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SPACE MANUFACTURING MODULES

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SUMMARY

This paper describes a proposed program by the Manufacturing Engineering Laboratory of the Marshall Space Flight Center that outlines an approach which would provide a capability for manufacturing in space.

The initial phase will initiate an investigation of the effect of zero gravity on manufacturing processes during earth orbit flight. A work package is described which is currently being prepared to fly with Apollo Applications Program Orbital Workshop (OW) Flight #2. It will consist of a Space Manufacturing Process Chamber integral with an electron beam heat source. The chamber is attached to the inside wall of the (OW)'s Multiple Docking Adapter. Several process investigation experiment modules are described which can alternately be inserted into the chamber.

As a second phase, an improved Space Manufacturing Process Chamber is being planned. It will be larger and more versatile than the first Space Manufacturing Process Chamber. It will be designed to accept larger work modules and will provide several types of energy sources plus a cooling capability. The second Space Manufacturing Process Chamber may be integrated into the hardware for a potential backup flight to Apollo Applications Program Flight #2.

A third phase proposes the development of a room size manufacturing module which would be designed to dock to an earth orbiting space station proposed for launch in the mid-1970's. This module would contain work area for at least two astronauts, facilities, raw materials, and manufacturing process chambers. This large module would provide for a continuing effort on manufacturing process investigations and for the production of small quantities of specialized items that can best be produced in the unique environment of zero gravity. These products would be returned to earth for evaluation and use in specialized industrial, medical, or Government applications.

INTRODUCTION

One of the new and extremely interesting programs being planned by NASA is an earth orbiting space station. At this time, NASA Headquarters, in conjunction with the Marshall Space Flight Center, the Manned Spacecraft Center, and Langley Research Center, is in the process of defining the requirements of a complete and sophisticated space station which could be launched in the mid-1970's.

The space station, whose life may be up to ten years, could carry on experiment programs in space physics, astronomy, space manufacturing, earth resources and meteorology, space biology, and bio-sciences.[1] One space station configuration consists of a large central vehicle which would contain the systems integration, life support and protective systems for the astronaut researchers. Attached to the periphery of the central station are modules which could contain the work area and apparatus for many of the proposed experiment programs described above. Some of the modules may require the ability to detach and fly free from the central space station during their experiment performance periods. Experiment monitoring can be carried out via closed circuit television and telemetry. Of particular interest to the Manufacturing Engineering Laboratory at the Marshall Space Flight Center is a module in which space manufacturing and material processing developments could be performed.[2]

The proposed objectives of establishing a space manufacturing capability are to produce materials and products which first, cannot be made on earth; second, fulfill a realistic and significant need of science and industry; and third, have a value commensurate to the cost of processing and transportation.

Since 1958, NASA has conducted programs to probe and understand space, to develop a safe place for man in this new environment, and to use this knowledge to advance science and technology for the benefit of mankind.

Manned Space Flight has focused on the mission of placing man on the moon and returning him safely to earth. The question now posed is how to use and exploit the advantages of the space environment, the presence of man in space, and the capabilities of experienced people to provide a continued space program.

During the past few years, NASA has conducted a series of in-house and contracted studies to determine those programs which offer the most return within the resources available. Based on these results, a manned earth orbital program is highly attractive for two primary reasons: First, the manned flights of Mercury, Gemini and Apollo and the development conducted for the Apollo Applications Program (AAP) have provided a basis for the contributions which manned orbital laboratories or observatories could make to our knowledge of the earth, the solar system, and the universe. Further, insights into the nature of life will accrue when scientists can carefully conduct biological experiments in the absence of gravity. Second, it is recognized that many possibilities exist to utilize the unique conditions of the space environment to produce new materials of high scientific and economic value.

A few of the possible processes that would be vastly enhanced by the absence of the strong gravitation effect of earth are: (1) the levitation melting of materials free of the contamination of the crucible, (2) the growing of single large crystals with vastly reduced dislocations, and (3) the blending, alloying and conversion of compacted powders into castings.

As a first phase toward material processing in space a work package is being prepared by the MSFC's Manufacturing Engineering Laboratory to fly with the AAP Flight #2 scheduled for launch in the early 1970's. The package will consist of a space manufacturing process chamber integral with an electron beam heat source.[3] Currently, five experiments have been approved for development in conjunction with the processing chamber. An additional experiment involving a gravity substitute workbench has also been approved for development and integration into the AAP Flight #2.

A second phase of this total program is also being planned - only the work described in Phase I has been approved; the other represents advanced planning. It will be a natural follow-on to the initial work started in the first phase and precede and be preparatory for the activities in the proposed third phase on the manufacturing and material processing module. The second phase program would develop a space manufacturing process chamber which will be larger and more versatile than the chamber described in Phase I. The second chamber would be designed to accept larger work modules and will provide several types of energy sources plus a cooling capability. The new chamber could be integrated into the hardware for a possible backup flight to the initial AAP experiments flight.[4]

The proposed third phase involves our participation in the development and use of the manufacturing and material processing module which conceptually could be designed to dock to an earth orbiting space station considered for launch in the mid-1970's. The module would contain working room for at least two astronauts, facilities, raw materials, and manufacturing process chambers.[5] This large module would provide for a continuing effort on manufacturing process investigations and for the production of small quantities of specialized items that can best be produced in the unique environment of zero gravity. Primary emphasis would be placed on processes which would yield products of economic value. These products would be returned to earth for evaluation and use in specialized industrial, medical, or Government applications.

PHASE I

As a first step toward achieving the capability of manufacturing useful products in space, it is intended to evaluate several of the promising materials processes aboard orbital space vehicles. This early evaluation can be accomplished in the Saturn I Orbital Workshop (OWS) of the AAP by utilizing a flight experiment apparatus already developed.

Electron beam welding and exothermal tube joining experiments initiated nearly two years ago were originally oriented toward the joining of materials in space. The original objectives of the experiments were to observe the effect of reduced gravity on a molten weld puddle, to measure the amount of spatter, and to determine the effect of weightlessness on the weld metal microstructure and strength.

With the recent emphasis on exploratory evaluation of material processes which eventually may allow the manufacture of useful products in space, the facilities developed for these two experiments have a broader utility. This equipment will be utilized as a materials processing chamber, using the electron beam system and the exotherm material as heat sources.[6] Within the chamber's limitations, a number of experimental tasks can be performed leading to useful products. Various candidate material processing techniques in space have been proposed for evaluation in the orbital workshop and space station. These have been well summarized in the conference on manufacturing technology unique to zero gravity held at the Marshall Space Flight Center on November 1, 1968. Of these, several were found to be within the capability of the chamber developed for electron beam welding and exothermal tube joining experiments. Five experimental tasks have been approved for the AAP-2 flight - metals melting, exothermic brazing, crystal growth, composite casting, and spherical casting.

Another experiment for a special workbench has been approved for the AAP-2 flight. It is a gravity substitute workbench using electrostatic and aerodynamic forces.[7] It will be used by the astronaut to disassemble and reassemble hardware. The workbench probably will not be used for experiments until Phase III product manufacturing program.

Although this tool cannot be considered a product, it does constitute an approved experiment and is preparatory for the space station manufacturing module.

A comprehensive industr survey will be conducted concurrent with the development of Phase I processes and equipment. The survey is of major consequence in planning the tasks and facility design for the Phase II and Phase III efforts. It is the intent of this survey to identify new items which could be manufactured in space; to delineate the degree to which the manufacture of an item is affected by the space environment; and to analyze each item in respect to: essentiality, application, monetary value, and scientific value.

Additionally, studies to determine the critical physical effects of weightlessness on materials and manufacturing processes will be conducted. Parametric criteria will be developed from these studies for use in evaluating the feasibility of performing candidate experiments in earth orbit.

From the first survey, a topography of product needs will be made, delineating those categories which offer the greatest potential return from manufacture in space and identifying the organizations associated with the basic products. Such a "map" will be a guide f for additional periodic detailed surveys. All survey data will be carefully screened for significant products with a complete record of their overall technical feasibility, industrial status, and potential application.

Since the most important aspect of the space environment related to manufacturing appears to be zero gravity, an expansion of the capability for true relative gravity testing at MSFC is envisioned. Drop tower facilities located at the Marshall test area could be employed where the short periods (approximately 4 seconds) of zero gravity are obtainable. Preliminary studies in such areas as bubble formation, electromagnetic field positioning of suspended objects, etc., could also be performed. It is anticipated that extensive testing would be performed aboard aircraft flying zero gravity parabolic trajectories. KC-135 aircraft already employed by MSFC in the performance of human factors analysis could be used in support of the space manufacturing program, thus providing usable zero gravity test times approaching 30 seconds. A longer duration, lower cost, rapid response capability might also be obtainable through modification of surplus fighter type aircraft. Detailed studies performed by the Manufacturing Engineering Laboratory have established the feasibility of this latter approach.

PHASE II

The second phase consists of an improved, enlarged processing chamber and of further tasks leading to those products specified in Phase I. The chamber will be approximately .75 meters in diameter by 1.2 meters in length.[8] It will contain a greater selection of heat sources, controlled cooling, instrumentation, and material positioning and handling devices.[9] Final chamber design will evolve after detailed studies have been completed.[10] Two primary factors to be considered are selection of heat sources and methods of manipulating materials within the chamber. Thirteen candidate heat sources are presently under investigation. The most promising of these appear to be induction, electrical resistance, and electron beam.[11] Six techniques for handling of materials within the chamber are also under study; the most promising of which appears to be pulsed magnetic fields. Other factors of consideration in chamber design include: (a) the thermodynamics of heat transfer, (b) total power requirements for operation of the chamber and experimental apparatus which is dependent on chamber power, (c) vacuum venting and control systems, (d) instrumentation for monitoring chamber operation and collecting experiment data, and (e) packaging constraints imposed by fixed vehicle interfaces.

Studies of facility configuration and function have been initiated and are considered basic, to be supplemented or changed as more definite requirements become known from industrial surveys and Phase I experiments. The tasks to be conducted in the chamber will be logical extensions of studies performed under Phase I and those identified in the industrial surveys, with emphasis on demonstrating the producibility of products. For example, in Phase I, a technique for a small crystal growth may be developed. This technique would then be applied in Phase II or III to the growth of a large crystal.

Examples of tasks are listed in the Appendix.[12]

PHASE III

A proposed Phase III effort would develop a manufacturing module which would be designed to remotely dock to an earth orbiting space station planned for launch in the mid to late 1970's. This module would contain working room for at least two astronauts, facilities, raw materials, and manufacturing and material processing chambers. The module configuration would be designed to contain a large airlock which could permit transfer of personnel, materials, process equipment, etc., between the space environment and the work area of the module.

An initial weight estimate of a typical structure and its associated equipment described would be approximately 23,000 pounds. Typical envelope dimensions are 6.7 meters diameter and 10.6 meters total length.

Zero gravity type manufacturing processes could be adversely affected by acceleration forces generated by movement within other parts of the space station. Periods of minimum acceleration could be obtained by free flying the module apart from the primary space station. After module separation and experiment completion, the module would reuse the remote control rendezvous and docking system which was initially required to dock it to the unmanned orbiting space station.

This module could provide for a continuing effort on manufacturing process investigations and production of small quantities of specialized items that can best be produced in the unique environment of near zero gravity. In addition to the absence of gravity, other significant environmental characteristics are the availability of high quality clean vacuum, low temperatures, and freedom from vibration. Products produced within the space environment would be returned to earth for detailed evaluation and use in specialized industrial, medical, or Government applications.

The manufacturing module, in addition to the processing equipment, would contain test apparatus, monitoring equipment, closed circuit television (module to earth) so that timely and intelligent adjustments in processes or experiments can be made by the researchers while remaining in earth orbit.

Efficient long term operation of the space manufacturing module and related systems dictates the development of a rapid on-site maintenance and repair capability.

The cost of transferring control systems, experiment packages and process chambers back to earth for maintenance and repair would be prohibitive; therefore, any component malfunction could readily abort a series of tasks should such a capability not exist.

The Phase III manufacturing module would incorporate a variety of sophisticated test and process equipment which would be expected to function properly under repeated use over the life span of the space station. Much of this equipment will be housed in the shirt sleeve environment of the module, thus facilitating ease of in-space maintenance and repair.

Maintenance of a periodic nature, such as charging of batteries, has been considered in the preparation of experiments already planned for AAP Flight #2. Planned maintenance of all experiment systems and repair of failed components will be essential for efficient long term operation of the manufacturing module.

Phase III effort could lead to the establishment of a space manufacturing and material processing complex for quantity production of selected components. It is anticipated that industrial participation will increase with each succeeding phase, and it is hoped that industry will assume a major responsibility and role in the programs to follow in the 1980's. Representative experiments for flight aboard the module are listed in the Appendix.[13]

APPENDIX

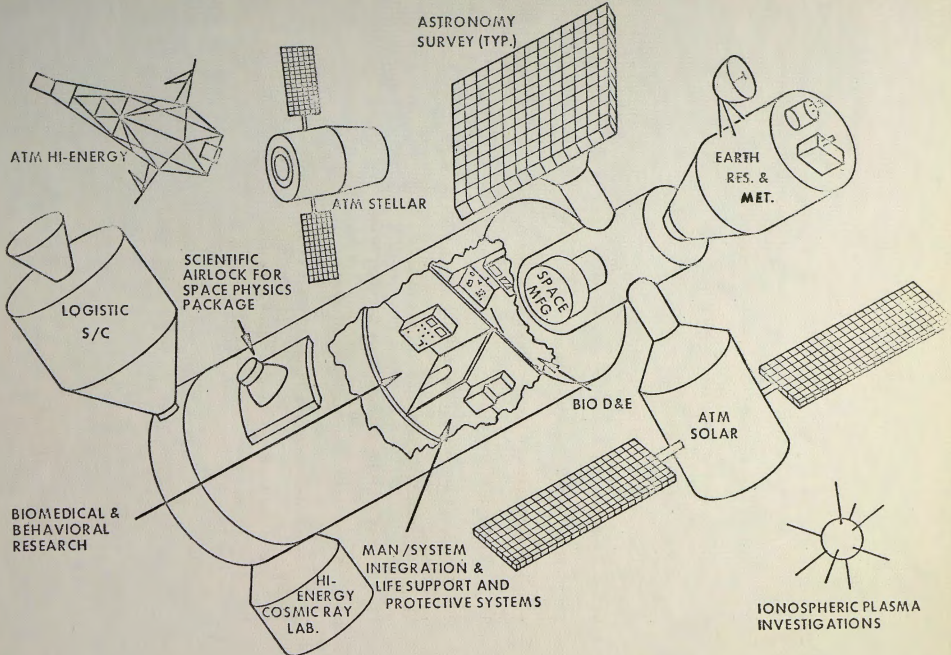

Figure 1 Typical Space Station Configuration and Candidate Experiments

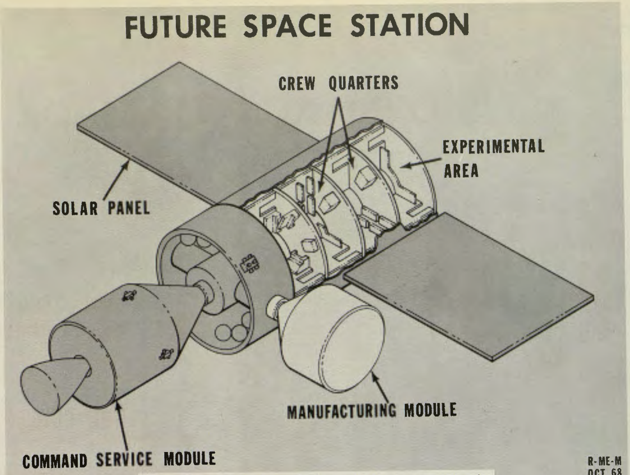

Figure 2 Future Space Station with Manufacturing Module

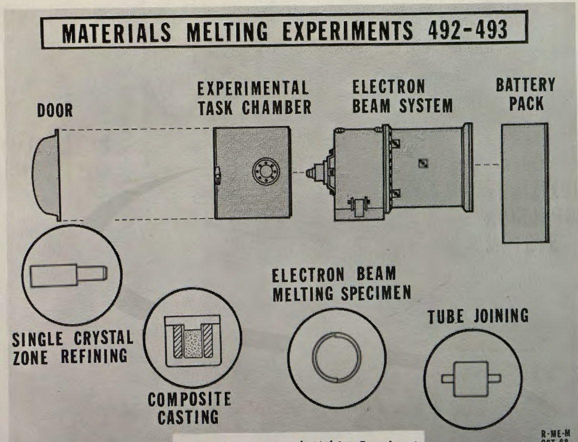

Figure 3 Materials Melting Experiment

S-IVB ORBITAL WORKSHOP

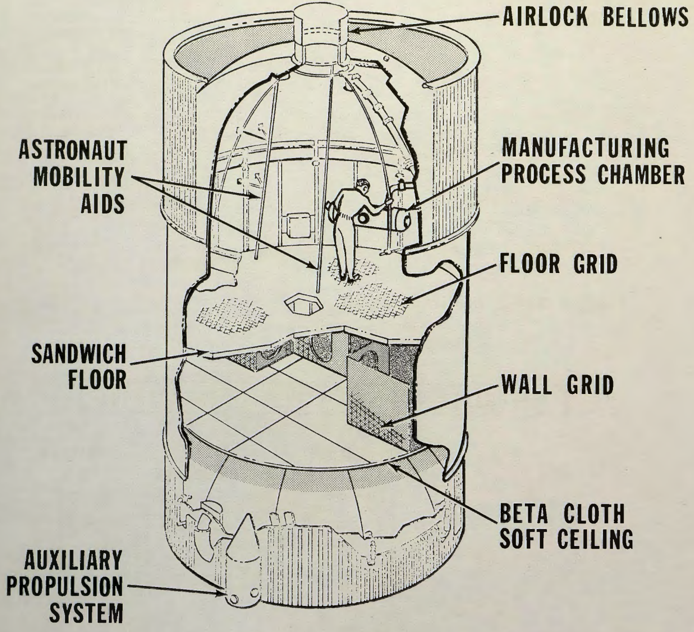

Figure 4 S-IVB Orbital Workshop Plan

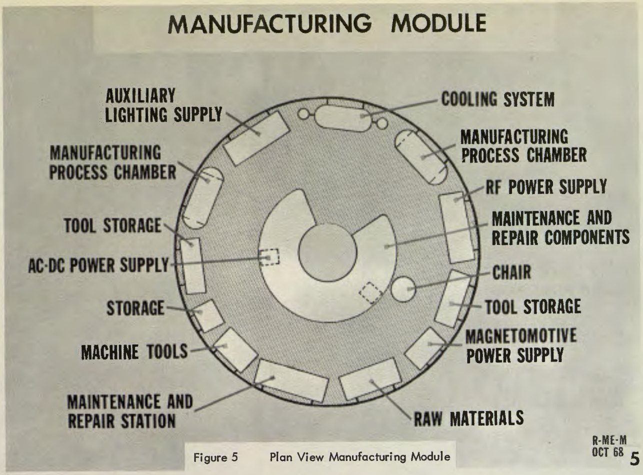

Figure 5 Plan View Manufacturing Module

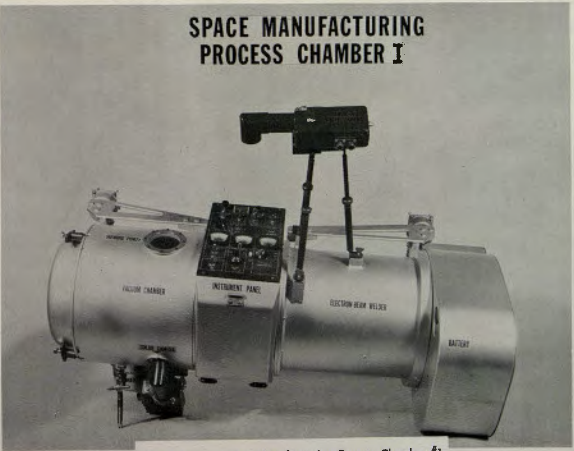

Figure 6 Space Manufacturing Process Chamber #1

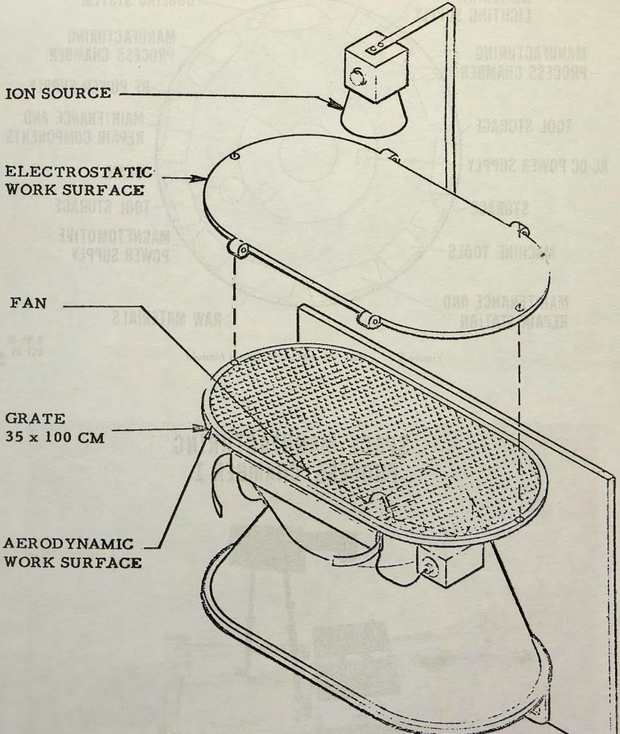

Figure 7 Gravity Substitute Workbench

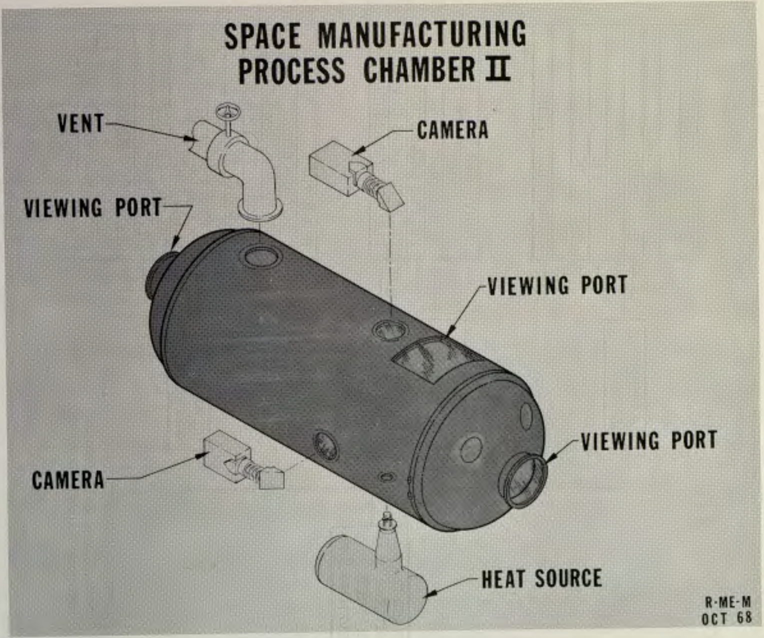

Figure 8 Space Manufacturing Process Chamber #2

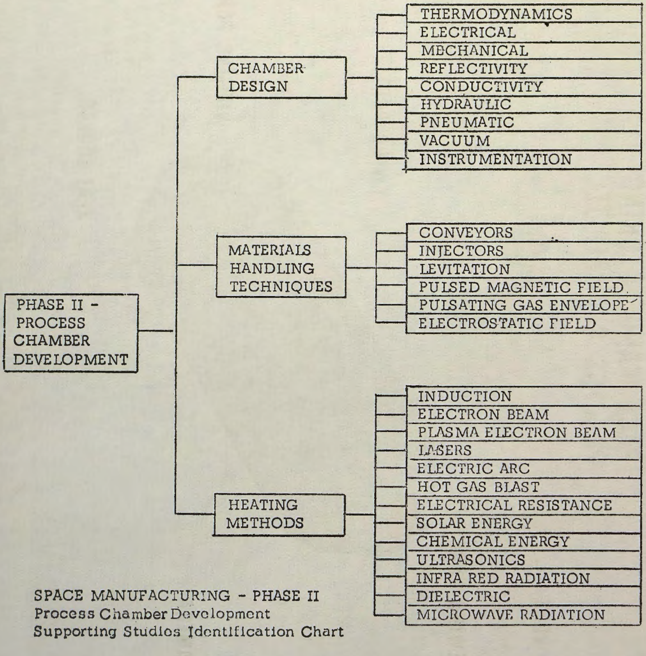

Figure 9 Areas of Investigation - Process Chamber #2

SUPPORTING STUDIES IDENTIFICATION CHART

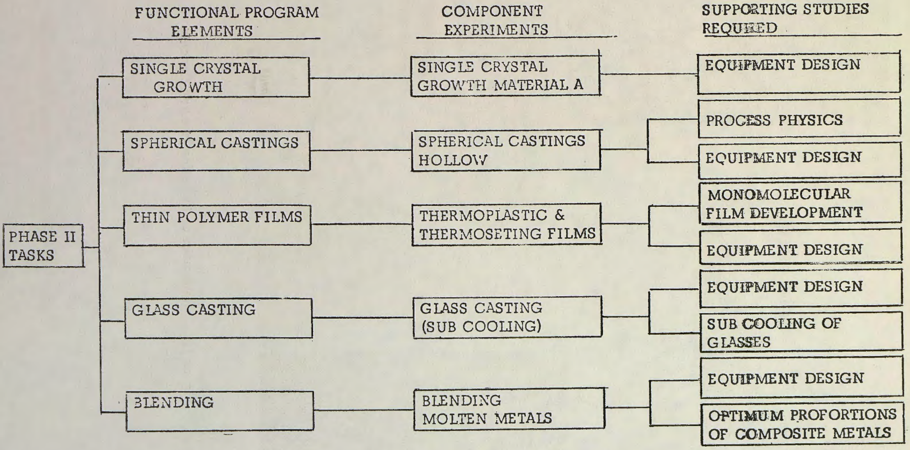

Figure 10 Product Manufacturing in Space Phase II Tasks

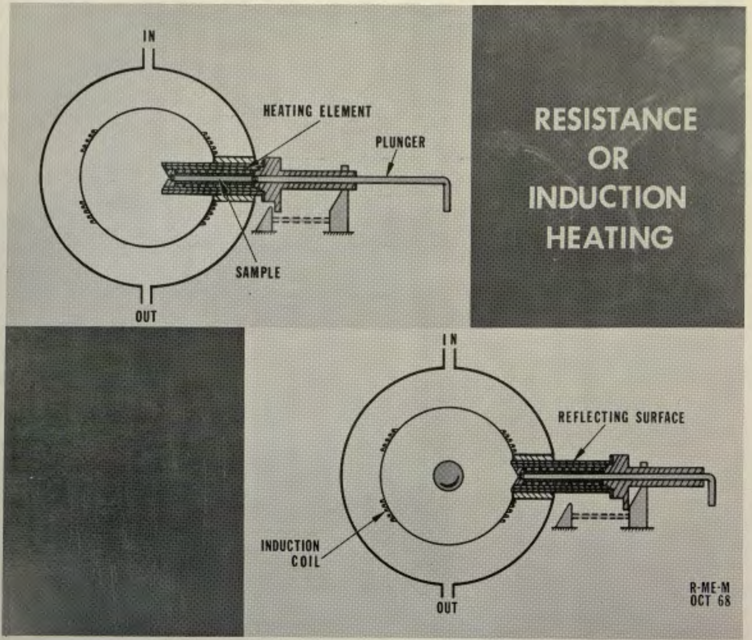

Figure 11 Resistance or Induction Heating Concept

SPACE MANUFACTURING MODULE

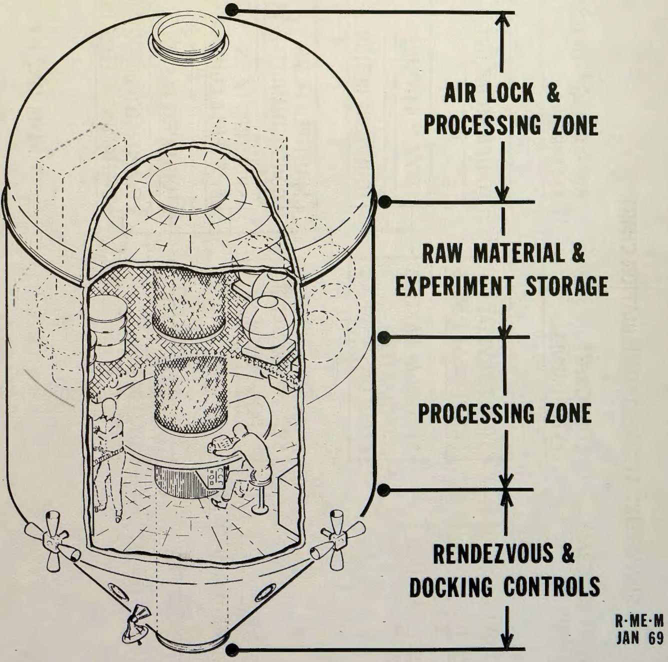

Figure 12 Space Manufacturing Module Cutaway View

SUPPORTING STUDIES IDENTIFICATION CHART

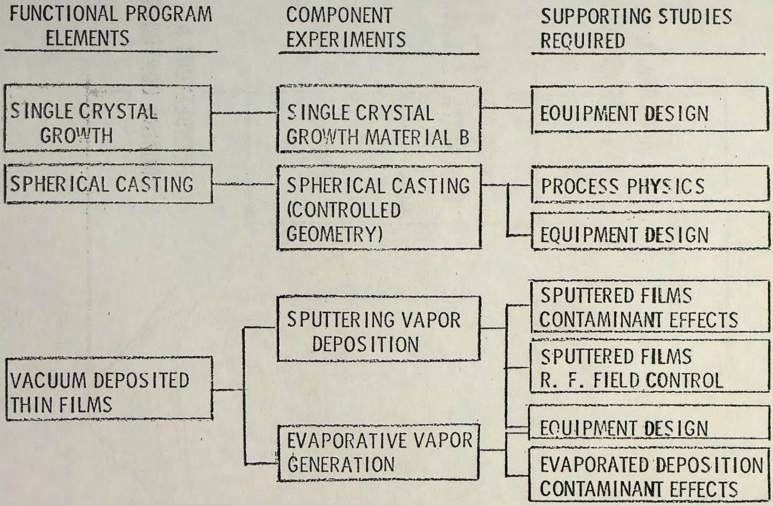

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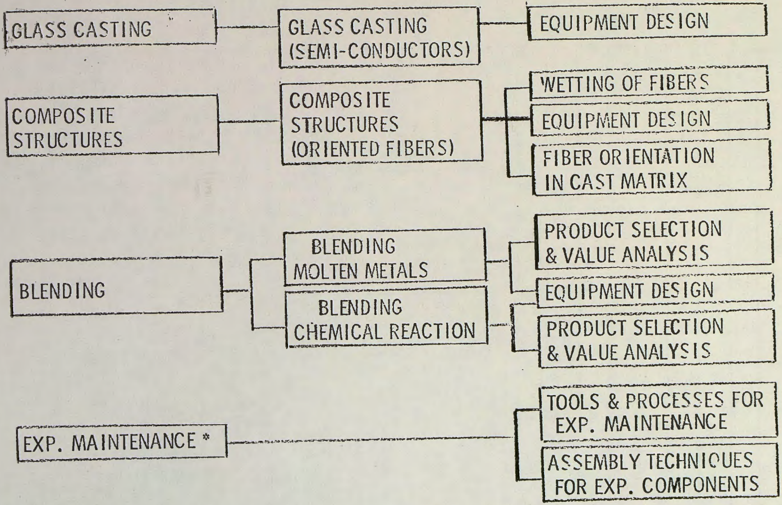
Figure 13 Space Manufacturing Phase III Tasks



* - Recognized Requirement not listed as a Functional Program Element

Figure 14 Space Manufacturing Phase III Tasks (continued)

EVOLUTIONARY PLAN

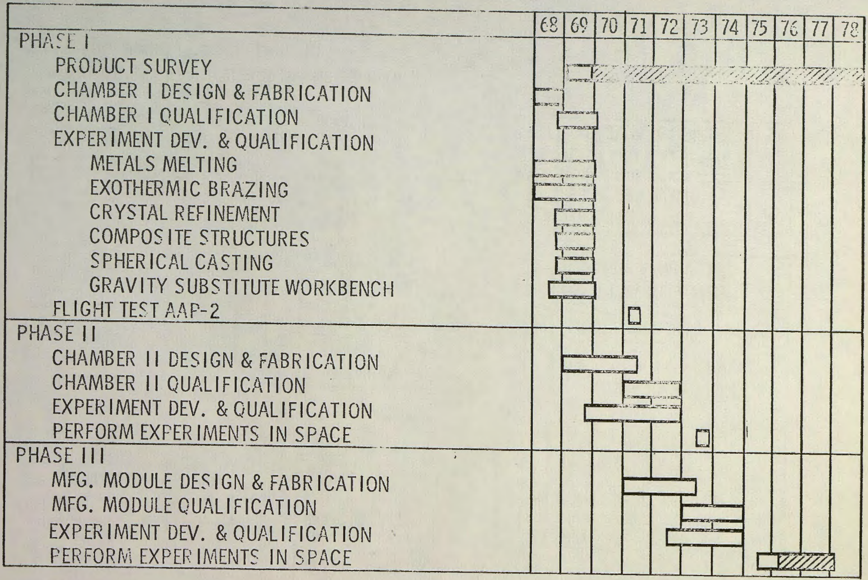


Figure 15 Product Manufacturing in Space Schedule