Publication No. U-3237

FINAL REPORT

STUDY OF THE AUTOMATED BIOLOGICAL LABORATORY PROJECT DEFINITION

VOLUME IV OF VI PROGRAM PLAN

Prepared for: Bioscience Programs Division
Office of Space Science and Applications
NASA Headquarters
Washington, D.C.

Under Contract: NASw-1065

Reporting Period: 10 August 1964 - 10 August 1965

Prepared by: Temple W. Neumann
Temple W. Neumann, Program Engineer

Approved: William Hostetler
William Hostetler, Program Manager

10 September 1965

AERONUTRONIC
DIVISION OF PHILCO CORPORATION
A SUBSIDIARY OF Ford Motor Company,
FORD ROAD/NEWPORT BEACH, CALIFORNIA

CONTENTS

CONTENTS (Continued)

SECTION 1

INTRODUCTION AND SUMMARY

The general purpose of the Automated Biological Laboratory Program Plan presented in this volume is to:

(1) Establish overall ABL mission requirements and constraints.

(2) Describe a conceptual system design meeting these requirements.

(3) Describe the program required specifically to define the scientific, engineering, hardware, and software aspects of the ABL and establish the schedule required to implement this program.

(4) Describe related and interfacing programs.

(5) Estimate budget and planning type costs for the total ABL program.

Sections of this Program Plan pertaining to the ABL mission, design, interfaces, and supporting programs summarize material which is covered in considerable detail in other volumes of this final report.

It is assumed that ABL effort will be directed towards a 1975 Voyager Mars mission which comprises a large capsule/lander and a flyby spacecraft, and that ABL surface operation will be nominally 2 years. Of course these mission objectives are subject to continuing evaluation in the perspective of overall Voyager mission planning.

Major interactions are indicated between the ABL program and related activities, including Voyager capsule interfaces, supporting technology and research programs, and facilities and special equipment requirements. Considerable emphasis is given to implications of sterilization requirements because of the strong impact on all phases of ABL.

Schedule and phasing discussion is presented in Section 4 which contains a preliminary PERT schedule chart for reference. The chart includes major activities of the ABL system integration contractor and subcontractors, and of NASA/JPL in direct support of the ABL program. Depth of detail on the chart does not include certain overall management and reporting activities which would be present in an actual program control process.

Schedule analysis has indicated requirements for early initiation of key activities including supporting technologies on which to base development and design, and construction of key facilities to accommodate assembly, testing, and operation. The schedule assumes that preliminary design and system definition continues without interruption from the current study activities.

Total costs for the ABL program are estimated at $106.8 million assuming launch at the 1975 Mars opportunity. Peak annual costs occur during FY 1970-1973 at $12.9 to $14.4 million per year. Cost of extending the program to 1977 and later missions is not included in these totals, although costs are included for post launch operations and data analysis through FY 1979 in direct support of the 1975 mission.

SECTION 2

BIOLOGICAL EXPLORATION OF MARS

The search for life on Mars has, of course, already begun. Many years of astronomical observations have produced considerable data on planetary characteristics. These data, currently under re-examination and comparison with results of the recent Mariner 4 Mars flyby observations, have been a source of analysis and speculation concerning the probability that life forms analagous to terrestrial organisms could survive or propagate on Mars. Corresponding data for other members of the solar system have also been examined to evaluate probabilities that life forms might survive or propagate.

Within the solar system, there has become recognized a zone in which earth-like life forms might survive or propagate. This planetary "biozone" is characterized by suitable regimes of temperature, atmosphere, radiation, and other parameters relevant to biological processes. Besides Earth, possible biozone planets have included Mars, Venus, Mercury, and Jupiter, in decreasing probability. Some natural satellites of these planets are also candidates.

The NASA program of space exploration has placed Mars at the top of priority ranking among possible planetary targets. Emphasis during the current ABL study has been on Mars exploration, but the analysis is readily extended to biological search on other planets.

Following the NASA/JPL spectacular Mariner 4 Mars flyby of November 1964 - August 1965, the Voyager project is currently being planned for exploration of Mars and possibly of other planets by unmanned spacecraft considerably larger and more complex than Mariner. Preliminary NASA studies have also

been made of subsequent manned expeditions to the planets with emphasis on Mars, and the Space Science Board of the National Academy of Sciences has recommended that Mars exploration during 1970-1985 become the major space program following manned trips to the moon.

2.1 VOYAGER MARS PROJECT

NASA has announced plans for a Voyager series of planetary spacecraft utilizing (at least initially) the Saturn 1B/Centaur launch vehicle. The first operational mission is scheduled for the 1971 Mars opportunity. Subsequent missions are planned for the opportunities of 1973, 1975, 1977, and beyond. It is currently planned to place the spacecraft in orbit about Mars and to land instrumented payloads on the Mars surface. Test flights are also planned for the 1969 Mars opportunity to acquire space flight technology information and possibly to test available scientific instruments which can contribute to the 1971 mission.

2.1.1 VOYAGER OBJECTIVES

Primary objective of the Voyager Mars Project is to perform experiments on the surface of and in orbit about Mars to acquire fundamental scientific information concerning Mars, including the existence and nature of extra-terrestrial life, the physics and chemistry of the planetary atmosphere, surface, interior, and other environmental characteristics.

Secondary objectives include performing experiments in the interplanetary medium to obtain scientific information concerning particles and fields in interplanetary space between the orbits of Earth and Mars, and the development of space flight technology.

2.1.2 SCHEDULE OF OPPOSITIONS AND FLIGHTS

The basic cycles of Mars launch opportunities are derived from the length of the Mars year (687.0 Earth days or 22.57 months), orbital eccentricity (0.0934), and orbital inclination to the ecliptic plane ($1^{\circ}50.'8$), together with corresponding Earth orbital characteristics. Mars launch opportunities occur a few months prior to each opposition and repeat at average intervals of 780 days or 25.6 months. A list of opposition dates and approximate launch opportunities is given in Table I.

TABLE I

MARS OPPOSITION DATES AND APPROXIMATE LAUNCH OPPORTUNITIES

Opposition	Launch
31 May 1969	February 1969
11 August 1971	May 1971
25 October 1973	July 1973
15 December 1975	September 1975
22 January 1978	October 1977
26 February 1980	November 1979

Earth to Mars flight times under consideration vary with launch vehicle capabilities, spacecraft weight, launch azimuth, and orbital parameters of Earth and Mars for the particular opposition. Flight times range from approximately 180 to 400 days (6 to 13 months).

2.1.3 VOYAGER MISSION PLAN

It is planned that two operational Voyager spacecraft will be launched during each Mars opportunity beginning with 1971. The series will include both orbital and lander missions. During 1969, test flights towards Mars are also planned to evaluate spacecraft systems, subsystems, and components, and to demonstrate operational procedures. A limited complement of 1971 experiments may be flown, if ready, in 1969 to support the 1971 mission.

The Voyager "overall" spacecraft comprises two modules: spacecraft (or "bus") and capsule (or "lander"). The capsule is separated from the spacecraft, enters the Mars atmosphere, and survives impact on the surface. The spacecraft either is captured into Mars orbit or continues on a flyby course, depending on mission requirements. Capsule separation may occur from an orbiting spacecraft, from a spacecraft prior to spacecraft capture into orbit, or from a flyby spacecraft.

Communication between capsule and Earth may be direct or by relay through the spacecraft.

Weight totals and distribution between modules are determined by the mission mode adopted. Retropropellant weight for spacecraft capture into Mars orbit may equal or exceed dry weight of the spacecraft, depending on the approach trajectory and on the desired orbit. Total capsule weight is strongly dependent on characteristics of the Mars atmosphere (for which adequate data are still unavailable) and on design of the capsule entry system. Current planning is for total capsule weights of about 2300 pounds in 1971 and 1973, and 4500 to 6000 pounds for 1975 and later.

After landing, the capsule positions itself for operation of its science payload and supporting systems. The sequence and duration of operations are programmed to match estimated priorities of planned experiments and reliabilities of operation. Planned design lifetimes on the surface have ranged from 2 days to 6 months for early (1971) capsules to 24 months for later (1975) capsules. Complete coverage of four Mars seasons would be provided by 24 months of operation.

A mobile science unit for Mars surface roving and a mobile sampling unit which returns soil samples to a stationary processing unit at the landing site have been studied. A further alternative is deployment of two or more smaller capsules at separated landing sites, with or without surface roving capability. All of these possible modes of surface operation provide wider ranges of sampling than a single immobile capsule.

Preliminary analysis of schedule requirements indicates that scientific or operational data from a Mars landing mission will become available sufficiently late that its probable interaction with the next mission (corresponding to an opposition about 25.6 months later) is almost negligible. Earliest probable utilization of such data is for the mission after next (corresponding to the opposition about 51.2 months later).

2.2 ABL MARS PROGRAM

2.2.1 OBJECTIVES

The ABL Mars program objectives are to provide, by means of a Voyager capsule payload constructed on the principals established by this study, a means to systematically and effectively explore Mars and other suitable bodies in our solar system, for life. The search for life in this context is taken in its broadest sense and includes the search for remnants of life (fossils), indirect evidence of life, and the necessary biochemical precursors to life. The results achieved in this study indicate that this can only be accomplished by a comprehensive program over a period of time--certainly more than a single mission--and employing individual payloads having improved capability for performing investigations in the manner of sound biological research.

2.2.2 MISSION SCHEDULE

The actual biological exploration of Mars must be protracted in time to accomplish the desired scientific objectives. However, it is difficult to say at exactly what point in the NASA planetary program such exploration missions should cease being simpler general exploration missions and should become the more comprehensive biological exploration missions. It is not unreasonable that the 1973 landing missions could be considered as initial ABL missions by incorporating many of the desirable features identified in this study. However, 1975 is the earliest mission which could reasonably be expected to accommodate the full ABL concept in a form approaching that defined in the study. The remainder of this program plan will, therefore, be predicated on this mission opportunity. This is also consistent with the ground rules established by NASA and employed for the technical effort on this study.

2.2.3 MISSION DESCRIPTION

a. Launch and Interplanetary Transit. This phase of the mission, except for the size and complexity of the payload, will be similar to the 1964-1965 Mariner Mars mission. Type I trajectories are anticipated because of their shorter elapsed time and more favorable communications range at encounter. For some mission opportunities, a Type II trajectory gives a more favorable arrival time at Mars from the standpoint of local conditions of interst, such as the passage of the dark wave phenomena; this is not the case in 1975, when Type II missions will arrive at Mars in the northern hemisphere summer or southern hemisphere winter. Type I 1975 missions appear to be more intersting, arriving in the spring in the northern hemisphere.

The lower energy requirements for the Type II trajectory are expected to have little influence on mission type selection because of the above considerations, and because Saturn class booster systems will have adequate performance by 1975 to allow mission optimization. Launch capability should be in the 8000 to 9000 pound payload class. The complete entry capsule, including the ABL as defined by this study, will weigh no more than 5500 pounds, and probably less depending on entry vehicle technology developments. This allows ample weight for the bus, sterilization shroud structures, injection system, and associated bus-mounted equipment.

b. Entry and Landing. The entry phase of Mars landing missions remains difficult to define precisely because of the continued lack of precise definition of the Martian atmosphere. The occultation data from Mariner may narrow this range. However, these data have not been published at the time of this report and it is still not clear whether retropropulsion will be required to decelerate the landed payload to velocities below those attained passively by the aerodynamic entry vehicle. Except for this uncertainty, the remaining entry vehicle aerodynamic shape, payload

separation, parachute deceleration, and terminal impact absorption requirements are straightforward applications of existing technology. These functions are described in Paragraph 5.6 of Volume III of this report.

c. Surface Operations. In a systematic detailed time-phase study of ABL operation on the Mars surface for the two year design life, the experimental programs were found to repeat on essentially a one-and-one-half-month cycle. One complete cycle is therefore repeated during each Martian season for each of 3 or 4 different sample sites. The fourth sample site could be eliminated in later cycles if interesting changes are not observed. A low level laboratory activity, rather than a constant high level of activity, is purposely planned to conserve consumable supplies for use in obtaining data over the full Martian year. The low level periods also provide time to recycle the laboratory back to its original internal state by, for example, removing trace contaminants which build up slowly with time from its internal atmosphere. Actual available power always exceeds the average required electrical power. No problem is presented for the radioisotope thermoelectric generator system which puts out this continuous power level for its design life of well in excess of two Earth years. No consumables (fuels or electrodes) limit its useful life. The detailed time-phase study referred to was developed to generate laboratory consumable volumes, electrical power requirements, data processing load, and command and control requirements.

One of the principal features of the ABL is its capability of being modified to perform alternative experiments and operations. Therefore, the indicated repetitive cycles referred to will undoubtedly not all be identical in content, but will probably be extensively modified to emphasize those experiments producing the most meaningful results. These modifications can occur either through internal feed-back from the results of preceding experiments, or by means of commands transmitted from Earth at the direction of scientists and in response to their evaluation of the progress of the experimental program.

SECTION 3

ABL PRELIMINARY DESIGN

3.1 GENERAL DESCRIPTION

3.1.1 DEFINITION OF THE AUTOMATED BIOLOGICAL LABORATORY

The Automated Biological Laboratory is a part of the Voyager capsule landed payload, and integrates closely with other subystems of that payload. Division of the total lander into "ABL" and "interfacing subsystems" requires careful evaluation of the primary functions performed. Certain of the subsystems are so intimately related to basic ABL functions that they are inseparable in a system sense. Others perform an essential function but are of a more general nature or support a number of capsule operations.

The portions of the landed payload that are considered part of the ABL for this study are shown in Figure 1. The intimate functional relationship of these subsystems make essential their integration as part of the laboratory. These subsystems can be further defined functionally:

(1) Sample acquisition.

  (a) Sampler deployment.

  (b) Sample pickup and transport.

  (c) Sample grading and storage.

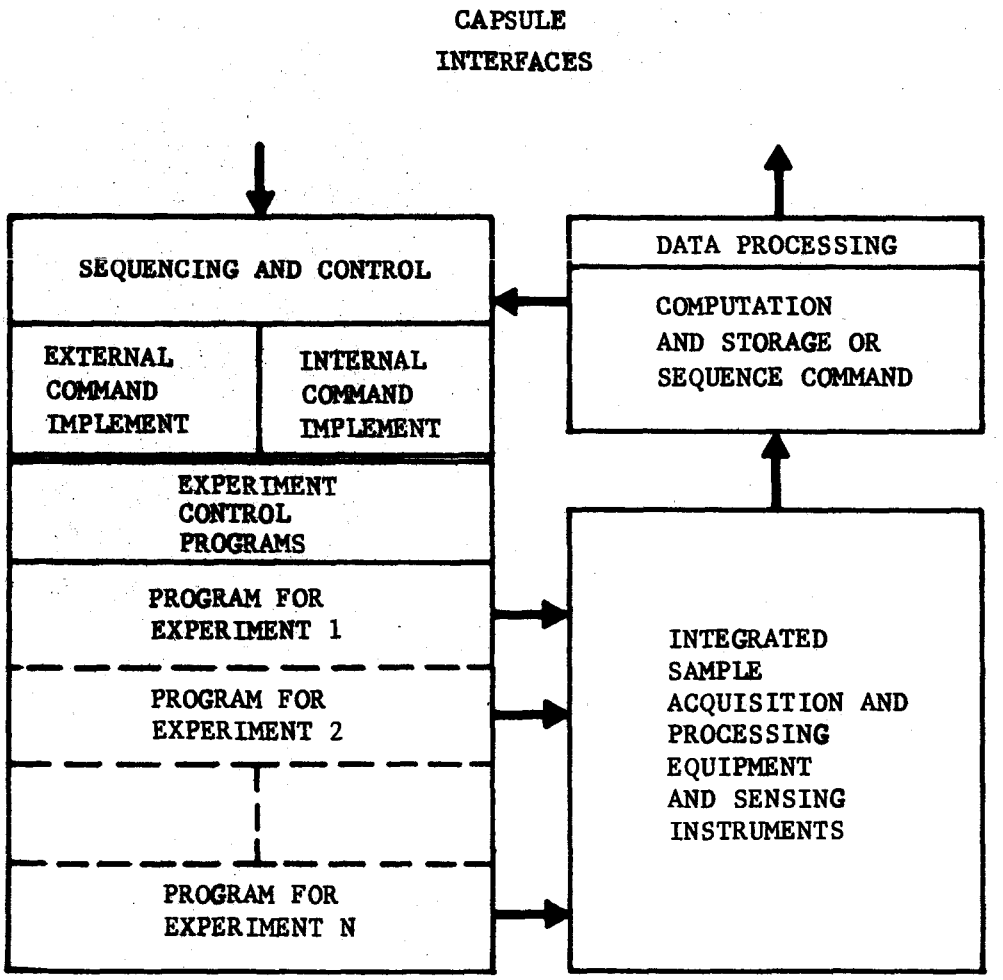


FIGURE 1. AUTOMATED BIOLOGICAL LABORATORY

(2) Chemical processing.

(a) Reagent storage and distribution.

(b) Reaction chamber operation.

(3) Experiment instrumentation.

(a) Sensor activation and deployment.

(b) Instrument operation and readout.

(4) Sequencing and control.

(a) Command implementation.

(b) Process sequencing.

(c) Experiment sequencing.

(5) Data processing.

(a) Evaluation and storage.

(b) Analysis and command generation.

In addition to these major subsystems, there are additional functional elements that interface closely with landed payload subsystems, but require adaptation to meet the special requirements of the ABL. These include:

(1) Integrating structure.

(2) Power adaptation.

(3) Environmental control adaptation.

Additional supporting subsystems that make up the total landed payload, along with the ABL include:

(1) Data encoding and decoding.

(2) Communication system.

(3) Power supply.

(4) Erection system.

(5) Structure.

(6) Environmental control.

3.1.2 SYSTEM CONSTRAINTS

The definition of the design point system parameters used in this study employed mission constraints specified for the study by NASA. The most important of these are listed in Table II.

TABLE II

PRINCIPAL STUDY CONSTRAINTS

Mission Time	1975
Mission Duration	Two Earth years on Mars
Payload Size	500 - 1000 pounds
Mission Philosophy	The mission is to be a comprehensive biological and related environmental surface exploration, probably following orbital and possibly simple entry or landing missions in 1969, 1971, and 1973.

3.2 SYSTEM DESCRIPTION

The ABL/lander configuration, which establishes the basis for the program plan is shown in Figure 2. The overall assembly is packaged into a spherical envelope 68 inches in diameter exclusive of any impact limiting material that may be used to protect it on landing. This configuration weighs approximately 1200 pounds and is intended to operate on the Martian surface for a period of two Earth years.

The configuration shown in Figure 2 is a complete self-contained landed payload with its own power supply, data processing, communications, and environmental control subsystems. The ABL concept employs the integrated laboratory approach in which it is possible to use analytical instruments and processing equipment in a variety of combinations and sequences. The heart of the laboratory, containing the reagent storage, chemical processing equipment, and the analytical instruments, is distributed immediately above and below the central horizontal plane of the sphere. This portion of the laboratory is pressurized and has a controlled atmosphere.

The primary sampling equipment is located on top of the laboratory, with secondary sampling beneath. In its surface operational mode, the laboratory is supported by three legs and has a mast structure, containing experimental instrumentatation which can be extended up to 15 feet; the mast is also used in conjunction with deployment of the remote soil sampler.

The major ABL susbystems and the primary interfacing subsystems are described in the following paragraphs.

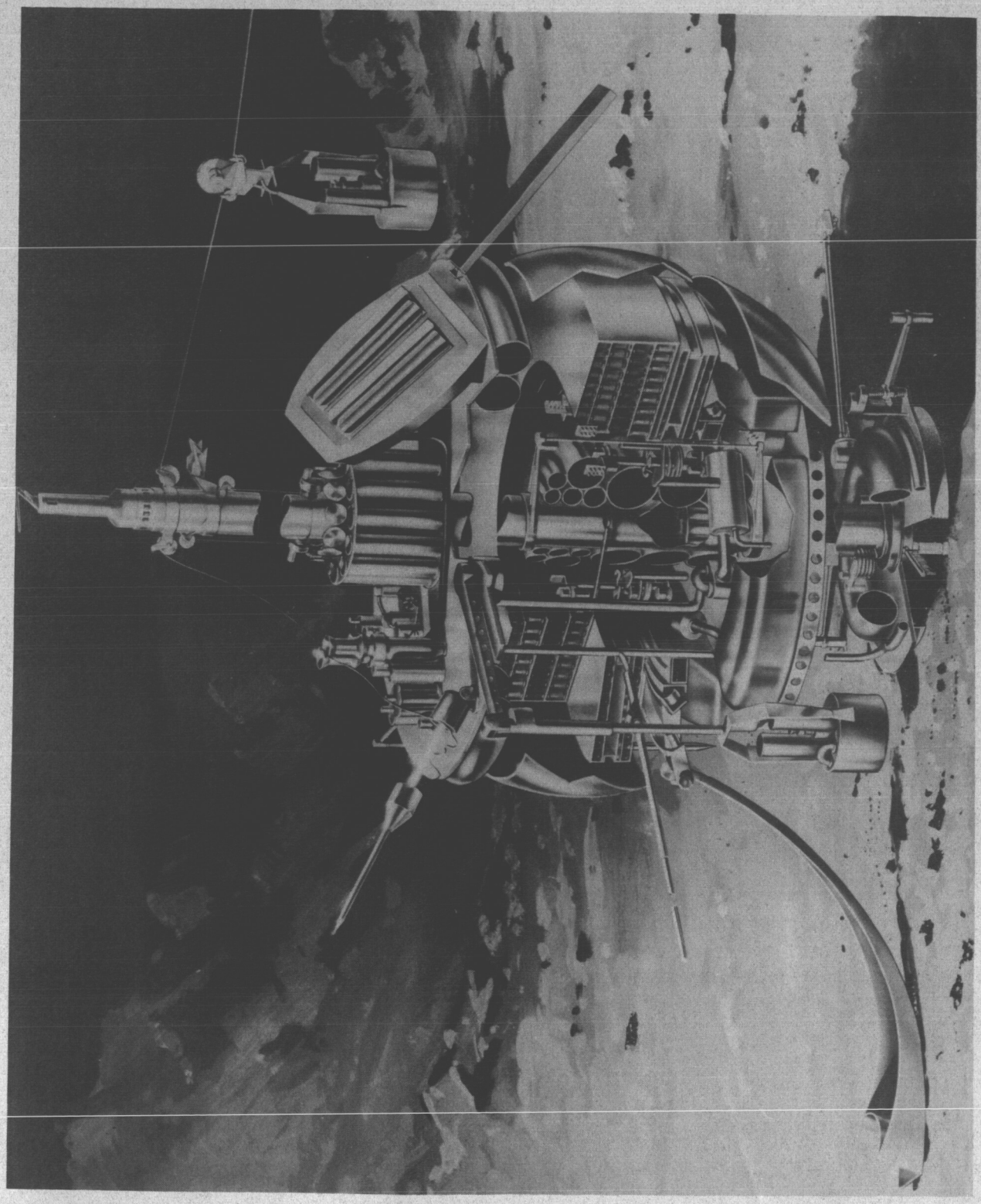


FIGURE 2. ABL DESIGN POINT CONFIGURATION

3.2.1 EXPERIMENTS

The ABL has been sized on the basis of performing 35 experiments with the capability of repeating each experiment approximately 60 times in the two year lifetime. The experiment complement consists of biological experiments to detect evidence of life by both chemical and growth culturing analyses supported by the necessary environmental measurements to provide correlative and interpretive data. The local environment of Mars is sampled by both visual and infrared scans of the surrounding terrain, by atmospheric gas samples, and by surface and subsurface soil samples. The flexibility of altering or adding experimental routines by Earth-based decisions and commands based on the preceding experimental results is incorporated into the laboratory capabilities.

3.2.2 INSTRUMENTS

The experimental sequences are supported by a complement of approximately 29 different types of analytical instruments. The bulk of the experimental data is produced by the following specialized instruments.

A facsimile imaging system is used to provide a visual scan of the surrounding terrain with a coordinate infrared map of the same area. This instrument may be operated in a sun tracking mode and as a solar insolation radiometer yielding either discrete or integrated values. The imaging system is mounted on top of the mast.

A spectral analyzer which combines the functions of an ultraviolet and visible spectrophotometer, a fluorometer, and a polarimeter is used to analyze chemical solutions for the absorption characteristics, fluorescence, and optical rotations associated with detecting biological constituents of life such as protein molecules, porphyrins, and nucleic acids. This instrument is mounted in one of the toroidal segments in the lower part of the central section.

An infrared spectrophotometer, located in one of the toroidal segments, is used to identify functional groups, such as carbon-hydrogen, carbon-carbon, nitrogen-hydrogen, and oxygen-hydrogen bonds.

Gas chromatographs are used to identify elemental gases and molecular constituents of the Martian atmosphere and chemical extracts prepared from Martian soil. Several varieties of column packings are required indicating the need for multiple instruments. These instruments are mounted on the upper deck of the central portion of the ABL.

A mass spectrometer is used in conjunction with the gas chromatograph or individually to detect and identify the atomic mass of molecular constituents from the same sources as described in the preceding paragraph. It is located in one of the toroidal segments.

An alpha-scattering instrument is used to perform elemental analyses on soil samples or on the residue of evaporated solutions by performing an integrated count of back-scattered alpha particles from the surface of the sample. A colliminated beam of alpha particles is directed on the sample and a count of back scattered particles at various angles is made over a period of time.

A variety of environmental and control sensors is used in conjunction with these instruments to obtain correlative environmental data and the requisite feedback control and calibration of the primary instruments.

3.2.3 CHEMICAL PROCESSING

The bulk of the chemical processing is performed in a single piece of equipment referred to as the chemical processor. It has the capability of performing the following functions:

(1) Preparation of a soil extract using a solvent.

(2) Perform solution filtrations.

(3) Preparation of controlled concentrations and varieties of solutions.

(4) Preparation of soil extracts using liquid/liquid phase separation techniques.

(5) Controlled evaporation of solutions to dryness.

(6) Controlled pyrolysis or oxidation of solid samples.

(7) Incubation of a growth culture with a soil sample.

The chemical processor receives the required reagents by two means. Gaseous supplies and bulk solvents are stored in the toroidal pressure vessels around the central mast and are fed through piping to a valve-controlled manifold at the processor. Specific small quantity reagents are stored in ampule form around the circumference of the ABL and are transported to the chemical processor with the internal mechanical transport system of the laboratory. The ampule is placed in the ampule feed mechanism of the chemical processor and is used as the dispenser for the reagent. Specialized empty versions of the ampule are used to transport partially processed liquid samples within the laboratory.

Thirteen chemical processors are arranged circumferentially around the central bulk reagent storage. Reagent ampule storage is arranged in a cylindrical fashion around the chemical processor with sufficient space left between the chemical processors and ampule storage for the internal transport mechanism to operate.

Auxiliary to the chemical processors are dialysis chambers to reduce salt concentrations in solutions and culture evaluation chambers with optical densitometers to detect changes in turbidity or culture growth. Each chemical processor utilizes throw-away elements, such as filters and chamber sealing elements, to provide the capability of easily cleaning and recycling the equipment to its initial condition. The capability to perform a dry heat bake sterilization cycle for the critical surfaces is incorporated into the design.

3.2.4 DATA PROCESSING

Data generated by the operation of the laboratory equipment must be processed for generation of internal commands or for storage and subsequent transmittal to Earth. It will be desirable to perform some form of data compression on some of the raw data as they come from the experimental equipment. Redundant data within an experiment output or between experiments can be removed in this way without loss of information. Considerable reduction of the data from imaging experiments can be obtained by various forms of coding to reduce the load on the communications link. The bulk of data will be stored on magnetic tape units for processing in this way before transmission. The memory capacity required for this function is provided with a redundancy factor of 2 by means of two separate magnetic tape units of 10^8 bits capacity.

3.2.5 SEQUENCING AND CONTROL

The sequencing of the experimental activity of the laboratory and the control of essential engineering functions of the ABL landed payload are performed by a central computer system. This computer contains, in addition to the temporary magnetic tape memory previously discussed, a central arithmetic and control unit, a main thin film or core memory of 6×10^5 bits capacity in which the executive control and preprogrammed portion of the experimental procedures are stored, and a backup wired memory of less than 10^5 bits capacity in which critical executive routines and instructions are stored against the possibility of their inadvertent loss from the main memory.

3.2.6 SAMPLING

The ABL acquires atmospheric gases and atmospheric-borne dust particles by means of a suction-blower system, with sampling repeated on a limited basis. This sampler is shown as the slender probe parallel to the surface at the ABL major diameter.

Soil samples are acquired at the laboratory landing site and at two remote sites per season resulting in a total of 12 sample sites in the two year lifetime. At each sample site, five subsample batches are collected as follows:

(1) An aerosolizing jet and brush with a pneumatic transport system is used to collect surface soil to a depth of 1 centimeter in particles sizes up to 300 microns in diameter.

(2) An auger-type cylindrical drill is used to collect soil samples to a depth of 20 centimeters. This sample is subdivided into 5 centimeter batches and processsed separately for experimental analysis. The soil sample is fed into a rotary pulverizer designed to break down agglomerated masses of particles. The effluent from the pulverizer is then graded by pneumatic sieving and transported into a combined cyclone particle collector and weight scale. The graded soil sample containing particles from 300 microns and less is weighed and measured into a filter unit for storage or transport to the appropriate chemical processor. The filter storage unit rotates, presenting a series of fresh filter units to the cyclone collector for a soil sample. This sample grading equipment is mounted on the top deck of the ABL, accessible to the remote or local sampler.

The on-site sampler is boom mounted so that it may be rotated over the edge of the laboratory and lowered to the surface, as shown on the near left side in Figure 2. By initially pressing the sample collector support structure into the surface, soil mechanics data are acquired, and characteristics of the surface measured to determine subsequent sampling procedures. The boom is used to return the sampler to the laboratory and position it on the pulverizer entrance. Soil is transferred from the cylindrical auger in incremental fashion until a complete 5 centimeter batch has been processed and analyzed. Subsequent batches are processed in the same manner until the soil sample from a given sampling site is exhausted.

The aerosol dust sampler is a cyclone particle collector mounted on the sample collector support

structure. This sample is pneumatically transferred to the laboratory using the same compressor system on the sample collector as is used to collect the sample. This sample is collected by rotating a brush carrying aerosolizing jets inside a shroud to suspend soil particles in the atmosphere. An open loop circulation system from the compressor to the shroud and back to the cyclone particle collector is used to gather the suspended soil particles.

Remote sampling sites are attained by ballistically deploying an anchor which is fixed to the end of a cable, in a high looping trajectory, as shown in the upper left part of Figure 2. After the anchor embeds itself in the soil, a winch takes up and preloads the cable. A sample collector similar to the boom mounted version is then attached to a trolley drive system on the cable which is used to carry the sampler along the cable. Power and control are furnished to the trolley and sampler with a wire control link deployed from the laboratory, as required. At the selected point the trolley stops; cable tension is relaxed sufficiently to place the sampler on the surface for sampling operation. The cable tension is then reapplied to lift the sampler from the surface and return it to the laboratory. This system eliminates the requirement for detailed knowledge of the local terrain, thus simplifying the transport problem and increasing the reliability for retrieving the sample. Reasonable range limit of this system is approximately 800 feet over a flat, level surface.

3.2.7 ENVIRONMENTAL CONTROL ADAPTATION

The environmental control for the ABL consists of two functions; (1) prevention of atmospheric contamination from either internal or external sources, and (2) thermal control of the laboratory environment. The chemical processing, reagent storage, and instrument sections of the laboratory are pressurized to essentially one Earth atmosphere with clean dry nitrogen. A closed loop internal circulation system is used to maintain uniform temperatures in the laboratory by convective heat transfer. A scrubber is located in this system to remove gases and compounds released into the internal atmosphere during ABL operation. It also filters solid particulate matter out of the atmosphere which may come from sources such

as dust from soil samples being processed. The scrubber is also used to clean the Martian atmosphere, if local air is used as a makeup gas to compensate for leakage.

A bypass on the closed loop circulation system is utilized to obtain waste heat from the RTG power supply as required to maintain the temperature of the laboratory above freezing. The net requirement for the laboratory is a heat input under most of the daily temperature variations encountered. Since the RTG is only 5 to 10 percent efficient, it produces 90 to 95 percent waste heat. This indicates that if some other type of primary power supply is used, it must also provide the power to maintain the laboratory at its operating temperature.

3.3 ABL INTERFACES

3.3.1 ELECTRICAL POWER

As indicated under environmental control considerations previously discussed, there exists a strong interaction between the electrical power supply and the thermal control of the laboratory. The RTG (radioisotope thermoelectric generator) is ideally suited to providing for these thermal requirements, as well as for the electrical loads of the ABL. The RTG is, in fact, such a perfect match to the operating requirements of the ABL landed payload that its availability on time and in the proper sizes and configurations for the mission is considered mandatory. No particular problems are anticipated in this regard, but some continued development is required. Fuel availability, fuel element packaging, general overall system performance upgrading, and, in particular, improvement in the shock and vibration sensitivity of the units are areas in which work should be pursued.

The design point ABL has requirements for a unit with 75 watts peak electrical power output; two such identical units are suggested for redundancy. They are shown as two finned cylinders mounted on the upper right side of the ABL in Figure 2. One peculiarity of the RTG system is the fact that it must dissipate heat continuously from the time it is assembled. When the RTG is enclosed within another system (such as the landed payload) means must be provided for removal of this heat, or the unit and adjacent equipment can be damaged. During the Earth-Mars transit phase, this must be done by means of a cooling loop to the exterior of the entry vehicle sterilization shroud. During the terminal sterilization of the system, this heat can be used to advantage by being shunted into the interior of the ABL payload in a controlled fashion, bringing up the internal temperature to the sterilization level in less time and with less severe thermal gradients than if the payload were heated only from the outside.

3.3.2 COMMUNICATIONS

Communication requirements for the ABL can be handled with very conservative extrapolations of current technology. A direct Mars-to-Earth link was found to be optimum in this study and was adopted for the primary mode; however, this does not preclude the use of an orbiter relay to attain higher bit rates if desired. Command control is maintained by means of an omnidirectional antenna and a command receiver on the ABL. Because of the extremely long range at Earth-Mars conjunction, and the use of a low gain omnidirectional receiving antenna for reliability, it was necessary to postulate the use of a 100 kw transmitter at all three DSN facilities. At present, this capability exists only in experimental but operating form at Goldstone.

The main telecommunication data link from the ABL to Earth is by means of an 80 watt transmitter working through a fan beam antenna of 15.5 db gain. The fan-shaped pattern of the antenna is oriented once on landing to lie in the ecliptic plane and symmetrically about the Mars-sun line at noon; thus, each day the Earth passes through the long dimension of the beam cross section. For the design point, this case gives a 3 hour transmission time per day.

For the parameters discussed, the communication link capacity varies from about 58 bits/sec at encounter to about 19 bits/sec six months later at conjunction. From this point the bit rate again increases to a value of approximately 300 bits/sec as Earth and Mars approach the next opposition. Assuming reasonable system mechanizations, this capability will result in a total data load of approximately 3×10^8 bits being transmitted in the 2 year period. The actual data load computed for the design point ABL system is 7×10^7 bits, giving a performance capability of approximately four times the design point load.

3.4 SYSTEM OPERATION

3.4.1 EXPERIMENT CYCLE

The ABL will land on the surface of Mars with a set of experimental sequences preprogrammed into its central control computer. These will have been developed by the participating principal investigators in various science disciplines, such as biology, chemistry, geology, and physics. Priority will initially be assigned those experiments designed to detect evidence of life on Mars. Evaluation of the results of these first experiments may shift the investigation techniques to emphasize experiments producing more interesting results, or, in case completely negative biological results are obtained, may be shifted to another field of investigation which could produce more rewarding information. The phasing of experiments and the rate at which they are performed can also be compressed

or expanded to allow a more comprehensive evaluation of an interesting transient phenomena, or to avoid the useless repetition of experiments when this is indicated. Thus, the principal investigators must receive and analyze data on a regular basis to evaluate their experimental results and to coordinate this in terms of the overall operation of the ABL.

3.4.2 SUMMARY OF LIFETIME OPERATION

At arrival on the Martian surface, the ABL will erect and orient itself to the local vertical which is required to provide proper operation of all the major subsystems. The first day of operation will initiate all those experiments not dependent on soil samples or a known orientation of the laboratory with surrounding terrain. During this day, the facsimile scanning system will go into a sun track mode to determine the proper orientation of the high gain communications antenna. This orientation is achieved by rotating the entire laboratory. A fan-shaped beam lying in the plane of the ecliptic will provide Earth view times of 3 hours per day in which to transmit data and receive instructions. Subsequent realignment of the beam is performed periodically by electronic switching of the phased array to raise or lower the beam, as required.

After the communications link is established, the laboratory begins all programmed surface operations. The total operating lifetime of the ABL will ultimately be determined by depletion of supplies in conjunction with the rate at which experiments are being performed by lifetime of the power supply, or by failures in the equipment. The lifetime could be less than 2 years, but it is also possible that it could be operational for periods appreciably in excess of 2 years. This is particularly true of those experiments not dependent on chemical supplies, such as the environmental experiments, the visual and infrared scanning equipment, background radiation counters, and the mass spectrometer. This type of secondary mission objective could strongly influence the selection of the type of power supply used, and might also affect the ultimate selection of the analytical instrument complement carried in the ABL.

SECTION 4

ABL DEVELOPMENT PROGRAM

4.1 ABL AND RELATED PROGRAMS

In order to meet the planned 1975 flight date, a number of related programs must be carefully planned and interlaced. Several of the major programs are noted in the following paragraphs and are discussed in more detail in Section 5.

4.1.1 AUTOMATED BIOLOGICAL LABORATORY DEVELOPMENT

This program is the primary subject of this preliminary program plan. It deals with the design, development, fabrication, delivery, and mission support of the ABL itself.

4.1.2 SCIENCE DEFINITION PROGRAM

This program would be conducted by NASA in parallel with the ABL development program. It includes the definition of the science mission, selection of principal investigators, definition of scientific experiments, and specification of experiment techniques. Because it interfaces so closely with the ABL development program, discussion of it is included in Paragraph 4.3 of the ABL program plan.

4.1.3 VOYAGER CAPSULE DEVELOPMENT PROGRAM

The ABL and capsule programs have a strong influence on each other. Major points of interface are noted in the ABL program plan.

4.1.4 SPACE FLIGHT OPERATIONS PROGRAM

This program covers the development of Earth-based data analysis and ABL control facilities for the operational period of the ABL on Mars. Near-real-time data analysis, evaluation, and operational command control will be required on a continuous basis throughout the operational life.

4.1.5 STERILIZATION PROGRAM

The current program for development of sterilization technology and parts qualification must continue and be partially directed to consider the problems of the ABL. This continuing program will furnish the requirements for terminal sterilization, fabrication and assembly procedures, sterilization assay, and other such technology developments.

4.2 ABL DEVELOPMENT PROGRAM

The schedule for the ABL development program is shown in Figure 3. A continuous program with a very early start is indicated, following directly behind the present conceptual study. The program divides logically into a number of phases discussed in following paragraphs.

4.2.1 PRELIMINARY DESIGN

The preliminary design phase commences in the fourth quarter of 1965 and continues to mid 1967. The primary effort in this phase is directed toward the specific definition of a nominal ABL compatible with the planned capability of the corresponding Voyager mission. The nominal ABL is used as a basic input for the science definition phase as discussed later.

In the preliminary design phase, variations of the basic configuration will be studied. The most desirable experiment and processing capability will be established, and the effect of increased and decreased capability traded-off. The specific science instrument complement required for various levels of capability will be determined, and the detailed characteristics of these instruments will be defined. The capability level investigated will vary from relatively simple experiments involving minimum processing, instrumentation, and data output, to very comprehensive systems at and beyond the upper limit of delivery system capability. The interaction of various instruments will be investigated to determine potential multiple use and flexibility in a number of applications. The instruments will be examined in detail to define specific design parameters, identify requirements for state of art improvements, and establish weight, size, and data parameters expected.

During this period, the supporting subsystems will be defined and the characteristics similarly analyzed. The designs will be carried to the detail required to permit making specific decisions concerning the methods

of operation, limits of performance, reliability, redundancy requirements, and interface requirements for all subsystems and systems. This information will be continuously translated into capsule requirements so that the effect on the overall system can be predicted.

Based on this engineering information and supporting science inputs from NASA, a nominal ABL will be defined. This design will represent the science capability and engineering configuration to be used as a basis for definition of the specific science program, and to initiate hardware development.

During the preliminary design effort, supporting programs in sterilization compatibility and experiment techniques are essential. As design tradeoff studies are conducted, specific materials and components will be identified that are essential to successful operation of the system. The compatibility of these with the sterilization requirements must be determined to identify early development requirements or possibly to eliminate certain approaches. Similarly, the adaptability of specific experimental processes to automatic operation must be investigated in the laboratory to assist in defining the complete capability required. Ignoring either of these test areas may result in designing into a corner that would require major modification of concept or approach later on.

The major output of the preliminary design phase then is:

(1) A specific definition of the nominal ABL intended for 1975 flight, including the instrument complement, sampling and processing capability, and the operating modes and limitations.

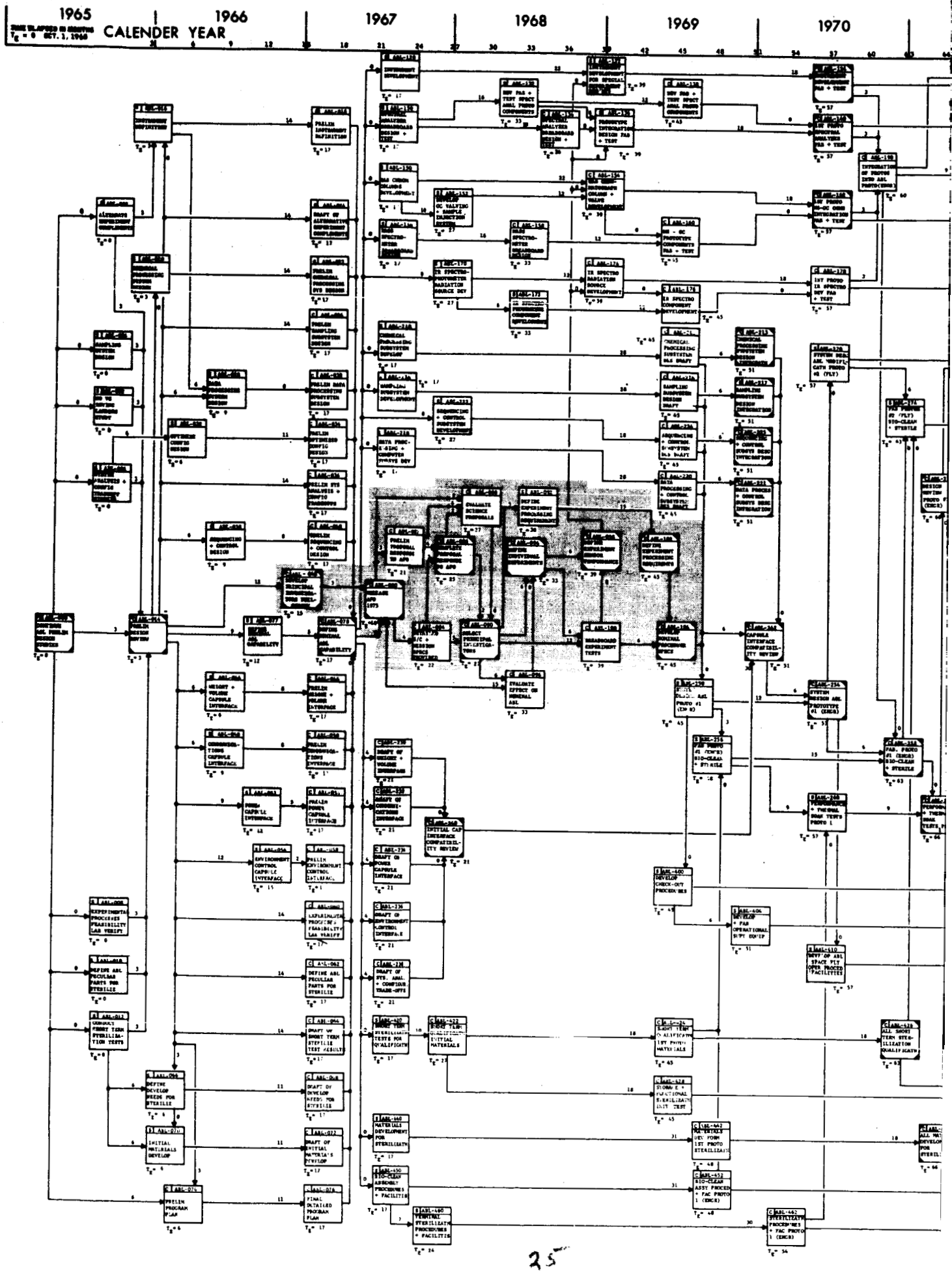
(2) A specific definition of the interface characteristics necessary to determine the total effect on the entry vehicle, landing, and support systems.

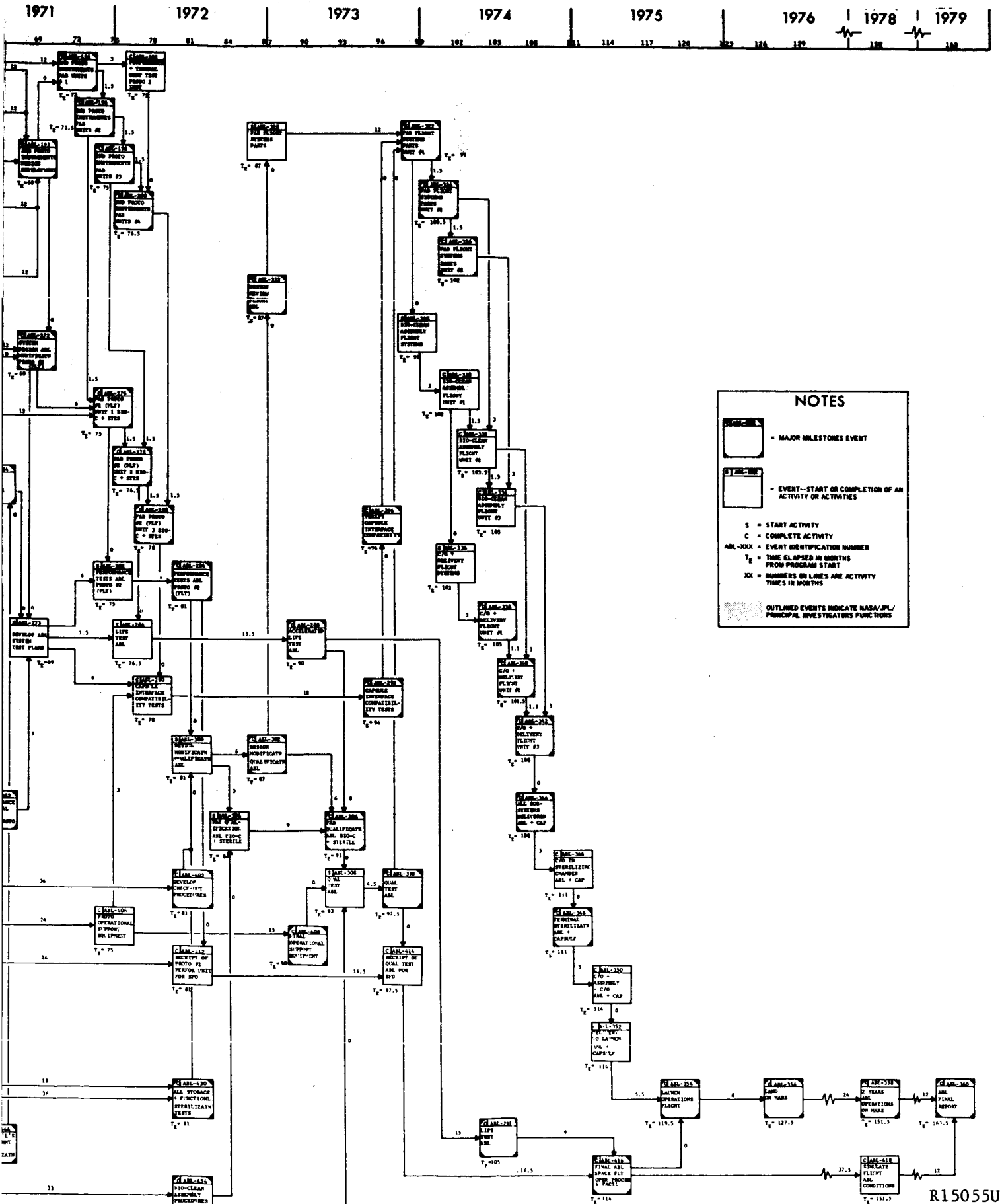
(3) A specific definition of major development requirements necessary to meet the performance parameters of the nominal ABL and the sterilization requirements of the Voyager system.

(4) A specific program plan defining the complete development, flight, and surface operations program, including the supporting and related programs essential to mission completion.

4.2.2 SCIENCE DEFINITION PROGRAM

The integrated laboratory concept of the ABL implies participation of the scientific community in a slightly different manner than normally considered in space programs. Conventionally, the spacecraft substantially provides


1965
1966
1967
1968
1969
1970
CALENDER YEAR



R15055U

FIGURE 3. AUTOMATED BIOLOGICAL LABORATORY PROGRAM PLAN PRELIMINARY PERT SCHEDULE

a test bed, delivery system, communication system, and functional support for individual experiments that are designed and furnished by the individual principal investigators. Each experimenter is completely responsible for the design, fabrication, and operation of his particular experiment.

In the integrated ABL, each principal investigator is furnished a laboratory that is capable of performing many types of experiments by selecting and sequencing the many individual processes and readouts that are available. An experimenter may therefore specify completely the experiment to be performed, with the data required, and he analyzes the results; however, he would not design the specific equipment to perform these functions.

Whereas this method of operation is unusual, it is not unique. It has been applied in essential form, for example, in the OSO program. There are undoubtedly many ways the science definition program and principal investigator participations could be handled. One reasonable way is discussed in the following paragraphs.

The science definition program would be handled directly by NASA, starting concurrently with the preliminary design and continuing to mid 1969. Principal investigator participation would continue through the development and flight program, lander operations on Mars, and subsequent data evaluation.

During the preliminary design program, the specific philosophy for the science program must be developed. Operating procedures must be established in detail to ensure maintaining the scientific integrity of the experiment program, to direct participation and control by the principal investigators where this is essential, to define acceptable interface arrangements for all participants, and to provide for adequate decision-making machinery during system development and Mars surface operations.

These operating procedures, the definition of the nominal ABL, and other mission information comprise the Announcement of Flight Opportunity (AFO) that is released for experiment proposals in the first quarter of 1967. This AFO would define the laboratory instrument complement, sampling, and processing capability, data processing and analysis capability, and generic description of science and experiment types contemplated. Potential principal investigators would respond to the AFO with the proposed experiments planned to utilize the specified ABL capability, or reasonable perturbations of it.

Evaluation of the science proposals would consider the potential effect on the overall ABL, complementarity of experiments and techniques, compatibility with efficient and economical use of the equipment, adaptability to utilization of various pieces of multipurpose equipment, balanced use of the overall system capability, and other such pertinent factors.

An initial selection of principal investigators would be made to participate in the final science definition. During this period the group of selected experiments would be further defined to maximize the combined information content and to optimize the ABL configuration. It is possible that specific experimental procedures and techniques would be modified where the experiment integrity would not be compromised, that experiment intent would be expanded to cover open areas or provide redundant related information, and that other such changes would be made in arriving at the final science program.

Concurrently, the principal investigators would develop the specific experimental techniques so that by the first of 1969 the specific instrument performance can be defined, and by mid 1969, the step-by-step experiment procedures are available. This information establishes the requirements for the corresponding parts of the ABL and defines the operating requirements for the related subsystems.

The principal investigators continue on the program, coordinating continuously with the ABL integrator as the hardware is developed and tested. They participate in development of operating procedures for Mars operations. During the operating life on Mars, they analyze the appropriate scientific data, and participate in command control of experiment operation and modification.

Because of the additional coordination required during the ABL development, the science definition and principal investigator selection must occur earlier than on the more conventional programs. For the 1971 Voyager mission, for instance, the principal investigator selection is planned about 5 years before the flight date; for the ABL Voyager mission, about 7 years lead time is planned.

4.2.3 SUBSYSTEM AND SYSTEM DEVELOPMENT

Development of the ABL would be initiated on the basis of the nominal system defined for the AFO in the preliminary design phase. In addition, continuous tradeoff and evaluation studies would be conducted in support of the science definition program which is proceeding concurrently. Specific effects on the various ABL subsystems would be fed into the development program as they occur.

Certain of the instruments and sensors considered for use in the ABL present the most critical development and lead time problems. Although instrument concepts are based on known principles used routinely in normal laboratory operation, development in the flight configuration with usable sizes, weights, power requirements, performance, and reliability presents challenging problems. Three major instruments included in the design point ABL are in this category.

The spectral analyzer is a special instrument that combines the functions of a fluorimeter, UV spectrometer, and polarimeter. Significant volume and weight advantages can be realized by multiple use of the structural, optical, and control systems that are common to the three instruments. In addition, the simplification of the sample handling system offers further advantages of reliability.

The various functions would be performed using common optics and energy sources, with multiple filters for the spectral ranges desired and different sensors for the various functions. The primary sensor is a photo multiplier; currently available types are suitable for relatively high g-level shocks, and are compatible with sterilization requirements. Primary development problems in space application designs are associated with the lens mounting system to maintain the required close optical alignment during and after shock and vibration, and during temperature changes that would be experienced in operation. Also, the complex lens assemblies which conventionally use special cements appear to be incompatible with heat sterilization. Special methods of compounding lenses must be developed.

Finally, this combination of instruments has not previously been assembled. Preliminary designs have been prepared that indicate the feasibility of such combination, but problems in doing this can be anticipated. Prediction of time required to solve problems not yet defined can be risky; however, estimates for the development time were made, based on previous work with instruments of similar complexity. The 3 year lead time for the first complete prototype does not allow signigicant slack, based on the estimates received; however, the additional 1 1/2 years for final prototype comfortably covers the total predicted time. These availability dates are keyed to the overall ABL development and test program. If intolerable development difficulties are experienced, single purpose instruments could be used with some compromise in system weight, volume, and related subsystem complexity.

The combined gas chromatograph and mass spectrometer is similarly conventional in principle as separate units, but has not previously been combined into a single unit in space flight configurations. The advantages realized by combining the instruments to permit continuous flow operation without intervening handling of the gas sample are major, and justify extensive development effort. The basic controls of the gas chromatograph are relatively conventional; primary problems are expected in miniaturization of the columns and development of packing techniques to obtain uniform and predictable performance. Considerable work has been done at JPL and NASA/Ames Research Center on this problem, and confidence is felt in solution of the problems. Compatibility with sterilization of some of the packing materials suggested has not been verified and this may present problems.

The mass spectrometer problems are associated with miniaturization of the instrument while maintaining the range and suitable operation at power levels sensibly available on the ABL. Units are currently available in the weight ranges required but with sensitivity characteristics not good enough for the application. Other units with reasonable sensitivity do not cover the necessary range. Prediction of solution of the development problems in the time required again involves real risk.

The IR spectrophotometer does not present the basic development problems of the two previous major instruments. Operation is well within the conventional ranges, although the flexibility of the instrument could be increased by increasing the normal linear range. Some mounting problems may be experienced with the radiation source if the vibration or shock environment is severe; preliminary investigation indicates that modified mounting or caging techniques are reasonable.

Other instruments and sensors are relatively conventional, and significant development problems are not anticipated. However, development should start concurrently with the other instruments to allow for unanticipated problems that might arise.

The instrument development will begin in the first quarter of 1967, based on the nominal design ABL used in the AFO. As the science definition program proceeds, additional information and requirements will be formulated for the instruments, although no major changes from the nominal performance requirements would be expected. Initial work will concentrate on the development of basic design, miniaturization, and compatibility with sterilization.

With the initial selection of experiments at the start of 1968, the instrument requirements are more definitive; by the end of 1968, the specific performance can be defined. Development of instruments and experiments is mutually dependent, and simultaneous work is essential. In fact, instrument developments of a related nature have been under way for some time at JPL, Ames Research Center, and other places under NASA sponsorship.

Since the instruments are the longest lead-time components of the ABL, it is important that their development start as soon as feasible. It is planned that the initial development would be of breadboard nature, during which the fundamental techniques would be established and sterilization compatibility determined. During this time, functional changes affecting range, resolution, sensitivity, etc., can be accepted with minor impact, as long as basic operating principles are not modified. The "brassboard," or prototype designs would be based on specific performance requirements, and would be fabricated of components that are (short term) qualified for sterilization, shock, and other environments.

Development of the other ABL subsystems would also proceed on the basis of the nominal ABL design. The sample acquisition and processing system is relatively independent of the other functional systems. Initial work would concentrate on the sample acquisition-development of the sampler, soil loosening and pickup, deployment of the sampler, sampler system control, etc. Preliminary work on sample grinding, grading, and handling would commence early; emphasis on this part of the system would increase as the experiments are defined and the specific processing requirements determined.

The chemical processing subsystem work is initially concentrated on development of reagent storage and handling techniques, transfer system, and mechanization of the reaction chamber operations. Knowing the types of processing involved, these aspects can be developed in detail. As the experiments are defined, the specific reagents and reagent quantities, precise sequencing, and process timing will be superimposed on the system design. Next to the instruments, the chemical processing system requires the longest lead time for development. Whereas the problems are primarily ones of detailed implementation, extensive development will be required to assure a reliable, long life system.

The data processing and analysis subsystem is based on current state of the art computer techniques. Initial work would concentrate on development of data compression techniques for the raw data output contemplated in the nominal ABL. This allies closely with the amount of data analysis and internal decision making that can be built into the ABL. It is not planned that adaptive learning techniques will be used.

The sequencing and control subsystem is also based on current state of the art. Significant work on this subsystem will be delayed until the preliminary definition of the experiments is available, and the initial system work on the processing and instrument design has been completed. Each of the processing and instrumentation steps will be programmed individually. Subroutines in the sequencing system will group these steps in various combinations to conduct complete experiment cycles. Modifications to these subroutines by internal or external command will be based on predicted and built-in changes that optimize potential sequential data, or analysis of data on Earth and reprogramming into sequences not previously planned.

Development of all the subsystems will continue past the complete definition of processing and sensing requirements to incorporate the final procedures developed. During this time, the engineering prototype assembly design will commence, so that the initial ABL prototype system testing can begin in mid 1970. Testing continues through the first quarter of 1971 as performance data are analyzed and indicated design modifications are incorporated. The first prototype assembly and all subsystem assembly will be conducted under cleanroom assembly conditions to identify special problems that may result. All materials and components will have demonstrated short term compatibility with the sterilization cycle. The complete assembly will be tested as assembled, and will then be subjected

to the sterilization heat cycle to identify any additional problems that may occur because of the materials and subsystem combinations.

As the engineering prototype cycle is under way, many problems of detail design, fabrication, and operation will be apparent. Concurrently with fabrication and test, design of the flight prototype will commence. The same clean assembly and sterilization considerations will apply, with incorporation of the lessons learned on the first prototype. The flight prototype should be very nearly the final configuration of the ABL, and in addition to extensive performance testing, will provide for system life tests, complete interface tests with the capsule and communications systems, development of AGE and system test equipment, development of capsule system checkout, assembly, and launch operations, and any other system functions in which the ABL plays a significant part.

The qualification hardware will follow the flight prototype by about a year to give maximum assurance that the qualification and flight systems will meet the mission requirements. The parts and subsystems for the qualification and flight units will be fabricated in the same production cycle. The first complete systems will be used for qualification test, with subsequent units for flight. Three complete flight units are programmed; two for launch and one for backup. All flight units will be available at the end of the third quarter of 1974.

The flight units will be fabricated and assembled under cleanroom conditions to minimize biological contamination. The system will be completely checked out and acceptance tested. The ABL will be delivered in the "bio-clean" but unsterile condition for integration with the complete capsule assembly.

4.2.4 SYSTEM ASSEMBLY

The ABL would be delivered to the sterilization and final assembly facility for integration into the complete capsule. It is anticipated that these final operations would occur at a central Government facility, or at the capsule integrator's facility.

All portions of the landing capsule system would be collected for simultaneous sterilization. It is assumed that sterilization would occur before final assembly, and that final assembly would be accomplished by "caterpillar tube" access to the sealed sterilization chamber. Therefore, qualification of sterilization heat soak parameters for the ABL would be on the basis that it is directly exposed to the ambient temperature.

The ABL would be checked out before and after the sterilization cycle. After the second checkout, assembly with the capsule would proceed through installation of the sterile shroud. The complete assembly process -- equipment required, procedures to be used, assembly level checkouts, etc. -- would have

been previously developed, using a flight prototype model in conjunction with the other capsule systems involved. A 6-month period is allowed for this final checkout and assembly in the sealed, sterile chamber.

After installation in the sterile shroud, the complete capsule is available for launch site operations. There the capsule is physically and functionally interfaced with the Voyager spacecraft, and the total Voyager spacecraft with the launch system. It is presumed that the capsule sterile shroud remains unopened during launch site operations. Any checkout and system functional operations are monitored through hermetic external connections. If failures occur within the sterile shroud envelope, the complete sterile assembly would be exchanged for the backup unit. Modification or repair requiring entrance inside the sterile shroud would be conducted at the sterile assembly facility, with the unit then being reassigned as the backup system.

For planning purposes, 4-1/2 months are allowed for launch site operations with the capsule. Some of the launch operations affecting the booster and spacecraft will occur before the capsule is required or available. Because of the restriction on access to the sterile assembly, the operations to be performed with the capsule at the launch site will be relatively limited.

4.2.5 SPACE FLIGHT OPERATIONS PROGRAM

The ABL is a relatively comprehensive payload that will require a parallel program for the development of ground based support and operation facilities to carry out the mission. The ABL will operate for 2 years on Mars. Because of the flexibility built into the ABL system, extensive near-real-time data analysis and decision making by the principal investigators are required to realize the full potential of the operating laboratory. This will require development of facilities, equipment, and extensive personnel training to make the maximum use of data that are obtained on a sequential basis, and to determine the most reasonable and most productive operational commands for continued experimentation.

Development of the mission operation procedures will start with the ABL engineering prototype availability in mid 1970. Participating scientists and engineers will develop operating and control procedures to use during surface operations. Development of corresponding facilities and equipment will be initiated for inclusion in the SFOF to be used for the mission.

So that the ABL can be properly controlled, the SFOF would be provided with a Mars operation duplicator and command generation simulators. The duplicator would be an ABL of flight configuration that would be operated in parallel with the ABL on Mars; it would precisely duplicate the condition of the operating ABL; as experiments are conducted, the process would be duplicated; if failures should occur, the corresponding portion of the duplicator would be disabled; commands sent to the Mars ABL would also be

transmitted to the duplicator. In this way the precise condition, capability, modified experiment potential, and effect of command functions can be continuously evaluated.

To support the operations, provision is required for near-real-time analysis of data from the ABL. This requires relatively continuous participation of principal investigators during portions of the experiment cycle. From this data analysis, potential redirection of the experiments will be generated, and the corresponding commands formulated.

To evaluate the effects of a large number of potential commands, the ABL may be simulated by a computer. The effects could then be quickly checked and the optimum command sequences selected. The actual effect of the command would be determined by insertion into a test ABL, and the effects evaluated. When confirmed, the command would be transmitted to the Mars ABL and the duplicator.

It is anticipated that the test ABL would be a flight prototype model, updated to flight configuration in all essential elements. This ABL would be available in mid 1970 for personnel training and development of procedures.

The duplicator ABL would be the qualification model, reworked to flight condition. This would be available in the last quarter of 1973 for integration into the SFOF system, and final rehearsal of operating procedures.

4.3 STERILIZATION PROGRAM

4.3.1 REQUIREMENTS

In broad terms, the sterilization program will be required to provide:

(1) Documentary support for the certification of sterility of the flight hardware through audits of the critical steps and through reports of the critical tests performed in the program to build sterility into the ABL.

(2) Technical support of the design effort through early identification of technical need and solutions arising out of the sterilization requirement.

(3) Technical support of the manufacturing departments through suitable training of personnel operating on or testing the hardware, and through provision of appropriate facilities and techniques for both the manufacture of the ABL and the certification of its final sterility.

The sterilization aspect of hardware development and qualification has no real schedule of its own. It must be smoothly and closely integrated, at each step, with the analogous efforts pertaining to technical and administrative objectives.

4.3.2 HARDWARE DEFINITION AND SELECTION

Hardware definition and selection start with the first iteration of design and development testing. This process has started during the current conceptual study and will continue through the preliminary design phase into early 1967. It is a continuing effort thereafter until final designs are established.

Sterilization testing is applied, of course, only at the levels of assembly at which there are reasonable questions of sterilization compatibility. The functions of the various subsystems will be divided into simple and complex parts so that lists of alternative materials and designs can be developed for sterilization compatibility screening as needs arise. Design revision will occur as the proof test data are developed. For the purposes of certification of sterility, documentation of proof test data is essential.

As the design begins to become firm in particular subsystems, the preparation of specifications pertaining to both procured and to contractor-fabricated parts will start. The sterilization program will provide suitable

information defining the acceptable materials, the appropriate packaging, and portions of the poststerilization functional proof testing. When appropriate, the sterilization program will provide audit of vendor facilities and capabilities as they pertain to the attainment of sterility in the final ABL.

The effort to prepare these specifications will start in the last quarter of 1966 and will carry through the third quarter of 1968.

4.3.3 HARDWARE DEVELOPMENT AND QUALIFICATION

The ABL will contain many commonly used parts, components, and materials, but will also use materials and parts not reasonably a part of other programs, e.g., growth media and reagents used in chemical processing may not otherwise be considered for sterilization compatibility. It is assumed that standard parts and components will generally be sterilization qualified in supporting technology programs. For those identified parts where this is not true and, for ABL peculiar parts, qualification is planned as part of this program.

It is essential that sterilization qualification of essential materials and parts be started very early. Qualification testing of ABL peculiar materials should start as early as mid 1966, and of ABL peculiar parts as early as the second quarter of 1967. The breadboard performance testing of subsystems starts in late 1967, with the sterilization related aspects starting about the first quarter of 1968. Specifically, the later breadboard subsystems and the "brassboard" and prototype subsystems would incorporate components and materials that have been short-term sterilization qualified. By the time of assembly of the engineering prototype, all components and materials should be qualified and into the 10,000 hour life test. Alternative models of materials, parts, and subsystems should be on life test in parallel so that failure of one does not endanger the program. These alternative models of critical subsystems must be interchangeable as far as the remainder of the system is concerned.

Toward the final stages of development of each subsystem, thermal soak evaluation and any necessary design revision will be performed. The analytical aspects of thermal soak will be performed concurrently with design. The laboratory proof tests will be applied only to reasonably complex assemblies in which the mathematical models used in the analysis might be expected to deviate significantly from the actual results. The effectiveness of the overall sterilization program depends critically on the thoroughness of the thermal soak model analysis and complete laboratory confirmation. At the subsystems level, the thermal soak confirmation should be complete by mid 1970. However, the final confirmation will be part of the proof test of the flight prototype.

4.3.4 PROCEDURES DEVELOPMENT

From the standpoint of the sterilization program, procedures development is intended to fulfill three broad objectives. The first objective is the definition of the steps to be performed in preparing, fabricating, assembling, and packaging of assemblies and parts. These steps must ultimately smoothly integrate the details of efficient manufacturing operations, cost control, reliability attainment, and built-in sterility. These procedures will be prepared before the engineering prototype assembly phase, and as the prototype program progresses will go through several iterations to attain this smooth integration.

Definition of manufacturing and quality control record requirements is the second objective. Here again, smooth integration with other program objectives is as important as the sterilization objective itself.

The third objective will be the definition of procedures for:

(1) Selection, training, and auditing the performance of personnel in a position to affect sterility.

(2) Verification of materials, parts, and facilities suitability.

(3) Detecting deviations from procedures, instituting corrective action, and follow-up.

(4) Monitoring and verification of contamination control.

These three objectives will represent a continuous effort throughout the program.

4.4 INTEGRATED TEST PROGRAM

The testing activities to be conducted during the ABL program divide into eight major phases:

(1) Component Evaluation Testing (Sterilization and Performance).

(2) Subsystem Breadboard Testing.

(3) Subsystem Prototype Testing.

(4) Engineering Prototype Assembly Testing.

(5) Flight Prototype Assembly Testing.

(6) Qualification Testing.

(7) Flight Checkout and Acceptance Testing.

(8) Mission Operation Evaluation Testing.

The time schedule for each test phase is based on estimates of design, fabrication and test time durations for each phase of equipment development. Scheduling of the major tests is shown in Figure 4. Minor schedule phasing in subsystem tests will occur between the various subsystems because of variance in subsystem complexity and present development status; however, completion of each phase as shown is required to satisfy a 1975 launch date.

During the preliminary design phase of the ABL program, a detailed integrated test program plan will be developed. This plan will include the specific major tests to be conducted, the environment and stress levels to be used, and the criteria for success. In general, the breadboard and prototype tests will impose stress level ranges more severe than those used for qualification; qualification test ranges are similarly more severe than those expected in actual operation; acceptance tests are in nominal ranges that will verify hardware duplication of the qualification models. A preliminary summary of the major testing planned is included in following paragraphs.

4.4.1 COMPONENT EVALUATION TESTING

The objective of the component evaluation test program is the definition of components which will survive the environments required for the Voyager mission. Particular emphasis is, of course, directed toward the requirement of surviving the heat sterilization cycles. Such component development programs have already begun in support of Voyager and will provide a base which later designs will expand.

Paramount to the ABL 1975 mission is the initiation of an evaluation program of components peculiar to ABL prior to the design of the subsystem prototypes. As shown on the Program Schedule, subsystem prototype design begins in 1968. Consequently, an evaluation program of components peculiar to ABL must begin with the preliminary design phase with extensive testing occurring in 1967 concurrently with the design of the breadboard subsystems. Because of the potential long term effects of the sterilization heat soak on materials, evaluation of many components potentially useful in the ABL design must begin more than a year prior to the time final results are required. The component evaluation tests must continue throughout the program until the final design configuration has been reached.

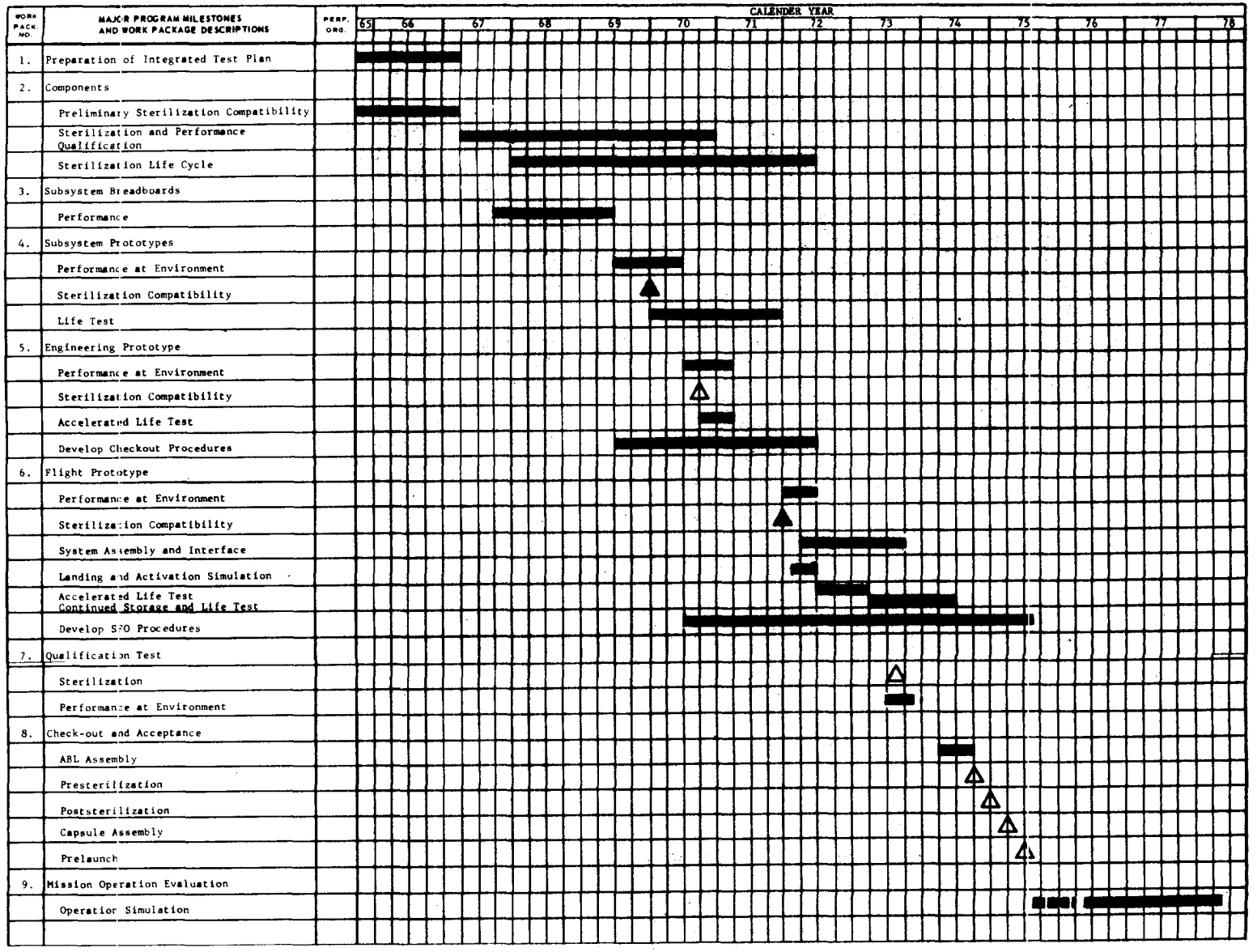


FIGURE 4. INTEGRATED TEST PROGRAM SCHEDULE

4.4.2 SUBSYSTEM BREADBOARD TESTING

Subsystem breadboard testing should begin as early as possible during the subsystem development programs. The objective of this testing is the verification of the feasibility of subsystem design. Consideration should be given the mission environments anticipated; however, survival of these environments is not an objective of the breadboard test program. The breadboard testing program should be continued during a significant portion of the subsystem prototype design so that a maximum exchange of information can be obtained between the working model and the new design.

4.4.3 SUBSYSTEM PROTOTYPE TESTING

Following demonstration of the feasibility of the subsystem design, the next task is to verify that the subsystem can perform its functions during a simulated mission environment. The purpose of the subsystem prototype test program is to subject the subsystem to the mission environments, to determine whether the design is satisfactory, and to indicate those areas within each subsystem requiring additional development. A second objective of this testing program is the preliminary determination of the thermal profile of the subsystem as it relates to the sterilization heat soak.

Two major characteristics will be evaluated on the subsystem prototypes: (1) compatibility with clean assembly and thermal heat soak requirements, and (2) performance under simulated environment.

The clean assembly prototype will be used to define problems in the fabrication and assembly of the subsystem under bioclean conditions. This unit will point out those areas requiring further design because of difficult assembly or repair procedures, and will serve to assist in the definition of clean room support requirements and initiation of definitive assembly procedures.

This unit will also be used to investigate the problems associated with the terminal sterilization heat soak; it will be instrumented to determine the heat soak characteristics during the terminal sterilization heat cycle. It will also be subjected to successive heat cycles to determine which areas are most sensitive or vary in performance after repeated heat cycles.

The performance testing subsystem prototypes will be subjected to the complete mission profile including at a minimum the following environments taking into account the appropriate operating configuration:

(1) Terminal Heat Soak - 135°C for 24 hours

(2) Launch, Transit, and Landing Environment

  (a) Vibration and shock

  (b) Vacuum and thermal

  (c) Radiation

(3) Mars Operation

  (a) Atmospheric simulation

  (b) Pressure and thermal

  (c) Radiation

The immediate results of testing this unit will be applied to the design phase of the engineering prototype. This unit will also be subjected to extended life tests under Martian environments so that results of repeated operations under these conditions can be available for the flight prototype design.

4.4.4 ENGINEERING PROTOTYPE TESTING

The engineering prototype will serve to define the interfaces between the subsystems in addition to further definition of the subsystems. The primary objective of the engineering prototype testing program will be to verify the operation of a complete ABL system. Again the major characteristics to be verified are the clean assembly compatibility, thermal soak characteristics, and performance at simulated environments.

One unit will be used to define the fabrication and assembly procedures associated with clean assembly. This unit, once again, is also used to investigate the thermal soak characteristics of the flight configuration with primary emphasis in determining the specifications for the terminal heat cycle of the flight units. Temperature will be measured at a large number of locations in the assembly to determine the actual temperature-time relationships. These tests must be conducted at this early stage of the development so that proper design changes, if required, can be introduced with a minimum of system alteration.

The engineering prototype configuration will be subjected to the same or similar environments used in the subsystem prototype tests. For the complete prototype, the sand and dust environment would be added to those previously used. The preliminary results of these performance tests will be incorporated into the design modifications of the flight prototype. In addition to the short term performance tests, the engineering prototype will be subjected to multiple operation tests. A typical test sequence is as follows:

(1) The ABL is checked out and tested on a subsystem or module basis to determine proper mechanical and electrical operation.

(2) The experiments are conducted without initial sample inputs. If the results are positive, additional tests or resterilization is required.

(3) After proper performance of Step (2), a controlled test sample is introduced and experiments conducted. Each sensor should give a predetermined indication. Additional test samples with different characteristics are introduced until all experiments and modifications thereof have been exercised, or the ABL is contaminated to the degree that no additional tests can be conducted.

(4) The ABL is resterilized and Steps (1) through (3) repeated.

(5) Steps (4) and (5) are repeated until performance evaluation is completed or system fails.

The engineering prototype will be used for initial development of ABL system checkout procedures. Complete operation of all subsystems during checkout would result in use of some of the expendable materials and contamination of some of the equipment. This is clearly not permissible for checkout of the flight units. In addition, after installation of the sterile shroud, only remote electrical signals can be used.

Starting during the engineering prototype design, the checkout problem will be analyzed; the completeness of checkout at each level of assembly will be defined, and methods and sensors for higher levels of check will be evaluated. Definition of the procedures and development of the special instrumentation in the ABL to implement the procedures will continue through the flight prototype so that feasible, comprehensive assurance of flight worthiness can be obtained even after the ABL is integrated with the capsule and enclosed in the sterile shroud.

Primary functional areas within the ABL requiring prelaunch checkout include:

(1) Initiation of startup operations on landing.

(2) Operation of the process sequencer, including proper steps within a process and proper process sequencing in an experiment routine.

(3) Interface between sequencer and processing equipment.

(4) Operation of the chemical processing mechanical manipulating systems corresponding to sequencing commands.

(5) Operation of the data processing subsystem, including input and output interfaces.

(6) Operation of the data computation system, including proper analysis of input data, and generation of proper output command signals.

(7) Operation of the data compression system, including verification of input-output correlation.

(8) Operation of the memory system including input and output address and interrogation interfaces.

(9) Operation of the command implementation system for all stored commands and random external commands.

(10) Operation of all sensors and instruments.

(11) Operation of thermal control subsystem.

4.4.5 FLIGHT PROTOTYPE TESTING

The flight prototype will incorporate all of the changes found necessary from the engineering prototype testing, feasible modifications desired by participating scientists, changes for interface compatibility, etc., and will include all diagnostic instrumentations required for checkout and condition monitoring during launch, transit, and Mars surface operation. It will be of planned flight configuration except as minor changes may be found necessary during testing. This prototype will be fabricated from sterilization qualified components, and will be processed exactly as planned for the flight units.

The first of these prototypes will be assembled and sterilized, and then subjected to the complete simulated mission, much as described for the engineering prototype in Paragraph 4.4.4. This will include multiple cycling of all systems to reveal any short term defects requiring change for the qualification units.

Another prototype model will be assembled and sterilized complete with a capsule or capsule simulator and subjected to simulated prelaunch, launch, transit, and entry environments to duplicate interface effects. After these tests it will be subjected to a simulated landing cycle, including impact; erection; deployment of experiments, sensors, sampling system, etc.; and initiation of the experiments. For this test, some adjustments might be required to allow for the difference in the Earth and Mars environments, i.e., atmosphere, temperature, radiation, and gravity. It may be desirable to use an airplane or tower drop to most adequately simulate the landing parameters, sampler deployment, and functioning of the equipment and experiments on natural terrain. It is possible that the landing parameters could be adequately simulated in a large space chamber, so that the other mission environments could be more closely duplicated. This would permit operation at a simulated Mars pressure, temperature cycle, atmospheric constituents, radiation, surface characteristics, and possibly wind, sand, and dust environments. The unit would be operated through a number of preprogrammed and commanded experiment cycles with the results compared to standard laboratory tests of the same samples. After the initial tests, this unit would be removed to a specially prepared pressure and temperature simulator for extended life test. The long term wear-out effects would be accelerated by substantially continuous cycling of the equipment so that data will be available for inclusion in final design changes for the qualification unit. Tests would continue on an intermittent basis to evaluate the effects that are purely time dependent.

Another prototype unit would be used for system integration and interface tests. This unit would be used at the sterile assembly facility for definition and practice of the sterilization and capsule assembly procedures. It would also be used in physical and functional interface tests with the associated parts of the system. Complete prototype AGE would be available for these system operations to determine the adequacy of this support equipment.

One prototype unit would be furnished to the Space Flight Operations Facility (SFOF) for development of the operations support procedures and science disciplines that will be used during flight and Mars surface operations. With this unit, the complete operation, control, command, and data analysis procedures would be worked out.

The Earth simulation of the Mars surface operations would be an integral part of the actual Mars mission. At this time, it is not clear whether the Space Flight Operations Facility would include a flight-type ABL, a

complete computer simulation of the system, or both - probably the latter. As the mission progresses, the SFOF ABL would be kept in a condition duplicating the one in operation on Mars, i.e., as specific operations were performed there, they would be duplicated here; if any portion of the system should fail, the failure would be duplicated, etc. As data are analyzed, potential commands would be evaluated on the computer simulator; the selected command sequence would be inserted into the SFOF ABL and the effect evaluated. Such simulation would be essential to system operation.

Simulation of a Voyager mission by an Earth orbit test of a complete system has been considered. Such a test could be very valuable for those systems which are functional during launch, transit, or the entry phase of the mission. However, some question exists as to the value of such a test on those systems which are inoperative during these phases of the mission. For the dormant systems, such as the ABL, the only environment which cannot be simulated on Earth is that of zero-g. All other environments - vibration, thermal, pressure, radiation, etc., can be simulated, and, consequently, the tests can be conducted under controlled and accessible conditions where test results can be readily evaluated. For these reasons it is not immediately evident that an orbital test of the ABL is justified; the final decision must consider the plans for an orbit test for other parts of the system, and tradeoffs of cost, data value, etc.

4.4.6 QUALIFICATION TESTS

The qualification tests are designed to verify the capability of the complete system to accomplish the mission objectives. The qualification unit must be of flight configuration, fabricated and assembled under flight conditions, and subjected to a complete complex of flight environments. A second qualification unit will be required which is not of exact flight configuration but is heavily instrumented for qualification of the terminal heat soak. This unit will contain thermal sensors capable of verifying that the proper temperature cycle was obtained.

4.4.7 FLIGHT CHECKOUT AND ACCEPTANCE TEST

Checkout and acceptance testing of the three flight units will be required. This test phase incorporates a complete functional test sequence, as established during the prototype phase, to verify correctness of manufacture and initial operation of the equipment. This checkout will be performed during assembly and prior to delivery, after delivery in the sterilization chamber, after sterilization and before capsule assembly, and after the integration is complete.

4.5 RELIABILITY PROGRAM

The utlimate value of the ABL system is directly proportional to its reliability. Design innovations or cost reductions are acceptable only when the tradeoff with reliability is favorable. To assure that the final ABL design is an optimum system and meets or exceeds the desired reliability, a forcing reliability program must be introduced at the outset of the development program. A reliability plan in compliance with NASA Reliability Publication NPC 250-1 is described in the following paragraphs.

The reliability program activities support and direct development activities of the ABL, and specific system reviews must be conducted at appropriate milestones during all phases of the program. The prime objective of these reviews is to provide assurance that all possible problem areas are detected and corrected before moving on to the next stage of the design.

4.5.1 RELIABILITY MODEL

Reliability can only be designed into a product; consequently, the ABL reliability program must be initiated during the preliminary design of the system so that the results of reliability analysis are available to the design engineer. During the preliminary design of the ABL, a reliability study will be conducted which establishes a system reliability objective and apportions this objective to appropriate lower assembly levels. This study must define what constitutes "mission success" and relate this definition to a model which incorporates the failure modes and rates of individual subsystems, instruments, and components along with a priority or weighing of each experiment.

Particular emphasis must be placed in the detection and analysis of failure modes with respect to the terminal heat soak. Because of the relatively little data available concerning the long term reliability of heat sterilized components and interfaces, initial failure rates will undoubtedly be based upon engineering estimates. As results are available from the component evaluation and subsystem prototype tests, these estimates will be updated and incorporated in the reliability model.

As soon as the reliability model is established, it can be used for a system analysis to determine which subsystems or components require redundancy because of their criticality to the mission success. Through analysis of the reliability model, those areas will be pointed out where redundancy of components, instruments, or even complete experiments is desirable because of high utilization, potential failure rates, or catastrophic results of improper operation. By conducting a tradeoff between reliability and system weight, size, and capability, an optimum complex of instruments and equipment can be chosen. This system will have taken into account the

potential sources of human error, the advantages and disadvantages of utilizing instruments common to more than one experiment, redundancy of critical functions, the optimum sequencing of experiments, etc.

4.5.2 SUBSYSTEM EVALUATION

During the subsystem development, the reliability component specialists will assist designers in selection, application, and procurement of detail parts, reviewing each part as it is used to assure proper part applications. Only parts that have a proven high reliability and that have been qualified to the expected environmental conditions can be used. Particular emphasis must be placed on selecting parts and materials which (1) will not be degraded or damaged by sterilization, and (2) have life times well in excess of that required, so that they can, with high probability, survive from final assembly through the two year operating period.

As results are made available from the component and subsystems tests, the reliability model will be updated to reflect the new data. The effects upon system reliability of these new data will be examined, and if the reliability analyses indicate that the objectives are not being met, the equipment design will be examined for possible modification, design simplification, or further addition of redundancy.

4.5.3 SYSTEM EVALUATION

At the conclusion of the engineering prototype test program a re-evaluation of the system reliability can be conducted and its conclusions and recommendations included in the flight prototype design. Throughout the design of the flight prototype the reliability engineers must be actively evaluating and investigating the impact of any design change upon system reliability.

After the design of the flight prototype, the overall level of reliability which the ABL will possess will have been established. Continued surveillance of the test programs and further identification of failure modes will be actively pursued; however, if the reliability program conducted in the earlier stages of development was successful, the remainder of the reliability program will have a monitoring rather than active function upon the overall system reliability.

4.5.4 FAILURE RECURRENCE PREVENTION PROGRAM

During the complete program, the reliability engineers closely monitor the results of the test programs and actively engage in a failure recurrence prevention program. This program provides the necessary discipline and procedures to report all malfunctions and discrepancies, to identify problem areas, to isolate causes of failures, to document the implementation of corrective actions, and to monitor the effectiveness of corrective actions. Additionally, the program provides for the collection and

retention of all forms of reliability data for future review and analysis. A failure report will be written for every failure that occurs. Immediate failure analysis action will then be initiated to accurately determine the mode and cause of failure. If corrective action is required, feedback is made to the responsible organization and systematic followup is accomplished to assure that adequate and timely action is taken.

SECTION 5

SUPPORTING AND RELATED PROGRAMS

5.1 VOYAGER CAPSULE PROGRAM

Development of the Voyager capsule for early (1971) mission is currently under study by NASA/JPL. It is planned to conduct a preliminary design study phase during 1965-1966 to establish basic 1971 capsule configuration and operational modes and to define the capsule interfaces with the spacecraft and with its science payload.

Preliminary estimates call for a 2,300-pound capsule for the 1971 (and probably 1973) mission and a 4,500 to 6,000-pound configuration for 1975 and later. It is expected that the smaller capsule will be accompanied by a spacecraft/orbiter, but the additional weight for the 1975 capsule will be accommodated by converting the spacecraft to a flyby mode with elimination of its retropropulsion capability. Thus, the capsule would enter the Mars atmosphere by direct flight rather than from orbital separation.

Possible variations in these modes are given elsewhere in this report, such as tradeoffs of weight for operational lifetime on Mars or for precision of landing site attainability, deployment of multiple capsules versus a single capsule to cover multiple landing sites, etc.

Overall design of the capsule is severly influenced by changes in the Mars atmosphere as our knowledge of the atmosphere increases. This design in turn influences capsule interfaces with the ABL and with the spacecraft. In general, decrease in surface atmospheric pressure (density) makes atmospheric deceleration more difficult and requires more weight which reduces the weight of the capsule science payload.

Initial evaluation of the ABL/capsule interfaces begins as a part of the ABL preliminary design in mid 1966. This is indicated on the Program Schedule (Figure 3). At mid 1967, the preliminary definition of the inter-interface is available.

Timing of capsule development initiation requires a difficult decision. Since the capsule design is strongly influenced by the Mars atmosphere, it is desirable to delay the start of development as long as possible so that the best information is available. On the other hand, the capsule represents relatively long lead time development problems, so that the risk is increased with delay.

The current data from the Mariner 4 mission are the best available, and have resulted in significant revision of earlier opinions concerning the Mars atmosphere, which were based on observations from Earth. It is possible that continued observations from Earth may confirm that the Mariner data are valid, but it is quite unlikely that such additional data would further refine the Mariner data.

The next close observation of Mars will be at the 1969 opportunity with a Voyager flyby and possible entry probe, according to current planning. These data will become available in late 1969 or early 1970. If these data required a major revision in entry and landing system techniques, it could have significant effect on the schedule. A more reasonable refinement of the atmospheric parameters would influence the heatshield shape and characteristics without schedule change or major effect on functional subsystems.

It is proposed that the initial capsule development start with the initial interface definition in mid 1967. Primary effort would be placed on the functional subsystems--communications, power supply, etc,--which like the ABL, remain the same over a broad range of vehicle size and shape. The capsule entry configuration would be developed to the level that permits interface mockups to be available for the interface tests with the ABL engineering prototype at mid 1970.

Any new data from the 1969 Voyager would be available at that time. Using the data from the interface tests and the best data then available on the Mars atmosphere, the final design of the entry configuration can continue on firm requirements. This allows about 2 years for completion of capsule prototypes for hard interface tests with the flight prototype ABL at the end of the 1st quarter of 1972. Considering the prior and parallel development of entry capsule technology for the 1971 and 1973 missions, and the early development of functional subsystems, availability of the flight capsules for assembly in the 3rd quarter of 1974 is feasible. Clearly, information from the 1971 or 1973 mission can have only very minor influence on the capsule design, and may have only a go or no-go effect.

5.2 SPACE FLIGHT OPERATIONS PROGRAM

The ABL development will require a parallel program for the development of ground based support and operation facilities to carry out the mission. Extensive near-real-time data analysis and decision making by the principal investigators are required to realize the full potential of the operating laboratory. This will require development of facilities, equipment, and extensive personnel training to make the maximum use of data that is obtained on a sequential basis, and to determine the most reasonable and most productive operational commands for continued experimentation. These facilities will be incorporated in the SFOF to be used for the mission.

So that the ABL can be properly controlled, the SFOF would be provided with a Mars operation duplicator and command generation simulators, as described in the program plan. To support the duplicator operation, provision is required for near-real-time analysis of data from the ABL. This requires relatively continuous participation of principal investigators during portions of the experiment cycle. From these data analyses, potential redirection of the experiments will be generated, and the corresponding commands formulated.

To evaluate the effects of a large number of potential commands, the ABL may be simulated by a computer. The effects could then be quickly checked and the optimum command sequences selected. The actual effect of the command would be determined by insertion into a test ABL, and the effects evaluated. When confirmed, the command would be transmitted to the Mars ABL and the duplicator.

A supporting program is necessary to develop the appropriate facility items and provide for development of techniques for their use. This program would start about mid 1970 when the ABL integrated system capability is relatively well established. It would continue through the complete Mars mission and subsequent evaluation of mission results.

5.3 TECHNOLOGY AND RESEARCH PROGRAMS

It is essential that areas of required technology to support ABL be identified during preliminary design studies so that adequate resources can be provided to develop the necessary technology. Some of the areas, already identified in the current ABL study, are discussed in the following paragraphs.

5.3.1 STERILIZATION

Sterilization standards and procedures are established by NASA/JPL and applied to the ABL and to other elements of the Voyager capsule. ABL development must be kept flexible to be responsive to possible modifications in sterilization rules.

Justification of sterilization constraints upon ABL are not considered a part of the ABL program. The philosophy to be followed is that adherence to the established procedures will ensure sterilization, and that verification of procedural conformity is sufficient to qualify flight hardware. In terms of current sterilization procedures, thermal soaking is verified by thermal design and thermal measurements. All interior portions of the ABL are considered sterilized when they have been exposed to the required temperature-time cycle.

As a supporting technology, it is necessary that continuing sterilization research be supported to verify or modify the established procedures, with a goal of relaxing requirements, if possible, so as to minimize adverse effects on ABL components and materials. Indicated avenues which could be pursued include synergistic combination of two or more sterilization procedures, each of which is less stringent and less productive than current procedures, or possibly a tradeoff of longer time treatment at lower intensity (lower temperature), etc.

Supporting research is required for assay techniques to verify adequacy of sterilization procedures. Assay methods must be developed which are appropriate to the ABL complement of components. After that comes development of techniques for monitoring and controlling contamination in the assembly and testing or checkout facilities.

By the current planning, several payloads will be landed on the surface of Mars prior to the ABL. It is presumed that these earlier missions will develop many of the sterilization techniques and solve many of the associated problems prior to the ABL program. However, because of the nature of the ABL, a number of special problems associated with biological instrumentation and materials will undoubtedly be revealed. Identification of needs for development of parts and materials which are compatible with sterilization procedures will be a major portion of the early effort. Such items will be identified in a qualified and preferred list from which subsystems can be designed for the ABL.

5.3.2 COMPONENT DEVELOPMENT

Identification of component development requirements will be made early in the ABL preliminary design period. It is expected that significant improvements will be possible in electronic microminiaturization with consequent reductions in weight and volume of data processing and communications equipment. A major candidate for continuing microminiaturization appears to be logic type circuitry, with advances in micromodule assembly technology playing a key role.

Additional areas for potential advances in computer technology include data processor operational speeds, material selection and design techniques for memory units and bulk data storage devices, and assembly and inspection techniques. Detailed study is recommended for application of data compression methodology.

Advances in microelectronics are also directly applicable to instrumentation design and construction. Close coordination during instrument development will permit advantage to be taken of such technology advances.

5.3.3 MARS ECOLOGY RESEARCH

It is possible to simulate many of the known Mars surface physical characteristics in a laboratory chamber in which Mars soil, temperature, atmosphere, etc., are controlled cyclicly to provide a Mars-like environment in which terrestrial organisms are seeded. Research with such a chamber has begun at Ames Research Center under direction of Dr. Richard S. Young.

The Mars ecology chamber permits studies such as evaluation of specific microorganism survival and growth characteristics with varying degrees of climatic severity, thus simulating seasonal and latitude effects and suggesting possible microclimate variations in microorganism distribution. Other possible research studies involve variation in assumed moisture content, location, and availability under Mars temperature and soil permeability conditions.

Current studies have concentrated on subsurface water migration as a function of permafrost zones associated with the polar caps. An important area of study is the vertical ecology under changing conditions at a given latitude. Simulation of vertical cuts may provide important information affecting optimum sampling depths, measurable conditions as a function of depth that relate to optimum sampling zones, or other information of importance to ABL experiment design. Pursuit of such research programs is urgently recommended.

5.4 EFFECTS OF OTHER PROGRAMS

It can be expected that additional Mars data will be provided during the period 1965-1975 which may influence decision on the 1975 mission and on the ABL. These data may come from Earth-based astronomical observations, from near-Earth astronomical observations based on balloon or satellite instrumentation, and from Mariner and early Voyager missions. At the present, the probability of obtaining significant Mars observations from the moon during Apollo lunar operations does not appear high.

Mars observations are inherently coupled to Mars opposition periods, spread between 1965 and 1975 into approximately 26 month intervals. Analysis of data requires several days up to many months, although preliminary results are sometimes available much sooner.

It appears likely that major environmental Mars data are well enough established that additional observations will probably narrow the range of uncertainty but not greatly influence ABL design. The most probable result would be to improve ABL performance by permitting better definition of instrumentation design requirements. Most important uncertainties are atmospheric parameters which strongly influence capsule design. ABL design may be secondarily affected by such changes, principally by possible adjustment in overall size and weight limitations.

Improved knowledge of Mars dimensional and orbital parameters will permit more reliable prediction of landing site and time. These data will most probably arise from current analysis of Mariner 4 data and from pre-1975 Voyager missions.

Increased confidence in ABL ability to deploy and obtain samples, as planned, will come from information that 1971 and 1973 Voyager landers have successfully survived landing and operated on the Mars surface. Surface unknowns which have greatest effect on such survival, include surface winds, surface topography and load-bearing characteristics, and dust bombardment. Some of these data may be deduced from nonlander observations (flyby or orbiter).

5.5 SPECIAL FACILITIES

Specialized facilities and major equipment are required for ABL development, fabrication, test, sterilization, and incorporation into the Voyager spacecraft system. These items are needed at the ABL systems contractor location and at NASA/JPL sites.

5.5.1 CLEAN AND STERILE ASSEMBLY

Current assembly requirements call for a Class 100 vertical laminar flow cleanroom. Such a facility will be completed in 1966 at the Aeronutronic Division Newport Beach location where it will be used to accumulate adequate

experience in operation and in monitoring contamination control before it is used in critical assembly operations. ABL instrumentation, components, and subassemblies will be developed and assembled, as required, in this facility. Design and proof-testing of the facility will proceed concurrently with the design of parts requiring it. Facilities will be specifically tailored to requirements of the parts assembled therein.

In the course of time, cleanroom requirements will be modified both with respect to specific procedures for use and with respect to categories of assemblies which may require special or different facilities. Requirements will be continually reviewed and appropriate facilities provided as needed.

For those components and subsystems requiring thermal isolation for protection during the terminal sterilization process and requiring sterile assembly before it, a suitable sterile assembly facility will be developed. Design and proof-testing of the sterile assembly facility and design of the parts requiring it will proceed concurrently as in the case of the clean assembly facility.

5.5.2 TERMINAL STERILIZATION AND HANDLING EQUIPMENT

It is assumed that overall capsule and ABL terminal sterilization (both prototype and flight units) will be conducted at a NASA facility to which the clean assembled ABL is transported for mating with the capsule. The same or a similar facility will be used for the more stringent qualification testing of flight prototype hardware, with higher temperature and increased time cycling.

Transportation between assembly facility and sterilization facility will be in special equipment designed for protecting and maintaining cleanliness. Subsequent transportation for testing and checkout and to the launch complex will require similar equipment for the capsule/ABL combination which protects and maintains sterility. Design of the above handling equipment requires consideration of the presence of RTG power supplies and the accompanying radiation shielding and heat dissipation needs, and also the needs for checkout and integration of ABL with capsule and spacecraft electrical and mechanical systems.

5.5.3 TEST OPERATIONS FACILITIES AND EQUIPMENT

Special facilities requirements for clean test operations are not fundamentally different from those required for clean assembly. The greatest additional impact on test facilities requirements will be those concerned with sterile proof testing of prototype capsules, and qualification testing of the flight model capsule, where in each case the tests must be performed in a sterile manner. In testing various modes of operation of the life detection components, resterilization of the proof test prototype may be required. Facilities associated with sterile test operations must be analyzed beginning in 1967 with proof-testing in mid 1969.

5.5.4 MARS ENVIRONMENT SIMULATORS AND MARS OPERATION DUPLICATOR

Mars Environment Simulator facilities are required to enclose the performance and life test prototype ABL units during their respective test sequences. The chambers must provide adequate simulation of Mars environmental conditions, such as diurnal temperature cycling and atmosphere composition, and possibly additional characteristics such as atmospheric pressure and insolation cycling. Detailed functional testing must be conducted in the major space chamber simulation facility at JPL where the highest degree of simulation is undertaken.

The chambers must be capable of preventing accidental introduction of materials which would bias the performance or life test results. In this sense, the chamber must be sterile and present a sterile barrier around the ABL to external microorganisms.

The Mars Operation Duplicator is an installation of the Space Flight Operations Facility in which operational configuration of the flight capsule is maintained as a duplicate of Mars conditions as closely as possible in real time. This is discussed in Paragraph 5.2.

5.5.5 CENTAUR COMBINED SYSTEMS TEST FACILITY

It is proposed to utilize, if possible, the existing NASA Centaur Spacecraft Combined System Test Facility operated in San Diego by General Dynamics/ Convair for joint testing of the Centaur third stage launch vehicle and the Voyager spacecraft. Testing comprises mechanical and electrical compatibility verification and simultaneous operation of Centaur and Voyager systems in a real time simulation of launch operations from assembly and checkout through separation of the spacecraft into interplanetary trajectory. Further extension of the tests would cover separation of capsule from spacecraft near Mars. In all cases, ABL systems are monitored for possible interference or incompatibility, and a realistic test of ABL effects on the Centaur/ Voyager Spacecraft/Capsule combination. Operation of the Combined System Test Facility may extend from prototype testing through flight unit testing.

SECTION 6

PROGRAM COSTS

6.1 BASIS OF COSTS

The program cost estimates includes herein are based on the program plan described in Section 4 of this volume. The summary PERT schedule was used as a basis for the costs; each of the events was evaluated, and an average effort level estimated for the appropriate function time indicated. For continuing support functions, such as program management, reliability, manufacturing support, etc., previously experienced factors were used with appropriate adjustment corresponding to the nature of the ABL program.

The PERT chart prepared for this program plan is of a summary nature. As a result, the cost estimate summary tended to show relative discontinuities as major events occurred. In the data presented in this section, the data were smoothed to present a more realistic evaluation, while retaining the same total level and substantially the same rate.

The cost estimates are based on the development and flight program for the ABL itself as defined in Section 3 of this volume. That is, it considers the scientific instruments, chemical processing system, sampling system, sequence and control system, data processing, analysis, and storage system, and the integration of these into a working ABL system. It does not include the associated lander systems, such as communications, power supply, lander structure, etc. It is presumed that the programs for these lander subsystems would be separately funded.

The science definition program is described in the program plan. On the PERT chart, a number of the associated events are shown in a shaded area. These tasks include development of the science philosophy, preparation

and release of the AFO, selection of principal investigators, and other functions assumed to be handled by NASA and/or JPL. Others, including definition of experiments and procedure requirements are presumed to be done by the principal investigators under separate funding. Cost estimates for these designated functions are not included here. It is noted that a number of events and functions are required by the ABL integrator to support this effort; estimates for this scientific, engineering, and administrative support have been included in the ABL cost.

In conduct of the ABL program, a number of breadboard and development prototype subsystems will be built and tested. In the program plan, a number of the hardware systems are separately designated for major tests. This cost estimate is based on the following quantities of major system hardware:

ITEM	QUANTITY
Engineering Prototype	1
Flight Prototype	3
Additional Set of Scientific Instruments	1
Qualification Units	2
Flight Units	3

It is anticipated that the prototype units would be used up in development tests.

Operational Support Equipment (OSE) is included in the costs. It was considered in complete sets with distribution as follows:

ABL Contractor	1 set
JPL	1 set
Sterile Assembly Facility	1 set
Launch Facility	1 set

It is clear that identical equipment is not required at all these locations, but the assumption does not significantly affect the total program costs.

6.2 TOTAL PROGRAM COSTS

The total program estimated costs are shown in Figure 5. This is a cumulative curve totaling $106.8 million for the total ABL program. Launch at the 1975 Mars opportunity is assumed, with significant mission operations

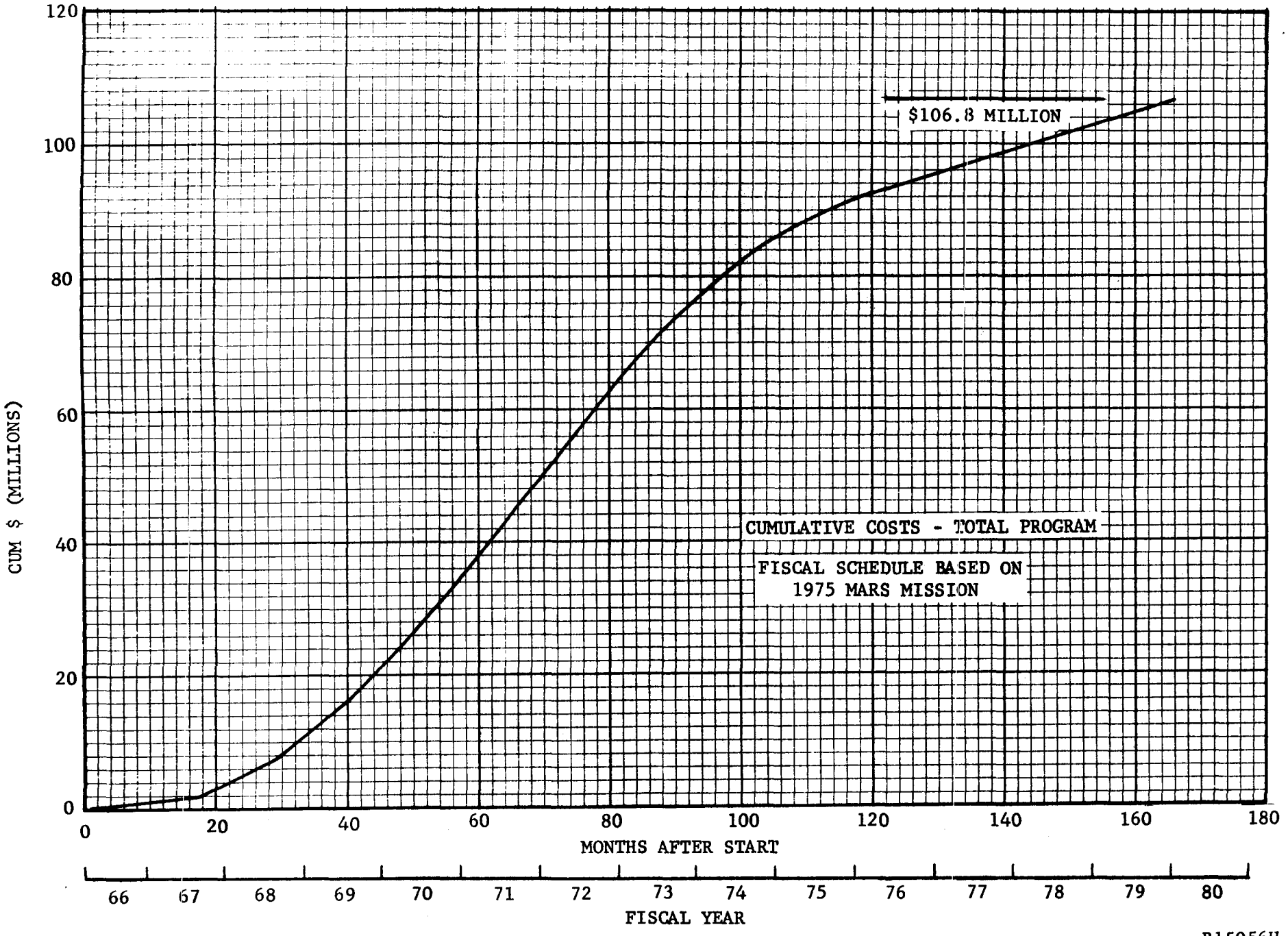


FIGURE 5. ABL PROGRAM COSTS

support being furnished through the 2 year operational life on Mars, and for a mission evaluation period thereafter.

The following estimated cost is tabulated by fiscal year:

ABL COST BY FISCAL YEAR - MILLIONS

FY	$M	FY	$M
1966	0.6	1973	12.9
1967	2.5	1974	9.5
1968	7.6	1975	5.6
1969	10.3	1976	3.9
1970	13.6	1977	3.8
1971	14.4	1978	3.7
1972	14.3	1979	4.1

The major contributer to the cost is manpower. The manpower distribution for the life of the program is shown in Figure 6. This program presumes a relatively low level preliminary design and system definition phase for the first 17 months. At that point, the hardware development and test begins, showing a sharp increase in engineering and technical support. Fabrication of major prototype hardware begins at about the 40th month. The increase in manpower loading rate at that point is largely manufacturing and support personnel. The qualification and flight hardware phase starts at about 80 months, with the accompanying decrease in development engineering manpower level. During flight hardware and launch operations, the manpower decreases to the support level for the mission operations and continues through the complete mission.

The manpower estimates are made on the basis of the complete job; no distinction is made between prime- and sub-contractor personnel. It is clear that significant subcontracting would occur, e.g., for some of the scientific instruments, where specialized experience indicates.

6.3 FEASIBILITY PROTOTYPE COSTS

It is of interest to examine the cost of a partial program that carries the development to the first complete engineering prototype ABL. It is presumed that such a prototype would be used to determine the feasibility

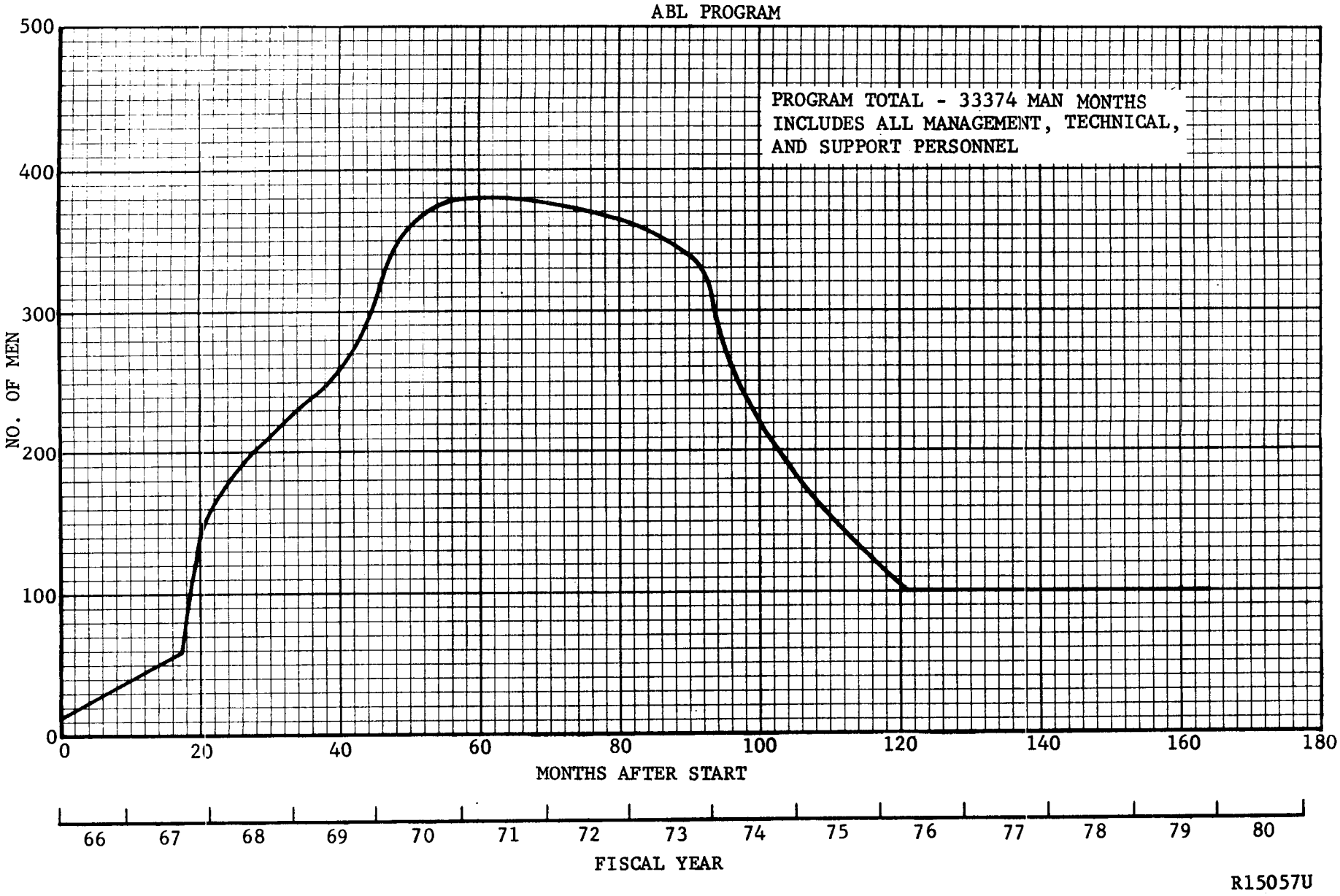


FIGURE 6. ABL PROGRAM

of the ABL concept, with the plan to continue on the same general developmental configuration, if successful. The program cost estimates have been evaluated to arrive at a reasonable estimate for this.

If an engineering prototype only is considered, it is likely that a specific "science definition program," as defined in the program plan herein, would not be conducted. (As noted, funds for support of the principal investigators are not included in this estimate.)

To make the configuration of the feasibility prototype meaningful, a reasonable science evaluation would be required; it is assumed that the science program coordination cost estimates included herein would be used for this.

It is reasonable that the preliminary design program would proceed as for the total plan. Hardware development would start at the same time and at the same level. However, at this point, specific interface coordination with a capsule integrator would not occur as it otherwise would. It is assumed that the sterilization program would proceed, although at a slightly reduced level; sterilization is a too fundamental parameter to be slighted in a feasibility determination. Any effort on following design and development of an improved prototype design would be eliminated, as would such items as mission support planning and equipment, OSE, major checkout procedures and equipment, or other early work aimed at later phases.

The result of this evaluation is shown in Figure 7. The engineering prototype is scheduled for completion at 63 months, and this is retained. The total program costs at that point are $41.7 million. As discussed, a small early reduction in effort occurs because there is no associated capsule program, but there is no significant divergence of cost until about the 50th month. At this point, fairly heavy work starts on engineering and design of prototype number 2; at about the same time development of OSE and other mission oriented work begins.

At the completion of the prototype, the total difference in the two programs is about $7.3 million, or a reduction of slightly over 17 percent. If a realistic prototype is developed, as described, it is clear that there is a distinct decision point at about 50 months from start for the ABL itself. The effect on the mission may be more severe in related programs of capsule development, power supply, etc.; from a total system standpoint, such a major decision for the 1975 mission may not be feasible.

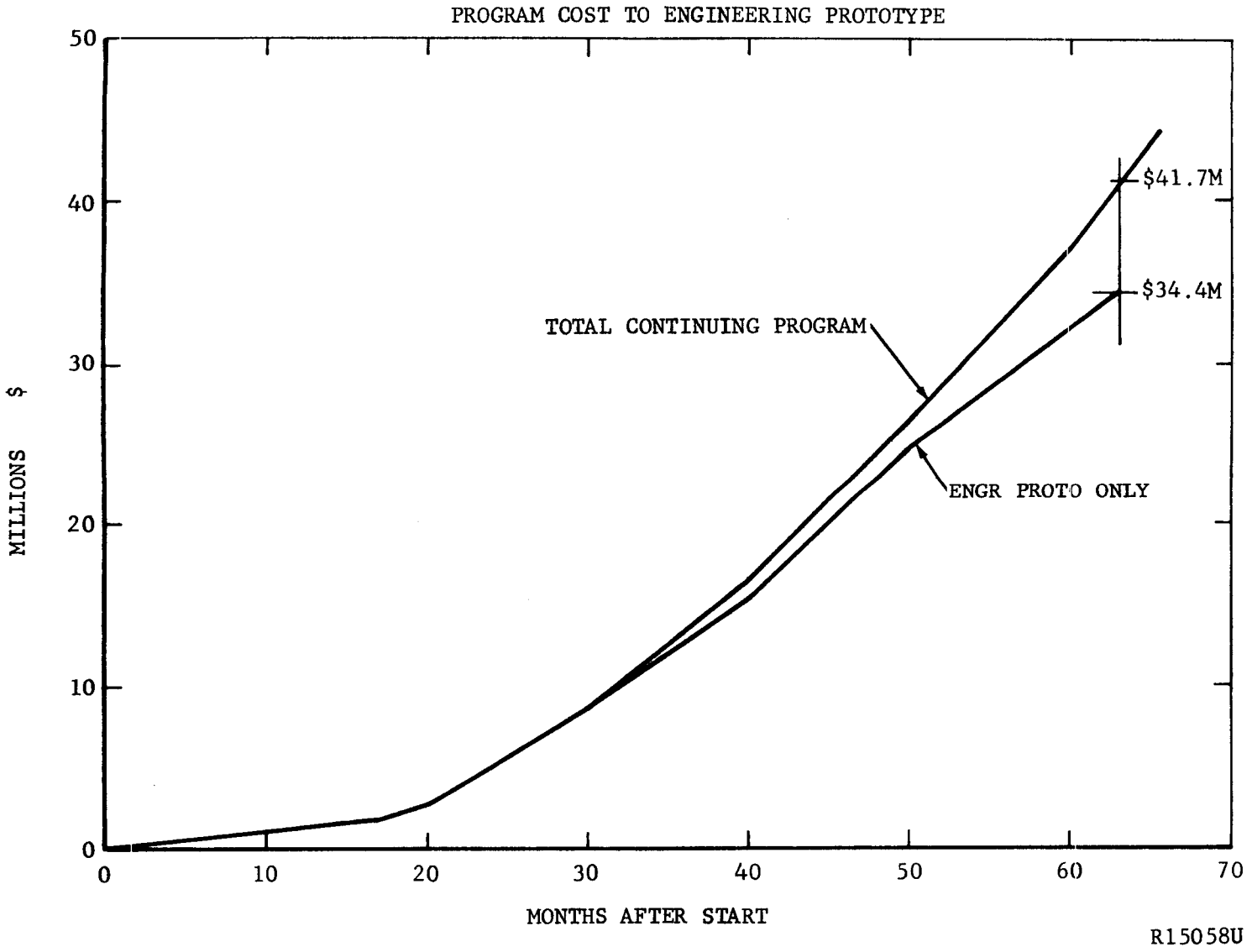


FIGURE 7. PROGRAM COST TO ENGINEERING