of us have at one time or another questioned whether we were really proving, by periodic exercise, that equipment will operate when needed, or whether we were really wearing it out. Except for equipment that will deteriorate if not exercised periodically, we do not actually know that a motor will operate when the switch is thrown, even if it had been operated only yesterday instead of last month.

In fact, on a new airplane being built for American Airlines by McDonnell-Douglas, there will be no periodic replacement of most components. When they malfunction, they will be replaced. American has found through careful analysis of failures that they were building in their own malfunctions by component replacement in a functioning system. We need to do some careful study of space systems along these lines.

TRADE-OFFS

Long life space stations must be serviced and supported or they will not meet their life objectives. In fact, the lives of the space crew will depend upon how well we plan and provide for their welfare. But all space support planning must be a trade-off when considered against our normal, on-ground approach. We simply do not have our familiar, on-ground basis for planning what a man can do, how materials behave, and what we can expect of equipment. We must learn to think in terms of space requirements, and this is not easy since we have had so little experience.

To gain this experience for planning, we must consider (1) the natural conditions of space, (2) man's basic capabilities under space conditions, and (3) the state of the art of space tools and equipment as they apply to each space program requirement. We will usually find some trade-off or work-around to satisfy the requirement under the space, personnel, or equipment restrictions. However, the trade-offs should become less numerous when we move further into the programs and increase our familiarity with space operations. Let us consider the following space conditions.

Natural Conditions of Space

All the inhospitable space conditions such as zero-gravity, vacuum, lack of oxygen, extremes of heat and cold, and the inability to return easily to earth are in this category. One must carefully consider them when planning any space program, although they are magnified for the long duration missions. For these, we must plan for crew rotation, rehabilitation of equipment, and periodic resupply of expendables and spares. Each time there is a resupply mission and each time man must leave the space craft for in-space servicing of experiments and satellites, the space conditions must be overcome by what he is able to carry. The protective clothing and the means for space locomotion are trade-offs in themselves. In a space suit, we trade freedom of action and maneuverability for warmth, oxygen, and protection from the space vacuum. This is the case with all space travel. We must thoroughly understand the hazards and find a way to work around them.

Man and Equipment Capability

Man's capability is his capacity for space work, including the various fault isolation, replacement/repair, and servicing tasks required in space. A knowledge of this capability is important since all maintainability requirements must be developed based upon the proven or expected capability of man and his space tools and equipment. If this is not known, simulation tests or actual in-space tests will be required to prepare man for the tasks expected of him.

Support equipment has definite limitations that must be considered in trade-off studies. Welding equipment can only be used under certain conditions and on certain materials. This and other such facts must be incorporated into the support procedures for in-space operations. The various space tools and equipment for performing service and repair operations must be combined with the life support equipment, the work platforms and stabilizers, and the various tethers and maneuvering units required for EVA operations. Typical tools are described in Tables III and IV of Reference 3.

Maintenance Modes

Another kind of trade-off that can be utilized to accomplish seemingly impossible tasks is a change in the maintenance mode. Instead of a manual mode for fault isolation and temporary replacement of an EVA component, it may be necessary to substitute redundancy replacements that can be cut into the system automatically upon failure or upon command. Then, at a more convenient time, the failed component can be manually replaced. In fact, on unmanned vehicles, the redundant replacement mode is the only possibility.

Inflatable hangars provide a possible work-around for difficult EVA tasks. They provide a space shelter that can be towed to a work site at a distance from a space station for work on a satellite or an experiment module. They provide a stable work platform for the personnel and a degree of environmental control, with the possibility for areas of artificial atmosphere.

SIMULATION

Simulation is extremely important in the development of support requirements for space programs since simulation test data are our only valid base for assumption, besides in-space testing. However, results from simulation tests must be taken with a grain of salt, the size of the grain being dependent upon how close the simulation is to the real world of space and the hardware we plan to fly there.

Simulator design requires a complete knowledge of the conditions of space and of the equipment to be used in it. It is usually not possible to completely duplicate all these conditions in a single test facility, but careful assessment of the test data in light of space conditions not duplicated, will give validity to the results. The conditions to be duplicated include those of the space environment, the conditions related to the space vehicle and its life support systems, and the expected man-capability in the space environment.

Mock-Ups

Some of the testing can be done in mock-ups that are not under simulated space environmental conditions. For instance, the study of man's capability under restricted spatial conditions only is perfectly valid so long as space environmental factors are not read into it. However, if the test data were processed through a computerized model that imposed the effects of space environment upon the data, this then could be considered. The mock-up testing is especially useful in establishing maintainability requirements and for testing equipment designs for accessibility and ease of maintenance.

Full-scale mock-ups should be used wherever possible since they provide direct data without scale-up worries. Mock-ups can be used under earth conditions or can be placed in simulated space chambers, as has been done with the Saturn Workshop in the simulated zero-g tank at Marshall Space Flight Center (a neutral buoyancy simulator).

Computerized Models

Computerized models based upon careful engineering analyses of known operational and test data and of anticipated operational conditions that are based upon expected program hardware have a real value for development of future requirements. The model permits system exercising for predicting malfunctions and for establishing the optimum parameters for isolation of malfunctions with subsequent system repairs. These parameters provide many of the maintainability requirements that form the basis for the maintainability concept and program, which must be integrated into the design of the program hardware.

The computerized model also provides bases for management direction and a variety of program decisions. Such things as determination of the optimum balance of hardware redundancy with manual repair operations will (1) provide assurance of desired mission life expectancy and (2) achieve the required weight and volume values for the mission hardware [4]. The model also provides the basis for comparative costs of equipment, including all its subsystems, and for different degrees of maintenance. Relative incidents of equipment failure for spare load planning can be obtained as can management visibility for fast response decision making, based upon computer integration of operational events, particularly those of an emergency nature.

Weightless Simulation

Weightless simulation is extremely important since it is the only approximation of space, except space itself, for the testing of man's capability, tools, and equipment under this environmental condition. Several zero-g approaches have been utilized, including a zero-g aircraft, water tank facilities, and a

6-degree of freedom simulator.[1] The tests have not been conclusive as to value for astronaut training for space activities, since space operation data for comparison purposes are scanty. However, the simulators have proved extremely valuable in testing equipment designs and man's ability to operate them.

The zero-g aircraft simulator does provide a 30-second period of true weightlessness per flight parabola. However, this test peroid is so short that most tasks cannot be completed, and the results are questionable. The subjects are extremely tense in an effort to complete the tests, and task times are not considered valid.

The water tank zero-g simulator appears to be more valuable, since the size of the component is no factor, nor is the time to complete tasks. There is an interesting observation from the Workshop neutral buoyancy simulator. The hazards of underwater work are not comparable to those of space, but the test subjects have exhibited concern at working in a potentially hostile environment. It is felt that this enhances the validity of the test results.

Habitats

The PX-15 (Ben Franklin) in the Gulf Stream Drift Mission (with Chet May gathering maintainability and support data) provides another kind of simulator. It does not duplicate the environmental conditions of space, but it does provide an isolated test chamber in which people are confined under restricted spatial conditions for an extended period of time. The operation is also potentially hazardous. We think we can correlate maintainability, maintenance, and operations data from this test to the operations in a space station. The PX-15 is certainly in a sort of space environment, although it has different natural characteristics than does space; however, these are just as hostile to man as are those of space and man's reactions should be nearly parallel. All life support systems must be carried, as must the required support equipment and spares, since resupply is not planned. Data regarding support operations and the suitability of the support program for the mission will be collected, as well as of the man-machine relationships. These data will be applied to planning for space station operations. The following data are to be collected:

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1. May, C. B., The Effectiveness of Weightlessness Simulators for Obtaining Maintainability Criteria for Space Programs, NASA-George C. Marshall Space Flight Center, Alabama 35812, 1967.

1. Maintainability of equipment.

2. Definition of onboard operations.

3. Manpower utilization.

4. Expendables consumption.

5. Evaluation of physiological measurement techniques.

6. Evaluation of man under stress.

7. Evaluation of man in an isolated, confined environment.

It is hoped that evaluation of the tests will show that such habitats provide a useful substitution for space operations, since launching a submersible is not quite as difficult as launching a space station and since it is also reusable.

RESUPPLY REQUIREMENTS

The requirements for resupply of long life space programs can be divided into those for ground support and those for in-space operations.

The ground support requirements are akin to the typical resupply requirements for current missile and space programs. There will be some changes because of the possible need for emergency launches caused by in-space problems.

These could include maintaining a vehicle ready for almost immediate launch, but techniques already developed for support of military missile systems should apply. The maintenance of the ground support equipment, which will need to operate for years, needs attention. There will be malfunctions caused by wear-out of components that will require a different kind of study than has been made to date on these units. The components that have a limited life must be identified so that adequate stocks of spares can be provided. It will also be necessary to provide redundant ground support equipment, which can be used for emergency operations in case on-line items are down for repair.

The resupply planning requirements for in-space operations are substantial. Not only must the quantity and schedule for each expendable and spare be planned, but how these fit into the planned resupply shuttle vehicles must be considered. The crew rotation requirements (to which support must provide inputs because of the operations support training for crew members) and the ever likely requirement for emergency replacements are also to be considered; therefore relative urgency of resupply requirements must be maintained upon a continuous basis to permit almost instant cargo substitutions.

There have been efforts to provide the program manager with visibility from which he can make almost instant management decisions for resupply operations. General Dynamics, for one company, has a computerized model for an aircraft that the manager can exercise on an immediate response basis for management decisions. They plan to apply the same approach to in-space operations to permit the same kind of response, including visibility for the loading of shuttle craft for resupply operations.

CONCLUSION

Our approach to definition of maintainability/support requirements for space programs is certainly not new. In fact, it is a reiteration of a normal engineering analysis and problem solving technique for complex problems. We work with the portions we can see and solve, with the expectation that the invisible portions will fall out as workable parts. It is rather like unwinding a tangled ball of string. One works on the loose ends, and when they have been unraveled, the whole ball can be unraveled.

What we have done is to provide validity to this unraveling approach in the solution of space support problems by considering in depth the interrelation of the functions of maintainability/support and how they apply to a space program. We have provided some of the operational parameters such as identification of space support tools and techniques, the capabilities of man in space, and the problems of the space environment. We have also provided some untangling tools such as mock-ups, the simulation chamber testing techniques, and the computerized system model approach.

Using these with progressive test data integration in a bootstrapping approach will enable us to identify the maintainability/support requirements for today as well as for any future long duration space program.

However, the most important thing is to minimize support problems by "designing for support" rather than "supporting the design". We know the hardware must be supported by service and repair, because components cannot be expected to function properly for 3 to 5 years. However, by designing for easy maintenance and for reliability, the support tasks can be minimized with reduction in crew requirements and in the spare load requirements. Also, a design for support approach, such as modular replacement, will reduce the complexity of the crew servicing and maintenance tasks commensurate with the space restrictions on man's capability. The approach outlined does provide for planning of in-space maintainability/support through early identification of requirements and does present reasonable assurance that long life space program support tasks are within our capability.

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MAINTAINABILITY/SUPPORT REQUIREMENTS FOR SPACE PROGRAMS

By Ward H. Cook and Chester B. May

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This document has also been reviewed and approved for technical accuracy.

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