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B70 12017

SUBJECT: Characteristics and Practicality of Environmental Control/Life Support System Evolution - Case 105-4

DATE: December 7, 1970

FROM: A. S. Kiersarsky
D. Macchia

ABSTRACT

Evolution of an Environmental Control/Life Support System (EC/LSS) is reviewed in terms of practicality, cost considerations, and current technology.

For purposes of illustrating practicality one particular path of EC/LSS evolution is described -- from Skylab type systems, to a completely closed loop system via an intermediate step involving wash water recovery. Based on hardware added, interfaces between new and existing components, and control and monitoring requirements it is shown that the intermediate step is relatively simple and the final step is practically a complete system change.

Results of the General Dynamics "Basic Subsystem Module" study are reviewed. In that study, evolution of the power, thermal control, structure, and EC/LSS systems was considered. It was shown that total cost increases with the number of evolutionary steps and that annual funding can only be reduced, as compared with direct development of the final system, if adequate time phasing is allowed between evolutionary steps.

Finally, it is shown that NASA has significant experience with integrated closed loop EC/LSS systems, so that an evolutionary approach is not required on the basis of technology status.

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MEMORANDUM FOR FILE

INTRODUCTION

A recent presentation on an alternate Space Station configuration (Ref. 1) included consideration of an evolutionary approach to subsystems development as a possible means of reducing Space Station initial cost and annual funding. As an example of evolution, Reference 1 discussed the environmental control/life support (EC/LS) system and that discussion is elaborated on herein.

The alternate Space Station configuration comprised two modules -- a living or habitability module and a systems module which can be replaced in orbit and returned to earth. The systems module incorporated power, attitude control, stabilization, thermal control, checkout, and most of the communications and EC/LS systems. Evolution was to be implemented by introducing improved systems modules.

For purposes of illustrating requirements and practicality one particular path of EC/LS system evolution is described. Following this is a review of the results of an early investigation by General Dynamics on definition and evolution of a systems module which serves to illustrate cost aspects of evolution. Finally, the state-of-the-art of integrated EC/LS systems is reviewed.

TYPES OF EVOLUTION

Generally, Space Station systems evolution can occur in the form of

- added capacity,
- added functions or subsystems, and
- improved subsystems.

Evolution by added capacity implies that Space Station operations start on a relatively small scale, and during the life of the station capacity would be increased by adding modules or subsystems for increased power, crew, or volume. Evolution in the form of new functions might entail such steps as adding oxygen and water reclamation. Evolution in the form of improved subsystems would be a means of improving the performance of existing functions. Examples include subsystem replacements that have higher reliability and/or performance, reduced maintenance requirements, or eliminate operational constraints.

Evolutionary approaches mean less development initially; therefore, the initial cost of such a station should be lower than for the desired final station configuration.

CHARACTERISTICS OF ONE POSSIBLE EVOLUTIONARY PATH

An approach for an evolutionary EC/LSS was examined utilizing a life support concept similar to Skylab to form the starting point for evolution. The initial system would ultimately evolve into a fully integrated EC/LSS that regenerates atmosphere and water supplies.

The evolutionary path considered for this study involves added functions and improved subsystems and is noted in Figure 1. Evolution by increased capacity is not considered. Briefly, step 1 is similar to Skylab. Water for showers, dishwashing, clotheswashing, and consumption is resupplied as well as metabolic oxygen and cabin atmospheric leakage. In step 2 wash water and fecal flush water are recovered, processed, and reused for the same purpose. Considerable savings in resupply weight amounting to over 22 lb/man-day of water (depending on wash requirements) result. In addition, a cryogenic atmosphere storage system is substituted for the gaseous system to reduce resupply weight by reducing tankage weight. Finally, in step 3, urine and humidity condensate are recovered and processed for use in the potable water supply, and oxygen is regenerated from CO_2 via a Sabatier reactor and water electrolysis. Small quantities of water and gaseous oxygen must still be resupplied to meet oxygen generation (by electrolysis) and repressurization requirements respectively.

Resupply requirements are reduced with each evolutionary step. As indicated in Figure 2 a reduction of 23,520 lb per quarter is possible for a 6 man crew by evolving from step 1 to step 3. This is achieved by the addition of more hardware. In this evolutionary example the additional hardware costs for oxygen and water regeneration lead to savings in logistics costs and this must be considered in the initial selection process.

An indication of the practicality of evolution is given by the ease of integrating new or improved subsystems into an existing system. This depends on the interfaces between EC/LS subsystems and other spacecraft subsystems, and between new and existing EC/LS subsystems. These interfaces consist of liquid, gas, and electrical power lines, and lines for control and monitoring.

A schematic of the evolutionary EC/LSS, Figure 3, illustrates the interface complexity and the hardware additions for each evolutionary step. Several points are apparent. The complete EC/LSS, step 3, requires more hardware and plumbing and is much more complex than step 1. Step 2 appears to be a relatively simple step in that it has only an N_2 pressurization gas interface with the existing step 1. However, it does have thermal control, power, control and monitoring, and cabin air circulation interfaces with other subsystems in the system module. This step, because of other subsystem interfaces, must be planned on initially. For example, plumbing lines and other provisions for addition of a wet john must be initially incorporated or allowed for. Step 3 involves the addition of much more hardware, has several important interfaces with the existing EC/LSS (step 1), and has many interfaces with the thermal control, power, control and monitoring, and cabin air circulation subsystems. This final step represents an extensive evolutionary addition.

The number of plumbing and power line connections with each step are fairly well indicated in Figure 3 but the many control and monitoring devices and sensors are not. The outputs from or inputs to this instrumentation would be via data buses to minimize the number of lines to and from control and monitoring consoles. This instrumentation and the associated software and control console requirements introduce additional complexity to each evolutionary step. An indication of this is given by the following listing of the total number of sensors and control devices for an integrated EC/LSS (from Reference 2).

Water management	73
Water reclamation	46
O_2 high pressure storage	9
N_2 high pressure storage	3
Cabin pressure control	13
O_2 generation	32
CO_2 collection	20
Cabin temperature and humidity	29
Coolant loop	12
Crew provisions	2
Face contaminant	3
Total	242

REQUIREMENTS FOR EVOLUTION

Selection of an evolutionary approach will require special attention to various factors for feasible and orderly evolution. Only in this way can interim and final systems performance be ensured.

During the initial design phase, studies are conducted to select, size and integrate the life support subsystems into an operational system. The depth and scope of this phase include the following:

- Prepare schematics of liquid, gas, and instrumentation connections for all evolutionary steps and define all component, subsystem and spacecraft interfaces.

- Size components and plumbing for the desired final evolutionary step or allow for additions of components and plumbing.

- Conduct analysis and test of component operating ranges for interim and final configurations.
- Establish, and design for, the requirements of evolutionary steps on other spacecraft systems such as power, thermal control, monitoring and control.
- Configure the system to meet packaging and maintenance requirements.
- Prepare interim and final test programs for system evaluation.

The first four items above imply, among other things, that a necessary step for an evolutionary process will be an evaluation of compatibility of the various inputs and outputs between initial equipment and systems additions. This also implies detailed knowledge of the final system. To achieve this compatibility the subsystems must be designed with sufficient capacity and broad operating range. (Otherwise, modular additions would be required.) The primary areas to be evaluated are

- fluid and gas flow rates
- system design pressures and temperatures,
- heat loads (both input and rejected),
- electrical power requirements, and
- control and monitoring instrumentation.

As previously discussed step 3 is a major addition, and places a significant demand not only on the EC/LSS but also on the spacecraft supporting systems. An example is the increased load on the electrical supply and thermal control system with the addition of step 3. Also in step 3, the CO_2 (which during step 1 was dumped overboard) must now be delivered to the CO_2 reduction unit. Here, sufficient CO_2 for Sabatier reduction unit operation must be ensured by the addition of an accumulator that permits continuous or cyclic operation.

Subsystems units of an EC/LSS are sized primarily on the basis of crew size and their metabolic and life support requirements. Secondary considerations are the provisions for systems module volume for storage and access for maintainability. Since unit size and systems module size are based on these parameters, it will be mandatory that complete configuration analyses be made during the initial design phase.

GENERAL DYNAMICS BASIC SUBSYSTEMS MODULE

A preliminary definition of a systems module similar to that defined for the alternate Space Station (ref. 1) was made by General Dynamics in 1967 (ref. 3). This earlier concept, called the "Basic Subsystem Module" (BSM), was to be adaptable to a variety of long duration space missions in low earth and synchronous orbits. Several configurations satisfying varied power, crew size, life, and logistics requirements were identified and evolution to more advanced configurations was studied. Initial configurations were to be available in 1971 and the final version in 1973.

Various BSM configurations (excluding those intended for synchronous orbit) are defined in Figure 4. It can be noted that the configurations generally progress in capacity (i.e., crew and power), complexity, resupply period, and lifetime. The first configuration or '71 Low Earth Orbit MDA uses some Skylab type systems and the Multiple Docking Adapter structure. It supports 3 men with a partially open loop life support system on a 90 day resupply period at a 5 KW power level. A new structure, support for 6 men for 2 years with no resupply, 10 KW of power, and closed loop life support are incorporated in the final configuration. The BSM configurations exhibit the three types of evolution---added capacity, added functions, improved subsystems; and show evolution of the power, thermal control, and structure subsystems as well as the life support.

General Dynamics estimated development costs for each BSM via different development paths. These results are shown in Figure 5 where the costs for each evolutionary step and the total cost for each path are indicated. Total cost ranges from about $275 million for direct development of the final BSM to $475 million for a three step development. The penalty for indirect development is apparent and results principally from considerable duplication of effort in test of new configurations. Close scrutiny of the detailed cost breakdowns illustrates this. Of the total non-recurring cost for each BSM (irrespective of path),

- test hardware accounts for ∿ 2/3,
  (combined test hardware is ∿ 1/3)
- testing accounts for ∿ 1/8, and
- developmental engineering accounts for ∿ 1/5.

An an example, going from the '71 3 man BSM to the '73 BSM requires combined systems test hardware amounting to $77 million. This is in addition to $46 million for combined system test hardware of the '71 3 man BSM. In contrast, direct development of the '73 BSM would require only $77 million for this item.

Test hardware (and development engineering) cost of intermediate subsystems not present in the final BSM are obviously additional cost items to the final evolutionary developed BSM. But total cost is not the sole criterion to evaluate evolutionary development. Initial costs of simpler configurations are cheaper, and if the next evolutionary development does not occur too soon, annual funding can be reduced. However, Figure 6 shows that the phasing between BSM's in the General Dynamics plan is too short and results in higher annual manpower (and cost) than required for an independently developed (non-evolutionary) BSM.

TECHNOLOGY STATUS

Activity directed towards development of integrated environmental control/life support systems has been underway at NASA for some time. This effort includes design, fabrication, and testing of components and entire systems. Figure 7, based on Reference 4, summarizes experience with integrated systems. Work on the "Integrated Life Support System" (ILSS) at Langley Research Center emphasized subsystem development and provided useful data on systems integration requirements. Other studies, involving 60 and 90 day manned tests were conducted in the "Douglas Space Cabin Simulator" (also sponsored by Langley). Objectives of the cabin simulator testing were to determine operating characteristics and power requirements of subsystems; to measure mass and thermal balance; investigate on-board operation, repair and maintenance; and determine man-system interactions.

Current activity includes development of a so called "Space Station Prototype Environmental and Thermal Control/Life Support" (SSP). Hamilton Standard, under contract to MSC is fabricating the SSP. The intent of the program is to develop a prototype which provides a basis for defining subsystem requirements; evaluate subsystem and system performance; and develop systems level technology in the areas of maintainability, packaging, fault detection and automation. Previously developed subsystems, summarized in Figure 8, are used throughout. Contract completion including testing is scheduled for early 1973.

The AILSS or "Advanced Integrated Life Support System" (ref. 2) is a conceptual study intended to provide a focus for advanced subsystem development. Some advanced subsystems have already been fabricated.

The preceeding review indicates that integrated EC/LSS planning and technology is quite advanced. This technology encompasses the components noted in the example evolutionary path and the BSM. Moreover, the component technology is very nearly state-of-the-art. It follows that any rationale for EC/LSS evolution from open loop systems, rather than direct development, cannot be based on immature technology.

SUMMARY AND CONCLUSIONS

Evolution of an EC/LSS has been reviewed in terms of requirements and practicality, cost, and necessity based on current technology status.

Evolution is feasible if planned initially. This entails design and analysis of all evolutionary steps, proper component and plumbing sizing, and establishment of design requirements on other subsystems. The complexity of each evolutionary step is approximately indicated by the amount of hardware added, the interfaces between new and existing components and subsystems, and the extra monitoring and control required. With regard to the EC/LSS it is shown that a relatively simple evolutionary step from a Skylab type system would be to recycle wash water. In contrast, evolving to a closed loop EC/LSS with complete water and oxygen recycling has major impact--much new hardware is added and all components of the EC/LSS as well as other spacecraft systems are affected.

An earlier study by General Dynamics of an evolutionary systems module considered evolution of the power, thermal control, EC/LSS, and structure subsystems. Evolution to added capacity, added functions, and improved subsystems was exhibited. It was

shown there that evolution significantly increases total development cost, principally as a result of repeated combined systems testing for each evolutionary step. Therefore, it is desired to minimize the number of steps. It is also shown that annual funding associated with evolutionary development can only be reduced if the evolutionary steps are well spaced in time.

Finally, development of a closed loop EC/LSS via an evolutionary path is not required for reasons of immature technology. Experience with integrated systems is significant and design and fabrication of a prototype is underway.

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2. "Alternate Mission Studies" (Advanced Integrated Life Support Systems), Hamilton Standard, NASA CR-66876, July 1969.

3. "Study for Basic Subsystem Module Preliminary Definition," General Dynamics Convair Division, NAS 9-6796, October 1967.

4. "Space Station Technology Program Plan - A Compilation of Requirements and Projected Utilization with Current Technology Status and Future Technology Projections," OMSF, November 1969.

ONE POSSIBLE EVOLUTIONARY PATH FOR EC/LSS

STEP 1 (SKYLAB TYPE)

- O_2/N_2 GAS ATMOSPHERIC SUPPLY
- MOL SIEVE CO_2 REMOVAL
- HUMIDITY CONTROL (DUMP H_2O)
- CHARCOAL AND CATALYIC BURNER CONTAMINANT REMOVAL
- DRY JOHN
- SHOWER, DISHWASHER, CLOTHESWASHER
- NO WATER RECOVERY
- TWO GAS CONTROL

STEP 2 (LOWER RESUPPLY)

- RECOVER WASH WATER FOR WASHING
- WET JOHN (RECOVER FLUSH WATER)
- CRYO O_2/N_2 GAS SUPPLY

STEP 3 (MINIMUM RESUPPLY)

- O_2 REGENERATION FROM CO_2 (SABATIER + ELECTROLYSIS)
- RECOVER URINE AND HIMIDITY CONDENSATE FOR POTABLE WATER

FIGURE 1

EC/LSS EXPENDABLES (PLUS TANKAGE)

	SKYLAB TYPE	LOWER RESUPPLY	MINIMUM RESUPPLY
H_2O	17820	4750	500
O_2	6100	3100	900
N_2	3200	2200	2200
TOTAL	27120	10050	3600

NOTES

10 LB/DAY LEAKAGE

30 LB/DAY/MAN H_2O

6 MAN CREW - 90 DAYS

12000 FT^3 VOLUME

1 PRESSURIZATION

FIGURE 2

EVOLUTIONARY LIFE SUPPORT SYSTEM

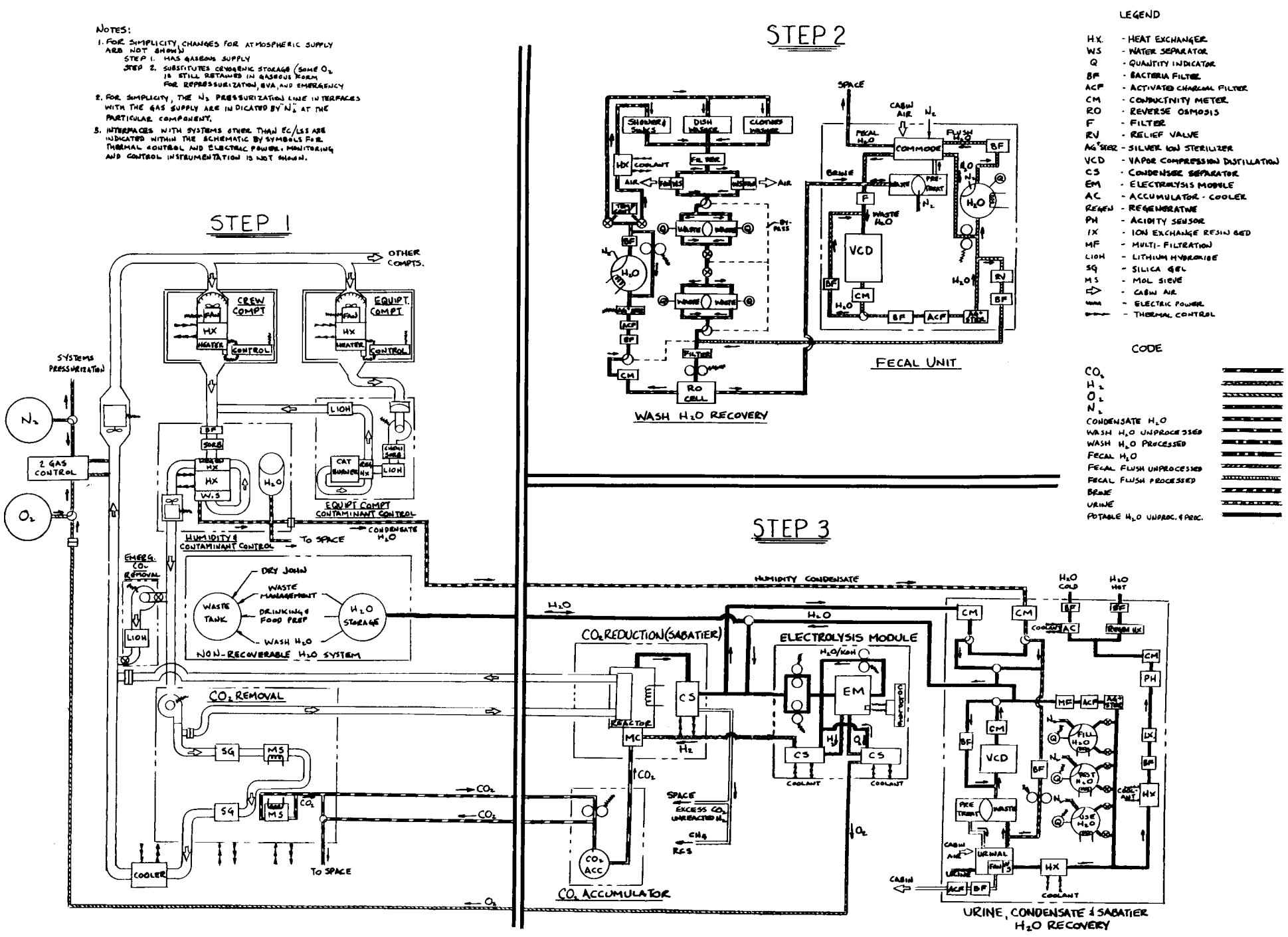


FIGURE 3

GENERAL DYNAMICS SUBSYSTEM MODULE DESCRIPTION

'71 LOW EARTH ORBIT MDA

- ONE YEAR LIFE
- 3 MAN
- 90 DAY RESUPPLY INTERVAL
- DEPLOYABLE AND INTEGRAL RADIATORS
- 5 KW SOLAR ARRAYS
- 7 PSIA
- CHARCOAL + CATALYTIC OXIDIZER CONTAMINANT CONTROL
- SUPERCRITICAL ATMOSPHERIC STORAGE
- 90 DAY ATMOSPHERE STORAGE + 45 DAY RESERVE
- MOL SIEVE CO_2 REMOVAL
- NON FLUSHING JOHN
- WATER RECOVERY EXCEPT FLUSH WATER
- 90 DAY WATER MAKEUP + 14 DAY RESERVE
- CONTROL MOMENT GYROS + RCS

'71 BSM (3 MAN)

SAME AS '71 MDA

+

NEW STRUCTURE

'71 BSM (6 MAN)

SAME AS '71 BSM (3 MAN)

+

- EXTRA SYSTEMS FOR 6 MEN
- HIGHER POWER (10 KW)
- LARGER DEPLOYABLE RADIATORS
- 10 PSIA

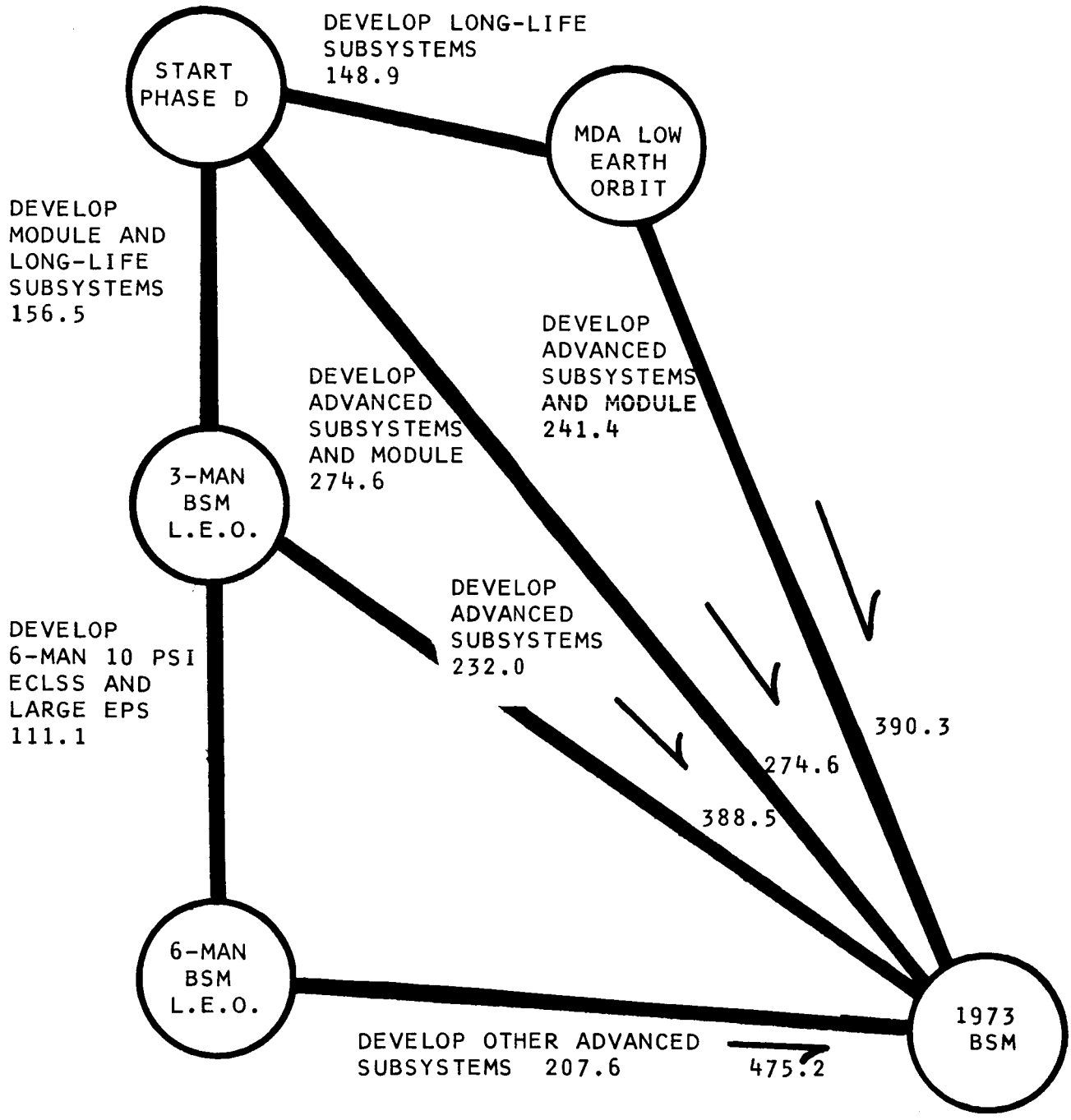
'73 BSM (6 MAN)

SAME AS '71 BSM (6 MAN)

+

- 2 YEAR LIFE
- SYSTEMS SIZED FOR 9 MEN
- NO RESUPPLY
- SUBCRITICAL ATMOSPHERIC STORAGE
- O_2 REGENERATION (SABATIER)
- FLUSHING JOHN
- COMPLETE WATER RECOVERY

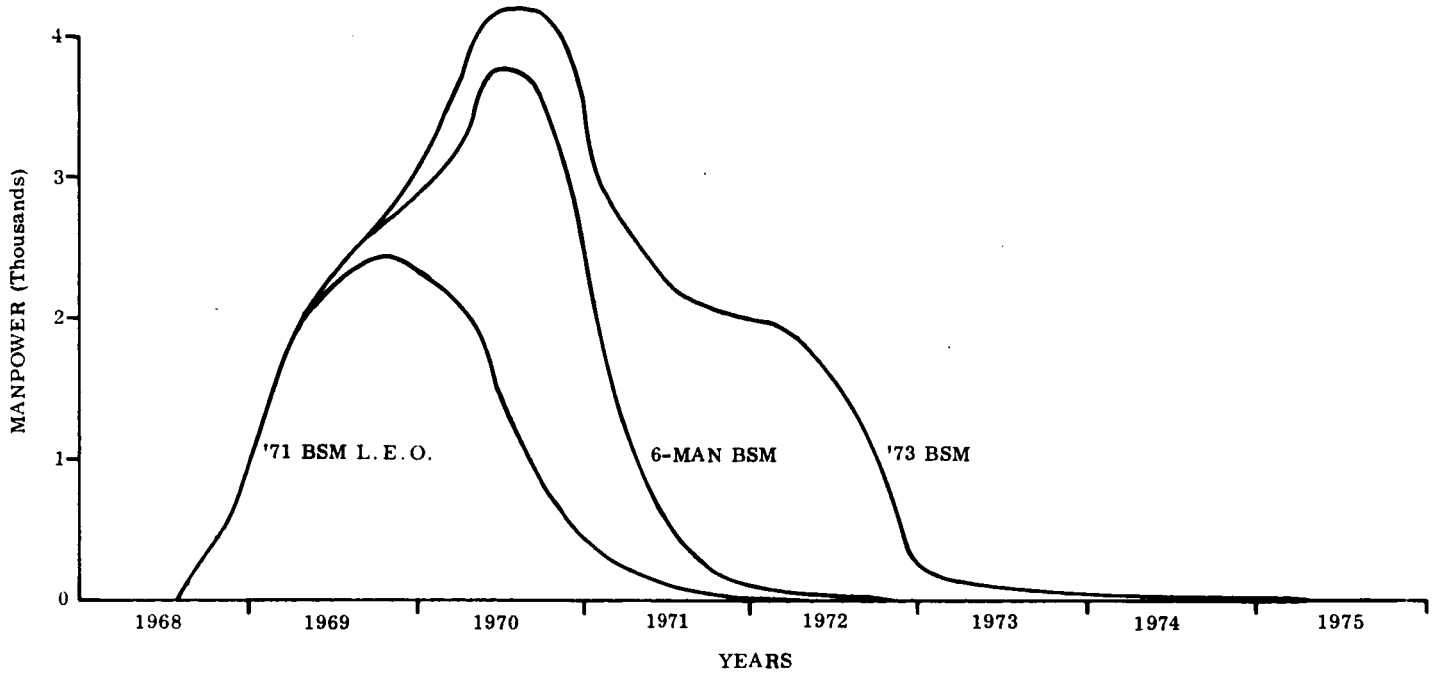
FIGURE 4



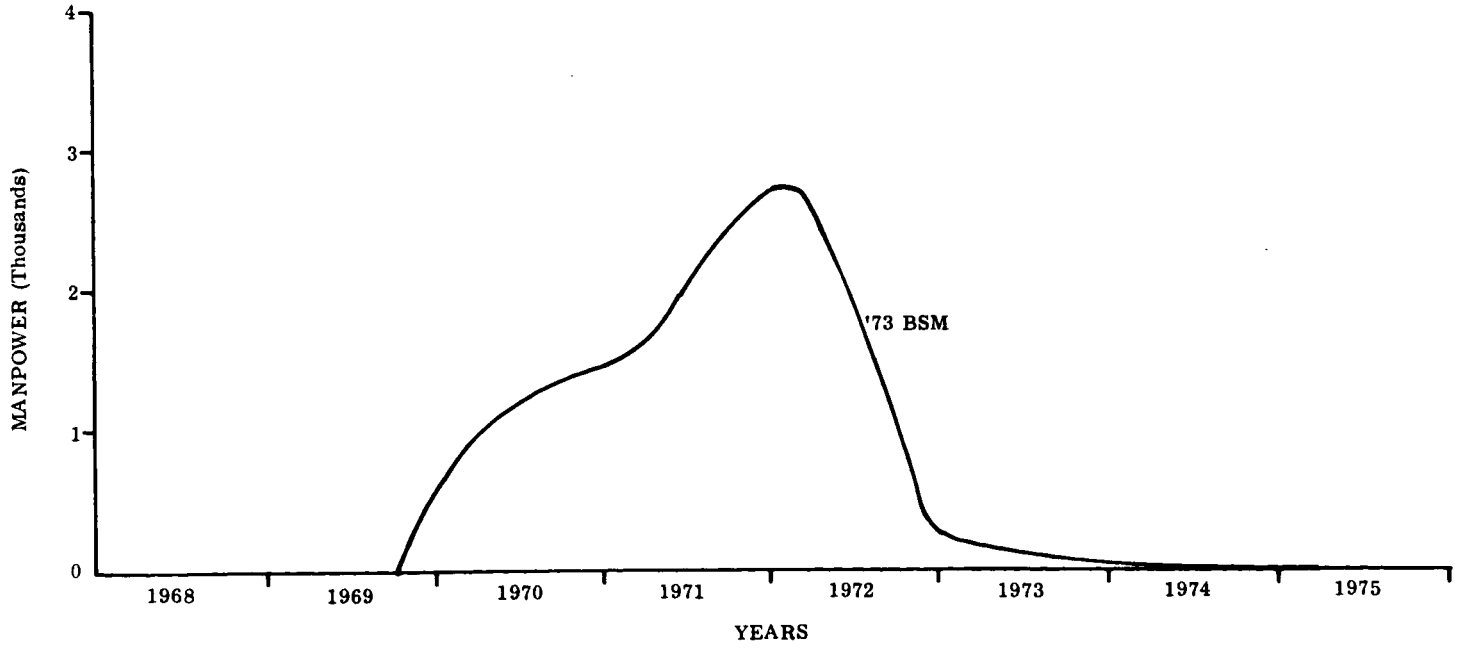
GENERAL DYNAMICS SUBSYSTEM MODULE
DEVELOPMENT PATHS AND COSTS (MILLIONS OF DOLLARS)

1967 ESTIMATE

FIGURE 5



Prime Contractor Direct Manpower for '71 BSM L. E. O., Six-Man, and '73 BSM



Prime Contractor Direct Manpower for Independently Developed '73 BSM

Figure 6

CURRENT NASA INTEGRATED LIFE SUPPORT SYSTEM PROGRAMS

SYSTEM	OBJECTIVE	MISSION CLASS	POWER SOURCE	PRESENT STATUS
ILSS (LRC)	MANNED CHAMBER TESTING OF VARIOUS LIFE SUPPORT SUBSYSTEMS; EMPHASIS ON SUBSYSTEMS	2-YEAR, 180-DAY RESUPPLY	SOLAR CELL OR NUCLEAR	MANNED TESTS RUN ON BREADBOARD SYSTEMS FOR UP TO 28 DAYS
DOUGLAS SPACE CABIN SIMULATOR (LRC)	MANNED CHAMBER TESTING OF SECOND GENERATION LIFE SUPPORT SYSTEM; EMPHASIS ON MAN-SYSTEM INTERACTION	2-YEAR, 180-DAY RESUPPLY	SOLAR CELL OR NUCLEAR	60-DAY AND 90-DAY MANNED TESTS COMPLETED, ADDITIONAL TESTING POSSIBLE
2-YEAR ENVIRONMENTAL CONTROL AND LIFE SUPPORT SYSTEM SSP (MSC)	DESIGN, DEVELOPMENT, AND MANNED TESTING OF A FLIGHT-PROTOTYPE LIFE SUPPORT SYSTEM; EMPHASIS ON MAINTAINABILITY, PACKAGING, FAULT DETECTION, AND SYSTEM AUTOMATION	2 TO 10-YEAR, 180-DAY RESUPPLY	SOLAR CELL OR NUCLEAR	CONTRACT EFFORT STARTED 11/69, HARDWARE FABRICATION TO START 1/71, COMPLETION EARLY '73
AILSS (LRC)	DEFINITION, DESIGN, AND POSSIBLE TESTING OF A LIFE SUPPORT SYSTEM WITH VIRTUALLY COMPLETE SYSTEM CLOSURE	500-DAY MISSION; NO RESUPPLY	SOLAR CELL OR NUCLEAR	STUDY PHASE AND BASIC SYSTEM DEFINITION COMPLETE

FIGURE 7

SUBSYSTEMS SELECTED FOR THE SSP

SUBSYSTEMS	METHOD	STATUS
CARBON DIOXIDE REMOVAL	MOLECULAR SIEVE	4-MAN ILSS DEVELOPMENT -- LRC IR AND D AT HSD IN PROGRESS
CARBON DIOXIDE REDUCTION	SABATIER REACTOR	4-MAN ILSS DEVELOPMENT -- LRC HSD DEVELOPMENT WORK
OXYGEN RECLAMATION	LIQUID FEED WATER ELECTROLYSIS	ILSS SYSTEM -- LRC 4-MAN PROTOTYPE DEVELOPED -- ALLIS-CHALMERS
CONTAMINANT REMOVAL	NONREGENERABLE CHARCOAL AND CATALYTIC OXIDATION	ILSS SYSTEM -- LRC MSC - DEVELOPED HARDWARE
ATMOSPHERIC SUPPLY	LIQUID FEED WATER ELECTROLYSIS	EXPERIMENTAL CELL DEVELOPMENT - GENERAL ELECTRIC
ATMOSPHERIC PRESSURE CONTROL	TWO-GAS CONTROL	AAP -- MOL HARDWARE
NITROGEN GENERATION	CRYOGENIC STORAGE OR AMMONIA CATALYTIC DECOMPOSITION	PROTOTYPE TESTING -- MSC
HUMIDITY CONTROL	EXTERNAL WICK SEPARATOR AND/ OR WATER-VAPOR ELECTROLYSIS	MOL DEVELOPMENT -- HSD 1-TO-4-MAN PROTOTYPE DEVELOPMENT -- ARC SYSTEM DEVELOPMENT -- HSD LABORATORY MODULE TESTING -- MSC
CABIN TEMPERATURE	HEAT EXCHANGERS AND FANS	STATE OF THE ART
WATER AND WASTE	VAPOR COMPRESSION REVERSE OSMOSIS AND MULTIFILTRATION	3-MAN INTEGRATED PROTOTYPE DEVELOPED -- MSC DEVELOPMENT SUPPORT CONTRACT -- AIRESEARCH
HEAT TRANSPORT CIRCUITS	WATER AND FLUOROCARBON	STATE OF THE ART
ECS RADIATOR	INTEGRAL, VALVE STAGNATION	HARDWARE DEVELOPMENT AND FABRICATION -- LTV

FIGURE 8

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