Technical Memorandum No. 33-243

Semiannual Review of

Research and Advanced Development

January 1, 1965 to June 30, 1965

Volume I. Supporting Research and Technology for the Office of Space Sciences and Applications, National Aeronautics and Space Administration

Frank E. Goddard, Jr.
Assistant Laboratory Director for
Research and Advanced Development

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

August 15, 1965

BLANK PAGE

PREFACE

This document has been prepared under the direction of the Office of Research and Advanced Development of the Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California.

The Semiannual Review of Research and Advanced Development is published in three volumes directed to the appropriate NASA funding offices:

Volume I	Supporting Research and Technology for the Office of Space Sciences and Applications
Volume II	Supporting Research and Technology for the Office of Advanced Research and Technology
Volume III	Supporting Research and Technology for the Office of Tracking and Data Acquisition (New Systems and Spacecraft Subsystems)

This issue reports progress for the period of January 1 to June 30, Fiscal Year 1965.

BLANK PAGE

PART A. LUNAR AND PLANETARY EXPLORATION

SCIENCE (185)

Instrumentation (185-24)

Space Chemistry (185-37)

PART A. LUNAR AND PLANETARY EXPLORATION (Cont'd)

PART A. LUNAR AND PLANETARY EXPLORATION (Cont'd)

PART A. LUNAR AND PLANETARY EXPLORATION (Cont'd)

PART A. LUNAR AND PLANETARY EXPLORATION (Cont'd)

PART A. LUNAR AND PLANETARY EXPLORATION (Cont'd)

PART A. LUNAR AND PLANETARY EXPLORATION (Cont'd)

PART B. PHYSICS AND ASTRONOMY

PART C. BIOSCIENCE

PART C. BIOSCIENCE (Cont'd)

PART D. MANNED SPACE SCIENCES

INTRODUCTION

This volume contains a review of all supporting research and technology in progress at the Jet Propulsion Laboratory during the period January 1 to June 30, 1965, under direction of the Office of Research and Advanced Development, for the Office of Space Sciences and Applications.

The work units are arranged in numerical sequence by NASA code in each subject section. To locate a desired unit, refer to the Table of Contents under the appropriate subject heading.

Part A
Lunar and Planetary Exploration

SCIENCE (185)

BLANK PAGE

INSTRUMENTATION (185-24)

PULSE HEIGHT ANALYZER DEVELOPMENT
NASA Work Unit 185-24-05-04
JPL 383-32601-2-3230

The objective of the Pulse Height Analyzer Development Program is the design of a general purpose, or universal, pulse height analyzer for space applications. It is expected that the proposed instrument will possess sufficient versatility to lend itself to application by any and all of the presently conceived space radiation experiments that require either pulse height analysis or multiscaler capability.

To ensure the desired versatility, JPL has solicited functional requirements from prominent scientists who might be considered to have a potential need for such an analyzer. Scientific groups contacted include those of Dr. Reines at Case Institute, Dr. Giaconni at American Science and Engineering, Dr. James Van Allen at State University of Iowa, Dr. James Simpson at University of Chicago, Dr. George Ludwig at Goddard Space Flight Center, Dr. Herbert Friedman at Naval Research Laboratories, and others. Requirements have been received from all but two of the groups contacted. Fortunately, the requirements submitted do not appear to be mutually exclusive.

A composite specification is now being generated from the requirements submitted. On completion of an adequate set of design specifications, a contract for the circuit design and breadboarding of the instrument will be placed with a competent company. The Request-For-Proposal packet has already been prepared. JPL will perform contract monitoring and provide technical and contractual liaison of the contract. JPL will also provide technical support by performing in-house investigation of troublesome functional and design problems. The completion of the breadboard will mark the end of Phase I (the circuit design phase) and the beginning of Phase II (the packaging phase) at JPL.

In reality there will be a considerable degree of overlap between the two phases. To accomplish an efficient transition from the first phase to the second phase, bilateral consultation is considered necessary. The circuit designer will be encouraged to use JPL packaging concepts whenever feasible in the breadboard construction. Conversely, once the breadboard has been constructed, it is expected that the designer will be retained as a consultant to ensure against packaging that might prove incompatible with circuit design.

Specifically, the analyzer will feature between 256 and 512 channels of memory storage. The instrument will be capable of dividing its memory in two or three subsections and perform pulse height analysis and multiscaling simultaneously. The instrument will not only tabulate pulses according to height but may also label each analysis with information regarding the direction from which the particle came or the gain of the amplifier used in supplying the pulse to the analog-digital computer for conversion. The most advanced techniques of circuit development will be used to yield a final instrument that will represent the best that the state of the art has to offer. Integrated circuitry, thin film memories, and other current techniques will be considered.

Almost as challenging as the design of the analyzer is the design of the evaluation test equipment. Such equipment must be able to measure the integral and differential linearity of the analyzer, check the logic margins over voltage and temperature extremes, measure the live time (or dead time) of the instrument during operation, and perform other rather sophisticated measurements. That portion of the system necessary for checking integral and differential linearity has already been designed and is now under construction.

The pulse height analyzer development program was funded in FY 1965 under two numbers: the 185 Lunar and Planetary Exploration Number, and the 867 Manned Lunar Science Number. Twenty-five percent was allotted under 185 and the remainder from 867. Funds were made available from one of these offices in April, while expenditures under the other office were not authorized until May.

Because of the rather long lead time required in placing a contract, the design and breadboard contract could not be awarded this fiscal year. However, the funds allotted in FY 1965 have been committed to the design contract that will be awarded in early FY 1966. The contract will likely be incrementally funded.

The accompanying milestone chart (Fig. 1) indicates the tentative schedule as it currently exists. The long-range schedule is shown, rather than detailed milestones for FY 1966, because a finer breakdown of the circuit design phase at this point would be meaningless. Our first milestone and immediate goal is to place the contract as early as practical in FY 1966.

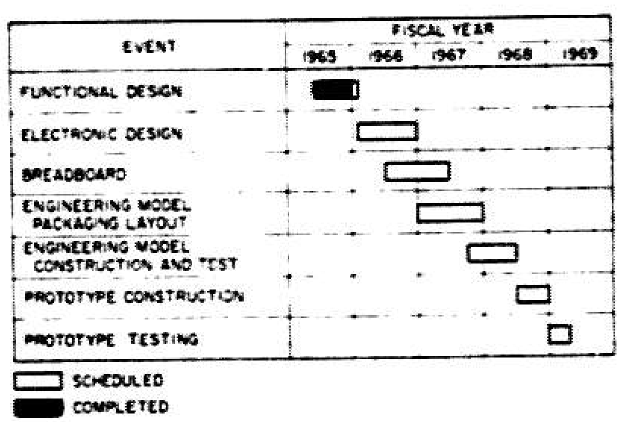


Fig. 1. Estimate of program milestones for pulse height analyzer development program.

SPACE CHEMISTRY (185-37)

INFRARED MULTIPLE DETECTOR SPECTROMETER INSTRUMENT DEVELOPMENT

NASA Work Unit 185-37-20-06; 185-37-20-09
JPL 383-31601-2-3230; 383-32001-2-3290

ACTIVITIES DURING REPORT PERIOD

The High Altitude Aircraft flight with the Scanning Ebert Spectrometer designed for the Mars-MC mission occurred as scheduled in October.

Hardware delivery has been completed on Contracts 950962 and 950968 and tests will be completed on NASA Program 866 in FY 1966.

The GSFC Balloon Flight was in February and the data analysis is in process and will be carried to completion under NASA Program 866 in FY 1966.

Data analysis of the High Altitude Aircraft flight data has not been carried to completion because of the higher quality of the balloon data and schedule commitments for the Balloon Flight.

FUTURE ACTIVITIES PLANNED

This task will be continued in FY 1966 under NASA Program 866.

BLANK PAGE

JPL Technical Memorandum No. 33-243, Vol. I

LUNAR AND PLANETARY X-RAY DIFFRACTION PROGRAM
NASA Work Unit 185-37-20-02; 185-37-20-03
JPL 383-30201-2-3250; 383-30301-2-3290

DATA INTERPRETATION STUDIES

Object

This study is aimed at full evaluation of the extent to which rocks can be analyzed by X-ray diffraction data alone and by diffraction plus partial X-ray spectra. It will provide a background for interpretation of lunar and planetary diffraction data and, conversely, will indicate the best combination of diffractometer optics and operating mode for any given petrological goal.

Recent Accomplishments

1. Determination of minimum detectable levels of minerals per matrix.
2. Systematic analysis of composition-abundance determination for olivines, rock-forming oxides, and alloys.
3. Evaluation of statistical uncertainties of determination of composition vs abundance.
4. Sensitivity of determination of iron content of diffraction sample by fluorescence and diffraction.
5. Devised a method for absorption corrections for iron fluorescence by diffraction data.
6. Short-term proton bombardment of silicates: changes in surface character and luminescence.
7. Effect of slit size on statistical errors vs resolution.

Activities in Progress

1. Systematic study of problems and reproducibility of specimen preparation as they affect quantitative rock analysis
2. Effect of scan speed on data quality.
3. Systematic studies of feldspars and sheet silicates.
4. Long-term proton bombardment.
5. Detectability and quantitative analysis of calcium and potassium in diffraction samples.

COMPONENT EVALUATION

Object

The study has the object of understanding the operational character of potential diffractometer components that are already in hand. This includes operation in a laboratory environment and other environments. It is designed to show areas of scientific weakness and supply data for specifications for improved equipment.

Recent Accomplishments

1. Comparison of operation of all Mark I side window proportional counters in hand as a function of temperature, vacuum, voltage, and input flux.

2. Parametric studies of the beryllium cup response.

3. X-ray tube performance vs temperature.

Activities Planned

1. Studies of specific loading of copper anodes vs temperature.

2. Specifications for new X-ray tube design.

3. Parametric study of diffraction peak characteristics vs divergence in equatorial and focal planes.

4. High voltage power supply research.

5. Mark I system field test.

ADVANCED DIFFRACTOMETER STUDIES

Object

This program has as its objective the generation of a body of knowledge concerning the performance characteristics and general engineering parameters of possible diffractometer configurations and, where appropriate, ancillary instrumentation. The essential goal is the definition of engineering breakpoints in light of the performance parameters required for the solution of given class of petrologic problems. Beside consideration of well-established techniques, investigation of advances in the state of the art that show particular potential is included in the scope of the study. In scientific objectives definition, the advanced diffractometer study interfaces strongly with the data interpretation study discussed below.

Recent Accomplishments

1. Comparison of Bragg-Brentano and Seemann-Bohlin geometries for rock analysis.

2. Preliminary evaluation of radioactive X-ray sources.

3. Evaluation of procedure and problems of ancillary counter for detection of fluorescent X-rays.

4. Discussions, evaluations, suggestions, etc. with MSC contractor on alternative detection systems.

Activities Planned

1. Evaluation of transmission specimen geometry.

2. Complete RA source studies.

3. Studies of films and intensifiers for detectors.

4. Utility and problems of microfocus hot filament source.

SAMPLING SYSTEMS

Object

The Mark I sampler is a subsystem that will provide the diffractometer with satisfactorily selected and prepared rock samples. It will be capable of acquiring multiple samples of either surface dust, solid bedrock, or bedrock beneath a shallow dust overlayer. Its functions consist of simultaneous penetration and pulverization of solid rock, acquisition of bedrock powder and of natural particulate material, transport of the acquired material to the diffractometer, and transfer of a portion of that material into the diffraction analysis position. The sampler device will form an integral part of the diffractometer system.

Recent Accomplishments

Several design schemes are being considered, and tests have been made with breadboard components. The results and the conclusions derived are in print. Fabrication of three complete breadboard samplers, each of which will test different sampler concepts, is now under way.

The current goal is to evaluate the empirical operation of each model so that the comparative performance and problems will be understood. Following testing, sufficient data will be on hand to write specifications for the best system. If and when a diffraction system may be used on an unmanned spacecraft, a prototype sampler can be constructed in a matter of a few months.

REPORTS

A detailed report summarizing the research in the lunar X-ray diffraction program between July 1, 1964 and April 1, 1965 has been published as JPL Technical Memorandum No. 33-218.

BLANK PAGE

INFRARED INTERFEROMETER FLIGHT MODEL/ DRIVE SYSTEM DEVELOPMENT

NASA Work Unit 185-37-20-05
JPL 383-30501-2-3230

ACTIVITIES DURING REPORT PERIOD

A breadboard of the drive system was tested and the system characteristics measured. Drive motors were purchased and characteristics measured. Electronics design of the power amplifier was started.

The results of this work indicated that the present design concepts are adequate but detail designs must be improved to meet the system requirements.

FUTURE ACTIVITIES PLANNED

No future activities are planned because this task is not funded in FY 1966.

BLANK PAGE

INFRARED INTERFEROMETER – SCIENCE FEASIBILITY STUDIES
NASA Work Unit 185-37-20-10; 185-37-20-11
JPL 383-32101-2-3250; 383-32201-2-3290

This work unit is part of a task to develop a flightworthy near-infrared interference spectrometer with a view to use on Voyager missions. The aim is to have sufficient resolution (1 cm^{-1} or better) to resolve the rotational structure in carbon dioxide.

The optical design of the interferometer shown in Fig. 1 (not to scale or proportion) is now under review for a possible patent application.

On the basis of the criteria laid down under this work unit, the fabrication of the optical system has been subcontracted; the cat's eyes to Perkin-Elmer and the beam splitters to Ferson Optics. The servocontrolled drive system and the design and fabrication of the mechanical components for a breadboard are under development at JPL.

The entire optical construction is of fused silica to reduce thermal effects and the motion based on springs to avoid friction effects. For testing, a simple screw drive will be used.

It appears that the detectivity of available PbSe detectors may have been underestimated. If so, then the time required for a single spectrum could be reduced by up to a factor of 50, i.e., 20 sec instead of 1000 sec. This would considerably reduce the vehicular requirements, which previously demanded a quasi-synchronous orbiter to avoid ground-smear. However, by the same token, the data rises sharply and could reach 20,000 bits/sec in the worst case. The mechanical problems of scanning at such speeds could become excessive. Part of the testing program will be aimed at explaining this.

Current FY 1966 schedules call for a completed optical breadboard by the end of the first quarter, testing completed during the second and third quarters and servodrive added at the end of the fourth quarter.

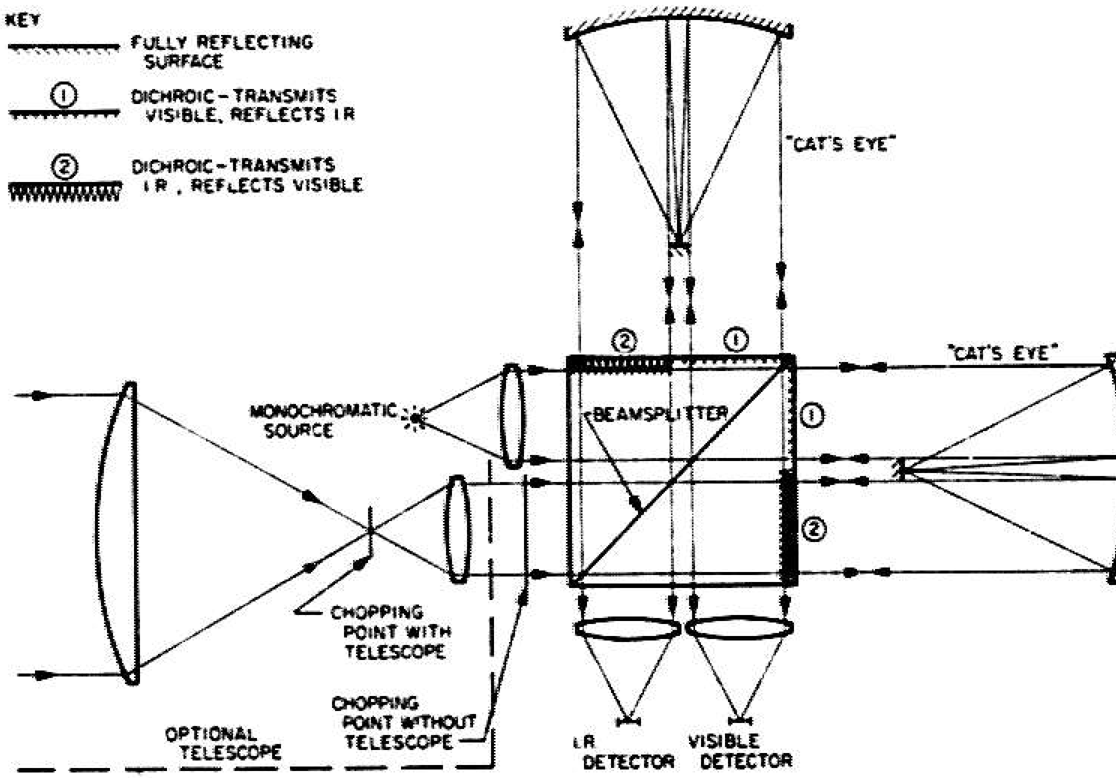


Fig. 1. Optical schematic of infrared interferometer

JPL Technical Memorandum No. 33-243, Vol. I

MICROWAVE RADIOMETRY DEVELOPMENT
NASA Work Unit 185-37-25-01
JPL 383-30901-2-3250

The purpose of this task is to provide microwave radiometry instrumentation for the Planetary Surface and Atmosphere Studies task and to develop techniques applicable to future spacecraft microwave experiments.

The variable frequency radiometer developed for planetary studies of Venus and Jupiter during 1964 (Fig. 1) is undergoing modifications to extend its frequency range. The previous frequency range of 20 to 24 gMc has been extended to 20 to 26 gMc. Extensive calibrations of this radiometer are now underway, and it will be field-tested in a summer observation program at the Table Mountain (Wrightwood) facility.

Antenna patterns were obtained on the Goldstone 30-ft antenna during January 1965 to facilitate data reduction of the Jupiter observations made immediately before that time. A report titled, "Further Antenna Pattern Measurements in the 13-mm Band on the Goldstone 30-foot Antenna," is being published in JPL SPS No. 37-33, Vol. IV and covers details of the measurements. Figure 2 shows the boresighting transmitter equipment used at Tiefort Mountain, approximately 13 mi away, to obtain the antenna patterns.

A procurement requisition with preliminary design parameters was initiated for a 30 to 40 gMc low noise amplifier. This amplifier, in conjunction with the existing 30 to 40 gMc variable frequency radiometer and a precision 18-ft antenna, will allow year round observations of Venus and Jupiter. No contractor has as yet been selected for fabricating the amplifier. It is anticipated the cost of this item will be approximately $70,000.

Future plans call for a continued observation program at Goldstone using the modified 20 to 26 gMc variable frequency radiometer; modification and improvement of the variable frequency (30 to 40 gMc) scanning radiometer by the addition of a low-noise amplifier, and installation on a precision antenna to be procured. Evaluation of the 30 to 40 gMc radiometer will be done in the framework of a scientific observation program aimed at Venus and Jupiter from the Table Mountain facility.

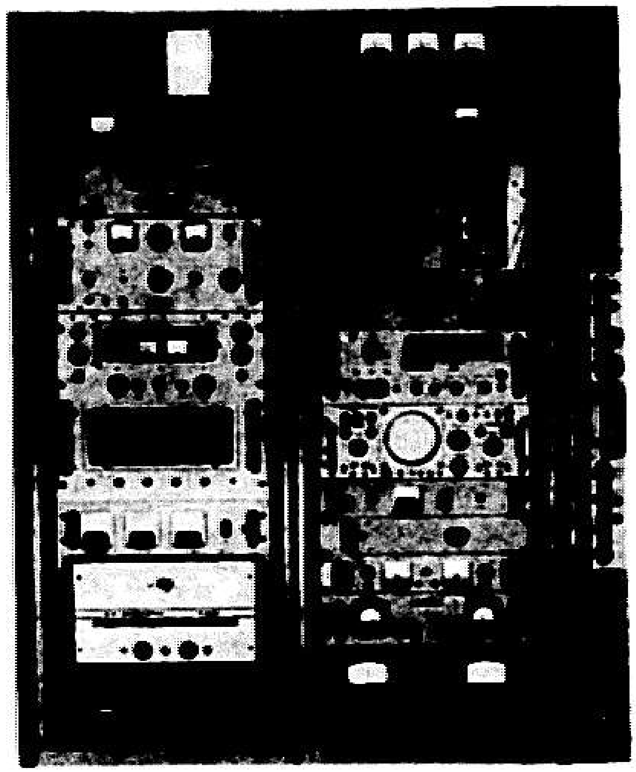


Fig. 1. Variable-frequency radiometer

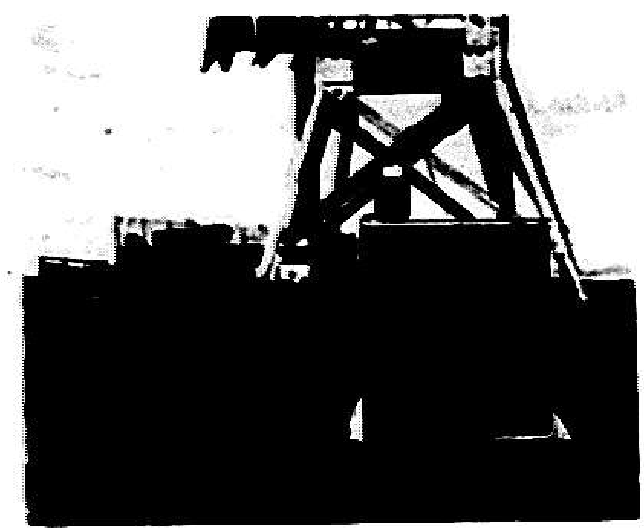


Fig. 2. Boresighting transmitter equipment

JPL Technical Memorandum No. 33-243, Vol. I

MASS SPECTROMETRY ADVANCED STUDIES
NASA Work Unit 185-37-26-01
JPL 383-31001-2-3250

LUNAR ATMOSPHERE MASS SPECTROMETER

Work has continued on the development of a cold electron emitter for the quadrupole mass spectrometer using a radioactive primary source of electrons and electron multiplication to achieve suitable ionizing currents. A titanium-doped tin oxide surface is being tested for secondary electron yields with titanium tritide foil as the source of primary electrons. Figure 1 is a schematic of the system being used to prepare conductive tin oxide coatings on glass test plates. Titanium is later vacuum-deposited over the tin oxide and then oxidized on a hot plate. Figure 2 shows the test jig and two coated glass plates used in the experiments. Strong secondary electron currents have been observed but stability problems caused by arcing at the contact to the oxide coating are now being investigated. The AVCO Corporation is researching similar coating methods and is now coating some electron source parts for JPL on a no-cost basis.

An ion-counting system has been completely tested and allows count rates as high as 10^6 random counts per second to be observed with background rates as low as 2 counts per second. Spherical grid focusing is being used in front of the electron multiplier ion detector and has increased ion transmission to the first dynode by a factor of five. The grid system, however, has not been optimized. Phosphor imaging techniques will be used in the first quarter of FY 1966 to accurately characterize the focusing properties of the system. The electron multiplier-grid system is shown in Fig. 3.

Our efforts on injecting random noise into the quadrupole mass filter are showing great promise. Figure 4 shows the results of injecting a pure frequency of 520 kc, 1 v rms on two of the quadrupole rods. The main drive frequency of the quadrupole was 1.42 Mc with 800 v peak-to-peak at mass 40. The two peaks shown are mass 40 and mass 28 with the resolution purposely degraded. As can be seen, the extremely small injected voltage completely attenuates the ion beam (dip in the center of each peak). It has been experimentally determined that to totally reject the same ion beam, a 5-v noise signal is required. Figure 5 is a schematic of the main oscillator and noise injection circuit being used. Figure 6 is a schematic of the notched noise circuit under construction.

On completion of a usable cold electron emitter, gas-solid interaction studies will begin. Request for bids have been let out for a multichannel analyzer readout system so the quadrupole mass filter can follow transient phenomena and print out data in the same format as that acquired in a flight experiment.

PLANETARY ATMOSPHERE MASS SPECTROMETER

Calibration of the magnetic sector mass spectrometer has continued in the last 6 mo. Little or no effort has been expended on the AFCRL quadrupole because the earliest conceivable mission for a Mars atmospheric compositional analysis is a Voyager landing capsule. Because the quadrupole breadboard does not have a pump, it is therefore suitable only for short term or descent analysis.

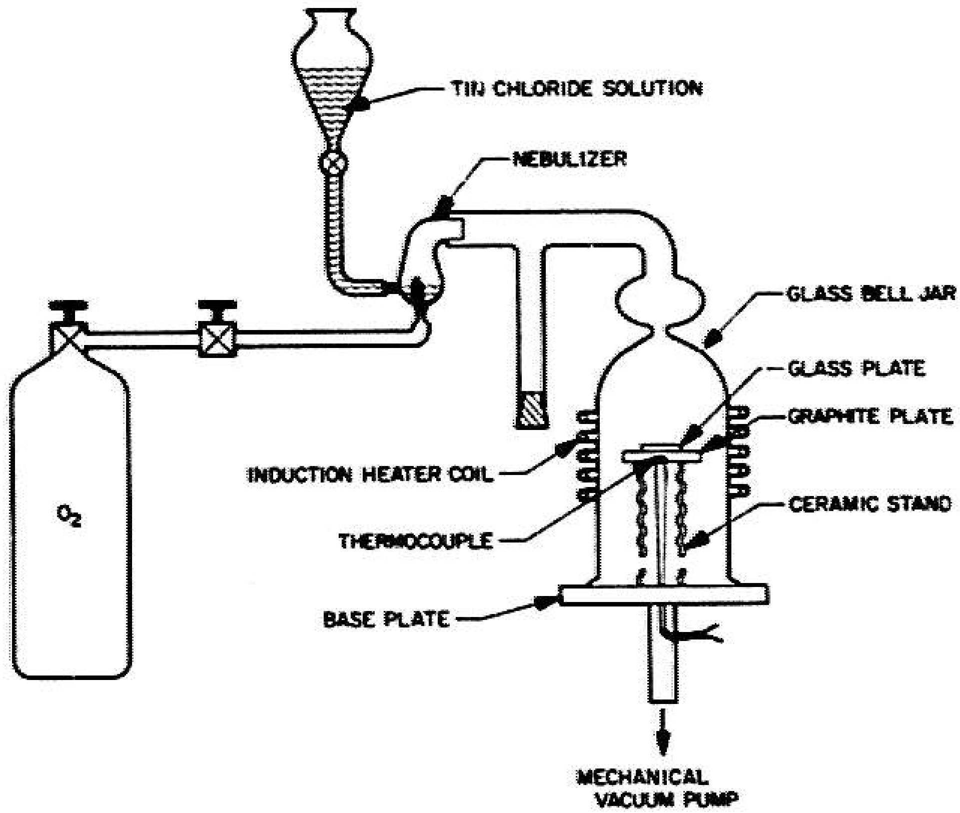


Fig. 1. Tin oxide coating system

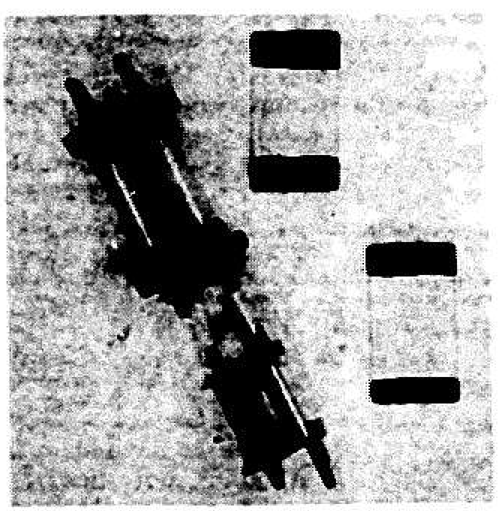


Fig. 2. Test jig for cold electron source

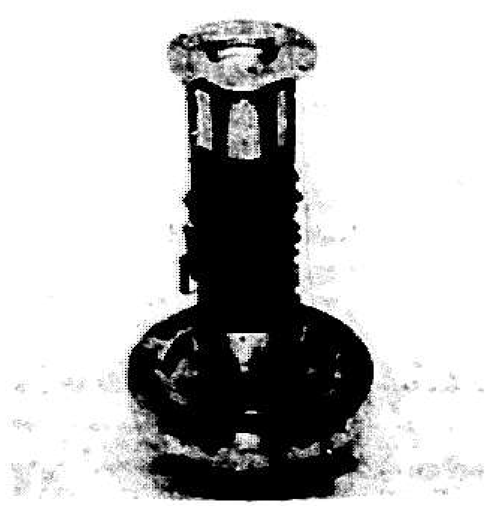


Fig. 3. Ion counting collector system for lunar atmosphere mass spectrometer

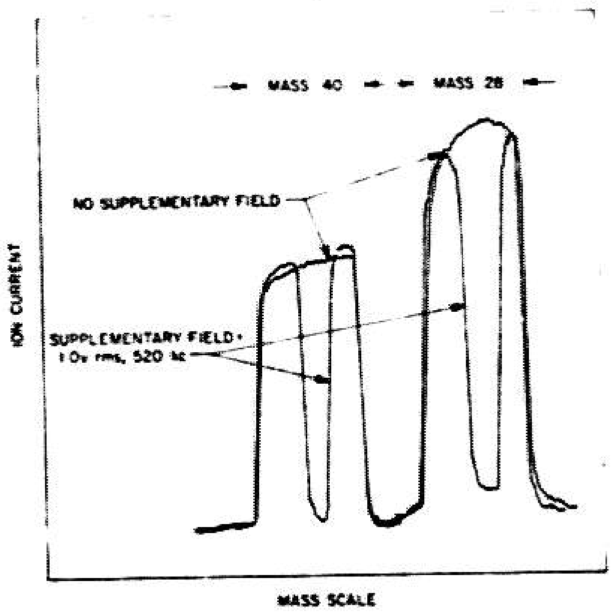


Fig. 4. Results of injecting a pure frequency (520 Kc. 1 v rms) on two of the quadrapole rods.

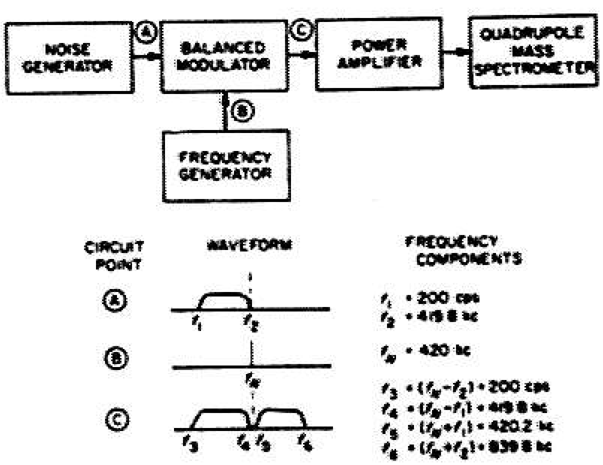


Fig. 5. Notched noise injection circuit for quadrupole mass spectrometer

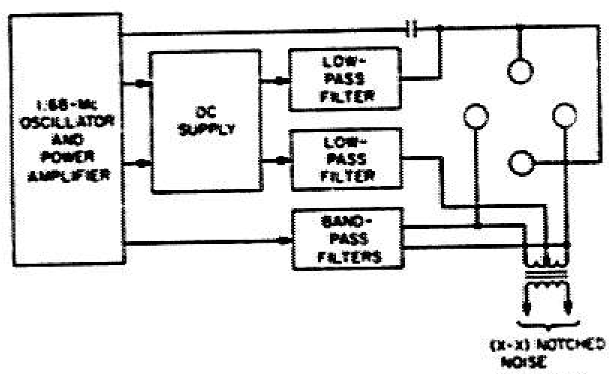


Fig. 6. Notched noise circuit for quadrupole mass spectrometer

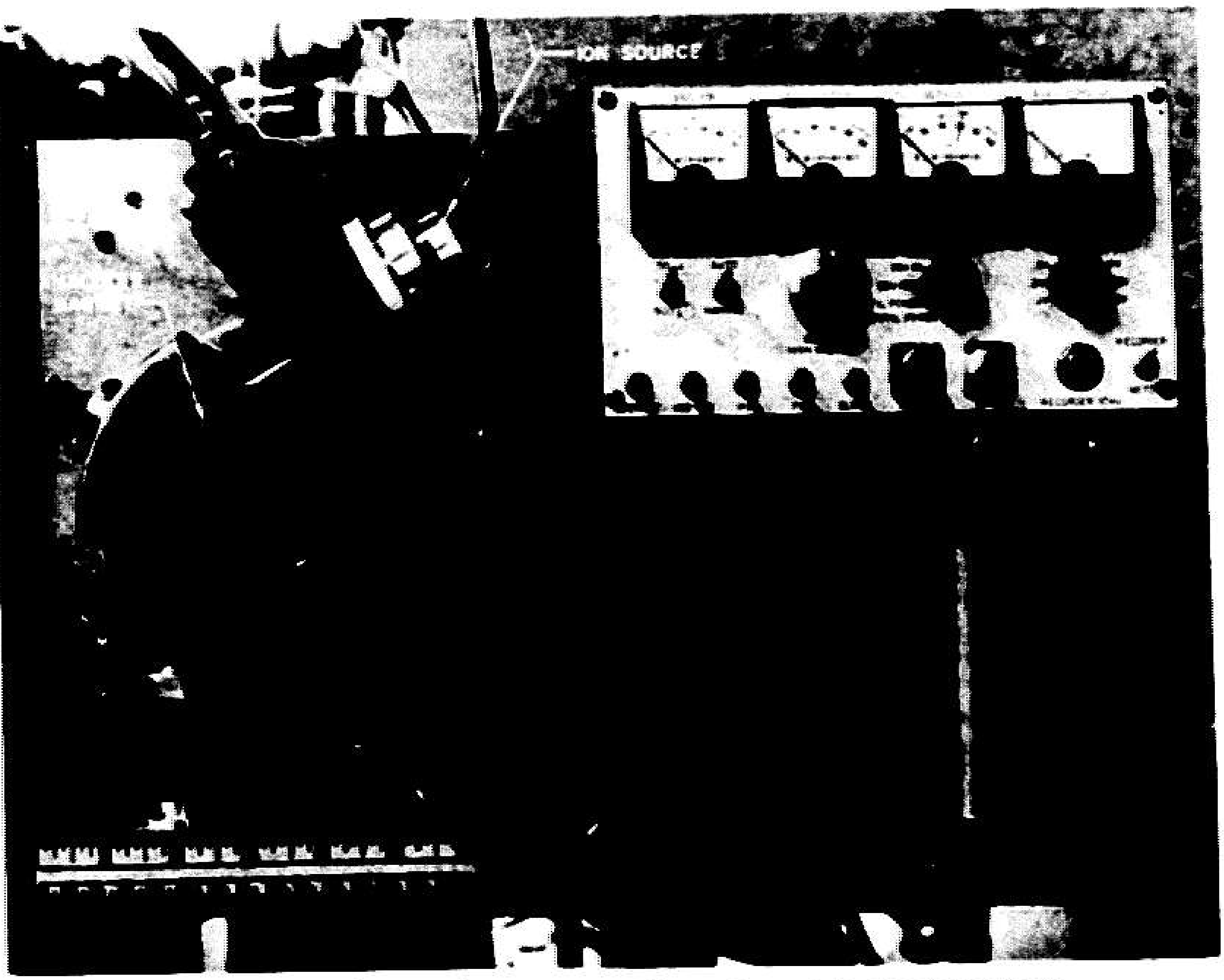


Fig. 7. 1-3/4 in., 60 deg magnetic sector mass spectrometer

Figure 7 is a photograph of the magnetic sector breadboard mass spectrometer constructed by Professor A. O. C. Nier at the University of Minnesota. Figure 8 shows data indicating the degree of stability of multiple ionization and fragmentation in this instrument. The large deviations from the mean at the low-intensity levels can be attributed to poor measurement accuracy caused by excessive ripple from a faulty 28-v power supply. Figure 9 shows a slight variation of the carbon dioxide fragmentation pattern while using argon as a control gas. This effect was not observed when the instrument was new. It is believed due to surface contamination, and the instrument is now being cleaned to eliminate this phenomena. Digital data readout equipment has been ordered, and experimentation on various modes of data handling will begin on its arrival. To date only theoretical analyses have been made pertaining to this phase of the task.

It is planned to fly the breadboard mass spectrometer in a U-2 aircraft at altitudes of between 70,000 and 100,000 ft in September. The atmospheric pressures at this altitude are comparable to the best Mars atmospheric models to date. The molecular leak reliability and ion pump memory problems are expected to be solved by this time. The data from this flight is expected to demonstrate the functional capability of the instrument for a Mars <u>Voyager</u> mission.

On receipt of the NASA <u>Voyager</u> AFO preparations are being made to propose the magnetic sector mass spectrometer for a Mars compositional analysis probe. Professor A. O. C. Nier, Dr. Gerhard F. Schilling, and Mr. C. E. Giffin are the anticipated experimenters. In anticipation of this flight opportunity, the engineering efforts on this instrument (packaging, impact testing, sterilization, etc.) are being considerably accelerated.

During the first quarter of FY 1966 the laboratory in which this work is being performed will be moved from a JPL annex to the main Laboratory. It is expected that close to 1 mo will be lost during the moving process.

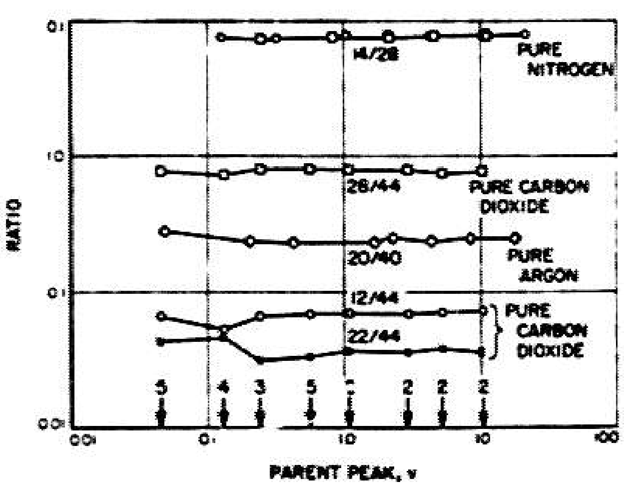


Fig. 8. Multiple ionization and fragmentation ratios for magnetic sector mass spectrometer

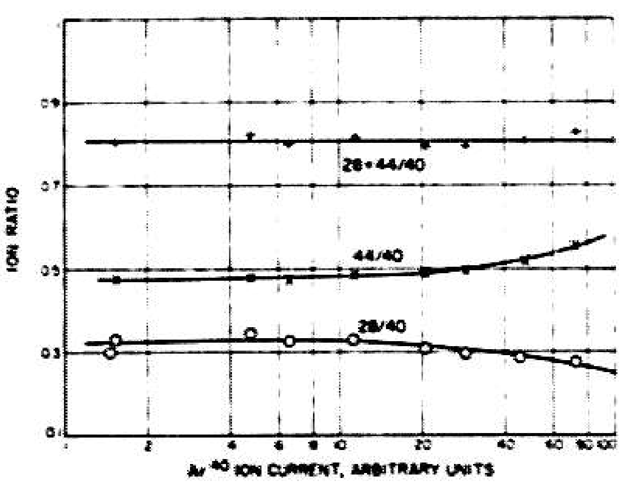


Fig. 9. Fragmentation of carbon dioxide Nier mass spectrometer (June 21, 1965)

BLANK PAGE

GAS CHROMATOGRAPH ATMOSPHERIC ANALYSIS INSTRUMENT DEVELOPMENT
NASA Work Unit 185-37-26-02
JPL 383-31101-2-3220

The development and evaluation of a Mars Atmospheric Gas Chromatograph has been completed. The chromatograph contains an automatic range-switching electrometer, automatic peak detection, and detector baseline compensation electronics. A dual cross-section ionization detector was also developed for the chromatograph. A 2-in. silica gel and a 9-in. molecular sieve column provide the capability of analyzing for carbon dioxide, argon, and nitrogen. The system is a completely automatic gas chromatograph except for the peak area measurement, the development of which was postponed because of a reduction in funding. In addition, because of the reduced funding, the development of digital baseline compensation was transferred to another account. This transfer was possible because of the circuit's application to other instruments.

The evaluation of the breadboard (including sensitivity, resolution, and accuracy) verified the scientific and engineering feasibility of using the gas chromatograph to analyze the atmosphere of Mars. A report on the development and evaluation is in process.

Because of its advanced state of readiness, the gas chromatograph was selected for high-impact technology studies. As a result of the high-impact work, funded under a separate account number, a sterilizable, high-impact gas chromatograph prototype is now being made.

BLANK PAGE

ATMOSPHERIC GAS CHROMATOGRAPH
NASA Work Unit 185-37-26-03
JPL 383-31201-2-3260

The progress in gas chromatography atmospheric analysis for the past 6 mo has included, among other accomplishments, the development of two devices of much use to this task. These are: a miniaturized pressure regulator and an electronic "de-tailer."

Pressure regulation problems have occurred throughout most of this program because of the extremely low flow rates that are used in the microgas chromatograph. Because of these problems, it was decided to build a miniaturized pressure regulator capable of regulating pressures at flow rates between 1/10 and 1 cc/min. The regulator works quite well and is illustrated in Fig.1 with an exploded view showing the internal part illustrated in Fig. 2.

Because a gas chromatograph is a pneumatic system, large amounts of mixing contributes to undesirable distortion of the sample peaks detected in the detector. The usual form of this distortion is tailing of the peak. Because in many systems it is most difficult to remove all causes of peak distortion, it would be useful to have a device that corrected the output signal for this distortion. Such a device has been built. The application is rigorous because Laplacian mathematics prove that peak distortion produced by mixing in the system can be corrected by this device. The device consists of three operational amplifiers, which together perform the following functions (as illustrated in Fig. 3): the signal is passed through a differentiator; the differential result is then added to the original signal; the result is a removal of the peak tailing and achievement of a symmetrical peak as shown in Fig. 4. This provides an aid in interpreting unresolved peaks, and therefore, helps to analyze mixtures in much shorter time.

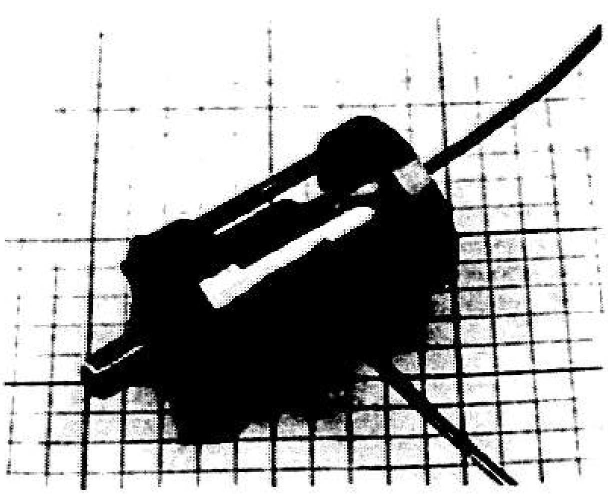


Fig. 1. Miniaturized pressure regulator

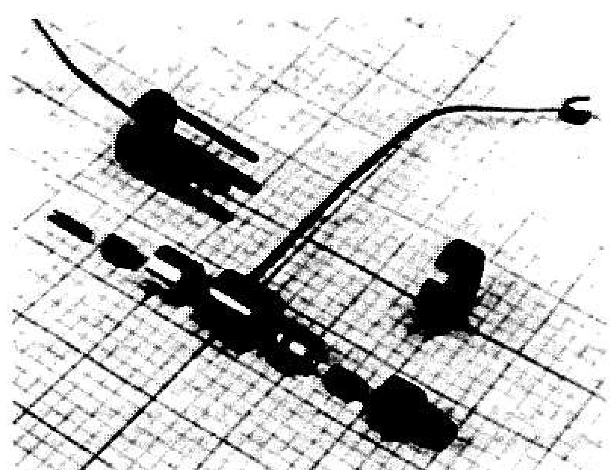


Fig. 2. Exploded view of miniaturized pressure regulator

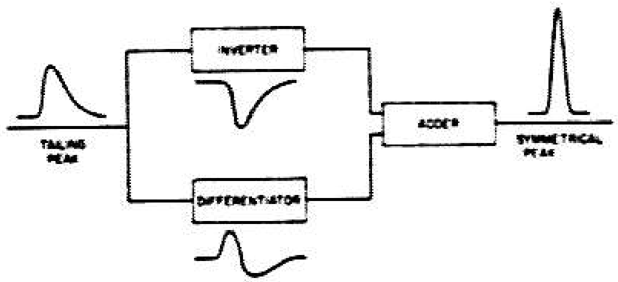


Fig. 3. Block diagram of electronic peak "de-tailer"

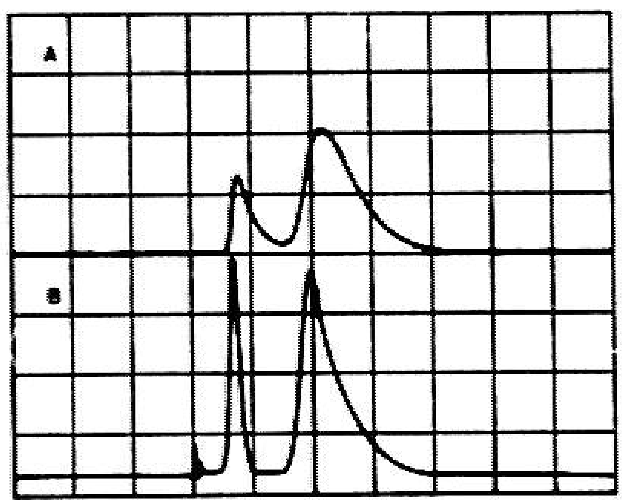


Fig. 4. Chromatogram
a) With tailing peaks
b) With peaks "de-tailed"

A low-noise, flexible version of this de-tailing device has been packaged with two bridge circuits for use as a laboratory, bench-type signal processing system. This feeds directly into an oscilloscope for readout. Using this system, rapid analysis of argon, nitrogen, and carbon dioxide has been made possible. The resulting analysis is shown in Fig. 5. This analysis time could be reduced substantially if certain parameters in the system were optimized. The analysis, as shown, required inserting a delay tube 6-1/2 in. long between the first detector and the molecular sieve column to resolve the carbon dioxide and argon peaks.

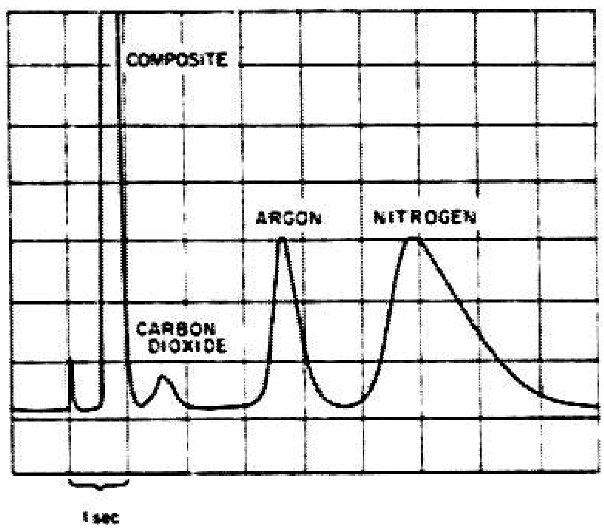


Fig. 5. Series column-detector system analysis

BLANK PAGE

GAMMA RAY SPECTROSCOPY
NASA Work Unit 185-37-26-04
JPL 383-31301-2-3290

Detector configuration studies have seen the conclusion of tests with the anticoincidence annulus. This design appears to be unpromising for a weight-limited package. Work with a double-crystal telescope has been resumed. The transmission and resolution characteristics of thin crystal-photomultiplier combinations have been studied. Edge-mounted crystals are being investigated as a means of minimizing mass absorption. A 4-ft-diameter hemisphere has been constructed and lined with uraninite ore to provide an enhanced 2π omnidirectional background for the crystal telescope studies.

A servosystem for gain stabilization has been designed and breadboarded. The system senses the location of a calibration peak and corrects the gain as required. A functional diagram is shown in Fig. 1. and successful operation is shown in Fig. 2.

The response of certain rock types to irradiation by an artificial source of xrays was reported in an SPS article (SPS No. 37-31, Vol. IV, p. 273). On a lunar orbiter the active Sun is expected to induce monitorable $K\alpha$ fluorescence in the surface.

Information has been submitted to MSSD on the 1138 forms for the Apollo AES Earth Orbiter checkouts and Lunar Orbiter flights. Plans for the next 1/2 yr call for emphasizing simulation experiments, calculations of expected xray and gamma responses, and firming up the type of detector(s) to be used. Two development contracts are anticipated during FY 1966.

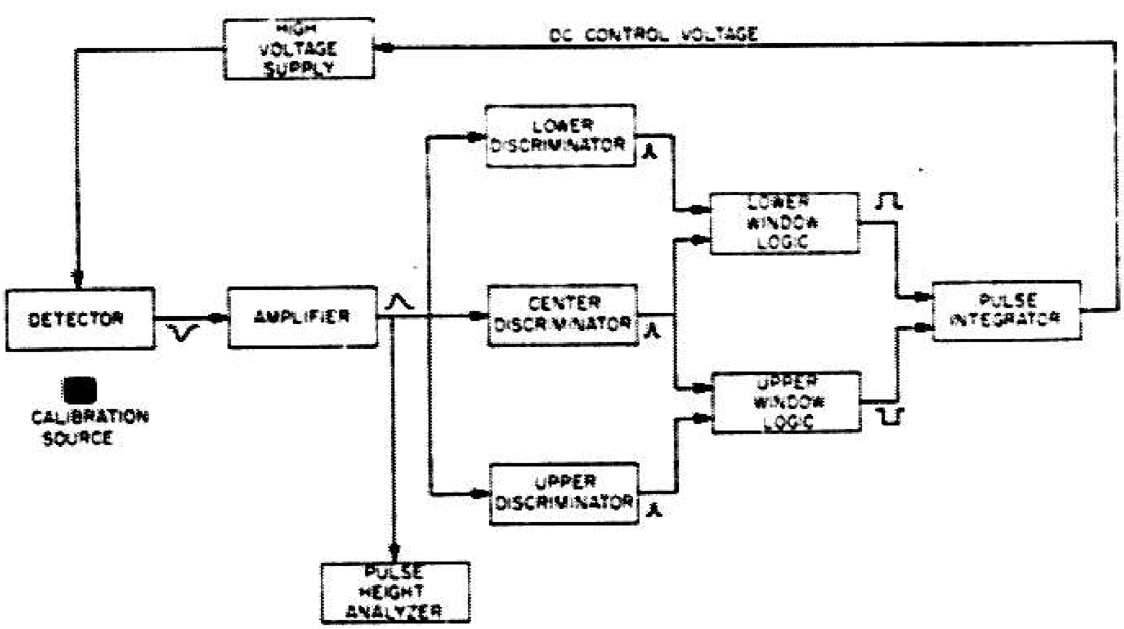


Fig. 1. Servogain stabilization system

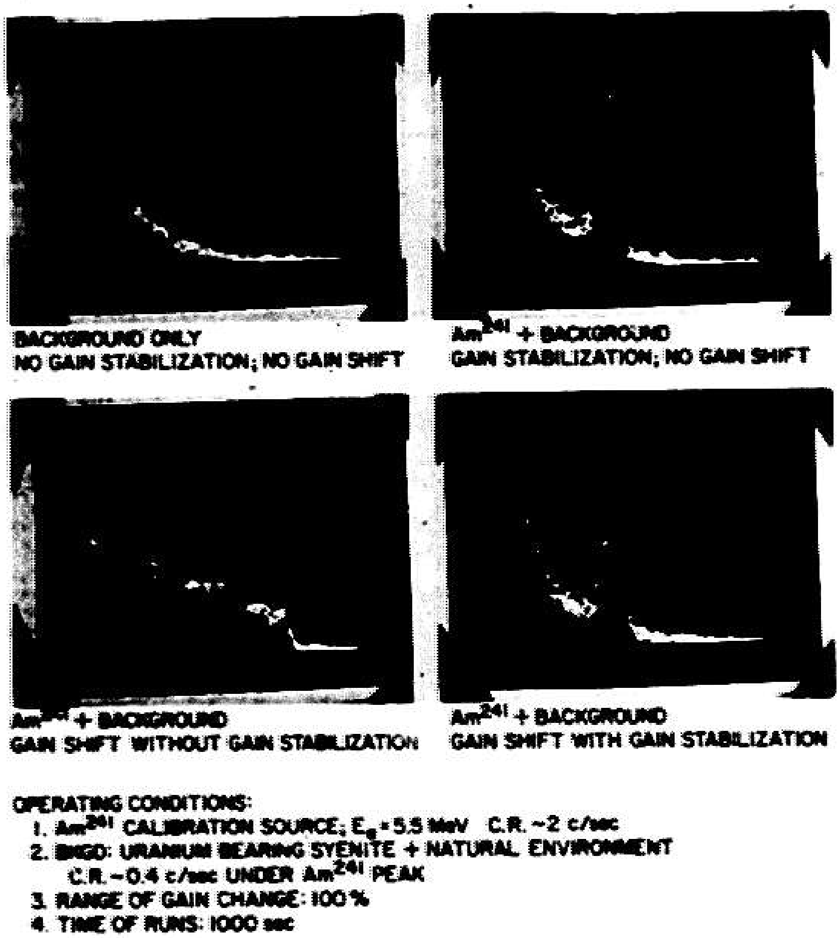


Fig. 2. Experimental data for servogain stabilization system

INFRARED SPECTROMETRY – FUNDAMENTAL TECHNIQUES AND APPLICATIONS

NASA Work Unit 185-37-26-06
JPL 383-30601-2-3250

LABORATORY SPECTROSCOPY OF SYNTHETIC ATMOSPHERES

The building for the Spectroscopy Laboratory and Absorption Tube facility was completed in January 1965. This facility will provide high resolution infrared spectra of gases over a wide range of temperature and pressure, in support of astronomical investigation of planetary atmospheres.

A multiple-reflection absorption tube, which should provide an optical path of at least 250 m through a gas sample maintained at any pressure from vacuum to 20 atm and any temperature from 100 to 700°K, has been fabricated and installed. The optical system of the absorption tube has been successfully operated at path lengths of more than 250 m at room temperature.

A 5-m Jarrell-Ash vacuum spectrograph has been installed in the building and should be operable by late summer 1965. A 1.8 m vacuum spectrometer has also been obtained and will be installed and activated concurrently with the larger instrument. The 1.8 m photometric instrument has achieved a resolution of 550,000 in its present temporary location. The 5-m photographic instrument is expected to exceed this resolution by a factor of two or more.

It can be expected that some long-path, high-resolution spectra of carbon dioxide at ambient temperature and moderate pressures will be obtained by early fall. Achievement of the full capabilities of temperature and pressure will require some additiona[illegible]ns.

INTERFEROMETRIC STUDIES

During and following the next fiscal year, this task will be divided in two tasks, titled "Interferometric Studies" and "Laboratory Spectroscopy of Synthetic Atmospheres." In this segment that part pertaining to Interferometric Studies is reported.

The objective in this task is the development and exploitation of Fourier spectroscopy as a tool for the investigation of infrared spectra with special emphasis on planetary atmospheres.

In this 1/2 yr, the JPL-CNRS planetary interferometer (which had been shipped to Dr. P. Connes at CNRS, Bellevue, France, last fall) was taken to the Coudé focus of the 78 in. telescope at Haute Provence, France, for the recent Mars opposition. Present throughout the observing period, March 7 to 29, were Dr. P. Connes of CNRS; Dr. R. Beer of JPL; and (for shorter periods) Dr. J. Pinard, M. G. Michel, and M. J. Maillard, all of CNRS. During this time, the instrument (which had been considerably modified during the winter in Paris) obtained 14 spectra of Mars at resolutions, all in the 1.4 to 1.7 μ region. Toward the end of April, Dr. Connes obtained several more spectra in the 2.2 μ region during the early evening hours.

Figure 1 shows an optical schematic of the instrument.

Figure 2 shows two views of the system.

Figure 3 is a representative Mars spectrum taken with the instrument showing resolution of the carbon dioxide bands.

It would be appropriate at this time to record appreciation for the efficiency and helpfulness of Dr. C. Ferenbach and his staff at the observatory without whom we could scarcely have succeeded.

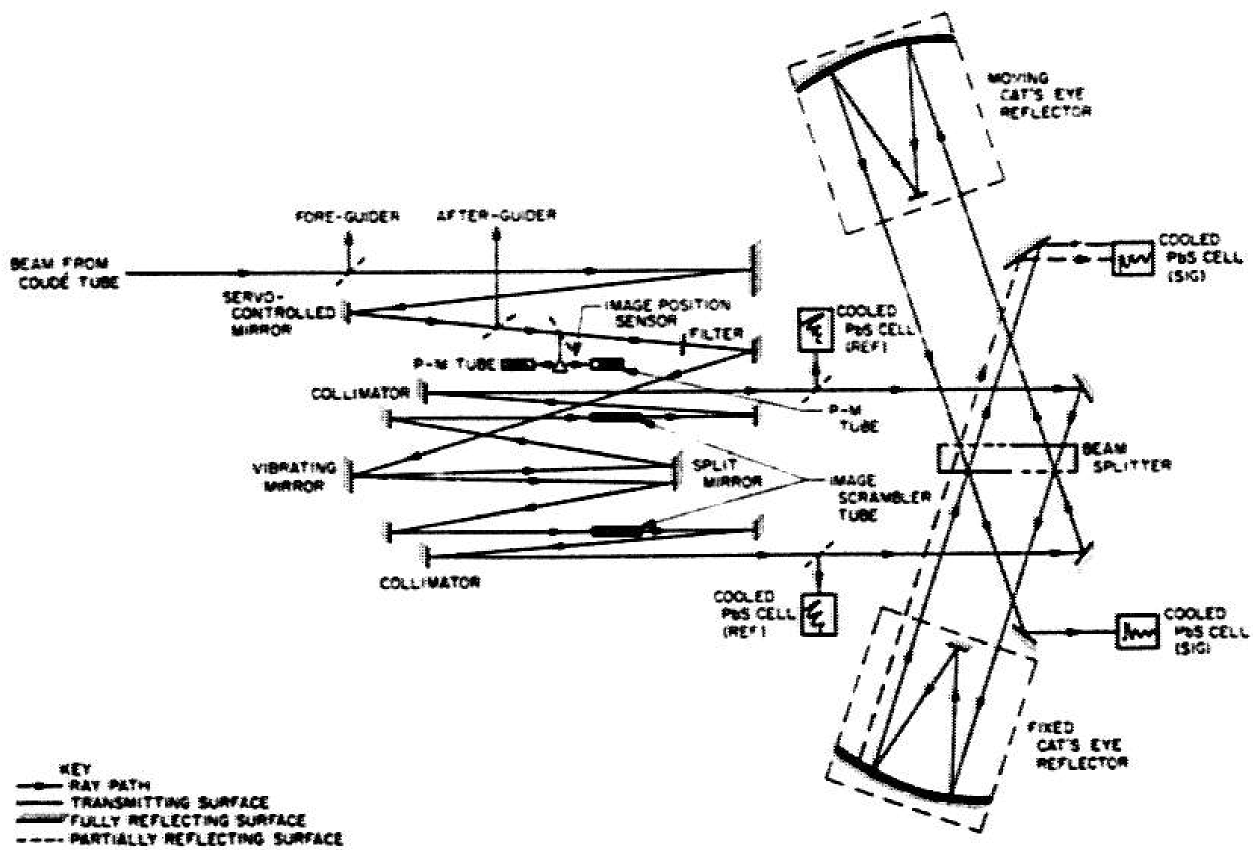


Fig. 1. Optical schematic of planetary interferometer

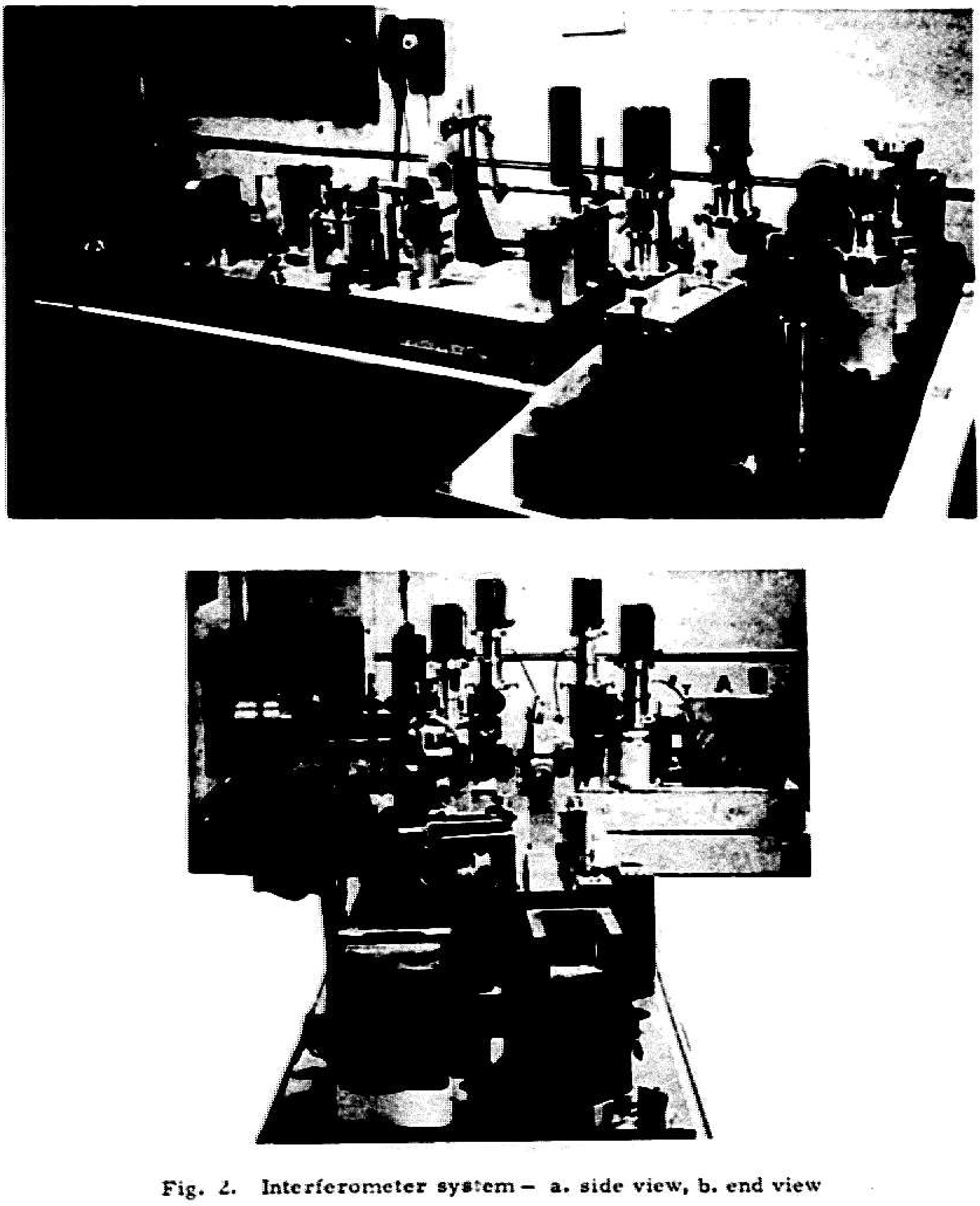


Fig. 2. Interferometer system — a. side view, b. end view

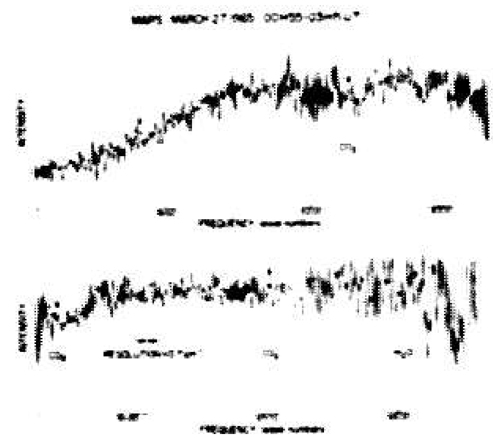


Fig. 3. Representative Mars spectrum

In the fall of this year, it is planned to return the instrument to Haute Provence and to obtain more spectra of Venus and Jupiter. It has been proposed that a new, engineered version be constructed at JPL for the next Mars opposition in 1967.

The other project in hand has been the construction of a Michelson interferometer of more classical design for use in the spectral region below 1000 cm^{-1} at resolutions of about 1 cm^{-1}. The objective to produce a more rugged interferometer system has been successfully carried out. Because it is primarily aimed at atmospheric studies in the pure rotational region, it will be flown in a balloon early in the next 1/2 yr and use the Sun as a source to primarily observe the water vapor in the stratosphere. The experiment is of an exploratory nature, because this region of the solar spectrum is essentially unknown. Free balloon facilities are being kindly provided by Dr. D. Murcray of the University of Denver and the system will be flown from Holloman Air Force Base, New Mexico.

Figure 4 shows a general view of the interferometer from above.

Figure 5 shows an electronic schematic of the system.

Figure 6 shows the instrument in its test stand being illuminated by solar radiation from a heliostat.

Figure 7 is a portion of a typical interferogram.

Future work with the system will be largely dependent on results obtained in the balloon flight.

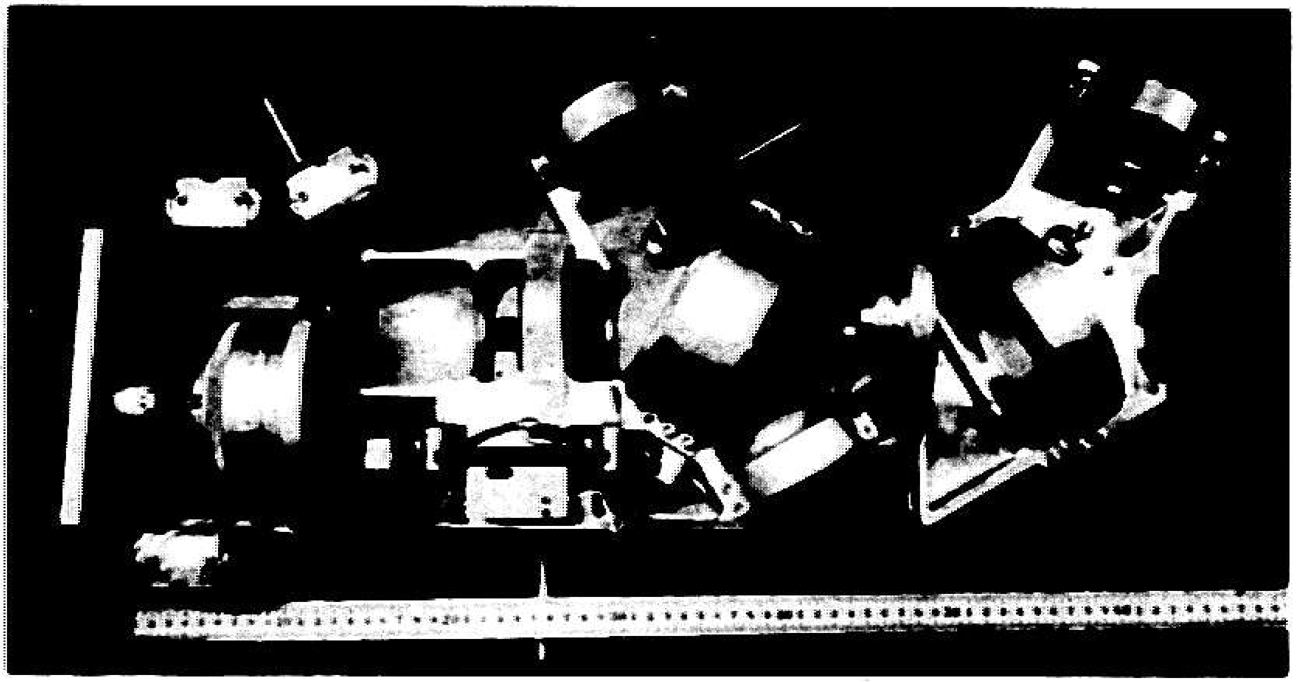


Fig. 4. Top view of far-infrared balloon-borne interferometer

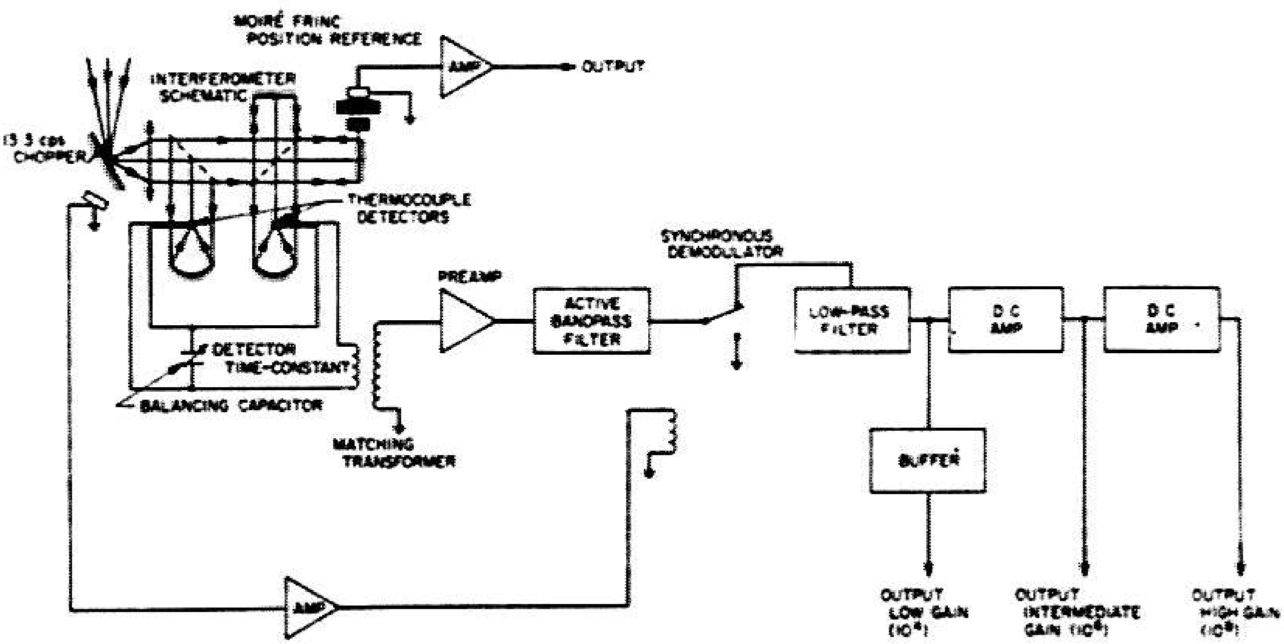


Fig. 5. Schematic of far-infrared balloon-borne interferometer

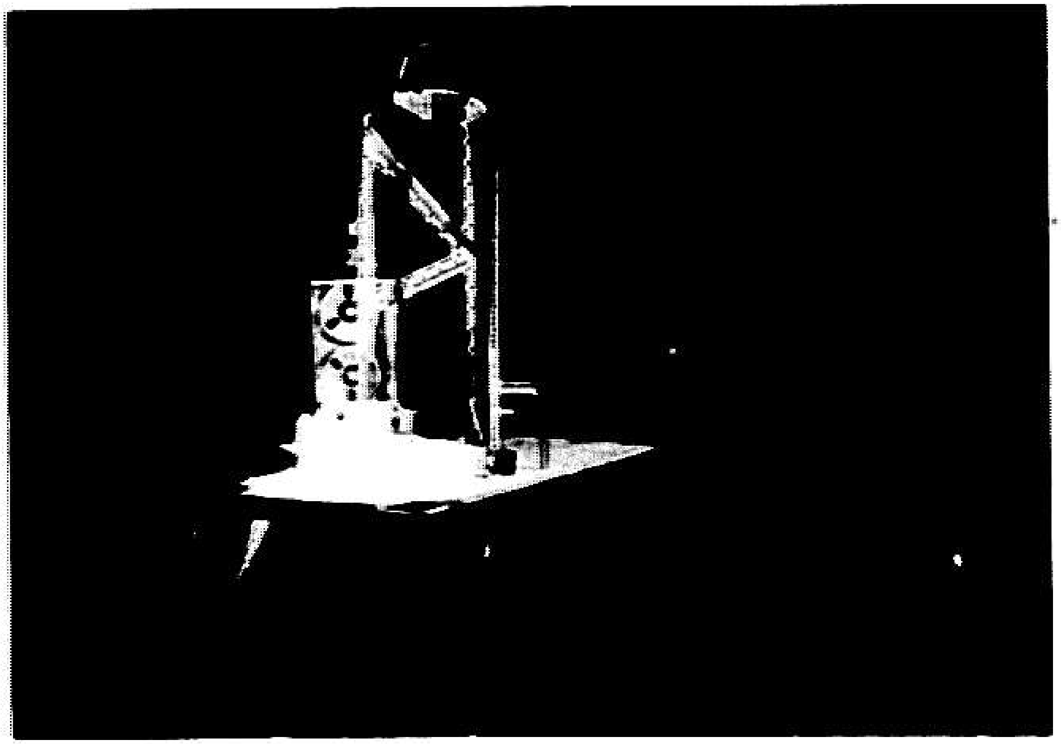


Fig. 6. Balloon-borne interferometer in test stand, illuminated by sunlight from heliostat

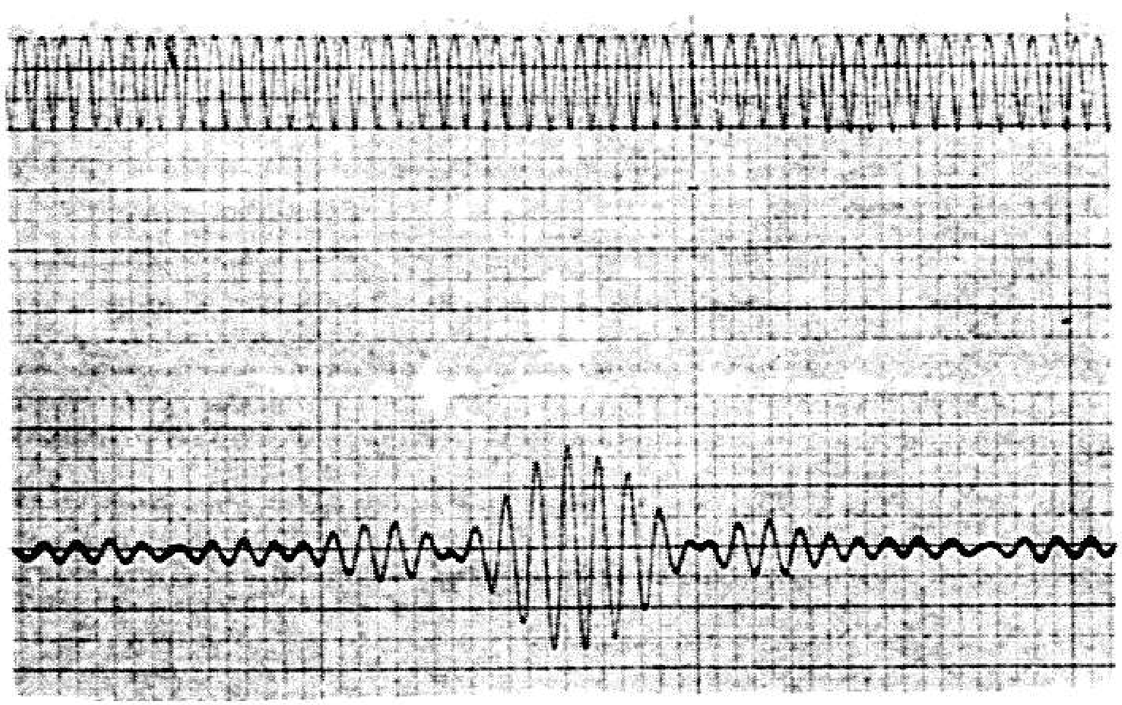


Fig. 7. Typical Laboratory solar interferogram

INFRARED SPECTROMETRY – CALIBRATION INSTRUMENTATION AND SCIENCE SUPPORT
NASA 185-37-26-07
JPL 383-30701-2-3290

This work unit consisted of two major activities during the last half of FY 1965: interferometric investigations of Mars on the Kitt Peak solar telescope and an evaluation of a 35 element PbSe detector assembly purchased during the first half of FY 1965. The first of these two activities is being concluded and the second will be transferred to NASA Program 866 in FY 1966.

INTERFEROMETRIC INVESTIGATIONS OF MARS

The instrument that was used on the McGrath solar telescope at Kitt Peak Observatory has been described in two SPS articles, the first in SPS No. 37-23, September 1963 and the second in SPS No. 37-31, May 1965. After laboratory experiments showed that reliable spectra could be obtained from interferograms in the spectral region from 2700 to 3300 cm^{-1}, the instrument was moved to Kitt Peak in April 1965.

It was immediately apparent that, despite the instrument's high efficiency (measured to be around 60%), the signal-to-noise ratio was extremely low. Because sufficient telescope time was available, several modifications were made to the instrument including attempts at photoelectric image stabilization and liquid nitrogen cooling of the detectors. Both were unsuccessful in improving the situation and were finally abandoned.

In all, seven Mars spectra were obtained along with several reference solar and lunar spectra. Because of the low signal-to-noise ratio, considerable work on the data reduction program will be required before the data can be released. The entire program will be reviewed in a forthcoming formal report.

PbSe DETECTOR EVALUATION

An evaluation of the performance of 35 PbSe detectors mounted in a single assembly was begun during the last half of FY 1965. The assembly was tested in a liquid nitrogen shrouded vacuum chamber, using a below-room-temperature black body as an energy source. The detectors have a field of view of approximately 18 deg that is completely filled by the black body source. Detector temperatures can be varied to determine their effect on detectivity. The entire setup is geared for comparative tests on the detectors.

Activities during this period covered installation and checkout of test instrumentation. Initial operational tests were performed that eliminated problem areas such as ground loops, etc., and developed special test setups such as calibration procedures for the amplifiers in the system. In FY 1966 detector evaluations will be carried out under NASA Program 366.

BLANK PAGE

GEOSAMPLING (GEOLOGICAL SAMPLING)
NASA Work Unit 185-37-26-08
JPL 383-31701-2-3220

Areas under investigation in geosampling during the reporting period were those considered most in need of development; namely, (1) acquisition of fragmented rock from under, and transport through, unconsolidated overburden material; (2) acquisition of high-porosity consolidated or unconsolidated particulate material; (3) acquisition of high-porosity vesicular material, particularly under a noncohesive overburden; and (4) particle size control of acquired samples.

OUTSIDE CONTRACT

A contract for $17,000 was placed with the Hughes Tool Company of Houston, Texas, for the design of a device that will acquire samples from hard rock in addition to the first three conditions noted above. A design review on the Hughes contract is scheduled for mid-July, and completion of design is expected about September 1. If the resulting detail design is considered feasible, a followon contract for approximately $40,000 is contemplated to construct a breadboard device.

IN-HOUSE EFFORTS

In-house efforts have been directed toward: (1) development of devices that are more efficient in the acquisition of high-porosity consolidated or unconsolidated particulate material or high-porosity vesicular material at the surface (drill-type devices are very inefficient in these types of materials); (2) various particulate transport methods and fragmentation by abrading devices; (3) developing control of particle-size in fragmentation by abrasion and drilling, and in the acquisition of overburden material.

SAMPLE ACQUISITION DEVICE FOR OVERBURDEN

Figure 1 shows a conical-shaped device designed to permit penetration of consolidated or unconsolidated overburden material or highly vesicular rock. The device has abrasive material on its exterior to fragment consolidated overburden or vesicular rock and is perforated with small holes to control the maximum size particles or fragments acquired. It has been tested in basalt rubble and in vesicular rock (pumice) and found promising. It has not yet been tested for particle density and shape sorting to which it will probably be susceptible in its present configuration. Methods of combining this device coaxially with a drill to share a common transport arrangement are being investigated.

SAMPLE TRANSPORT DEVICES

Figure 2 shows a helical conveyor under development that shows promise for some applications. A tendency for jamming can be eliminated by limiting the size of particles fed into it. In its present form, it further pulverizes the material it conveys. This characteristic, which may be an advantage or a disadvantage, is being investigated. Work has been started on vibratory conveying, but is now awaiting delivery of vibration equipment on order. Work has also been started on aerosol transport investigations. Continuous aerosol conveying has been discarded because of anticipated sealing difficulties, and batch conveying is being investigated. In this system, particulate material is acquired in a hollow drill or other acquisition device and the admittance holes closed when a sufficient amount has been introduced; this material is to be conveyed to an inertial separator with a "puff" of gas, very little of which can leak out past the valve. This apparatus, Fig. 3, is now being installed in a vacuum vessel for testing.

SAMPLING BY GRINDING DEVICES

Investigations have also been made on abrading devices, because they could conceivably serve to fragment and transport rock as well as particulate material, to remove shallow overburden layers over rock. Work carried out to date has consisted of testing these abrading devices on hard rock (basalt). The fragmentation process tends, in general, to produce finer grain size samples than drilling devices, although preliminary investigations have indicated that particle size can be somewhat controlled through varying the operating parameters of the grinder, as shown in Fig. 4. The best samples obtained in grinding so far have been inferior to those obtained with the rotary impact drill as determined by x-ray diffractograms of the samples. These determinations are clouded by the degradation of the diffractogram by overcomminution of the samples. Investigations are now underway to determine the feasibility of removing overburden with brushes mounted alongside and on the same shaft as the grinding device; this device is shown on Fig. 5. Following this, we plan to work with acquisition devices (sample collectors) and finally to investigate mechanisms for rotating and manipulating the grinder.

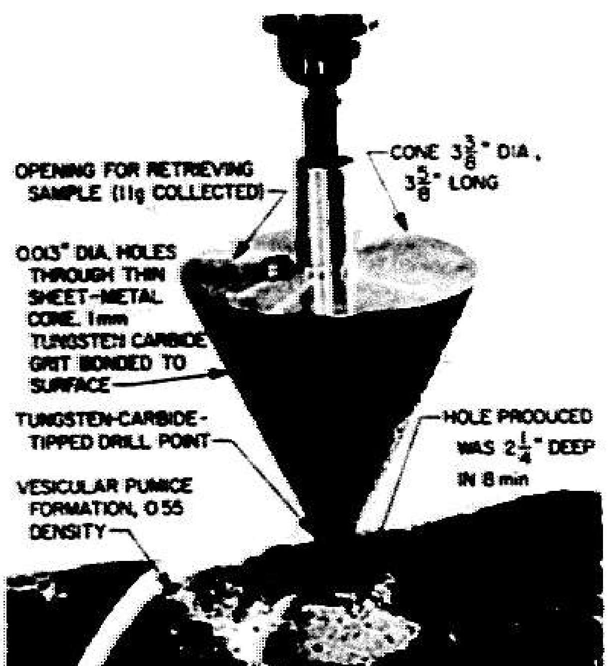


Fig. 1. Conical sampler

PARTICLE SIZE CONTROL WITH ROTARY-IMPACT DRILL

In our investigations for the feasibility of controlling particle size with a drill, the problem is to obtain larger particle sizes (say 100 μ size) in appreciable amounts. We have varied the drilling parameters over a wide range and produced no significant change in particle size distribution except when we change drill rotational speed relative to impact rate. When this ratio is made large, the drill mode approaches rotary drilling and overcomminution results, producing a predominantly fine sample (with resulting poor diffractogram); see Fig. 6a. When rotational speed is reduced relative to impact rate, a point is finally reached where the particle size distribution tends to be appreciably coarser; see Fig. 6b. As might be expected, we also obtain a coarser particle-size distribution when starting a hole than when the drill is fully seated. This may be attributed to

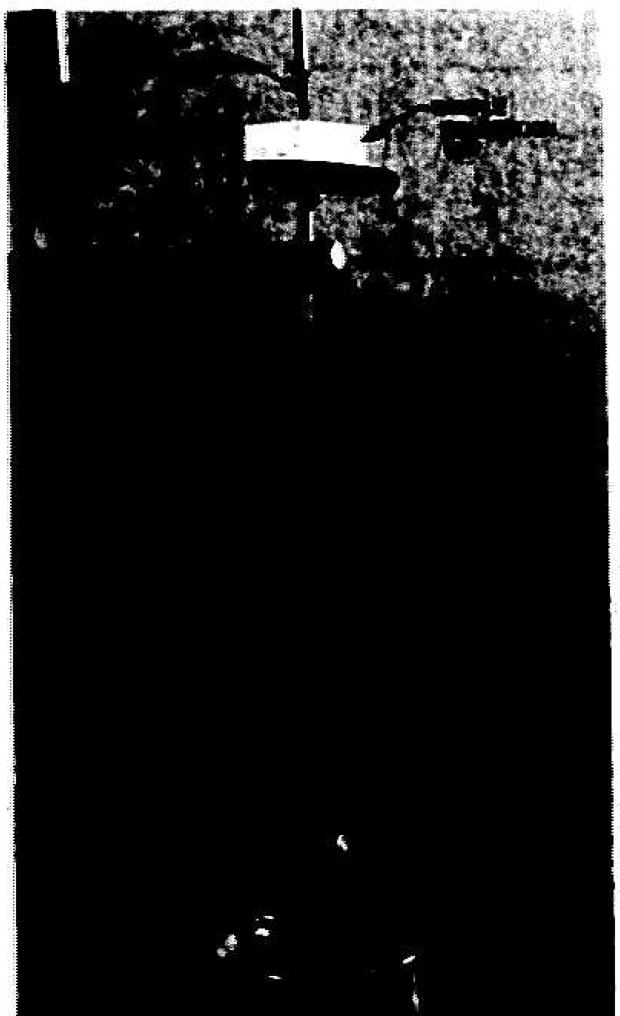


Fig. 2. Helical conveyor. Particulate material-picked up by the rotating helix is thrown outward to drag against the stationary casing, causing the material to ride up the helix to be ejected at the top

cratering. With most acquisition and transport methods, the first quantity of fragmented rock produced cannot be retrieved. Work will continue along these lines.

MISCELLANEOUS

We have also expended some effort to complete the designs of breadboard samplers, partially developed under the Surveyor II XRD program, and are having these fabricated.

Although we have expended some effort in the direction of explosively actuated samplers, we have discontinued any further effort in this direction other than encouraging the Hughes Tool Company to investigate such devices independently.

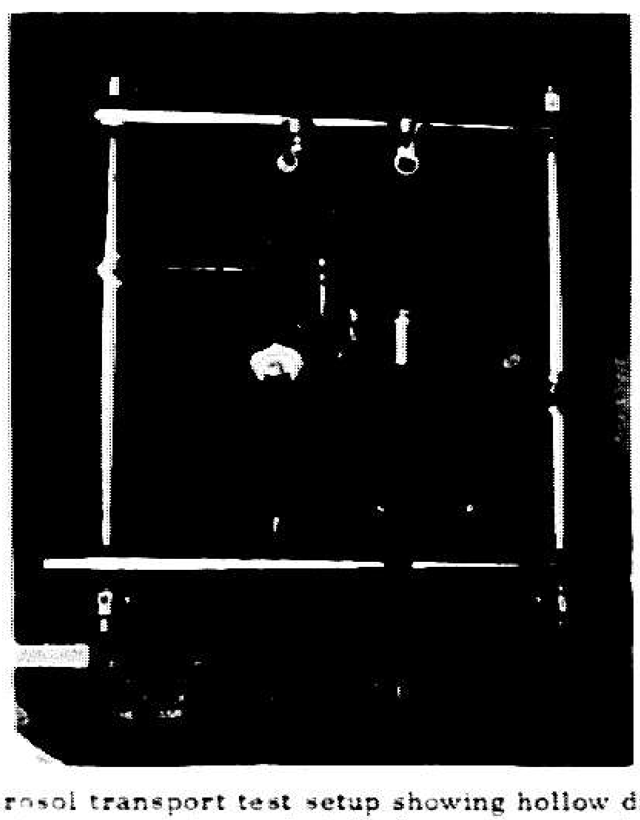


Fig. 3. Aerosol transport test setup showing hollow drill stem and inertial separator being installed in a vacuum chamber

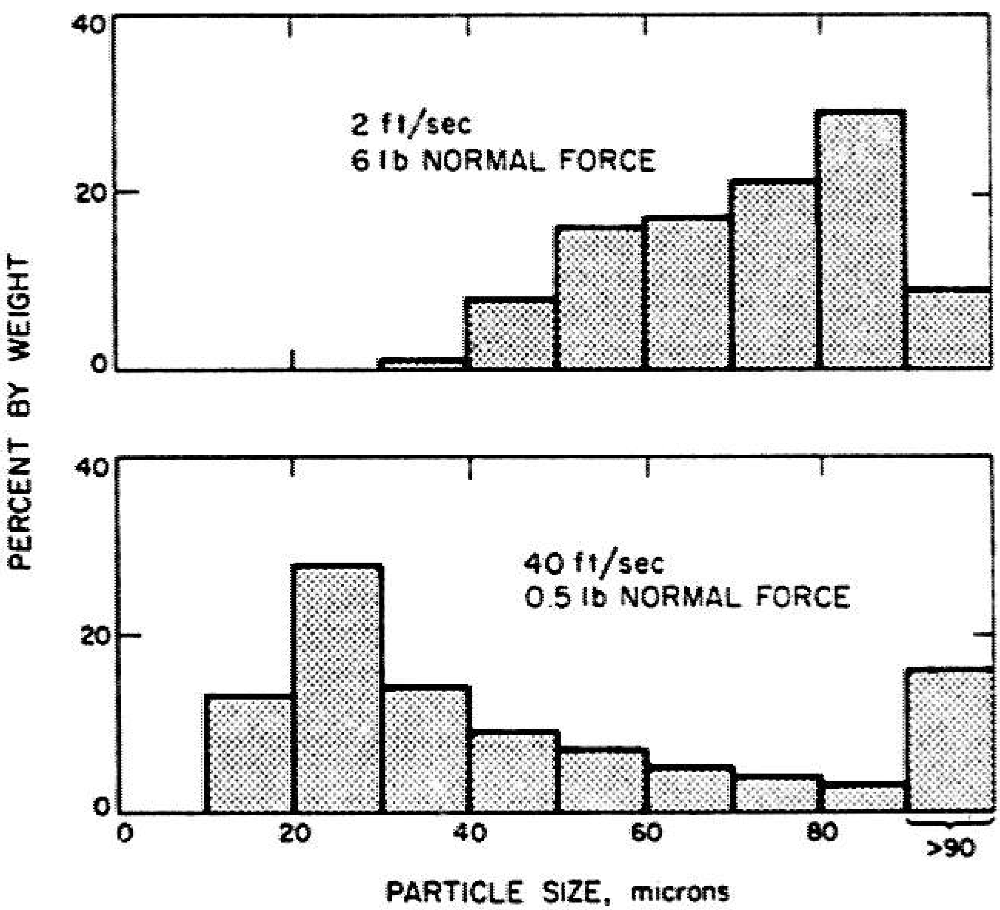


Fig. 4. Fragmentation by grinding. Rock (basalt) fragmented with diamond grinding wheel, 24 grit (D24-25M-1/8 x 68), at surface speeds of 2 and 40 ft/sec

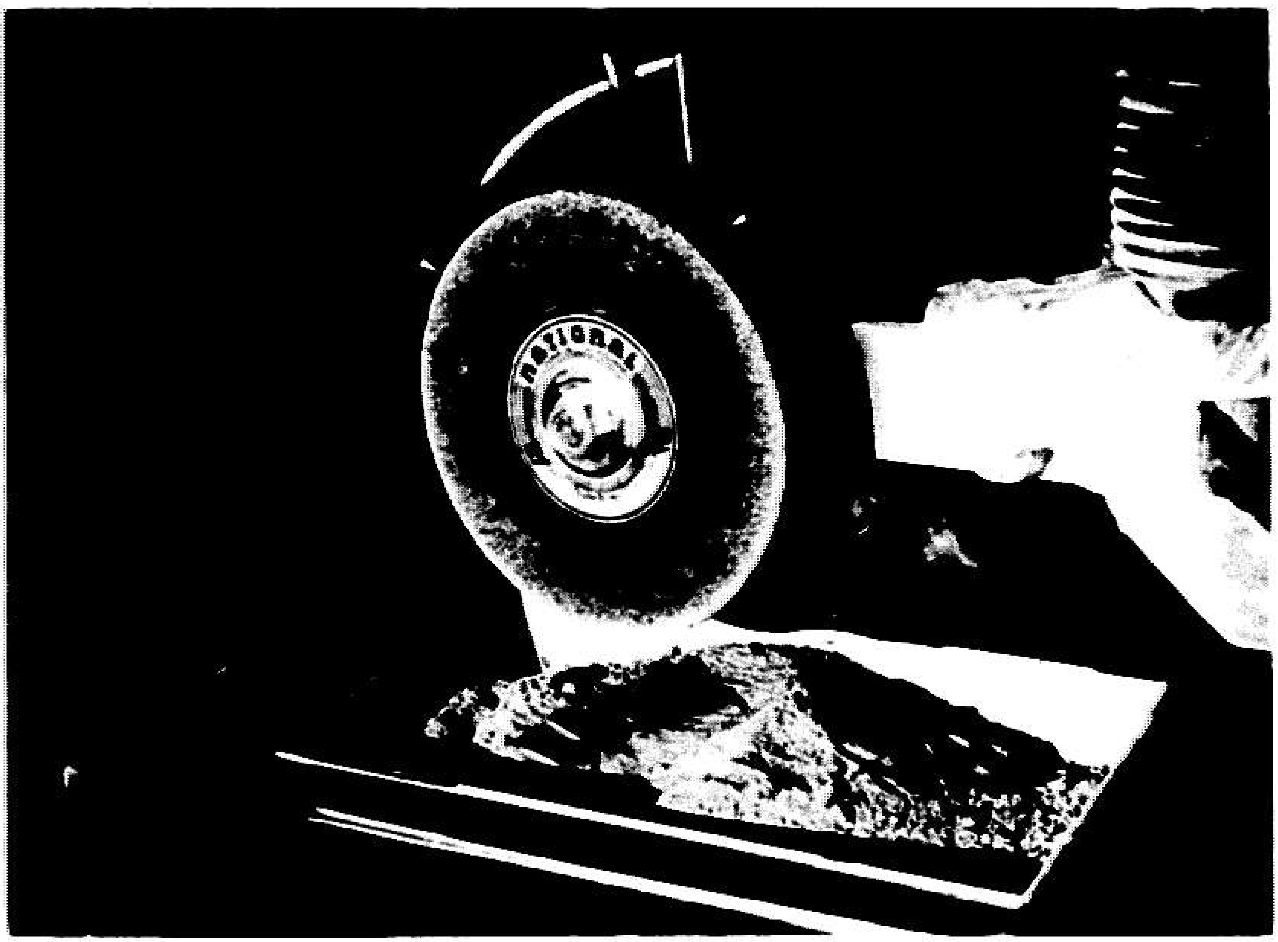


Fig. 5. Grinding device for fragmenting rock. Test setup in vacuum chamber. Brush acquires or sweeps away over burden. Grinding wheel fragments and acquires exposed surface of rock.

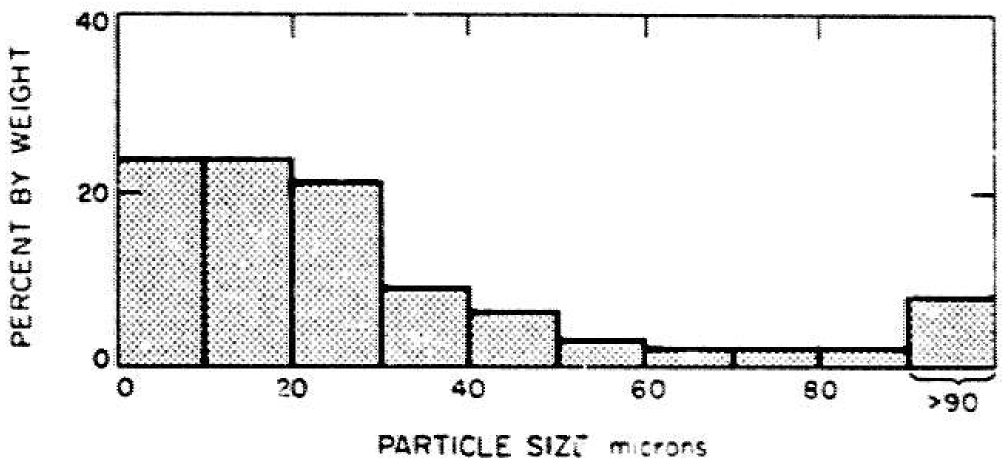


Fig. 6a. Fragmentation by rotary-impact drill. Low-impact rate, 900-deg rotation per impact (approaches rotary drilling mode)

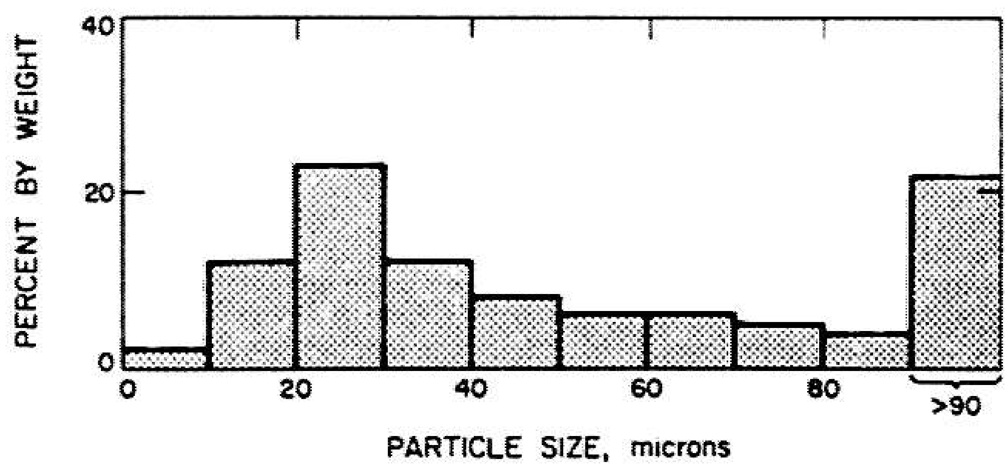


Fig. 6b. High impact rate, 22 1/2-deg rotation per impact

BLANK PAGE

DETECTION OF LIFE RELATED COMPOUNDS *
GAS CHROMATOGRAPHY-MASS SPECTROMETRY STUDIES

NASA Work Unit 185-37-26-09*
JPL 383-31501-2-3250

It must be noted at the outset of this report that progress in the last 6 mo has been strongly curtailed because of lack of manpower resulting from the high priority given the Biosatellite Program. This problem has now been alleviated, and a full-time engineer is at work on this task.

The test system was designed and constructed at JPL for determining the effectiveness of ion and chemical pumping of hydrogen carrier gas. The titanium sublimation pump was also built at JPL and is shown in detail in Fig. 1. The calibration of the test system is under way and preliminary results will be available shortly. Data on the pumping speed and capacity of titanium films will be obtained to determine the most suitable geometry for a flightworthy pump.

Diffusive separators for the enrichment of organic samples in the gas chromatographic effluent have been obtained. The testing and optimization of these devices are awaiting the delivery of the gas ion source for the 12 in. JPL mass spectrometer. This ion source is due at JPL on August 1, 1965. The testing program will be geared toward maximizing sample to carrier gas enrichment factors for flow rates compatible with the ion and chemical pumping mechanism being studied now. Flow rates of 0.1 scc H_2/min or less in conjunction with capillary gas chromatography will be studied.

A significant effort has been made over the last 6 mo to evaluate high resolution mass spectrometers for use in the Detection of Life Related Compounds Task in the JPL Chemistry Section. Particular emphasis was placed on the use of the JPL computer center in reducing mass spectral data taken on magnetic tape. This effort was coordinated with Dr. S. R. Lipsky at Yale University and has resulted in an extremely versatile and proven high resolution mass spectrometer system at Yale of the type required by JPL.

*Jointly Funded Under NASA Code 189-55-03-01 and 185-37-26-10.

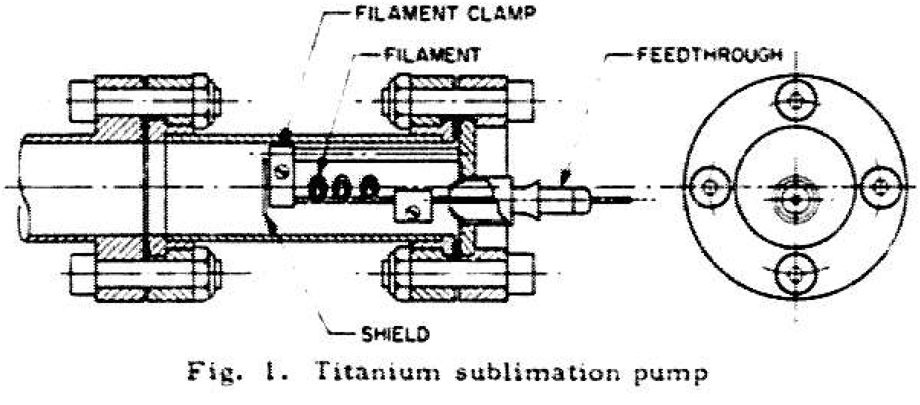


Fig. 1. Titanium sublimation pump

A paper was presented at the last AAAS meetings in Montreal, titled "Detection of Life Related Compounds on Planetary Surfaces by Gas Chromatography-Mass Spectrometry Tecnniques." The paper outlined the JPL approach to life detection on Mars and was very well received. Out of 724 papers presented at this meeting, the JPL paper is one of eight still in contention for the Newcomb Cleveland Prize awarded to the outstanding paper of the meeting. This prize carries with it a bronze medal and $1000.

During the first quarter of FY 1966 the laboratory in which this work unit is being performed will be moved from a JPL annex to the main Laboratory. It is expected that close to 1 mo will be lost during the moving process.

DETECTION OF LIFE-RELATED COMPOUNDS
NASA Work Unit 185-37-26-10*
JPL 383-31801-2-3260

The scientific objective of this task is to provide information for defining a chemical life detection experiment. The analytical procedure being developed is based on the combined techniques of gas chromatography and mass spectrometry. The procedure to be followed is: (1) thermal treatment of the sample to yield volatile fragments, (2) separation of these volatiles by gas chromatography, and (3) mass spectrometer determination of the components (or components) present in each gas chromatograph peak.

GAS CHROMATOGRAPH-MASS SPECTROMETER STUDIES

The immediate activities of this task are concerned with the two main interface problems in uniting a gas chromatograph and a mass spectrometer; i.e., enrichment of sample components in the chromatograph effluent and removal of carrier gas from the effluent stream. The work on these problems involves: (1) investigation of enrichment devices used intermediate to the two instruments, and (2) study of pumping methods for removal of carrier gas. Molecular separator devices to be used in this work were ordered from Sweden and have been received. The test system to be used in studying pumping methods is nearing completion.

GAS CHROMATOGRAPHY-MASS SPECTROMETER TECHNIQUES, PREPARATION OF ORGANIC SAMPLES FOR GAS PHASE ANALYSIS, AND GAS CHROMATOGRAPH-MASS SPECTROMETER ANALYTICAL SYSTEM

The activities under this task are primarily concerned with the study of methods for sample preparation and treatment for use in the detection of biologically important substances. Thermal treatment procedures were investigated to convert nonvolatile samples to substances of sufficient volatility to be separated and detected by gas chromatography and analyzed by mass spectrometry.

An extensive study of the pyrolysis of mesoporphyrin has been completed. The pyrolysis conditions were determined that yielded the greatest amount of representative fragments. Based on this study, similar work was done with deuteroporphyrin, etioporphyrin, protoporphyrin, hematoporphyrin, phylloporphyrin, pyrroporphyrin, and etiochlorin (of the chlorophyll series), in which the ideal pyrolysis conditions were determined, and the representative fragments identified. The analytical techniques used included gas chromatography, mass spectrometry, and nuclear magnetic resonance. A series of papers reporting this work are planned to be submitted for publication. The first is now in draft.

---

*Jointly Funded Under NASA Code 189-55-03-01 and 185-37-26-09

The study of methods of sample treatment for detection of biological substances in soils has also been continued. Samples of a desert soil were pyrolyzed in a reducing atmosphere of hydrogen: 45 to 60 min, 400 to 450°C. The reaction products were collected and analyzed by gas chromatographic and mass spectrometric methods. Of the products that have been identified, the predominant ones are: carbon dioxide, ethylene, methane, ethane, and butenes.

MAJOR PURCHASES

Bids have been requested from manufacturers to supply a high-resolution mass spectrometer for use in this program. The instrument will allow faster analyses of the products of pyrolysis studies; in addition, the instrument will be connected to a gas chromatograph (using separator devices) so that a laboratory instrumental system may be studied.

FUTURE PROGRAM

Gas Chromatograph-Mass Spectrometer Studies

Pumping methods for the removal of carrier gas will be investigated. Chemical pumping as well as ionic pumping are to be considered. The development of molecular separator enrichment devices will continue toward optimization of the units for use in the instrumental system to be assembled. The pumping system and enrichment devices will be assembled into a breadboard simulating their use in a gas chromatograph mass spectrometer instrumental system.

The time sequencing of mass spectral scanning of the gas chromatograph effluent will be studied with a specially modified mass spectrometer so that a scan initiation will occur at the most opportune time.

Work will continue on the handling of data from a combined gas chromatograph-mass spectrometer system.

Chemical Studies

Pyrolysis studies will be performed on representative desert soils containing 0.5 to 10% organic matter. These studies will involve a determination of the best pyrolysis conditions to yield the most useful information concerning the structure of the organic material present. In addition, varying amounts of pure compounds such as the porphyrins, whose pyrolysis patterns are known, will be added to samples of the soils and the pyrolysis of the mixture studied.

Work on other pure compounds such as the peptides and metallo-porphyrins will continue.

Instrumental Techniques

The high-resolution mass spectrometer will be acquired and put in operation. A laboratory instrumental system will be assembled having a thermal treatment unit, a gas chromatograph, molecular separators, and the mass spectrometer as contiguous units.

The study of thermal treatment techniques will continue. The possibility of performing differential thermal analysis (DTA) and fluorometric analysis on the sample simultaneously with the pyrolysis will be investigated. DTA studies will include rapid heating rate analyses.

Gas chromatographic studies planned will include the development of suitable column packing to separate the polar organic compounds that are obtained during the pyrolysis of high molecular weight organic materials; in addition, feasibility studies in the use of very low flow rates will be performed.

BLANK PAGE

ULTRAVIOLET SPECTROMETER — INSTRUMENT DEVELOPMENT
NASA Work Unit 185-37-26-11
JPL 383-32301-2-3230

ACTIVITIES DURING REPORT PERIOD

The grating thermal-vacuum test has been completed with the grating having been cycled between -40 and +60°C while in a vacuum of 10^{-8} mm Hg for a period of 65 days. No visible changes in the grating have taken place; however, no qualitative tests have been made as yet. As a spectrometer becomes available from the POGO Ultraviolet Spectrometer program, tests will be made on the grating.

The mechanical design concepts for the solution to the problems of mirror mounting, grating motor drive, and thermal distortion associated with the telescope secondary mirror are now complete. Detail design is being deferred pending the results of the Voyager instrument selection.

Labko Scientific, Inc. (Contract No. 950983, "Single Channel Stabilized DC Analog Preamplifier") has progressed through the early breadboard and now is in the final design stage. Delivery will be in the first quarter of FY 1966.

The new vacuum chamber is operating and the calibration sources are installed. A thermal wall and platform are being installed in the chamber for instrument development tests.

FUTURE ACTIVITIES PLANNED

There are no future activities planned because this task is not expected to extend into FY 1966.

BLANK PAGE

ULTRAVIOLET SPECTROMETER – SCIENCE
NASA Work Unit 185-37-26-12
JPL 383-32401-1-3280

The objective of this work unit is to perform experimental research, develop theoretical background, and supervise instrument design of ultraviolet spectrometer 1000 to 4200A for planetary flyby spacecraft.

WINDOWLESS PHOTOMULTIPLIER TUBE

Development of a windowless photomultiplier tube for spectral range below lithium fluoride cutoff, 1050A, proceeded. Tubes with cesium iodide photocathodes, silver magnesium dynodes, and blow-off windows have been flown as piggy back experiments on two Aerobee rockets: 4.111 on January 13, 1965 and 4.112 on June 29, 1965.

Four tubes with copper beryllium dynodes and cathodes of potassium bromide, rubidium iodide, cesium bromide, and cesium iodide have been developed under subcontract. Their spectral and electrical characteristics have been measured.

SPECTRAL RESPONSE OF PHOTOCATHODES

The laboratory study of the spectral response of the several photocathodes continued. The installation of pumps to provide differential pumping for windowless ultraviolet light source and McPherson model 225 spectrometer is in program under contract.

DOCUMENTATION

Theoretical calculations of planetary ultraviolet spectra have been completed and included in a manuscript titled "Ultraviolet Spectroscopy of Planets."

BLANK PAGE

IONOSPHERIC AND RADIO PHYSICS (185-39)

HIGH-ALTITUDE ROCKET RADAR
NASA Work Unit 185-39-05-01; 185-39-05-02
JPL 383-90101-X-3240; 324-90201-X-3250

The objectives of the rocket radar project include the development of a flight-worthy radar, the acquisition of radar echo data at various altitudes from 90 to 180 km, and the clarification of the relationship between the echo shape and the surface characteristics.

The implementation of the project consists of developing two flight radar systems and a ground support station. Aerobee rockets will be used to carry the radars over the White Sands Missile Range, where the radar antennas will be oriented to look at the Earth.

During the second half of FY 1965, both flight systems were assembled and tested; a portable ground support station was constructed. The first flight was conducted on June 30, 1965. No echo data was obtained because the transmitter (apparently) arced in the high-voltage section of the modulator. This arcing may have been caused by loss of pressure in the payload. The payload was recovered by parachute. The skin of the Aerobee was split open near the transmitter. The real cause of the failure will not be known until the postflight testing is completed. The second flight will not be scheduled until the problem has been solved.

BLANK PAGE

ASTRONOMY (185-41)

LUNAR SPECTRAL PHOTOGRAPHY
NASA Work Unit 185-41-02-01
JPL 383-10101-2-3250

(This work unit is jointly funded under NASA Code 190-42-03-01. Refer to the Manned Space Science Section for the appropriate report.)

BLANK PAGE

OPTICAL ASTRONOMY
NASA Work Unit 185-41-21-01
JPL 383-10201-2-3250

EQUIPMENT

A major improvement in research equipment has been undertaken at Table Mountain Observatory. A contract was signed June 8 for a new 24-in. reflector with f/16 Cassegrain and (approximately) f/36 Coudé foci. The mounting will be of the modern single pier cross-axis type with precision drives and controls. Optics will be of fused silica with slope errors not to exceed 1/2 part per million. The contract calls for 36 wk delivery.

Preliminary design of a building to house the new telescope has been completed, and plant planning is now finishing final drawings for it. Construction is scheduled to begin in September with FY 1965 funds already committed to the task.

Improvements in the optics and dome of the existing 16-in. facility are under way and scheduled for completion in September and August respectively. Part of the equipment is on order to enable us to conduct a photographic patrol for lunar luminescence.

INTERNAL OBSERVING PROGRAM

For the past 3 yr an extensive program of direct photography has been carried out with the 16-in. reflector, particularly of Venus and Mars. The past 6 mo have encompassed a Mars opposition and a Mariner flight to Mars, so the emphasis has been strongly Martian. With added support of the Mariner Project Office, Charles Capen has been responsible for an intensive "Mars patrol" using our own 16-in. reflector and a 30-in. reflector very kindly made available to us by the Astrogeology Branch of the U. S. Geological Survey. Preliminary results of this "patrol," which will continue into September, have already been submitted to the Mariner Project. A formal technical report on the entire patrol will be available in December.

Because the observation of peculiar red spots in the vicinity of the lunar crater Aristarchus late in 1963 by Greenacre and coworkers at Lowell Observatory, an Aristarchus patrol has been carried out at appropriate times by James Young, Charles Capen, and others. Weather and viewing were particularly bad during critical observing times so far during 1965. Anyhow, no events have been observed.

EXTERNAL OBSERVING PROGRAM

Dr. Ronald Schorn obtained 4 wk of observing time on the 82-in. reflector at the McDonald Observatory during this reporting period, Dr. Hyron Spinrad and Roger Moore (of RAND Corp.) working with him part of this time. They obtained a large number of high-dispersion spectra of Mars in the 8700 Å region suitable for determination of carbon dioxide and water abundances. Dr. Spinrad also obtained a number of quality spectra of the same region with the 120-in. reflector of the Lick Observatory. All of these spectra are being reduced, and a preliminary value of carbon dioxide and water abundance to follow as soon thereafter as is practical.

These observers also obtained a number of excellent photographs of Mars that will be quite useful in developing a picture of Martian conditions during this "Mariner year."

Robert Younkin has continued spectrophotometric measurements of the planets from 3200 Å to 1.1 μ with the Mt. Wilson 60-in. reflector, primary emphasis being given to Mars this year. The monochromatic color of the planet has been measured as a function of phase angle, and the specific intensity of the maria (dark areas) compared to the continents (bright areas). The absorption band of limonite near 8000 Å is totally missing from continental spectra, in contradiction to the assumptions of many authors. This work will soon be submitted for publication and will be presented at the summer meeting of the American Astronomical Society. Younkin has also obtained a number of superb Martian photographs in support of the general effort being made to cover Mars as thoroughly as possible.

Ray Newburn and Dr. Hyron Spinrad obtained good new infrared spectra of Uranus, Neptune, and Titan during eight nights at the 84-in. reflector of the Kitt Peak National Observatory (four nights in October and four in February). Work on these plates is proceeding and will be supplemented by one additional observing run this coming fall. A study of water vapor in cool stars was made by Spinrad and Newburn as fill-in work at Kitt Peak when planets were not appropriately placed in the sky. A paper based on earlier work of this sort, "A Low-Dispersion Spectroscopic Search for Water Vapor in Cool Stars" was published this spring in the Astrophysical Journal, Vol. 141, No. 3, pp. 965-975. A second paper based on the 84-in. data will be sent to press within a few weeks.

Spinrad, Schorn, Newburn, and Younkin have all searched for any spectroscopic evidence of atmospheric gases on the four Galilean satellites of Jupiter. All results to date have been negative. Upper limits will be set and published. Schorn and Spinrad have obtained excellent spectrographic results on the Venus 1.05 μ carbon dioxide band. These are now being studied by Dr. Louise Gray and Robert McClatchey to determine the temperature and pressure conditions under which the band was formed.

This spring Drs. Pierre and Janine Connes and Dr. Reinhard Beer obtained the finest spectra of Mars ever taken in the 1.56 μ region, as described elsewhere in this semiannual report. These results will be combined with the new carbon dioxide abundance of Spinrad and Schorn to give a new accurate value for the surface pressure of Mars. Preliminary results should be available some time in September.

Although some additional observing will be made during the coming 6 mo, the major part of the effort of the optical astronomy group will be devoted to the reduction and publication of data taken during the past 6 (and more) mo.

RADIO ASTRONOMY
NASA Work Unit 185-41-21-02
JPL 383-10301-2-3250

RADIOMETRIC MOON MAPPING AT 3 MILLIMETERS

An attempt is being made to determine the nature of the lunar surface material by means of radiometric studies of the Moon's 3.3-mm wavelength thermal emission.

The manner in which the Moon's surface heats up and cools down during a lunation is determined by the physical characteristics of the surface and subsurface material. By studying the Moon's thermal behavior at millimeter wavelengths, it should be possible to add to our knowledge of the lunar material's density, thermal conductivity, specific heat, dielectric constant, and absorption coefficient for microwave radiation.

Radiometric maps showing microwave brightness temperature across the lunar disk have been obtained for 14 phases of the Moon with the Aerospace Corporation 15-ft radio telescope. The antenna beam of 2.9 min arc afforded a resolution on the Moon's surface of approximately 260 mi, permitting separate studies to be made of five different maria and the one large highland area. After taking into consideration such factors as emissivity, sidelobe smoothing, and the gradual cooling toward the lunar poles, it was found that all five maria are warmer than the highlands by the following amounts (average over a lunation): 2.3, 2.3, 2.4, 2.7, and 2.8° K. It is difficult to reconcile such a large temperature difference with the value expected from albedo considerations (1.5°K), and there may be evidence here for associating a lower dielectric constant with the maria. Furthermore, in the case of the maria regions extending from Imbrium to Nubium, the temperature excess varied throughout a lunation between approximately 0 and +6°K. Mare Tranquillitatis showed almost no variation (1.0 ±0.7 pe °K), and Mare Serenitatis showed a large variation (9.0 ±1.4 pe°K) that is out of phase with the others.

Between the latitudes -50 and +50 deg the observed "polar cooling" is in agreement with the theoretical relation that specifies the temperature will decrease toward the poles according to the fourth root of the cosine of the latitude.

An analysis is now under way that should result in determinations of the coefficient of microwave absorption and thermal inertia (involving density, thermal conductivity, and specific heat) for the highland and five maria regions. Preliminary results suggest that it will be necessary to invoke the presence of a "bare rock" type surface component, comprising approximately 2% of the lunar surface area. Possibly this component may be associated with the many sharp-edged, "young-looking" craters detected in the *Ranger* photographs.

RADIO ASTRONOMY OBSERVATIONS OF VENUS AND JUPITER

For slightly more than 2 wk during July 1964, Venus was observed at nine frequencies between 20.6 and 24.0 Gc using the 30-ft millimeter wave radio telescope located at the Venus site. During December and January, Jupiter was observed at center frequencies of 23.443, 23.900, and 24.005 Gc. The results are summarized as follows:

<u>Venus</u>

1. There is a broad brightness temperature minimum centered between 21.5 and 22 Gc.

2. There is the suggestion of fine structure in the data.

3. Two of the frequencies, 21.5 and 23.5 Gc, suggest a positive correlation with 2800 Mc/s solar flux centered at a lag of about 1.5 days. This is approximately the time of flight for 800 km/sec solar protons.

4. The 22.20 and 22.23 Gc temperatures are respectively about 60 and 150°K higher on the average than those frequencies nearest on either side, although an anomalous behavior in the radiometer output at 22.23 Gc puts little weight on the results at this frequency. However, a consideration of the effect of this behavior on the reduced data suggests that the 22.23 Gc temperatures are actually lower limits and the daily histograms appear to substantiate this because the distributions are strongly asymmetric on the low side. A plot of the Venus brightness temperatures is seen in Fig. 1.

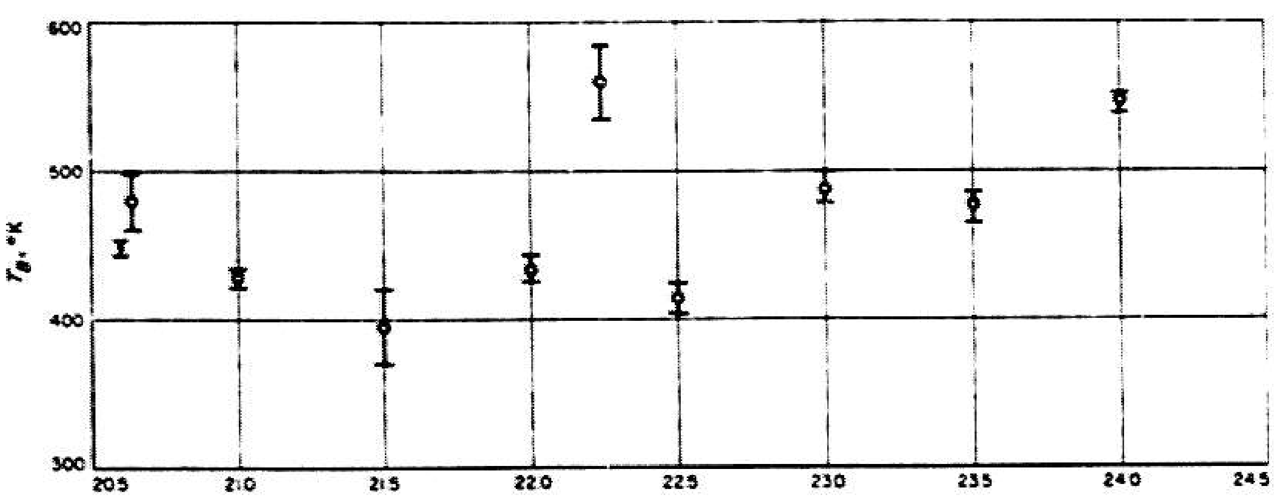


Fig. 1. Venus brightness temperatures

Jupiter

1. The measured brightness temperatures are: 23.445 Gc at 111°K; 23.900 Gc at 144°K; and 24.005 Gc at 134°K. The relative probable errors are about 4°K. A side band at 23.900 Gc is situated at the 3.3 mm line of NH_3. This suggests the possibility of the 3.3 mm line of NH_3 being in emission.

2. Two of the three frequencies exhibit fairly weak but positive correlation with solar 2800 Mc flux for lags of between 11 and 13 days.

While both programs suggest very exciting possibilities regarding conditions in the atmospheres of these planets, the results clearly need to be substantiated. Both programs suffered from short observing periods and the suggested correlations noted above could well be a result of poor statistics. If substantiated, it is clear that:

1. A means for identifying molecules in the Venus atmosphere for microwave rotational lines would be available and subsequent narrow band frequency sweep measurements would allow estimates of the upper atmospheric structure (i.e., down to where the flux of particles from the Sun are stopped).

2. Solar particle flux on Venus could be monitored by observing the brightness temperature at several closely spaced frequencies. The suggested information should contribute greatly to the study of the degree of homogeneity of solar particle-field phenomena in interplanetary space. If Jupiter temperatures are correlated with solar activity the same applies to Jupiter as well. This would greatly enhance particle and field measurements from space probes.

PROPOSED OBSERVING PROGRAM

We propose to use the 30-ft radio telescope and radiometer system to observe both Jupiter and Venus over the period December 1 through February 14 (Jupiter from December 1 through December 7, Venus from December 8 through February 14). It is hoped that the concluding date is flexible if interesting things start occurring on the Sun. We would probably observe Venus at two or three frequencies during the Jupiter program and similarly for Jupiter during the Venus program. To bolster the manpower, several students from Brigham Young University would be available.

Venus will be observed at a number of frequencies from 19 to 26 Gc. This increased frequency coverage will allow measurements to be made of the brightness temperature at frequencies that are needed to substantiate the suggested general trend in the spectrum noted above. Measurements in the vicinity of the water line at 22.23 Gc and most of the previously observed frequencies will be needed. Jupiter will be observed at the same frequencies as before and perhaps on the two others.

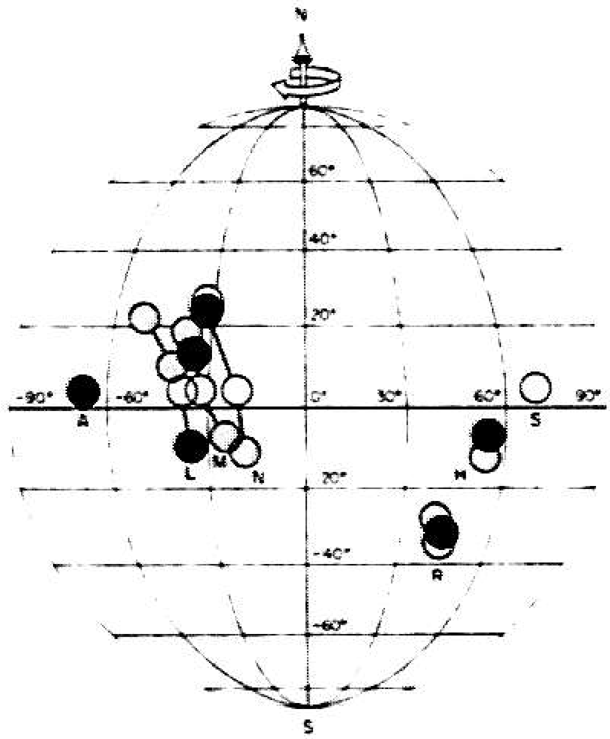


Fig. 2. Location of features on surface of Venus derived from 1964 CW radar spectra

CW RADAR STUDIES OF VENUS

Between February and August, 1964, when Venus was closest to the Earth, radar observations were made of the planet at the NASA/JPL Deep Space Instrumentation Facility at Goldstone, California. One of the experiments undertaken was to obtain high-resolution spectra of the reflection from Venus of a single radio frequency of 2388 mc (λ = 12.5 cm), commonly referred to as a CW (continuous wave) signal. These observations were made in close cooperation with the Telecommunications Division.

As was mentioned in the previous review, the rotation period and spin axis of Venus can be found from the changes in the way in which the base of the CW spectra changes with time. The measurements indicate a sidereal retrograde period of 249 days ±6 days with the spin axis pointed toward R.A. 76 ±5 deg and Dec. -67 ±4 deg. Note that the probable error of the R.A. has been substantially reduced from 44 to ±5 deg. These data indicate that the axis of Venus is very likely within 10 deg of its orbit pole.

Effort has continued in locating surface features on Venus. Figure 2 shows the revised positions of the features seen on the CW spectra. The black circles show the most reliable positions of the features on the planet. The gray circles are less reliable positions, while the unfilled circles are quite tentative. The circles that are connected by lines all represent the same feature and the data is not sufficient to decide unambiguously which circle marks the true position. Zero longitude has been chosen as the meridian that was directed toward the Earth at 00 hours UT on the day of the 1964 conjunction of Venus: June 19, 1964.

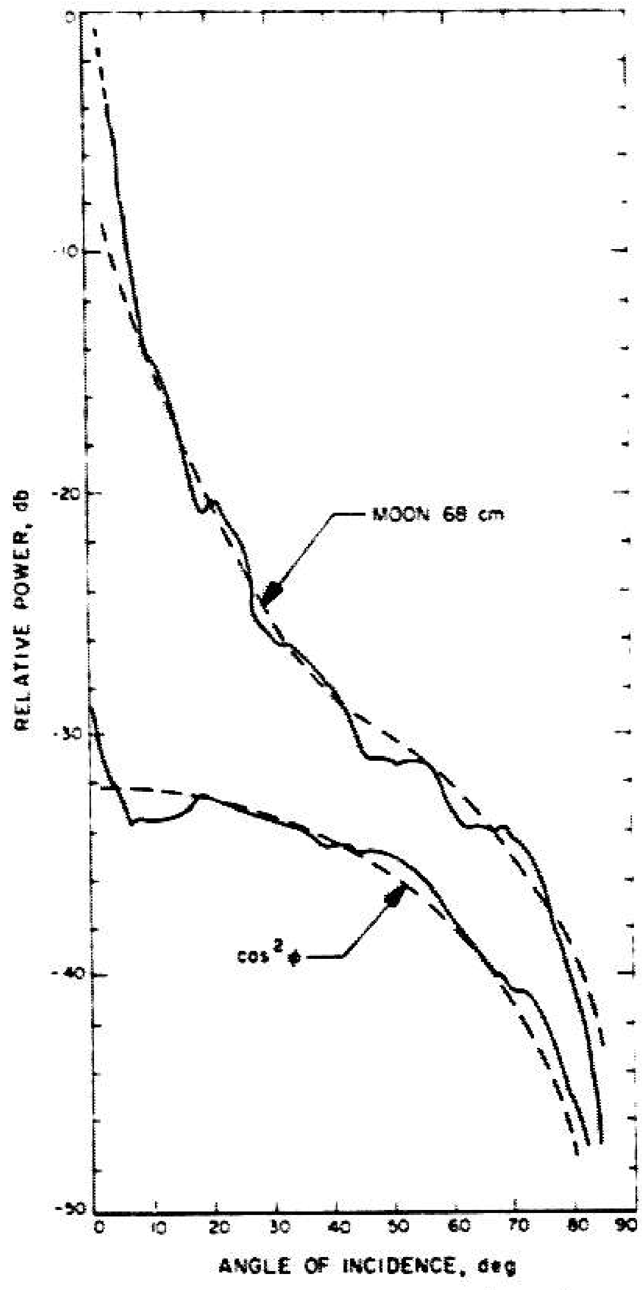


Fig. 3. Venus backscattering functions

A backscattering function has been computed for Venus based on the CW spectra and is shown in Fig. 3. The upper solid curve is for the polarized spectra and the lower solid curve is for the depolarized spectra. This kind of information is being used to obtain information on the planet's surface structure. The upper dashed curve is the backscattering function of the Moon measured at 68 cm by G. H. Pettengill. It was matched to the Venus curve at 10 deg. The close agreement between these curves suggests that the basic scattering mechanism is the same for the Moon and Venus, but that Venus is considerably smoother. The lower dashed curve shows the backscattering function of the form $\cos^2 \phi$ which corresponds to Lambert scattering.

By using the two Venus backscattering functions shown in Fig. 3 the degree of polarization as a function of the angle of incidence can be derived. This information gives another clue to the nature of Venus' surface. Figure 4 shows the percent polarization obtained from the Venus data and similar data obtained from laboratory measurements made of sand, gravel, and stone. The laboratory measurements were made by W. H. Peake and R. C. Taylor both at Ohio State University. The gray area in Fig. 4 is the estimated error of the Venus data. It appears that Venus cannot be primarily covered with sand but that large amounts of gravel and stone-sized material must be present.

A paper titled "Study of Venus by CW Radar--Results of the 1964 Conjunction" was presented by R. L. Carpenter at the March 14-17, 1965 meeting of the American Astronomical Society at Lexington, Kentucky. An abstract of the paper appears in the March 1965 issue of The Astronomical Journal. A more detailed paper on the radar results was presented by R. L. Carpenter at the Gordon Research Conference on "Chemistry and Physics of Space," on July 1, 1965, held at Tilton, New Hampshire.

Currently, a paper is about ready for publication on the 1964 Venus radar results. Also, preparations are being made for further radar observations of Venus during its January 1966 conjunction.

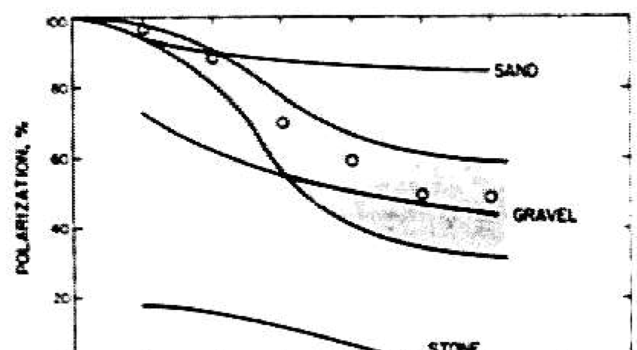


Fig. 4. Polarization of Venus radar reflection vs angle of incidence

PLANETOLOGY (185-42)

INFRARED THERMAL EMISSION FROM SILICATES
NASA Work Unit 185-42-20-01
JPL 383-20101-2-3250

(This work unit is jointly funded under NASA code 190-42-20-20. See the Manned Space Science section for the appropriate report.)

BLANK PAGE

PETROGRAPHIC STUDIES
NASA Work Unit 185-42-20-02
JPL 383-20201-2-3250

LUNAR AND PLANETARY PETROGRAPHIC MICROSCOPE DEVELOPMENT

Work in the last half of FY 1965 on the petrographic microscope has consisted of design and fabrication of a sample-processing hopper and screen assembly. The encapsulation mechanism requires grains with diameters greater than about 300 μ. A screen has been developed for this sizing process. The preliminary breadboard hopper was effectively a vibrating cup with a 300 μ screen that excluded the fine particles. However, it is feared that fine particles at the lunar surface may adhere to one another and to the meshes of the screen and that the lunar gravity may not be strong enough to break the interparticle bonds.

Accordingly, a hopper and screen mechanism was conceived that forces the particles through the screen centrifugally and sweeps the screen with a Teflon brush. The screw and brush mechanism was designed and partially fabricated; work is continuing under the supervision of Mr. George Hotz.

A tentative design has also been produced for the system that contains the objective lens, the analyzer, eyepieces, and the vidicon camera. It is desirable to have the vidicon remain in a fixed position during viewing and to have the objective lens remain in focus after magnification changes. The interposition of a slider containing three eyepiece lenses between the objective lens and the vidicon faceplate appears to be the best way to attack the problem of changing magnification.

A request for proposals to design and fabricate a prototype microscope was sent to vendors in mid-June. The proposals are due in mid-July.

BLANK PAGE

PLANETARY ATMOSPHERES (185-47)

AERONOMY
NASA Work Unit 185-47-01-01
JPL 383-70101-1-3280

The objective of this work unit is to conduct a balanced research program in laboratory, observational, and theoretical upper atmosphere physics.

TABLE MOUNTAIN AIRGLOW OBSERVATORY

The ultraviolet night airglow has been measured with a spectrometer and memory unit using pulse-counting techniques.

UPPER ATMOSPHERE PHENOMENA

Laboratory measurements of upper atmosphere phenomena using optical and electron paramagnetic resonance spectrometers continued. Comparison of laboratory source of Herzberg bands with flight spectra of J. Hennes of Astrophysics branch, GSFC has been carried out.

DOCUMENTATION

Theoretical calculations of upper atmosphere phenomena have been published as follows:

"Calculations of Ultraviolet Molecular Nitrogen Emissions from the Aurora," A. E. S. Green and C. A. Barth, Journal of Geophysical Research Vol. 70, 1083-1092 (1965).

"Rocket Measurement of the Photoelectron – Excited Ultraviolet Dayglow," C. A. Barth and J. B. Pearce, Space Research VI, COSPAR, Buenos Aires, 1965.

"Rocket Measurement of the Ultraviolet Aurora," J. B. Pearce and C. A. Barth, Transactions American Geophysical Union Vol. 46, 60 (1965).

BLANK PAGE

MODEL ATMOSPHERES
NASA Work Unit 185-47-26-02
JPL 383-70201-2-3250

The long-term objective of the model atmospheres program is to establish the physical parameters that define a particular planetary atmosphere. This involves the use of both experimental observations and theoretical calculations. The required experimental observations include the astronomical measurement of the spectra of planet-atmosphere systems, more detailed measurement from space probes, and laboratory spectra of gases. Theoretical atmospheric models will be compared with these experimental findings and updated to agree with the most recent information.

PROGRESS SINCE JANUARY 1965

Theoretical work in support of a remote atmospheric temperature sounding experiment has required much of our time and effort. A computer program for computing atmospheric transmission had previously been developed, but only recently have experimental values of atmospheric transmission become available for comparison. The work of D. Murcray et al. of the University of Denver has provided such experimental data and a comparison with our calculations is shown in Fig. 1. Figure 2 represents a particular temperature profile for the Earth's atmosphere, and Fig. 3 represents the corresponding emergent spectral distribution of radiation.

Initial tests of this experiment have been conducted in the Earth's atmosphere and the results are now in the process of being reduced. To interpret these data, a series of "computer experiments" have been run. A given temperature distribution is assumed to exist (see Fig. 4, Real atmospheric model) and an inversion scheme is carried out by an iterative procedure. To introduce the least bias into the initial temperature distribution, an isothermal atmosphere is adopted. The resulting temperature distributions obtained in the first four iterations are presented in Fig. 4. It is seen there that the final result is almost identical with the original temperature distribution. To determine the effect of both systematic and random errors of measurement, similar tests were run with such built-in errors. The results of these tests are presented in Fig. 5 and 6 for 10% systematic and 2% random error, respectively. Recently, the effect of a triangular slit function has been included in the radiation calculations and the resulting smoothing is shown by the solid curve in Fig. 3. The use of the slit function in the entire inversion scheme has not yet been completed and so is not included here. This is the major item remaining in this program before some real data is interpreted.

In addition to the temperature sounding experiment, work has continued in support of astronomical observations of infrared spectra. This work has taken two different forms:

1. It has been necessary to determine band strengths and individual line strengths for many of the carbon dioxide bands located in the 1.6 and 2.0 μ regions. Attempts to fit theoretical transmission calculations to laboratory data have been used when the available laboratory spectra were measured under conditions

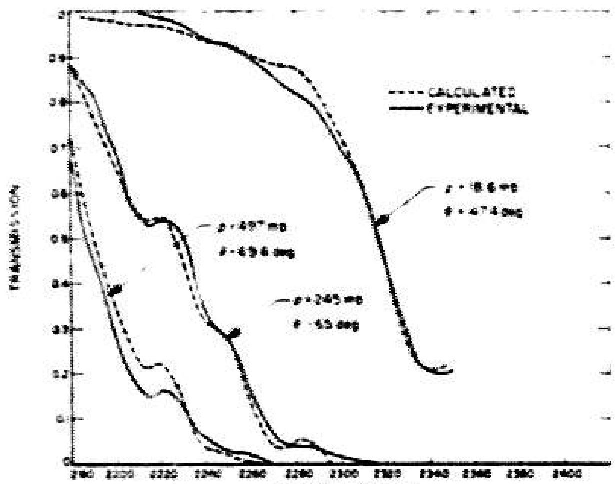


Fig. 1. Comparison with data of Murcray

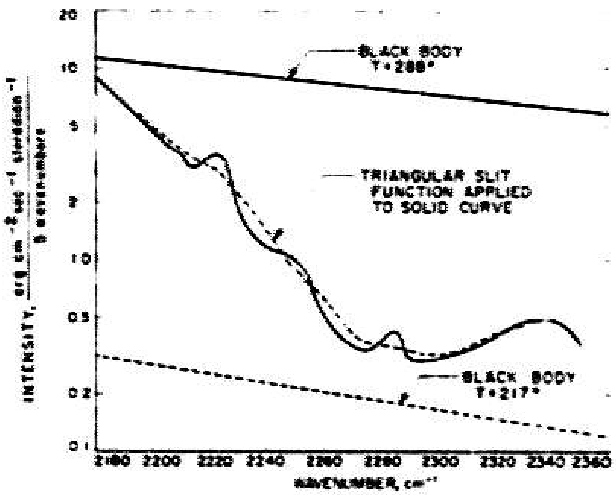


Fig. 3. Intensity distribution emerging from "standard" Earth atmosphere

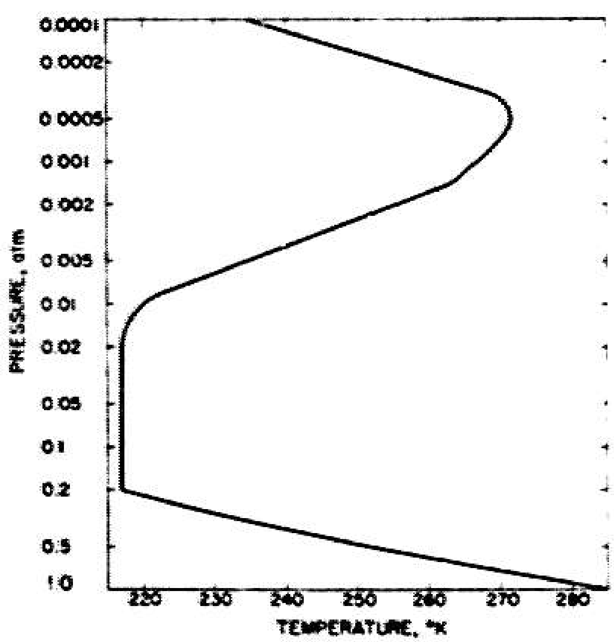


Fig. 2. "Standard" Earth atmosphere

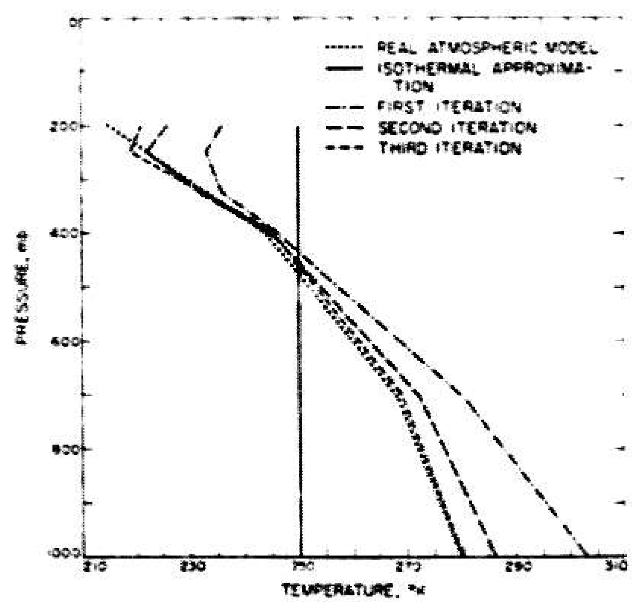


Fig. 4. Spectral distribution of radiation measured without error

that do not allow equivalent widths of individual lines to be measured. Figure 7 shows such a calculation for the 2 μ region. If equivalent widths of individual lines can be measured, a more straightforward approach can be used.

2. The possibility of determining both atmospheric pressure and absorber concentration from the equivalent widths of two rotational lines is being investigated. In the past, the procedure has been to find a region (or a line) of very weak absorption and another region (or line) of very strong absorption, and to determine an absorber concentration from the weak line and a mp product from the strong line. Apparently it should be possible to pick any two lines as long as they are not both either weak or strong for the determination of both m and p. Thus, the measurement of a single carbon dioxide band should provide many combinations of lines that will overdetermine m and p. We intend to further investigate this next year.

Recently (last March) spectra were obtained by Pierre Connes and Reinhard Beer, at Haute Provence in France, of Mars, Venus, and Jupiter.* The possibility of computing a better value of the surface pressure from the observations has prompted a need for laboratory data for the carbon dioxide bands in the 1.6 μ region. D. Burch of Aeronutronic has obtained such data but did not have sufficient support for the reduction of that data to a suitable form for the evaluation of astronomical

*See report on Optical Astronomy, NASA Work Unit 185-41-21-01

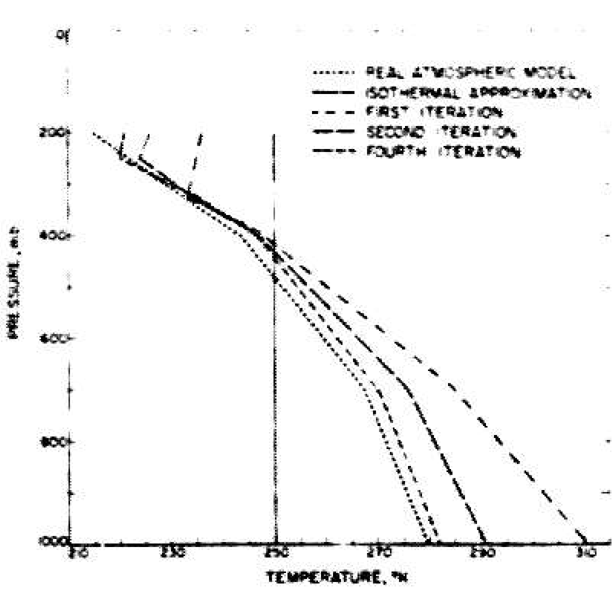


Fig. 5. 10% systematic error

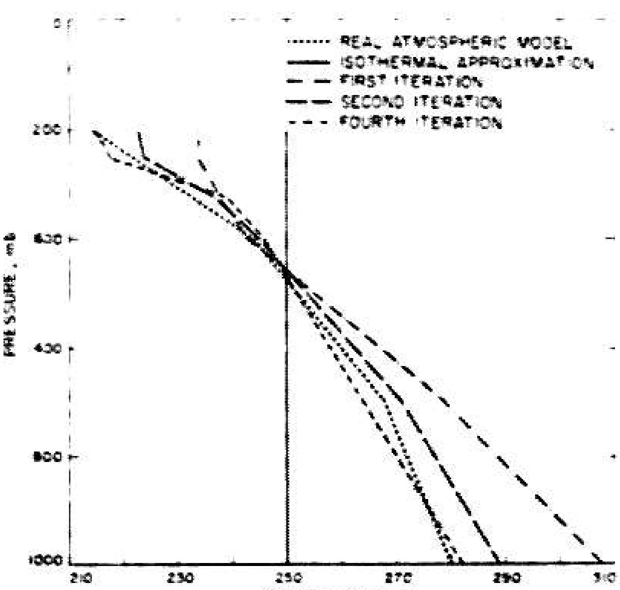


Fig. 6. 2% random error

spectra. A contract has recently been let by JPL to Aeronutronic specifically for that purpose. These data should become available to us within the next few months.

A theoretical study of radiative transfer by scattering in inhomogeneous finite atmospheres is underway; our goal is to integrate this study with the theoretical studies described above. Preliminary results for two-layer scattering atmospheres have been obtained, and the first in a series of reports on this study is now being prepared. Figure 8 compares theoretical limb-darkening curves for a two-layer semi-infinite atmosphere with two semi-infinite isotropic-scattering atmospheres. Scattering is isotropic in the two-layer model, the top layer having an albedo $\omega_0 = 0.5$ and an optical thickness $\tau = 0.5$, while the bottom layer $\omega_0 = 0.9$. Work has started on the effects of ground reflections and higher orders of scattering.

PROPOSED WORK FOR FY 1966

In addition to the obvious extension of the work indicated in the above sections, the following specific tasks will be undertaken in order to work toward the above-mentioned long term goals:

1. Analyze the data obtained from the two flights of the spectrometer and compare the results obtained for the temperature structure of

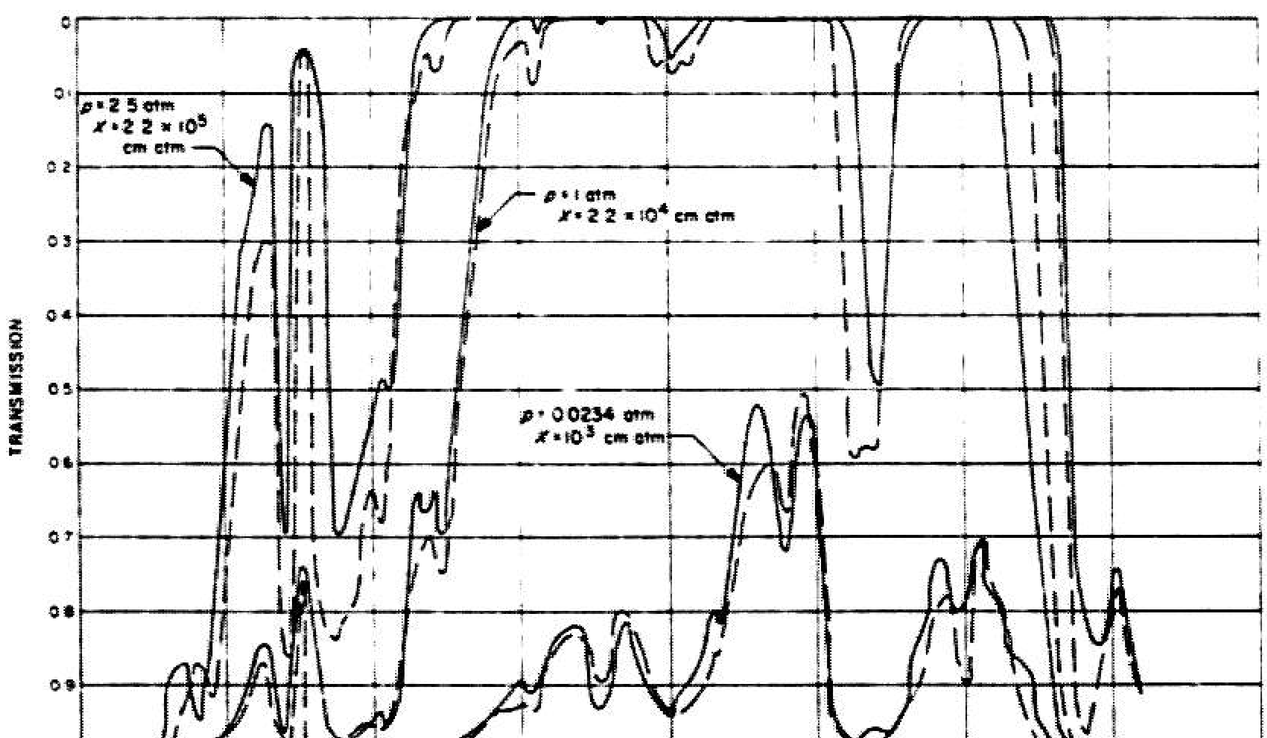


Fig. 7. Transmission of 2.0 μ carbon dioxide bands

the terrestrial atmosphere with radiosonde observations. This is not a straightforward data reduction problem and could involve considerable alteration of the methods which we will initially attempt to involve. If initial attempts are not successful, this project could involve a considerable effort.

2. Evaluate the various reported values of the physical parameters of the Martian atmosphere and establish the best model atmosphere for Mars consistent with these parameters.

3. Calculate radiative equilibrium vertical temperature profiles and their aerographic, seasonal, and diurnal variations. This will involve detailed solutions of the radiative transfer equation as a function of frequency within the carbon dioxide bands that are important to the atmospheric thermal balance.

4. Investigate the atmospheres of Venus and Jupiter and develop model atmospheres.

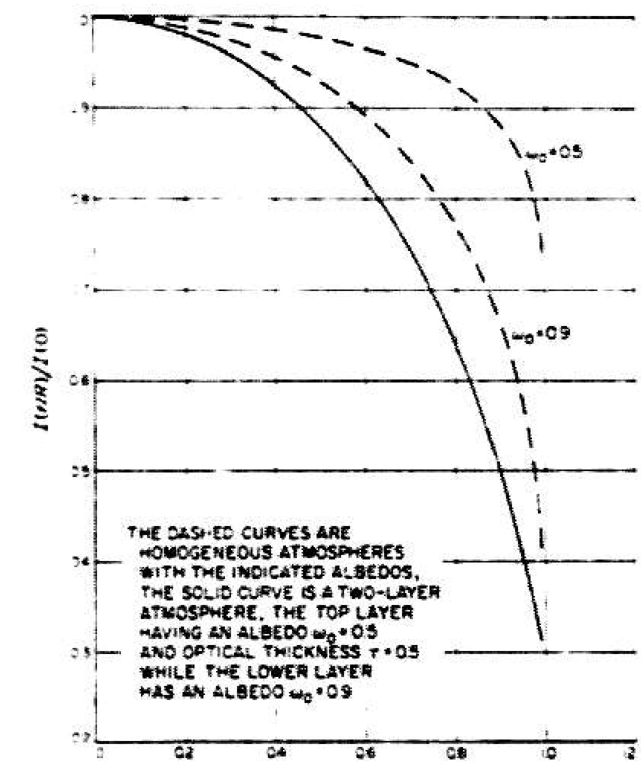


Fig. 8. Limb-darkening curves for semi-infinite, isotropic-scattering atmospheres

5. Interpret ground-based observations of Mars and Venus and experimental data obtained in the JPL spectroscopy laboratory for molecules expected to exist in the atmospheres of these planets.

6. Extend the calculations on scattering atmospheres to models which can be hoped to compare favorably with observations and develop the new methodology required for the integration of this study with the other studies listed above.

SPECIFIC ATMOSPHERIC COMPONENT ANALYSIS
NASA Work Unit 185-47-26-06
JPL 383-70601-2-3290

The objective of this program has been to develop instruments for the quantitative measurement of specific gases in planetary atmospheres. As previously reported, this effort has been done on a limited basis during FY 1965 with the aim of closing out the task as an SRT program at the end of the fiscal year. It is anticipated that the methods studied may find application in the Voyager program.

RUTHERFORD EXPERIMENT

This experiment is designed to measure the expected major components of the Martian atmosphere (nitrogen, carbon dioxide, and argon) by alpha-particle bombardment. The engineering breadboard model was installed in a vacuum chamber at the laboratory in January. Checkout of instrument operation has been made using a standard Am^{241} alpha source and a commercial (TMC) pulse-height analyzer. The instrument meets specifications on energy scale, resolution, operation of discriminators (energy windows), and readout of counts in the digital electronics (square root converter).

The feasibility of atmospheric analysis by this technique has been demonstrated earlier in the program; accurate measurements of nitrogen and argon in air have been previously reported. A more extensive series of analyses of mixtures of nitrogen, carbon dioxide, and argon planned for this period have not been conducted because of manpower limitations.

It should be noted, for possible use in the Voyager program, that heat-sterilizable semiconductor detectors satisfying the requirements of this experiment have been successfully developed under a JPL contract.

KRYPTONATE EXPERIMENT

This technique is designed to measure oxygen concentrations down to very low levels. Radioactive Krypton-85 is incorporated in the surface of a copper foil. When the copper is heated in a gas mixture containing oxygen, the copper is oxidized and Krypton-85 is released. The partial pressure of oxygen in the gas is determined from the rate of loss of radioactivity.

The study contract with Parametrics, Incorporated was completed in January, and the final report was delivered to JPL during this period. Technical accomplishments under this contract have been previously reported.

The in-house activity during this period has been directed toward the verification of loss-rate of Krypton-85 from copper foils as a function of oxygen concentration, source temperature, and total pressure.

A test system has been built that permits simultaneous measurement and recording of source temperature, power dissipation, gas pressure and flow rate, and counting rate of beta particles from the source. Kryptonated copper sources, prepared at Parametrics by the ion-bombardment technique, have been tested at various oxygen concentrations, temperatures, and pressures.

Tests conducted at a total pressure of one atmosphere with gas mixtures containing 114 ppm and 17 ppm oxygen have, in general, given Krypton-85 loss rates that are consistent with the sensitivity and half-order reaction found by Parametrics. The results indicate that at 700°C, loss rates of about 7%/min would be observed at 1 ppm and one atmosphere, or about 1%/min at 1 ppm and 20 millibars.

Considerable difficulty has been encountered in performing tests at reduced pressures because of small leaks in the system. Because of this problem, loss-rates at reduced pressures have not been verified experimentally. The test system has been redesigned and should be capable of low-pressure operation if the program is resumed.

ALUMINUM-OXIDE SENSOR

This technique has been developed to measure water vapor down to extremely low concentrations (frost point -110°C) by use of simple impedance changes in an aluminum-oxide film.

The study contract with Parametrics was completed in January and the final report was delivered to JPL during this period. Technical accomplishments under this contract have been previously reported. No in-house work was planned for this reporting period.

ADVANCED TECHNICAL DEVELOPMENT (186)

BLANK PAGE

PLANETARY QUARANTINE STERILIZATION (186-58)

ACTUATOR STERILIZATION
NASA Work Unit 186-58-02-01
JPL 384-82801-2-3440

DETENTING MOTOR

This development was undertaken to provide a prime mover for advanced type spacecraft hinge actuators. Actuators of this type may be required on the Voyager capsule.

The development of a sterilizable detenting servomotor was performed by Vernatron Corporation following direction from JPL. The motor is to operate as a conventional two phase servomotor and to have the feature of stopping within 100μ after power cut off. After stopping, the motor holds in a detenting manner with approximately one tenth the running torque.

The development was successful. Three production prototype motors (Fig. 1) have been received and have met the functional, sterilization (both heat and ethylene oxide)and environmental requirements.

The mechanical design makes use of Bartemp bearings and stainless steel shaft and housing. The Bartemp bearings at 500°F are capable of running at rated load for periods in excess of 2,000 hrs. The material used in the laminations, shaft, and housing will suffer no degradation or change at 500°F. This temperature is below the annealling temperatures of the lamination material. All soldering makes use of high-temperature solder with a melting point of 700°F. The bonding and impregnation resin is Dow Corning 997. This will withstand continual temperature in excess of 500°F. The copper wire used for winding the coil is Anaconda ML, a high-temperature insulated wire. ML is a DuPont Polyimide similar to nylon. It has a trade name designation PYRE-ML. The PYRE-ML compound will withstand soak temperatures at 500°C for 24 hr without serious degradation or weight loss. At 250°C, the weight loss is about 5% in 20,000 hrs. It does not cold flow; that is, it would not leave a wire bare of insulation upon long application of force over sharp edges. However, it must be cured properly at the time of manufacture to be safe against the possibility of cold flow.

In addition to the typical spacecraft applications for which the motor was developed, there are numerous industrial applications. A few are:

1. Micro positioning servo controls for machine tools.
2. Elevator drive systems.
3. Any type electrical positioning mechanism.
4. Switching devices.
5. Similar systems.

JPL is making a patent application on this motor.

Future Activities Planned

A final report will be written during the next quarter. The motor will be used in the first experimental antenna actuator now being fabricated.

JET VANE ACTUATOR

An advanced-type jet vane actuator using typical autopilot performance requirements is under development at Aeroflex Laboratory in Plainview, Long Island, New York. The actuator is to be a moving-coil type using flexural bearings. The actuator is being developed to stand a temperature soak of 500°F and to be compatible with ethylene oxide gas.

Aeroflex had some difficulty with the flexural bearing for the jet vane actuator. A structural dynamic analysis conducted by JPL predicted the difficulty that was encountered with the first flexural bearing configuration.

A three-beam cross flex configuration is presently under development. The tribeam flex pivot appears promising. The contract is being revised to eliminate product design and prototype fabrication. The revised contract will require a completed development of the flexural bearing as the first step. The second step will be completion of feasibility and testing of the breadboard model.

The Electron and Laser Beam Symposium conducted at Pennsylvania State University March 31 to April 2, 1965, was attended for the purpose of gaining familiarization with electron-beam welding. This can have wide use in the fabrication of precision parts for actuators. Aeroflex Laboratories are planning to use electron beam welding in the fabrication of the flexural bearing in the jet vane actuator.

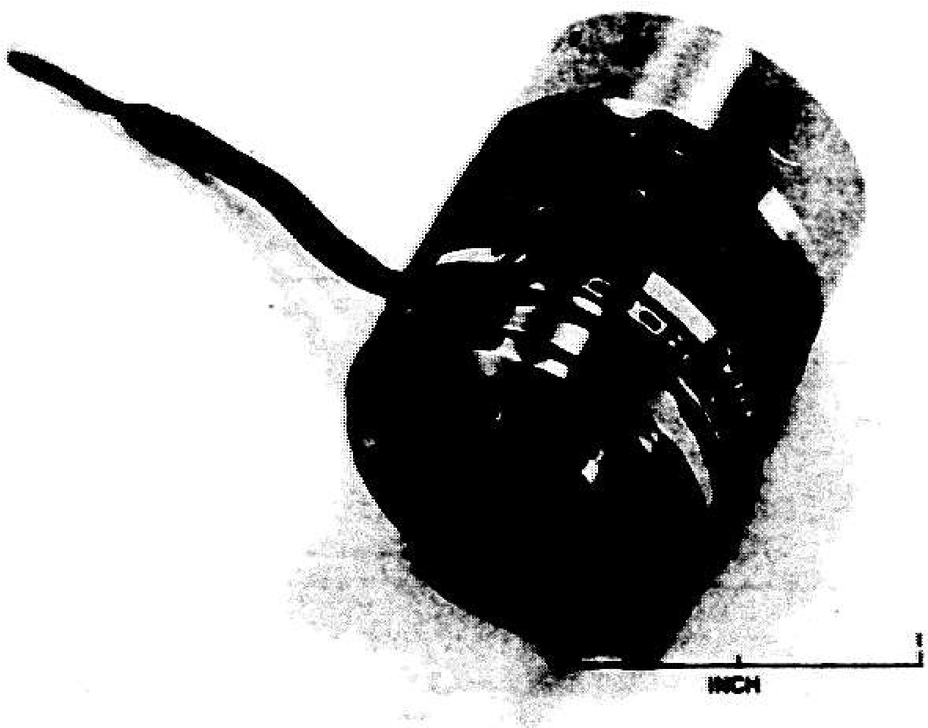


Fig. 1. Servo motor (Vernation Corp.)

BLANK PAGE

JPL Technical Memorandum No. 33-243, Vol. I

HIGH TEMPERATURE PHOTOCATHODE IMAGE DISSECTOR

NASA Work Unit 186-58-02-02
JPL 384-82501-2-3440

The goal of this program is to obtain a flightworthy electrostatic image dissector, capable of enduring heat and gas sterilization, that can be used in all celestial sensors requiring high sensitivity. Important applications will be star sensors for attitude control of spacecraft, orbiters and landers, and long-range Earth sensors for pointing antennas on soft landers.

PROGRESS

Gas sterilization (12% ethylene oxide and 88% freon 12, by weight) is not considered to be a problem. Heat sterilization (145°C for 36 hrs) has adverse effects on the most sensitive photocathodes because they generally employ cesium which is quite volatile at the sterilization temperature. Because of this inherent weakness in phototubes using cesium the bi-alkali photocathode has been given primary attention. Other workers in this field have shown that the bi-alkali surface is intrinsically better able to withstand elevated temperatures, if only because the alkali metals sodium and potassium have a lower vapor pressure and are less likely to migrate. Emphasis was placed on obtaining the highest possible sensitivity. Further, special attention was paid to the multiplier gain which can be obtained with these tubes, since in the absence of cesium the secondary emission ratio of conventional silver magnesium dynodes is somewhat reduced.

The approach to the problem of achieving useful cathode sensitivity and gain involved the fabrication of over thirty 2-in. photomultiplier tubes, each one incorporating a processing experiment. Each tube was processed under the closest possible control to study the various effects of the activation schedule on sensitivity, gain, and stability when repeatedly sterilized. Heating and cooling rates, temperature, activation times, pressure, photo-response, gain, and leakage were monitored throughout the processing of each tube.

Each group of tubes has been subjected to six sterilization cycles. General improvements in photo-response and stability have resulted with each group of tubes. Figure 1 illustrates the effect of sterilization on photo-response. Two interesting characteristics are worth noting. First, the initial photo-response is as good as the best 5-11 photocathode without the use of cesium. Second, the photo-response has stabilized by the second or third cycle. (20% stability is considered acceptable for sensor applications.) Figure 2 shows that multiplier gain remains quite stable through three cycles of sterilization and does not suffer an initial loss in sensitivity. Although performance is somewhat erratic with subsequent cycles, improvement should come with more experience. Figure 3 shows the spectral characteristics of the bi-alkali tubes before and after sterilization. The drop in photo-response noted in Fig. 1 has been determined to be caused by a decrease in the red sensitivity of the tube. The quantum efficiency (generally between 7 and 10%) remains roughly constant at $= 0.45\mu$ with repeated sterilization cycles, while the efficiency at longer wavelengths decreases. For tube 1223 the quantum efficiency at 0.45μ was within 2% before and after cycling. All tubes have not been completely evaluated as yet.

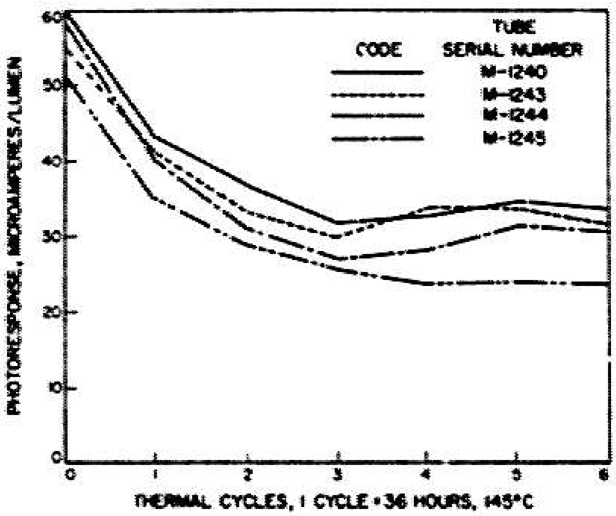


Fig. 1. Effect of thermal cycling on photocathode response

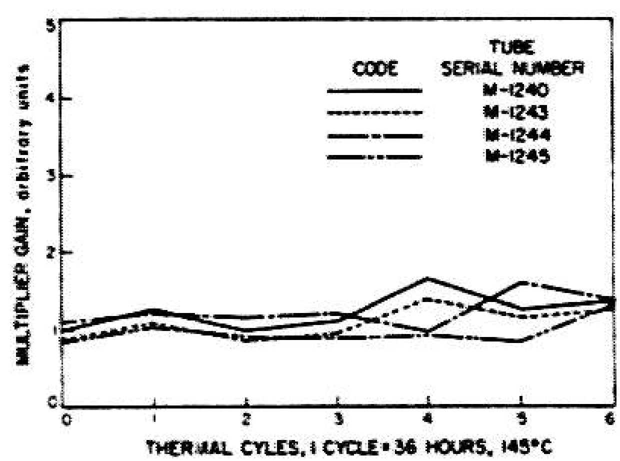


Fig. 2. Effect of thermal cycling on multiplier gain

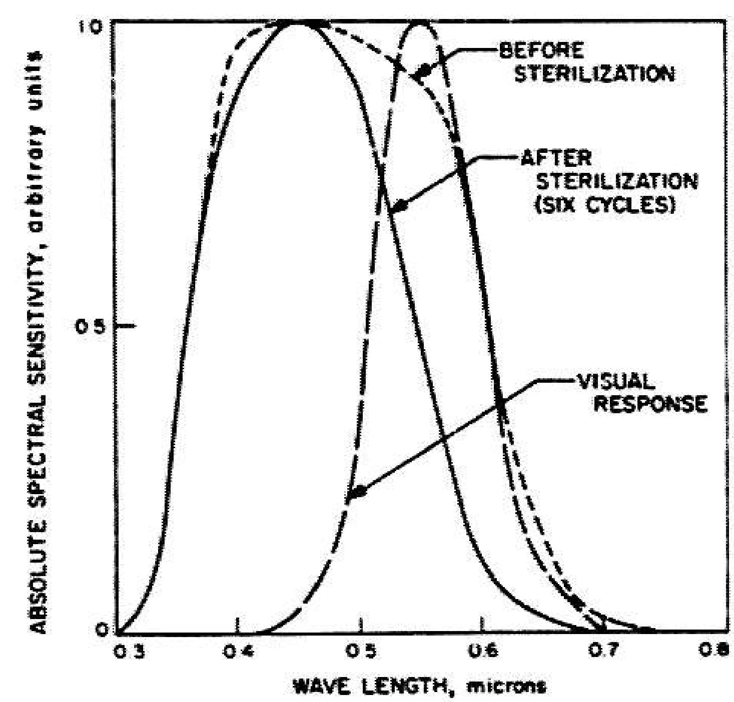


Fig. 3. Spectral response characteristics of the CBS bi-alkali photo tube (tube 1223)

EFFORT PLANNED FOR THE NEXT SIX MONTHS

Transferring technology learned from the development of 2 in. photomultipliers to the image dissector geometry is to be accomplished during the next six months. Two tubes will be delivered and evaluated on this program. An extension to the contract will be written to allow the contractor to optimize the activation schedules in the image dissector geometry and to provide life test data.

TECHNOLOGICAL FALL-OUT

The 2 in. sterilizable photomultiplier tube developed on this contract should be useful to many of the scientific experiments being considered for Voyager missions. It is recommended that interested scientists should followup the development of this tube with CBS, since there are no known sensor applications that require a 2 in. photomultiplier.

INERTIAL SENSORS - STERILIZATION
NASA Work Unit 186-58-02-03
JPL 384-82701-2-3440

GYRO DEVELOPMENT

It is the intent of this program to develop the Honeywell GG159C gas bearing gyro to be capable of surviving five sterilization cycles without catastrophic failure. The development effort progressed through materials and subcomponent investigations and was followed by the fabrication and evaluation of a complete gyro.

As part of the development program the contractor (Honeywell) was required to establish the gyro presterilization performance coefficients and then subject the gyro to five sterilization cycles with a standard performance evaluation after each cycle.

The contractor progressed through the second sterilization cycle and performance was only slightly outside design goals. The goals are tabulated below:

Performance coefficient	Maximum change from sterilization, deg/hr
Mass unbalance	±0.14
Reaction torque	±0.1

After the third sterilization cycle, however, the spin motor failed to start. The motor was released by snapping the gyro about its spin axis. It is believed that in addition to damage caused from sterilization, this snapping could easily have caused reaction torque and mass balance changes. After the motor was released the drift rates exceeded the design goal. All of the drift test results are shown in Table 1.

Table 1. Drift test results

Drift coefficient	Mass unbalance, deg/hr		Reaction
	Input axis	Spin axis	Torque, deg/hr
Reference	+0.53	-0.58	+0.09
1st sterilization, change	+0.08	+0.14	+0.04
2nd sterilization, change	-0.07	-0.15	+0.01
3rd sterilization, change	+0.53	-0.74	+0.09

After a complete preteardown evaluation to identify the failure cause it was concluded that physical contact between the rotor and some nonrotating motor part was the probable failure cause. The gyro was then disassembled and it was discovered that there was physical contact between the motor hysteresis ring and the stator cover. This contact resulted from stator cover distortion caused from thermal expansion differences between the stator cover and dissimilar materials in contact with it. This is one area that was overlooked in the design evaluation. Having uncovered the problem area additional material evaluation and design changes were undertaken. Subsequent extensive evaluation of the redesigned spin motor assembly demonstrated that the redesigned stator cover could survive sterilization without failure. However, a stator winding shorted out after a number of sterilization cycles. This problem was solved by increasing the epoxy back fill to improve insulation. Following this correction the gyro was built up, and a reference performance evaluation was conducted. The performance was erratic and a subsequent gyro teardown exposed a dielectric failure in the gimbal suspension pump. A new pump was built with special care being exercised to prevent a recurrent failure. Again the gyro was rebuilt and this time it went through the complete test sequence, including five sterilization cycles, without catastrophic failure.

TEST RESULTS

The test results are summarized in Fig. 1 and Table 2. Referring to Fig. 1, one can see that the mass unbalance and reaction torque have a definite trend with each sterilization cycle. The mass unbalance trend may be caused from floatation fluid absorption and the reaction torque shifts are likely from flex lead null shifts. Fluid torque is reasonably stable indicating the case stability. The overall performance shift with sterilization cycles did not meet performance goals, however, passing sterilization without catastrophic failure is considered a significant accomplishment in itself. If the gyro were used in an application as it is, electrical trimming could be conducted externally after thermal sterilization. Of course, the best solution is to uncover the cause of this drift trend and eliminate or reduce it to an acceptable level.

The gyro has been delivered to JPL. Further evaluation is planned to determine the drift shift cause, if possible, and establish the number of sterilization cycles which the gyro can be exposed to without catastrophic failure.

Table 2. Torque shifts and random drift

Cycle number	Torque shifts, deg/hr			Random drift, deg/hr 4 hr, 1σ		Drift trend, deg/hr/hr	
	RT	MU_{IA}	MU_{SRA}	OAV	IAV	OAV	IAV
Reference	---	---	---	0.003	0.002	0.0002	0.0007
1	-0.26	0.26	-0.34	0.003	0.002	-0.0007	-0.0004
2	-0.07	-0.02	-0.09	0.001	0.001	0.0002	-0.0002
3	-0.07	-0.08	-0.07	0.001	0.002	-0.0005	-0.0010
4	-0.09	-0.08	-0.10	0.001	0.002	-0.0005	-0.0009
5	-0.04	-0.08	-0.13	0.002	0.003	0.0008	-0.0013

In addition to the JPL evaluation program, plans are formulated to purchase more sterilizable gyros for evaluation in FY 1966.

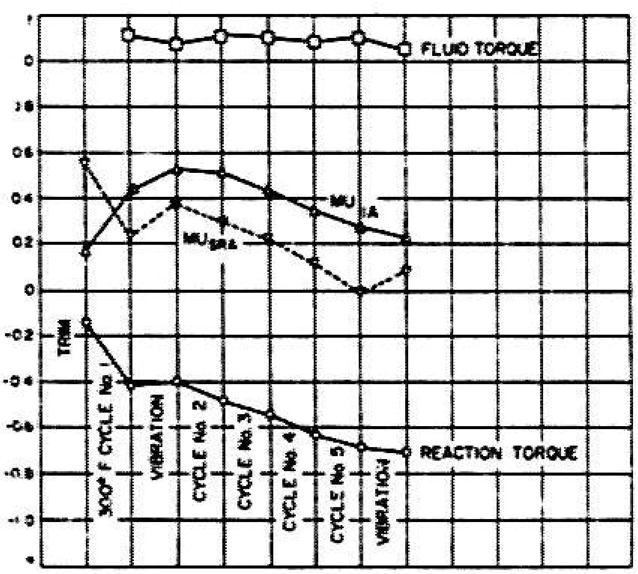


Fig. 1. Gyro balance torque history

BLANK PAGE

TAPE RECORDER STERILIZATION
NASA Work Unit 186-58-03-01
JPL 384-85601-2-3341

DECONTAMINATION TESTING

Decontamination testing of the sterilizable Mariner C type of tape recorder transport case with ethylene oxide was successfully completed. Leak checks and internal gas analysis indicated no problems.

ASSEMBLY AND OPERATION

The sterilizable Mariner C type of transport was completely assembled, using the most successful of the AMC sterilizable heads, and subjected to complete JPL heat sterilization testing (three 36-hr periods at 145°C). Upon subsequent attempted operation, it was found that the transport started normally with no indications of sticking or binding. The head outputs, flutter, and AM were normal. About 25 passes of the tape were made prior to opening the case. Upon opening the case, the following observations were made:

1. A black stain on the Dow 17 finish adjacent to the Viton seal rubber.
2. Whitish crystals adjacent to the seal towards the inside of the case.
3. A soft gray deposit on the reel housing which soon volatized.
4. A surface phenomenon on the beryllium copper clutch spring and capstan "True-Arc" (C-Clamp) which gave the appearance of fine diamond dust.
5. Slight creepage and a crack in the epoxy of the AMC head (not located in the tape path). The gap remained constant with no shifting or stepping.
6. An etched or dulled appearance of the brass flywheel, the clear anodized aluminum pulleys, and all solder connections.

Figures 1 and 2 are photographs of the opened transport following sterilization.

EVALUATION AND ANALYSIS

A thorough evaluation and analysis of the sterilization test results is continuing. A sample of Viton rubber, cured to magnesium, was tested at JPL to investigate the reactions described in (1) and (2) above and for sulphur and chlorine presence as the effect of sulphur on beryllium copper is similar to that observed on the spring and True-Arc. The Viton is a fluoro-hydrocarbon, and did not contain sulphur or chlorine either in formula or as contaminants. However, Dow-Corning No. 55 silicone grease was used as an aid to hermetic sealing the transport case.

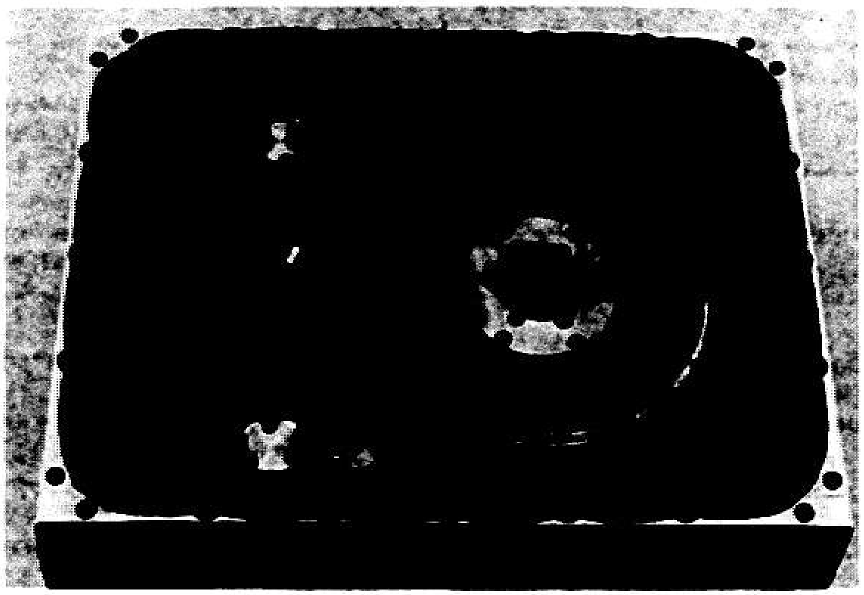


Fig. 1. Sterilized magnetic tape recorder (front view)

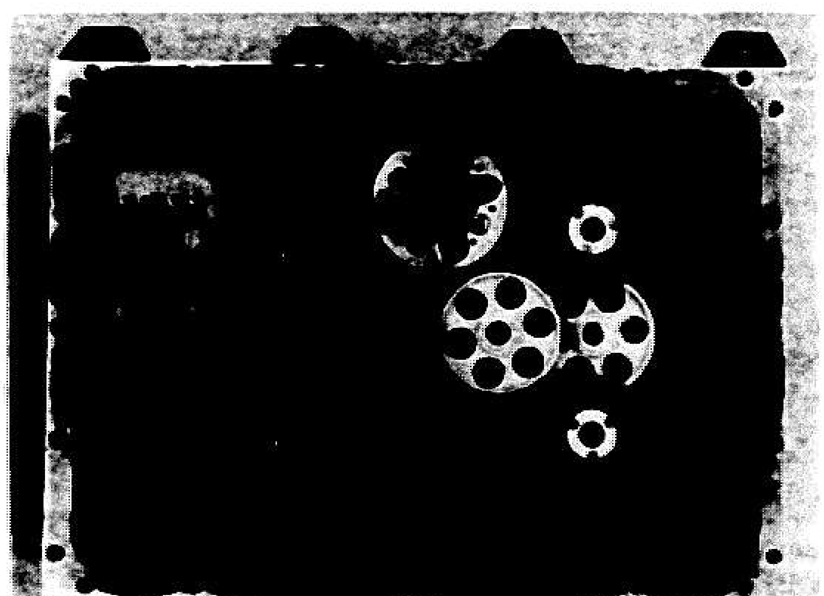


Fig. 2. Sterilized magnetic tape recorder (rear view)

Previous testing on the case involving leak checks before, after, and during heat sterilization and chemical decontamination had not utilized this grease. Since these tests were successful, this grease is probably unnecessary. Unfortunately, however, it was applied to the sealing area prior to sterilization and is believed to account for the whitish crystals (which analysis shows to be mainly silicon and magnesium). In addition, the No. 55 pneumatic grease was tested for sulphur and chlorine and was found to contain chlorinated aromatic silicon with lithium oleate plus some diphatic hydrocarbon additives. Furthermore, the total volatile material was found to be over 16% when the grease is heated to 110°C for 23 hr.

TESTING PROGRAM

Following examination of the transport, a life-testing program was undertaken. A capstan bearing failure occurred after five days (it became noisy and resulted in increased flutter) and another failed after ten days. This is attributed to insufficient lubricant. However, it could also be due to contamination of the lubricant.

DOCUMENTATION

A paper summarizing the tape recorder sterilization program to date was written. It is presently being incorporated into a comprehensive paper that will include the entire JPL telecommunications sterilization activity.

FUTURE ACTIVITIES PLANNED

Activities planned for the next six months are summarized as follows:

1. Investigate the following areas to determine the extent of work required to establish reliable sterilization compatibility and undertake development efforts in one or more of these areas if deemed necessary:

    a. Bearing lubricants.

    b. Bearing and capstan design.

    c. Head design and head materials.

    d. Magnetic tape binders.

    e. Epoxies and cements.

    f. Temperature history of metals.

    g. End-of-tape sensors.

2. Continue in-house investigation and analysis of the <u>Mariner C</u> type of tape recorder transport sterilization test results.

3. Investigate the sterilizability of a typical isoelastic reel-to-reel type transport.

4. Complete the writing and publication of a comprehensive JPL telecommunications paper on sterilization that shall include a summary of the tape recorder sterilization program to date.

ATMOSPHERIC INSTRUMENTS STERILIZATION
NASA Work Unit 186-58-06-01
JPL 384-84101-2-3220

Since the funding and manpower for Atmospheric Instruments Sterilization was somewhat limited, it was felt the effort would best be utilized if devoted to developing a single instrument that was completely sterilizable, rather than to the investigation of various components from different instruments. The gas chromatograph seemed the best choice for two reasons: (1) it was well along in its development and (2) its capability of either atmospheric or organic analysis made it a likely candidate for a flight program.

As a result of preliminary thermal sterilization tests and discussions with the JPL Engineering Mechanics Division, all of the mechanical components used in the Mars Gas Chromatograph breadboard were redesigned. The sterilization effort was integrated into the high-impact development to produce components resistant both to sterilization and high impact.

The primary problem in thermal sterilization of the mechanical components was maintaining tight seals on the sample valve and detectors. This was resolved by designing them such that the Teflon insulators were well contained and could not deform under thermal stresses.

Since the separation columns, when being activated, are subjected to temperatures well in excess of sterilization limits, they did not pose a thermal problem. However, as in the case of the valves and detectors, care was taken to insure proper sealing.

Components from the JPL Spec. ZPP-2010-SPL-A (Sterilization Parts List) were used in the development of the electronics wherever possible. In the few cases where new or untried devices were necessary in the circuits, the Parts Reliability Group added the component to their sterilization evaluation program. A summary of the atmospheric instruments sterilization progress was submitted for publication in a JPL technical report on sterilization activities.

A sterilizable, high-impact gas chromatograph prototype is currently being fabricated. Testing is expected to be completed by October. At that time, a final report describing the development and test results will be prepared.

BLANK PAGE

STERILIZABLE, RUGGEDIZED ELECTRO-OPTICAL IMAGE DETECTOR
NASA Work Unit 186-58-06-03
JPL 384-84301-2-3220

In August of 1964, Statement of Work No. 3475 and request for proposal were submitted to industry for the study and development of a sterilizable, ruggedized vidicon image detector suitable for use in lunar and planetary missions. The effort requested included two tasks. Task I consisted of study and analysis of the sterilization of photoconductors culminating in a photoconductor capable of withstanding the high-temperature sterilization compatibility test. Task II consisted of design and development of a sterilizable, ruggedized vidicon which was to be ruggedized to withstand 3000 g shock.

The statement of work highlights are listed below:

1. Image quality similar to presently used slow scan vidicons.
2. Electrostatic deflection and focus.
3. Usable target area of 11 mm^2 in a 1-in. envelope.
4. Low-power heater.
5. Minimum weight.
6. Survive storage at temperature between 0 and 21°C at 10^{-6}mm Hg for not less than 18 mo.
7. Survive sterilization.
   a. Three cycles of 36-hr each at 145 ±2°C in dry nitrogen returning to room temperature conditions between cycles.
   b. 24-hour soak in a mixture of Ethylene Oxide and Freon 12 at 24°C and 35% relative humidity.
   c. As above but at 40°C.

Proposals were received from General Electric, General Electrodynamics Corp., Westinghouse, and Radio Corp. of America.

CONTRACT SELECTION

A team of space television specialists was chosen to review and evaluate the proposals. Included on the team was a consultant, Dr. Bube of Stanford University, an expert in the field of photoconductivity. Based on the inputs from the team, RCA was chosen as the most likely vendor to succeed for the following reasons:

1. They have considerable experience in ASOS material for slow scan vidicons.

2. They do not propose a material research program which could not possibly be completed in the ten months' time required in the statement of work.

3. They have performed an admittedly short sterilization test, but nevertheless achieved success.

4. They have considerable experience in the use of ceramics and ceramics-modular construction.

NEGOTIATIONS

RCA's initial bid of approximately $250,000 was more than the available funds. However, it was the team's opinion that RCA was best qualified to do both tasks. It was felt that by reducing the quantity of deliverable items at the program conclusion, the bid would be within the allowed budget. Although lack of funds affected the program in magnitude, the design work, fabrication techniques, sterilization, and high-impact survival aspects will all be completed. Additional testing will be done to qualify the design in terms of the total sterilization and ruggedization requirements.

Final negotiations with RCA were completed in February 1965, with receipt of the adjusted quote reflecting rate changes. The final dollar figure arrived at was $175,023, and the contract was initiated on May 21, 1965.

Negotiations were commenced on December 15. The extended period of negotiations was primarily due to the data requirement portion of the contract. JPL is very concerned about getting into a possible sole-source situation with RCA, which would not be difficult with a device such as a sterilizable, ruggedized vidicon. Because of this concern JPL was attempting to avoid a possible sole-source situation by contractually tying up the rights to the developed device and the knowledge gained from the development. Eventually, after much legal consultation, it was decided to risk the sole-source potentiality to get the program under way, since it appeared that no method existed to avoid the sole-source situation. RCA has been in the vidicon business a long time and has many proprietary procedures and materials associated with vidicon manufacture and development.

PROGRAM DEVELOPMENT

The vidicon was developed nearly 18 years ago, and has not been changed substantially until recently. Vidicons have been used only in entertainment and industrial application where no high temperatures or shock environments existed. The development of space photography, using television cameras, has required the industry to develop new techniques in photoconductor and electron gun fabrication for programs such as Ranger, Mariner, and Surveyor, to name a few. Future programs, such as Voyager, will require even newer fabrication techniques because of the much harsher environment. The sterilizable, ruggedized vidicon program was designed to develop a vidicon capable of surviving both sterilization and high impacts, since a sterilizable component would logically find application in a high-impact environment.

SCHEDULE

Figure 1 shows the milestone expected through FY 1966. The work in the beginning of the program emphasizes material procurements, electron gun design, and initial sterilizable photoconductor testing. The initial mating of the photoconductor and the electron gun is scheduled for the second quarter of FY 1966, and prototype delivery is scheduled for the fourth quarter, with the final report due in the first weeks of FY 1967. This schedule is predicated upon a May 21 "go ahead."

PROGRESS

Work has now commenced and is on schedule. Not much time has elasped since "go ahead," but some significant steps have been taken.

The electron lens design is complete, as is the deflection design. The orignal idea for sealing the quartz faceplate to the tube envelope has been changed to a simpler method that is similar to the sealing technique used on commercial vidicons and that has proven very satisfactory.

The design of the heater-cathode structure is proceeding well; some consideration is being given to a directly heated cathode to reduce power consumption.

Four bids on the ceramics have been requested; two have been received. Very close tolerances were specified, but is apparently no problem.

The evaporation of the initial faceplates for sterilization testing is under way; no results are available at this writing. The facilities for both gas and heat sterilization are ready.

Figure 2 is a rendition of the probable configuration of the vidicon.

The FY 1965 funding has provided only a minimal effort, resulting in less than adequate testing and too few deliverable items for thorough evaluation. The FY 1966 program will augment the FY 1965 program and bring the total effort to a high confidence level by increased environmental testing and evaluation. Long-range plans call for integration of this vidicon in a miniature high-impact, sterilizable camera.

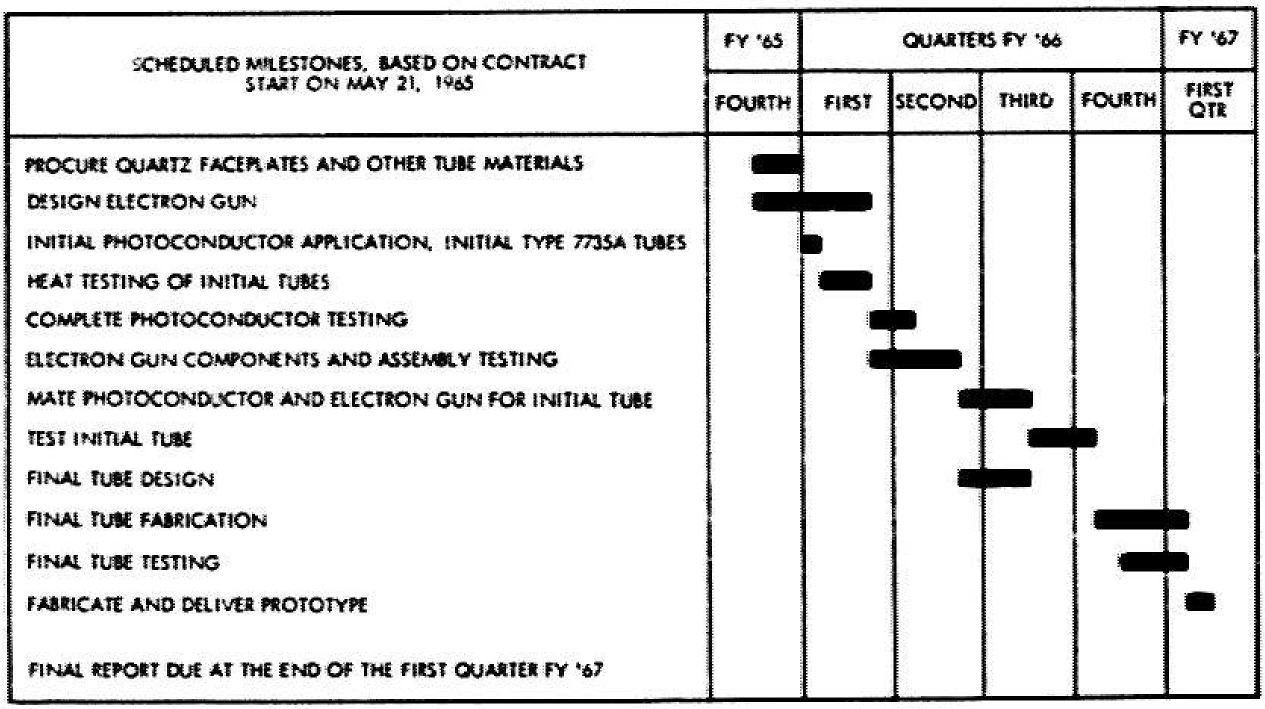


Fig. 1. Sterilizable, ruggedized, electro-optical image sensor milestones

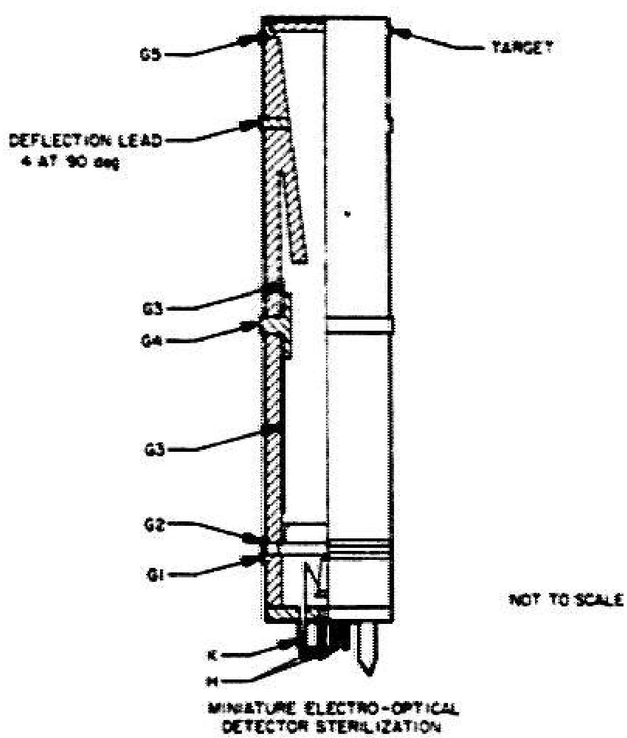


Fig. 2. Proposed 1-in.-diameter electrostatically focused and deflected ceramic vidicon

BLANK PAGE

REED-CAPACITOR MODULATOR STERILIZATION
NASA Work Unit 186-58-06-04
JPL 384-84401-2-3220

The reed-capacitor modulator has been developed over the last two years under a contract with the Kinelogic Corporation of Pasadena. Since early August 1964, Kinelogic's efforts have been directed toward perfecting the device so that it could endure heat sterilization without being adversely affected. A study of this problem and the refinement of the necessary technology was completed in December 1964. At this time, the construction of proof test model (PTM) 15 was begun. This unit was to be built to demonstrate the success of the heat sterilization technology and the overall soundness of the design. With the completion of this unit and delivery of final detailed drawings and assembly procedures, the contract would be complete. The scheduled date of completion was February 1, 1965. While the final detailed drawings and assembly procedures have been received from the Kinelogic Corporation, delivery of PTM 15 has been frustrated by unfavorable circumstances and a series of mishaps.

One of the most serious setbacks was the loss of the two engineers who created the design and who had been responsible for the development of the dynamic capacitor. Both men left Kinelogic on January 1, 1965. Prior to their leaving a new vacuum sealing technique had been initiated on the dynamic capacitor. This type of seal was found to be unworkable by the new project engineer. In an attempt to salvage parts that had been tinned for use in the new solder-seal procedure, a strong solder stripping agent was used. These parts were then later assembled using the earlier established heliarc welding method for vacuum sealing. After PTM 15 was constructed, it was then subjected to the heat sterilization test (JPL specification XS0-30275-TSTA, dated 24 May 1963), which it passed with encouraging results (see data shown in Table 1).

Table 1. Heat sterilization test

Test	Resonant frequency, cps	Conversion efficiency, %	Contact potential mv	Transducer voltage mv, rms
Before Heat sterilization (measured at 25°C)	4645	9.0	25	47
After heat sterilization (measured at 25°C)	4647	9.2	26	48

Following the heat sterilization test, a 200-hr thermal cycling test was started on PTM 15. Two-thirds of the test had been completed when the temperature chamber failed. After a one-wk delay, the chamber was repaired and the test was to be rerun. It was found, however, that PTM 15 had lost its vacuum and the source of the leak was apparently the vacuum pinchoff tube.

A conference was held at Kinelogic February 22, 1965, and it was agreed that priority would be given to the fabrication of a dynamic capacitor which was urgently needed for JPL's high-impact gas chromatograph effort. Work on PTM 15 was not restarted until the latter part of April 1965, when it was found that a vacuum leak had developed in the high-insulation terminals of the drive anvil. A replacement drive anvil became available May 3, 1965, at which time reassembly of PTM 15 was continued.

The cause of the vacuum leak has not been definitely established, but evidence points strongly to it being either (1) solder stripper attacking the terminals or (2) thermal stresses produced during heliarc welding. Since heliarc welding has been used successfully with the same type terminals in the past, with a leak-free history, the solder stripper is the more suspect of the two causes. However, to minimize the likelihood of any such future failure occurring, it was decided to use the relatively new ion welding technique which would greatly reduce thermal stresses. Since the number of organizations having ion welding facilities is limited, further time was consumed in locating an organization that could and would perform this job.

PTM 15 was sealed on June 7, 1965. At that time, evacuation and final testing began. On June 18, 1965, the vacuum chamber containing PTM 15 lost power due to a circuit overload. This resulted in the dynamic capacitor becoming contaminated. Before delivery of this unit can be accomplished, it will have to be disassembled, cleaned, reassembled, ion welded, and evacuated; then sterilization plus thermal cycling tests must be rerun. Earliest delivery is now expected around the middle of July.

In addition to Kinelogic's activities with the dynamic capacitor, high-impact tests were performed on an earlier unit (PTM 9) at JPL's high-impact testing facilities under the direction of Section 355. The capacitor was impacted a total of six times at levels of 5,000 and 10,000 g at impact velocities up to 190 ft/sec. Certain abnormalities were noted in the operation of this capacitor prior to and during the course of the test series; however, it could be made to operate reasonably well after every test except the last one, a lateral impact of 10,000 g at 190 ft/sec. Because of design changes incorporated to increase shock resistance (i.e., decreased anvil mass, greater number of support points, etc.), it is reasonable to believe that the current design will survive 10,000 g impacts.

Also during this period, a report was written on the control techniques developed by Kinelogic that enables the dynamic capacitor to survive thermal sterilization. In the paper, which will appear in a future sterilization program technical report, special emphasis is placed on the contact potential problem.

JPL Technical Memorandum No. 33-243, Vol. I

SENSOR STERILIZATION AND TEST PROGRAM
NASA Work Unit 186-58-06-06
JPL 384-84601-2-3220

During this year, tasks for the development of sterilizable components, funded during previous years, were monitored to or toward completion and instrumentation to be used during the followon evaluation and testing program. Two additional tasks were funded from the budget of the current year: (1) optimization of the reliability and yield of sterilizable Geiger-Meuller tubes and (2) development of a sterilizable detector-scintillation crystal assembly using a solid-state optical detector rather than a detector with a temperature-sensitive photocathode surface. A contract for the performance of the first task has been awarded to EON Corporation. A contract for the second new task will be awarded to Isomet Corporation.

PHOTOMULTIPLIER TUBES

The effort for the development of sterilizable photomultiplier tubes of two types is being provided by Electro Mechanical Research, Inc. The contract funding was provided by the FY 1963 program under JPL 5491-3240. The contractor is now performing the sterilization and environmental test program on the tubes resulting from the development phase. The results following dry heat sterilization appear quite encouraging for the tubes with a response in the UV, but the tubes with a response in the visible region leave much to be desired both in the amount and predictability of the change in characteristic value. The work being performed under the present contract will be completed by the end of September 1965.

SOLID-STATE RADIATION DETECTORS

The development of these devices is being performed by the Special Products Division of Technical Measurement Corporation. The contract was funded as a part of the FY 1963 program and is identified as JPL Job No. 5492-3240. Four detector types are being developed; all but one major problem appear to be under control. One detector type, required for measurement of protons with energies to 10 Mev, must have a large depletion depth and a resolution better than 50 Kev FWHM. To accomplish this, silicon crystals having a high resistivity (10K ohm-cm minimum) and no crystal defects must be used. As of this time a reliable source has not been found.

At the present time a group of detectors, of all four types, is being subjected to the total sterilization and environmental requirement. After successfully completing the testing program, the results should indicate that, when the proper materials are available, the contractor is capable of producing detectors which satisfy our requirements. It is anticipated that the performance on this contract will be completed during August 1965.

GEIGER-MUELLER TUBES

The development of sterilizable Geiger-Mueller tubes was performed by EON Corporation. The funding for this contract was provided by the FY 1963 program and is identified as JPL Job No. 5493-3240. Tubes of two types, thin side wall and mica end window, were successfully developed and tested. As discussed in the opening paragraphs of this report, the contractor has been awarded a followon contract to further enhance the reliability of the tubes.

INORGANIC SCINTILLATION CRYSTALS

The development of these sterilizable crystals is being conducted by Isomet Corporation. This task was funded by the FY 1964 program and is identified as NASA Work Unit 186-58-00-08.

Early in the program Thallium activated Sodium Iodide crystals were selected as the area of primary interest, among existing crystal types, because of the better value of pulse height resolution obtainable. Although very hygroscopic and fragile the contractor has satisfactorily packaged the crystals to withstand the sterilization and environmental requirements. A number of samples in the final configuration are now being final tested.

OPTICAL COUPLING MATERIAL

The development of sterilizable optical coupling material was performed by Dow Corning Corporation as a part of the FY 1964 program and bears the NASA Work Unit number 186-58-00-11. The work was successfully completed and the final report received in March 1965.

FOLLOWON TEST PROGRAM

The instrumentation required for the testing of components delivered at the completion of the development contracts has been selected and purchased. The actual testing program will commence early in the second quarter of FY 1966. The development models will be tested to verify the results obtained by the contractor. An additional quantity of each item will be purchased to test manufacturing reproducibility and to obtain statistical information for reliability evaluation.

STERILIZABLE CAPSULE DATA BUFFER
NASA Work Unit 186-58-06-07
JPL 384-84701-X-3240

The objective of this task is to develop a sterilizable capsule data buffer memory system. This type of memory system is required as a part of a science capsule system for advanced planetary missions. The effort is divided into two major areas: (1) construction of a conventional magnetic core memory and subsequent testing to verify that it is heat-sterilizable and (2) study and development of advanced solid-state memory systems which are heat-sterilizable.

MAGNETIC CORE MEMORY

Due to continued delays in procurement, JPL contract 950776 with Electronic Memories Inc. for the development of a sterilizable 8000-word magnetic core memory was not reactivated as scheduled. Therefore, no technical progress was made on this program during this period. However, all procurement and technical details have been resolved and approved and the contract should be reactivated early in the next reporting period.

Activities planned for the next six months are summarized as follows:

1. Reactivate JPL contract 950776.
2. Complete one sterilizable magnetic core memory unit and initiate testing at JPL.

SOLID-STATE MEMORY

A study of memory devices and schemes which are available or under active development has been made and a report has been written. An industry survey of solid-state memory technology has also been made. The survey included the following organizations (which were visited): IBM, Owego, N. Y., Burroughs, Paoli, Pa., Univac, St. Paul, RCA, Needham and Natick, Mass., Bell Laboratories, Allentown, Pa., and Librascope, Glendale, California. Informal discussions have also been held with people at the Langley Research Center. Participation in the JPL Solid-State Data Storage Working Group effects information exchange with other memory efforts at JPL. Laboratory evaluation of two thin permalloy film devices was begun; the IBM chain-store and the Toko woven plane. This effort is still in its initial stage, however, and no significant conclusions regarding these devices can be made at this time.

The applicability of encapsulating materials which are sterilizable and will not induce stresses on encapsulated components have been investigated. Stress-inducing encapsulants are not permissible because of the magnetostrictive properties of most memory devices. One of these materials has already been used to encapsulate flight electronics similar to those used in memories.

An RFP has been issued for a random access, nondestructive readout memory. A memory system which represents the ultimate in the present state of the art of the technology is sought. Sterilizability is a requirement of all components proposed for use in this system. The development is to be performed in two phases.

The first phase includes the development of a small breadboard memory system and a packaging study of a larger system which utilizes the same electronic design and organization as the small breadboard system. The capacity of the breadboard system is to be 128 words of 10 bits each. The anticipated starting date of the contract is September 20, 1965.

The second phase of the contract includes the development of a larger prototype system which is to be studied in the first phase. The prototype system is to be in flight-packaged form and have a capacity of 1024 words of 20 bits each.

STERILIZABLE BATTERY DEVELOPMENT
NASA Work Unit 186-58-07-01
JPL 384-81501-2-3420

The battery for the Voyager project must possess certain power properties after heat sterilization. The ability to function adequately depends upon the extent to which its elements can withstand the degrading conditions during sterilization. The alkaline silver-zinc or silver-cadmium systems are the only candidates which seem to be capable of satisfying the energy density requirements. The chemical environment of a 40% aqueous potassium hydroxide solution containing silver species is so extremely reactive that the conventional elements fail and new materials are necessary. In addition, the battery must also sustain severe shock and vibration loads; consequently the new materials must have particular mechanical characteristics. In order to develop the required battery an intensive project has been formulated and is being expedited.

PROBLEM AREAS

Each component of the battery has been considered as a problem area. The importance of some areas was delineated in the conclusions of contract No. 950364 with the Delco-Remy Corp. in which it was shown that no available separator material performed satisfactorily following sterilization; the development of new separator materials was mandatory. It was shown also that the battery case was chemically attacked and was unable to sustain the gas pressures produced during sterilization, and thus a different case material was necessary. Although no great deterioration of the electrodes was observed under the limited experimental conditions used, it is believed that the zinc electrode may deteriorate severely under the complete sterilization conditions and a concentrated research and development program will be undertaken on the zinc electrode. Other areas will be included as the problems appear.

SEPARATOR DEVELOPMENT

Since the development of a suitable separator was recognized to be mandatory, the search for new materials was the first undertaking. Two separator research and development programs are in progress, both leading to the fabrication of separators from organic polymeric materials. In a contract with the Radiation Applications Inc., L. I. City, N. Y., polyethylene is the base polymer and different procedures are used for crosslinking and grafting with acrylic acid. The Narmco Division of Whittaker Corp., San Diego, Calif., will synthesize new polymeric materials for which films will be formed and tested as separators.

The RAI contract (JPL 951015) began in Sept. 1964, and will end in Aug. 1965. It is divided into two major phases: (1) The preparation and testing of 51 materials based on polyethylene; (2) The production of 500 ft^2 quantities of two materials which have been shown to have the best heat sterilization and electrical cycling properties. In phase I, six different preparative methods have been used (in these a Co^{60} source is used for all reactions except as noted): (1) electronbeam irradiation crosslinking followed by grafting with acrylic acid; (2) precrosslinking with divinylbenzene and grafting with acrylic acid; (3) simultaneous crosslinking with divinylbenzene and grafting with acrylic acid; (4) grafting with acrylic acid followed by crosslinking with divinylbenzene; (5) fractionation to remove low-molecular-weight fractions followed by electronbeam irradiation crosslinking and grafting with acrylic acid; (6) grafting with acrylic acid under different relative humidities. The samples from these preparations are tested for compliance with standards established for exchange capacity, tensile strength, and electrical resistance, these tests being done before and after heat sterilization at 137 and 145°C. Samples which pass these tests satisfactorily are assembled in cells with silver and zinc electrodes and tested for electrical capacity in a cycling procedure. The two materials which are to be prepared in 500 ft^2 quantities are to be selected from those which attain a better than 90% capacity retention.

Five materials are being considered as candidates for phase 2, the preparation of 500 ft^2 quantities, in virtue of possessing satisfactory test properties. One of these, a material prepared by precrosslinking with an electronbeam to a 70 Mrad dose followed by double grafting with acrylic acid, is in the final stages of preparation. Of the other four possibilities, the preparation of one differs from that already selected only by the precrosslinking dosage. The other three have been prepared using divinylbenzene crosslinking procedures. To investigate materials prepared by two distinctly different methods the second sample for the 500 ft^2 quantity will be selected from those crosslinked with divinylbenzene.

The Narmco contract, which began June, 1965, is a three phase program. In the first phase eight polymers will be synthesized: (1) poly -2, 2' – (trimethylene) -5, 5' – bibenzimidazole, (2) poly -2, 2' (octamethylene) -5, 5' bibenzimidazole, (3) poly -2, 2' – (trimethylene) -5, 5' bibenzothiazole, (4) poly -2, 2' – (octamethylene) -5, 5' bibenzothiazole, (5) poly -2, 2' (trimethlylene) -5, 5' – bibenzoxazole, (6) poly -2, 2' (octamethylene) -5, 5' bibenzoxazole, (7) poly -2, 2' (p, p' – oxybix (phenylene)) -7, 7' biquinoxaline, and (8) poly -2, 2' – (p, p' – oxybis (phenylene)) -7, 7' oxybis-quinoxaline. In the second phase films will be prepared from polymers having the required characteristics of resistivity, tensile strength, and an oxidation stability in 40% KOH at 145°C. These films will be evaluated in a third phase after heat sterilization on the basis of the same characteristics as in phase 2 and also on diffusion properties.

RELATED DEVELOPMENT

More recently, an entire research and development project for a heat sterilizable, high-impact battery was defined in a request for proposal, the responses to which are now being evaluated. All elements and phases of fabrication and testing of the battery were covered and a complementary contract and in-house effort was described. Negotiation of contracts will begin as soon as practical. The in-house effort is being implemented with personnel and facilities so that a concerted, coordinated program will evolve. This effort is being carried out in close coordination with the Voyager program.

JPL Technical Memorandum No. 33-243, Vol. I

STERILIZED SOLID ROCKET DEVELOPMENT
NASA Work Unit 186-58-08-01
JPL 384-81901-2-3810

The major problems in the development of solid rocket motors which can withstand the heat sterilization cycles are accommodation of the effects of large differences in thermal expansion coefficients between the motor components and the ability of the materials to be stable at elevated (300°F) temperatures.

Solid propellants typically have a thermal expansion coefficient of 5×10^{-5} in/in°F, and the case materials are a factor of 5 less. Thus, when these materials are combined in a motor design, provision must be made to allow for the movement due to thermal expansion, and the design must be within the mechanical strength of the materials and the bonds between materials. The technique of using slotted grains, which allows for expansion and contraction and reduces the stress levels in a motor design where the propellant is bonded to the motor case wall, has been investigated experimentally; the test results are encouraging and indicate that a slotted grain approach can be utilized in the design of heat sterilizable motors.

Figure 1 shows a view of a 3-in. -diameter by 4 ft long test motor case with a slotted propellant grain that has been potted into the case and restricted within a RTV silicon elastomer. Figure 2 shows the failure of the silicon between the slots after three heat sterilization cycles (145°C, 36 hr). Figure 3 shows the results of x-ray inspection. Bond failures, which appeared after the first heat cycle, have occurred at two stress concentration points of the grain. With improved grain design (which would minimize stress concentrations) and better potting materials, it is felt that case-supported slotted grain designs can be utilized to advantage in heat sterilizable motors. It should be noted that the nonslotted case-supported control grain failed after the first heat cycle; Fig. 4 illustrates this failure.

The results of solid rocket motor sterilization studies have been reported in JPL Technical Report No. 32-725, titled Sterilized Solid-Propellant Rocket Motors for Mars Landing Missions, dated March 30, 1965, and classified Confidential. This report discusses the utilization of ethylene oxide sterilant in a polyurethane propellant, the results of screening tests conducted on seven developed propellants supplied by industry, the results of a heat-sterilizable silicon propellant development program, and the feasibility study conducted on borane compositions. The unclassified portions of this report are being incorporated into an unclassified Revision 1.

Future work on development of heat sterilizable solid rocket motors includes a motor design study and the investigation and demonstration of motor design approaches. Future work will be limited, however, due to the severe manpower shortage.

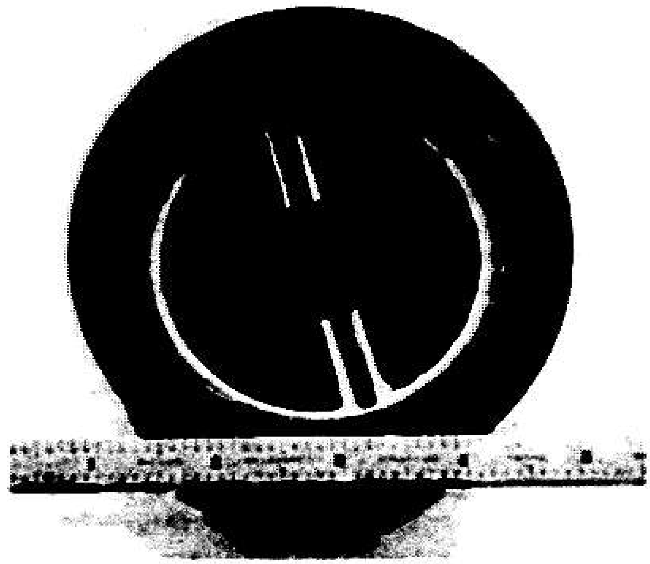


Fig. 1. Test motor case with potted, slotted propellant grain, restricted within RTV silicon elastomer

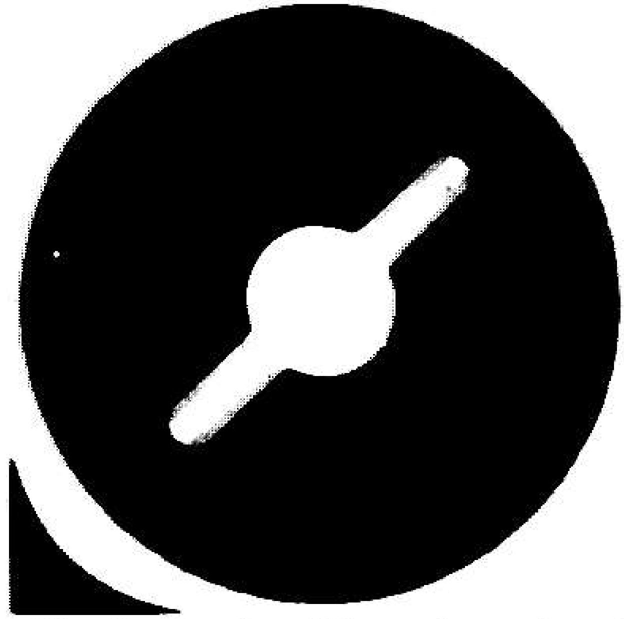


Fig. 3. Results of X-ray inspection of motor case with failed silicon after heat sterilization (3 cycles: 145°C, 36 hr)

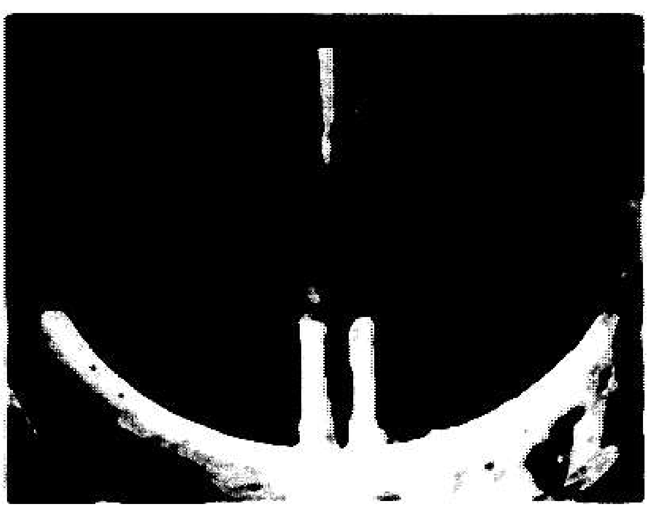


Fig. 2. Motor case showing failure of silicon after three sterilization cycles (145°C, 36 hr)

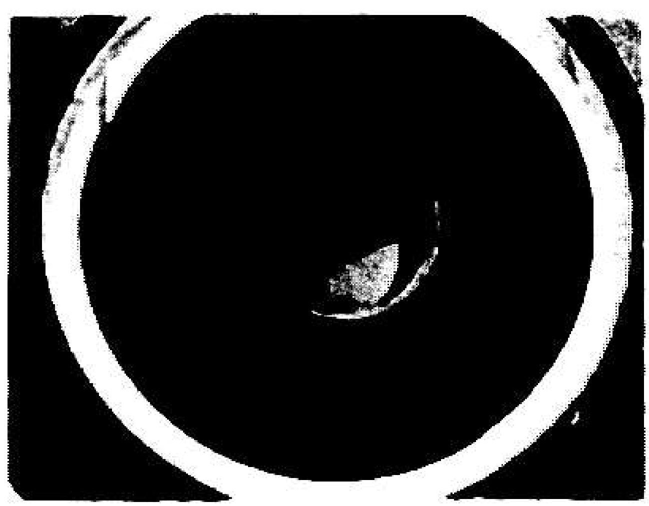


Fig. 4. Nonslotted case-supported control grain failure after first heat cycle

STERILIZABLE PROPULSION SYSTEM DEVELOPMENT
NASA Work Unit 186-58-08-02
JPL 384-82101-2-3840

The original FY 1965 task was cancelled during the 2nd quarter due to OSSA funding constraints. A small amount of closeout funding was made available during the third quarter, however, and these funds were used to complete and publish a report documenting previous analytical investigations performed under this program. This report[1] contains an analysis which presents the general relationship among the thermodynamic and spatial variables of a closed system consisting of liquid propellant within a propellant tank with various ullage volumes and prepressurization levels. From these relationships, curves are presented illustrating the variation of tank mass, wall thickness, and tank pressure at sterilization temperature for several typical liquid propellants.

For FY 1966 it has been proposed to conduct a two-phase experimental program to establish the feasibility of conducting heat sterilization of a typical liquid monopropellant system similar to the type employed on Mariner IV. The first phase will involve extensive compatibility testing of various materials with the propellant, and the second phase will involve sterilization and subsequent operation of the complete system. These tasks will both be handled by subcontract.

[1]Curtis, H. D., Harper, A. D., Optimization of System Operating Parameters for Heat Sterilizable Liquid Propulsion Systems, Technical Memorandum. No. 33-211, Jet Propulsion Laboratory, Pasadena, California, June 1, 1965.

BLANK PAGE

JPL Technical Memorandum No. 33-243, Vol. I

EFFECTS OF STERILIZATION ON ELECTRICAL CONNECTIONS
NASA Work Unit 186-58-09-03
JPL 384-85001-2-3570

ELECTRICAL SOLDERED AND WELDED JOINTS

In connection with determining the sterilizability of electrical joints to be used in sterilizable electronic assemblies, a statement of work was drafted which described typical material combinations for soldered connections and welded joints expected to be used in Voyager electronic equipment. The description of soldered connections consisted of various electronic component lead materials soldered to terminals, electrical wire soldered to terminals, and stranded conductors soldered to two types of connector terminal cups. The welded joints represent component lead materials resistance-welded to interconnect ribbon.

Any degradation that may occur from the sterilization of electrical joints is not expected to affect the solder material but rather the joint bond or interface. Thus, the test plan consists of mechanical tests, electrical tests during vibration, and metallographic examination of the various soldered joints and welded joints before and after heat sterilization. The type of joint considered most likely to be bearing a load during sterilization is the soldered connection between a conductor and an electrical connector cup. Therefore, stress rupture tests are also specified for this type of joint. An evaluation of soldered gold-plated surfaces is being accomplished by specific tests of component lead materials with and without gold plating and by electron microprobe analyses to determine the nature of gold diffusion in soldered and welded joints. Figure 1 presents an outline of the test plan for the joints.

Solderability tests, before and after the ethylene oxide and heat sterilization treatments, are conducted on the separate materials before soldering. Since on some parts soldering may have to be done after the preliminary sterilization treatments, the effects of these exposures on metallic surfaces must be determined.

The statement of work was contained in an RFP sent to several companies qualified to perform this type of development and test program. An evaluation of the companies' proposals resulted in the award of a cost-plus-fixed-fee contract (No. 951069) to the Hughes Aircraft Company on March 18, 1965 for $20,307. An added scope of effort for the solderability tests, estimated at $2849, has been negotiated. This contract was let with funds from FY 1964 Work Unit No. 186-58-00-18, Packaging Sterilization. All of the FY 1965 funds from 186-58-09-03-55 are being used to support the multipin electrical connector portion of this work unit.

At this date the detailed test plan submitted by the contractor has been approved, the test equipment and fixtures have been prepared, and the majority of the test specimens have been fabricated. A schedule delay has been caused by the receipt of two materials from a vendor which did not comply with the order specification requirements and which were accompanied by erroneous certifications.

A part of the planned activities will depend upon whether the electrical soldered and welded joint tests indicate any joined material combinations that are unacceptably degraded by the sterilization treatments. If there are damaged joints,

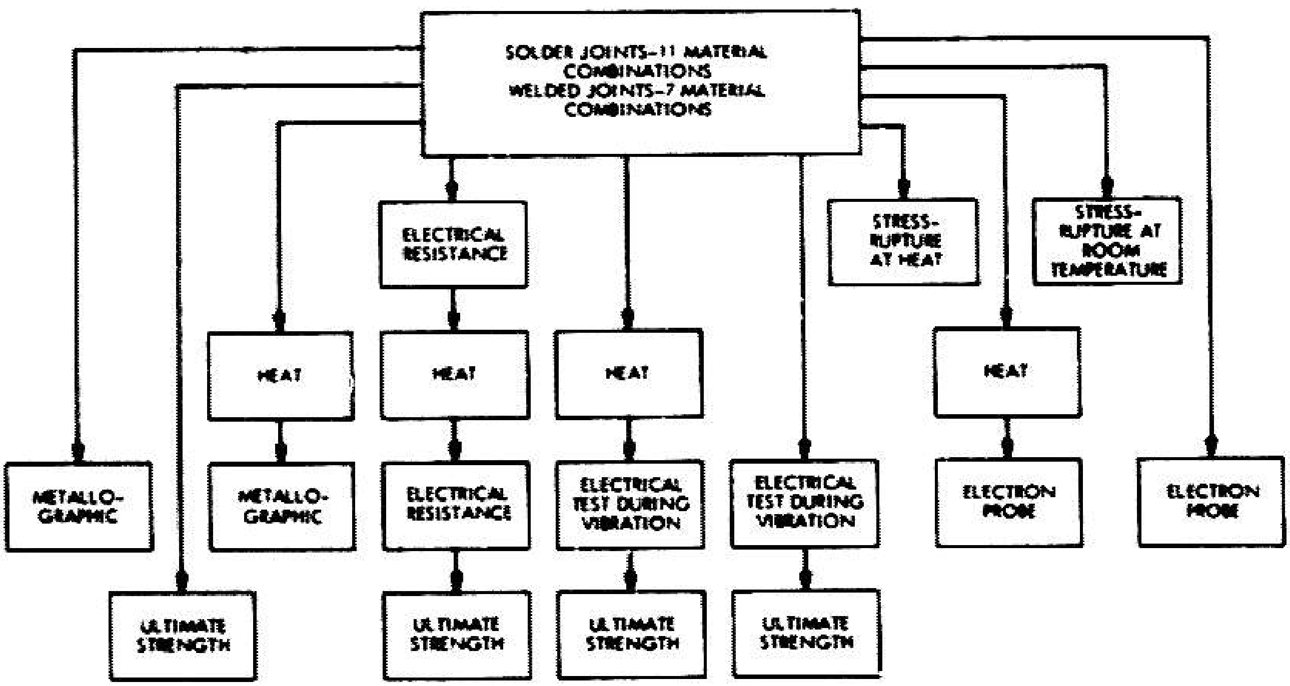


Fig. 1. Flow diagram of testing for soldered and welded joints

an analysis will be made of the physical mechanism responsible for the damage. Other material combinations will be substituted for the failed ones and tested, if they are new joint types.

A new area of planned activity is a detailed metallurgical study of nonmagnetic welded interconnections.

ELECTRICAL MULTIPIN CONNECTORS

A preliminary study of 16 types of electrical connectors indicated that four rectangular and three circular configurations showed promise for evaluation in sterilizable applications. Candidate connectors in this group are of the types specified in NAS 1599, MIL-C-3800, MIL-C-8384, MIL-C-26482, and MIL-C-26500. The selected rectangular connectors are intended to replace a Cannon D subminiature connector which demonstrated poor contact continuity after repeated mating and unmating in previous hardware uses. Samples from a lot of another type of rectangular connector were tested for cure of the diallyl phthalate insert material. The test indicated an incomplete cure of the polymer as shown in Fig. 2.

A statement of work was prepared which described various tests to be conducted on the candidate connectors before and after the ethylene oxide decontamination and heat sterilization treatments. The tests are mechanical and electrical including dielectric strength, insulation resistance, contact resistance, coupling and uncoupling torque, air leakage, insert retention, and contact retention.

The RFP containing this statement of work resulted in proposals from five companies. These proposals are now being evaluated. The connector specimens for the proposed test program have been procured and prepared for testing. The contract to be placed for this work will be funded by this work unit and by funds from 186-58-13-03-55, Sterilizable Electronic Modules.

Future activities will include the improvement of connector materials and design details shown to be necessary on any connector types that failed to pass FY 1965 sterilization effects tests. The testing and selection of additional types of multipin connectors that may be required and the testing of RF connectors and electrical wires will be conducted under FY 1966 Work Unit 186-58-13-06-55, Sterilizable Connectors, Wires, and Cabling Accessories.

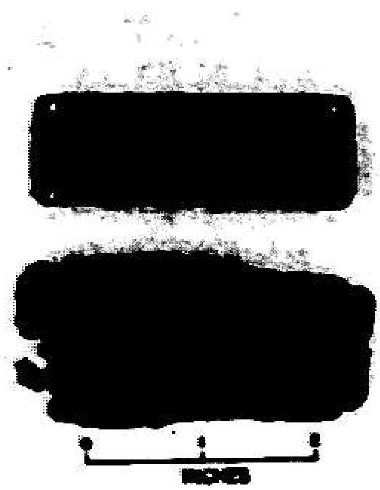


Fig. 2. Deterioration of connector insert material resulting from test for completeness of cure

STERILIZATION EFFECTS ON THERMAL CONTROL SURFACES
NASA Work Unit 186-58-11-01
JPL 384-85201-2-3510

The purpose of this task is to determine the extent of any effects of dry heat and ethylene oxide sterilization procedures on spacecraft temperature control surfaces. Certain optical and mechanical effects have been examined using JPL equipment while negotiations for a full-scale measurement contract were being carried out. The measurement contract, which will include investigation of the sterilization effect on UV degradation of white paint, has been awarded to the Hughes Aircraft Company.

The results of the preliminary in-house investigation on optical and mechanical property effects can be summarized as follows. Optically, only the ZnO-silicate-base paint was unaffected in the white paint group tested. The gold plate appeared to show increased solar absorptance after dry heat sterilization. Mechanically, metal coatings were unaffected after the sterilization process, but the ZnO-silicate-base paint deteriorated in adhesive properties.

OPTICAL EFFECTS OF STERILIZATION PROCESSES

White paints ARF-2, S-13, and PV-100 as well as gold plate have been sterilized and the solar absorptance has been measured; unsterilized control samples were tested in the same way to observe changes caused by the sterilization process. The sterilization exposure was dry heat per JPL Specification XSO-30275-TST-A at 300 and 275°F. The test results are shown in Table 1.

Table 1. Effect of sterilization processes on solar absorptance

Material	Control	275°F	300°F
PV-100	0.25	0.29	0.31
ARF-2	0.21	0.22	0.23
S-13	0.24	0.24	0.25
Gold plate	0.27	0.28	0.34

The following preliminary conclusions are drawn from the results shown in Table 1:

1. The ZnO base paints, ARF-2 and S-13, are not affected by dry heat sterilization.

2. PV-100 is adversely affected by the dry heat sterilization process, with a 25% increase in solar absorptance.

3. Gold plate assumes a slightly mottled (purple) appearance with an accompanying rise in α_s of from 0.01 to 0.07 units, or 4% to 26%. No explanation for this event presents itself, except for possible plating bath contaminants remaining and showing a color on heating.

MECHANICAL EFFECTS OF STERILIZATION PROCESSES

The change in appearance after dry heat sterilization of two of the white-painted surfaces is shown in Fig. 1 and 2. Figure 1, the ZnO-base, ARF-2 paint shows no color change, but a deterioration in its adherence properties is quite apparent. The plates shown in the top row have undergone an adhesion test in which a piece of adhesive tape was stuck to the surface and quickly jerked away. The parallel scribe marks indicate the taped area. The lower row plates were bent to about 90 deg around a 1-in. -round mandrel to check the strength of the paint film. It can be seen that the ARF-2 paint shows no great film strength under any circumstances. The color of the PV-100 white is distinctly altered as is the film strength.

CONTRACTED EFFORT

The contract awarded to Hughes Aircraft Company will deal with measuring changes in solar absorptance and emittance brought about by the sterilization processes and the combination of sterilization and ultraviolet (UV) irradiation. The sterilization procedures and tests will be as follows:

1. Samples will be subjected to dry heat per JPL Specification XSO-30275-TST-A (3 to 36 hr soaks at 295°F in dry N_2 atmosphere). Surfaces to be tested are: PV-100, ARF-2, and S-13 white paints, Cat-a-lac flat black paint, buffed aluminum, gold-plated aluminum, and vapor-deposited aluminum or aluminum. Solar absorptance and emittance will be measured and compared to unsterilized controls. In addition, ARF-2 and S-13 paints will be evaluated for changes in solar absorptance after exposure to the sterilization cycles and UV irradiation.

2. The effect of exposure to Ethylene Oxide (ETO) per JPL Specification GMO-50198-ETS-A followed by dry heat sterilization will be measured for the same surfaces as detailed in the foregoing paragraph. Solar absorptance and emittance will be measured after the ETO treatment only. A second group of samples will be measured after being subject to ETO and dry heat. Degradation of the solar absorptance properties of ARF-2 and S-13 after exposure to ETO, heat, and UV irradiation will also be evaluated.

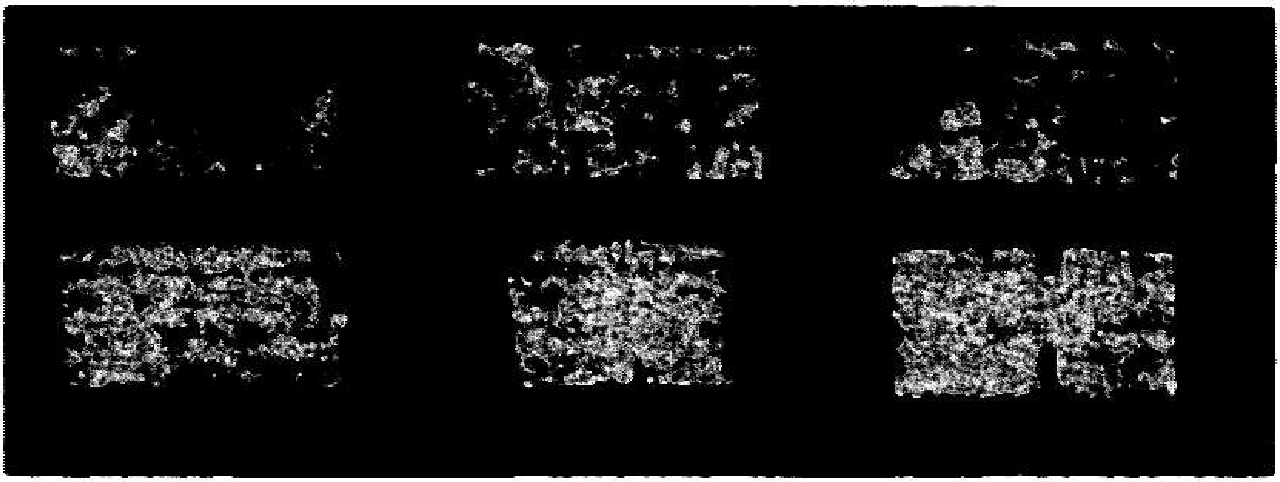


Fig. 1. Surface appearance and mechanical strength of ARF-2 white paint (dry heat sterilization)

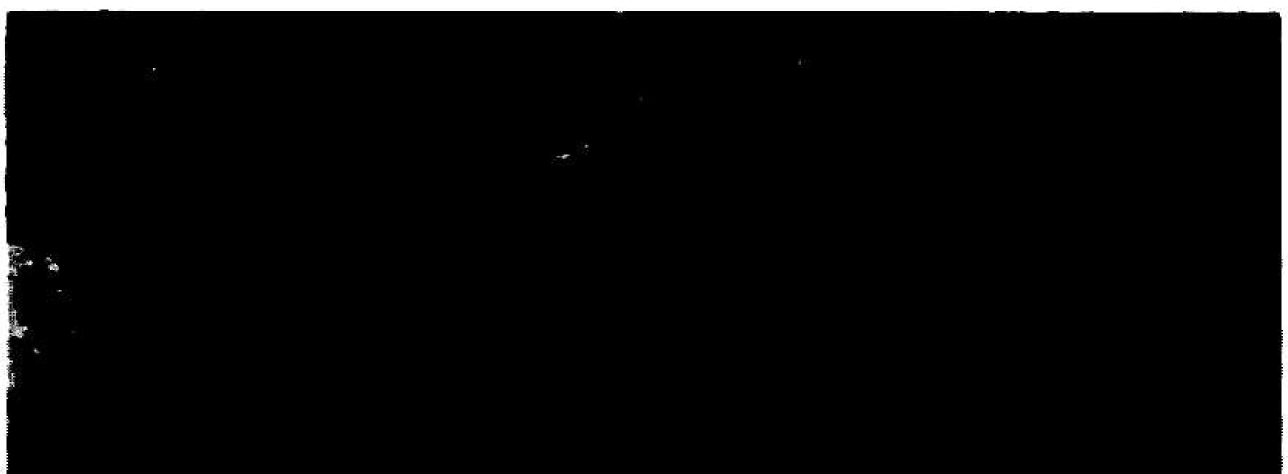


Fig. 2. Surface appearance and mechanical strength of PV-100 white paint (dry heat sterilization)

BLANK PAGE

JPL Technical Memorandum No. 33-243, Vol. I

STERILIZABLE PYROTECHNICS DEVELOPMENT PROGRAM
NASA Work Unit 186-58-12-01
JPL 384-82301-2-3810

STERILIZABLE SQUIB INITIATOR

A contract for development of a small ceramic 4-pin sterilizable nonmagnetic squib header was let to the Hercules Powder Company in February 1965, for completion in September 1965 (JPL Contract 950186). Hercules have subcontracted part of this work to the International Telephone and Telegraph Company. Progress was delayed in May and early June as the result of a staff change at Hercules.

Proposals have been sought and received for development of a small mating connector. the MIL-C-26482 connectors typically used with squibs are considered to be needlessly bulky and heavy for most spacecraft applications. It is anticipated that a contract for connector development will be negotiated by August 1965.

Proposals are being sought for development of a sterilizable static-discharge shunt for squib headers. It is envisaged that a cermet-type material may prove satisfactory for this purpose. It is hoped that a relevant contract can be negotiated and work completed by December 1965.

Limited in-house work on deposited-film bridges (nichrome on ceramic) has given encouraging results. it is proposed to conduct further in-house work and then let a contract by September 1965 for development of manufacturing techniques.

Close working relationships are being maintained with MSC Houston to provide rapid interchange of technical information relating to squib development.

PERCUSSION INITIATION

A program is being undertaken to resolve anomolies reported in the behavior of G-11 and G-16 percussion primers exposed to sterilization temperatures. To this end a primer sensitivity tester has been constructed (to U. S. Ordnance Dept. Dwg 81-3-44) and 1,000 of each of the two types of primers have been purchased.

Exposure and testing of these primers should be complete before December 1965. Contact will be maintained with Frankford Arsenal where the same primers are also being evaluated.

TEST EQUIPMENT

Apart from the primer sensitivity tester mentioned above. the following specialized equipment is being purchased, constructed, or assembled:

Time-domain Reflectometer (for nondestructive squib testing)

50 kv Vacuum-Capacitor Static Discharge Assembly (for evaluation of squibs)

80,000 psi (nominal 100,000 psi) Static Pressure Test Assembly (for evaluation of squib headers)

This equipment should be in service before December 1965. It is proposed to commence work on a third-harmonic test assembly (for nondestructive squib tests) before August 1965.

SUPPORTING TECHNOLOGIES

Strong efforts are being made to improve test techniques and test analysis techniques with a view to getting meaningful results at lowest cost.

One outcome of these efforts has been the rationalization (apparently for the first time) of squib firing curves, and correlation of these curves with squib thermal time constants as measured by the third-harmonic technique. A "universal" firing curve has been evolved and is proving useful in detection of anomolous squib behavior.

Testing of squib firing characteristics by variables rather than by attributes has proven very satisfactory. A similar approach for squib no-fire characteristics is beginning to show promise.

Attempts to measure squib thermal time constants by display of a bridge voltage pulse against its time derivative have been unsuccessful to date; as yet the third-harmonic technique appears to be the most satisfactory method.

It is hoped that publication (scheduled for July) by Rocketdyne of its Sensitivity (attribute) Study for Marshall Space Flight Center will provide useful improvements in the area of small-sample test methods. It is proposed to engage the services of a consulting statistician familiar with small-sample problems to adapt up-to-date techniques to the needs of the pyrotechnic sterilization program.

Tables of two-sided tolerance factors for the normal distribution have been prepared by an IBM 7090 program, and have been published as JPL Technical Memorandum 33-217.

JPL Technical Memorandum No. 33-243, Vol. I

ESTABLISH AN APPROVED LIST OF HEAT STERILIZATION ELECTRONIC COMPONENT PARTS
NASA Work Unit 186-58-13-01
JPL 384-80101-2-1520

The primary objective of this program is to establish a Sterilization Parts List (JPL Specification ZPP-2010-SPL) that tabulates the electronic component parts capable of withstanding several 36-hr periods of nonoperational storage at 145 ±2°C, in accordance with JPL Spec. No. XSO-30275-TST-A, without significant degradation. A secondary objective is to use the test results to compare vendor quality and perform analysis of long term failure modes.

As an example of a typical Sterilization Test Program, the selected manufacturer part types are each divided into four groups as follows

Group A – No temperature cycling (control group).

Group B – Three temperature cycles, each cycle consisting of 36 hr at 145°C, followed by 24 hr at 25°C.

Group C – Six temperature cycles as shown in Group B.

Group D – Six temperature cycles as shown in Group B.

After temperature cycling, parametric measurements are compared with initial test results and analyzed for significant changes. All groups are then subjected to a 10,000-hr life test to simulate the long flight periods of planetary missions. During this life test, Groups A, B, and C are operated at maximum rated dc voltage and temperature. Group D parts are stored at maximum rated temperature, nonoperational. Group B (3 cycles) and Group C (6 cycles) are compared with Group A (no cycles) at specific periods during the life test to detect significant changes.

Upon completion of the 10,000-hr life test, Group D parts are removed from temperature storage and, in conjunction with Group C, are subjected to maximum rated dc voltage and temperature for an additional 250 hr life test period.

The purpose of testing Group D is to simulate conditions similar to extended nonoperational missions where equipments (parts) are turned on remotely only near the destination. Group C is included as a control group operated at maximum rated dc voltage and temperature to simulate an extended operational mission. The following outlines progress of the individual tests (see Fig. 1):

1. ZPP-2101-GEN, CAPACITOR TEST, CONTRACT NO. 950585

The test has been completed and the final report from the test agency is in preparation. Negotiations to continue the parts on life test for an additional 6,000 hr is in progress. Results to date have indicated that heat sterilization poses severe problems with certain of the capacitors tested. Consequently, a comprehensive follow-on test has been funded and will begin as soon as practicable. A

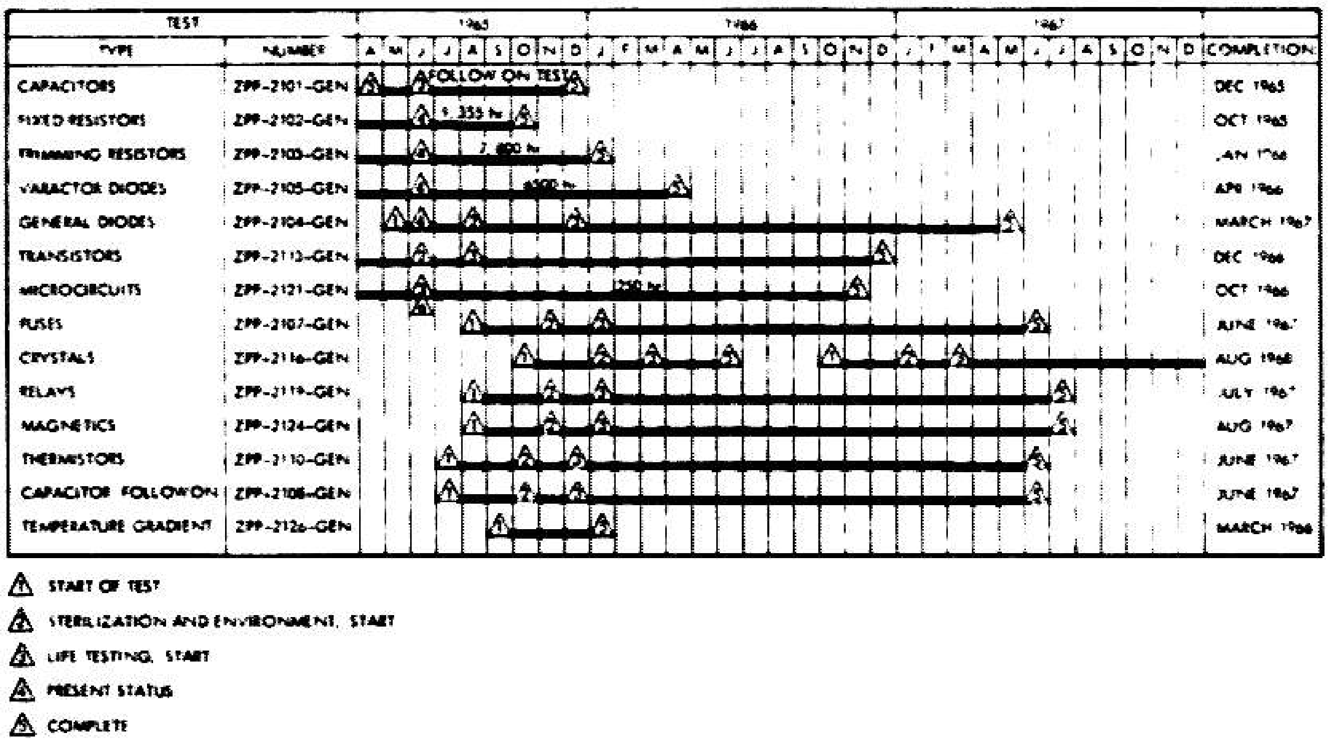


Fig. 1. Electronic parts sterilization program schedule

2,000-hr interim report, outlining the problems in detail, is available from Section 152. An 8000-hr Section Report is in production.

2. ZPP-2102-GEN, FIXED RESISTOR TEST, CONTRACT NO. 950584

The 8,000-hr measurements were completed. The parts are back on life test, and they are at the 9355-hr period. There have been no major problems due to heat sterilization. A 2,000-hr interim report is available from Section 152.

3. ZPP-2103-GEN, TRIMMING RESISTOR TEST, CONTRACT NO. 950790

The 6,000-hr measurements were completed. The parts are back on life test and are at the 7800-hr period. There have been no major problems due to heat sterilization. A 2,000-hr interim report is available from Section 152.

4. ZPP-2104-GEN, GENERAL DIODE TEST, CONTRACT NO. 950788

The contract to perform the test was awarded to the Boeing Co., Huntsville, Alabama. They have received the parts and are preparing the equipment and test fixtures.

5. ZPP-2105-GEN, VARACTOR DIODE TEST, CONTRACT NO. 950859

The 6,000-hr measurements were completed. The parts are back on life test, and they are at the 6500-hr period. There have been no major problems due to heat sterilization. A 2000-hr interim report will be available from Section 152 by July 15, 1965.

6. ZPP-2107-GEN, FUSE TEST

The responses to the RFP's were unsatisfactory. Consequently, the scope of the test was reduced, and the test was sent out for rebid. Three new test agencies were added to the original responders. The replys to the rebid are being evaluated.

7. ZPP-2110-GEN, THERMISTOR TEST

Sperry Utah has been selected to perform the test. Negotiations have been completed and JPL and NASA are in the process of approving the contract. The test should start by July 15, 1965.

8. ZPP-2113-GEN-A, TRANSISTOR TEST, CONTRACT NO. 950885

The test was awarded to Motorola Semiconductor Division. The test started February 2, 1965. The parts have been grouped, labeled, helium leak tested and sterilization temperature cycled.

Initial and post-temperature cycling measurements were completed. The parts are now undergoing environmental testing. There have been no major problems to date.

9. ZPP-2116-GEN, CRYSTAL TEST

The test program is being delayed due to an inability to locate sufficient sources for procurement of the crystals. Request for price and delivery information was sent to 22 crystal manufacturers and only [illegible] responded. This was probably due to the severe environmental requirements of the JPL crystal procurement specifications. It is anticipated that a sufficient number of sources (5 or 6) will be located in the near future.

10. ZPP-2119-GEN, RELAY TEST

Sperry Utah Co. was selected to perform the test. Negotiations were completed and the contract is being approved by JPL and NASA.

11. ZPP-2121-GEN, MICROCIRCUIT TEST

Environmental testing and sterilization heat cycling have been completed including all necessary measurements. The parts were put on life and the 250 measurements completed. The parts are back on life test and they are now at the 400-hr period.

12. ZPP-2124-GEN, INDUCTOR TEST

Philco, WDL has been selected to perform the test. Negotiations have been completed and the contract is in the process of being approved by JPL and NASA.

13. ZPP-2108-GEN, CAPACITOR FOLLOW-ON TEST

Preston Scientific Corp. has been selected to perform the test. Negotiations have been completed and the contract is in the process of being approved by JPL and NASA.

14. ZPP-2126-GEN, TEMPERATURE GRADIENT TEST

To avoid duplication of effort with Section 357, the scope of the test has been reduced to include only temperature gradient studies between the interior and exterior of component parts when placed in a 145°C ambient temperature. The reduction deleted thermal expansion and contraction due to temperature cycling, and temperature gradients within enclosed equipment from the test program.

NOTE:

(1) All electronic part test procedures used in the sterilization program have been documented and released through either the ZPP number series or the preceding 674 series.

(2) In addition to the quarterly and the semi-annual reports, the electronic parts sterilization task has been documented in monthly status r orts.

BLANK PAGE

JPL Technical Memorandum No. 33-243, Vol. I

STERILIZABLE POLYMERS
NASA Work Unit 186-58-13-02
JPL 384-83801-2-3510

Approximately 171 polymeric products have been subjected to heat and 20 products to ethylene oxide-Freon 12 (ETO-F12), under JPL's Polymer Sterilization task, to determine their suitability for use in spacecraft construction. In the past six months, candidate products were tested for changes in physical, mechanical, and electrical properties after exposure to the sterilization regimes.

Of the 171 products submitted, 87 survived preliminary heat screening, 30 are marginal, and 22 failed. Thirty-two products were initially submitted to Hughes Aircraft Company (HAC) for ETO-F12 screening.

Additional products of interest from other JPL Sections are being added to the master screening list. Therefore, it is anticipated that screening and evaluating of products will be more extensive than previously indicated and will be continued until a suitable list of products is available for all spacecraft applications. Figure 1 shows the sequence in which the products are being exposed.

LITERATURE SEARCH

Literature searches were conducted to gain information regarding the chemical and thermal characteristics of respective products. The purpose of this effort, once the generic names were established, was to eliminate those products which were unsuitable for construction of a sterilizable spacecraft. Information derived from the search only provided guidelines to the testing activities. Because of the nature of many commercial product formulations used, it was difficult to get a true picture of their chemical and thermal characteristics.

IN-HOUSE ACTIVITIES (DRY HEAT STERILIZATION)

Testing activities on the dry heat phase of this task are being carried out by the JPL Polymer Research Section (Section 382) under the direction of the Materials Section (Section 351). A list of polymeric products was compiled from Mariner II drawings and products currently used at JPL. These products were selected as being representative based on their performance on successful spacecraft missions.

Applicable test methods were assigned to each category of polymeric products to test those properties which must be known for spacecraft design. Product testing activities have proceeded as planned. Each of the candidate products was first subjected to a preliminary thermal screening of 40 hr at 149°C to determine its suitability for further exposure to the "type approval" cycles (3 cycles, 36 hr each at 145°C in dry nitrogen per JPL Specification XSO-30275-TST-A).

The additional exposure time and temperature beyond the specification requirements is to give a slight design margin. To date, 168 of the initial 171 products submitted for evaluation have received preliminary thermal screening. Subsequent to the preliminary screening, 71 products have been subjected to 149°C, in nitrogen for 120 hr, and 28 are in various phases of testing. Figure 2 presents product categories and tentative sterilization ratings after preliminary screening.

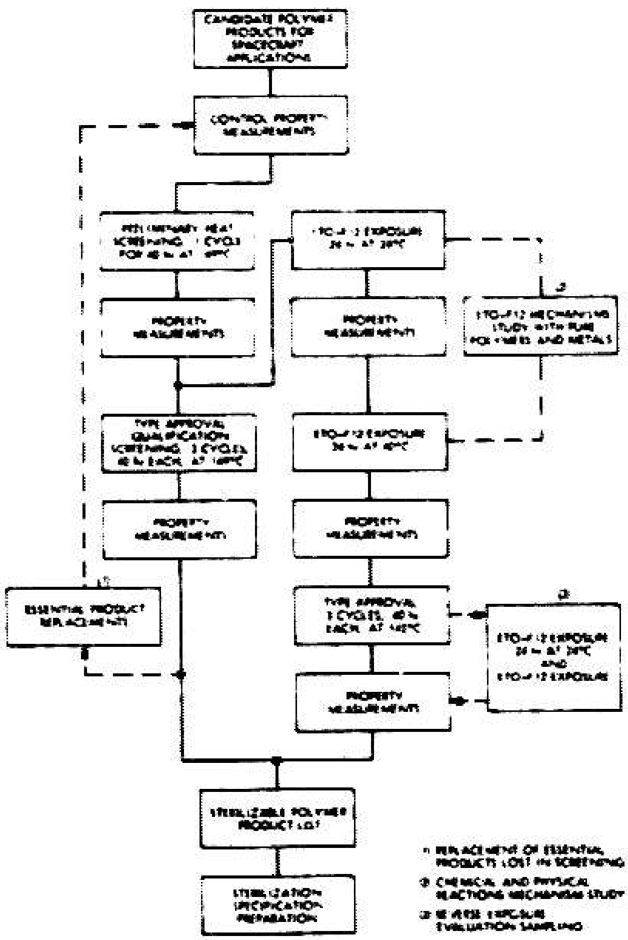


Fig. 1. Polymer sterilization program

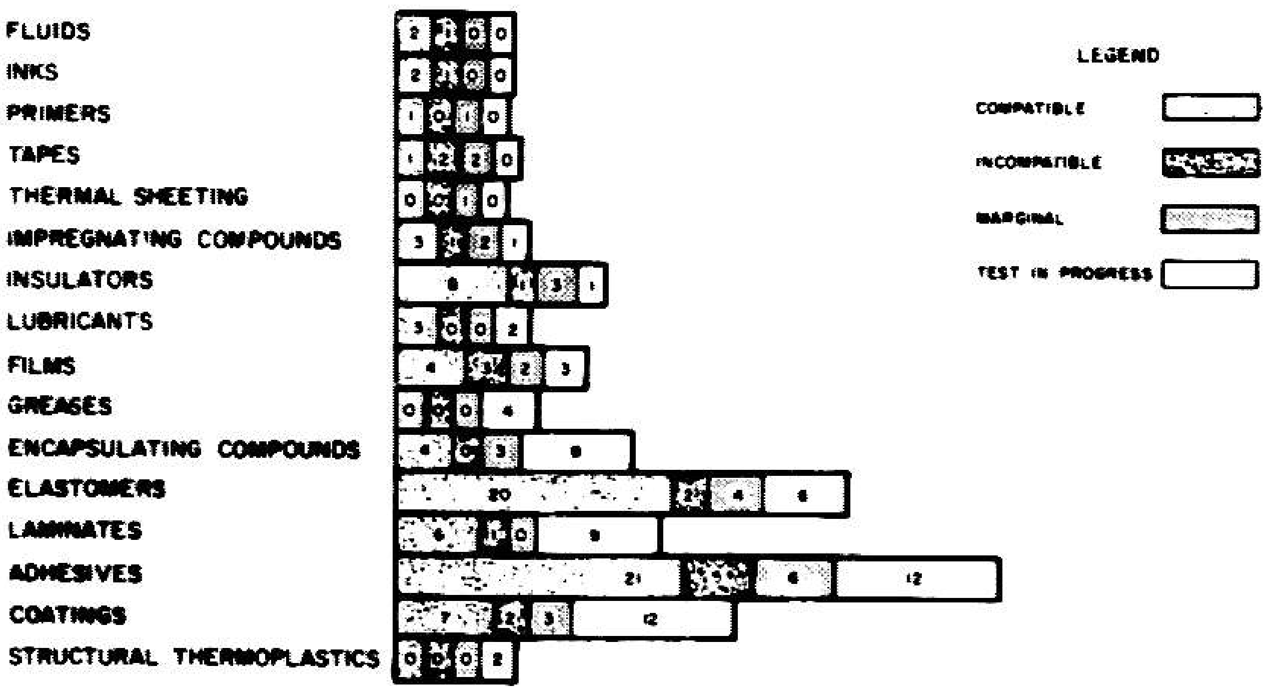


Fig. 2. Categories of products and tentative thermal sterilization rating (exposure 149°C for 40 hr in nitrogen)

CONTRACTED ACTIVITIES (ETO-F12 AND HEAT STERILIZATION)

Approximately 75 products have been submitted to Hughes Aircraft Company for evaluation with ethylene oxide-Freon 12 gas mixture. Products which were submitted to HAC are compatible with the dry heat sterilization regime. Of the 75 products submitted, 20 products have satisfactorily withstood the ETO-F12 decontamination followed by dry heat sterilization. Some 360 data points were collected from the 20 products tested. Thirty products are in process of being evaluated, 12 products are being fabricated for test, and 35 products have been ordered.

Because of the anticipated sequence of component fabrication and decontamination, it was necessary to determine if the reverse exposure (heat followed by ETO-F12) would be detrimental to products. Therefore, a limited number of products were exposed first to heat, then to ETO-F12 to assess any detrimental effects. Sufficient data has been generated to indicate that this reverse exposure has no detrimental effect on products and further evaluation was therefore discontinued.

In an effort to better understand the cause and effect of decontaminant gas on products and metallic surfaces, a mechanism study is being carried out to determine chemical and physical reactions with ETO-F12 using pure polymers and metallic surfaces. These evaluating procedures are consistent with the program plan and tasks to be accomplished.

MEETINGS

Joint meetings have been held with Stanford Research Institute, HAC, and JPL's Polymer Research Section to coordinate the various sterilization tasks. The purpose of these meetings was to avoid duplication of effort and to exchange information concerning product evaluation.

DISCUSSION OF RESULTS (DRY HEAT)

No significant trends have been established in the dry heat testing to predict thermal behavior of any generic family of commercial products. Thermal behavior of commercial products is influenced by the various additives (e.g., flexibilizers, plasticizers, diluents, etc.) used in commercial formulations. It is the additives in many products that create problems which make it difficult to predict product performance.

DISCUSSION OF RESULTS (ETO)

While some products did exhibit slight changes of hardness and tensile shear due to the ETO-F12 and dry heat exposures, none were catastrophic. Results from the ETO-F12 work indicates that silicone and epoxy polymers, both pure and commercial grade, are capable of physically adsorbing one to four percent by weight of sterilant gas. Silicone compounds release all but a fraction of a percent of sorbed gas when exposed to vacuum, with little change in physical or mechanical properties. Epoxy compounds retain a lesser amount of gas in the sorbed state, but show a more pronounced change in properties suggesting that a chemical reaction also occurs during exposure.

The exposure of silicone materials to sterilant gas and then to extended heat cycling produced a greater loss of tensile properties than exposure to heat followed by gas. This effect suggests that chemical interaction is favored by the gas-heat regime.

Based on the sterilization program progress to date, no real problems have yet been encountered, and it is conceivable that the objectives of the program will be met.

BLANK PAGE

STERILIZABLE ELECTRONIC MODULES
NASA Work Unit 186-58-13-03
JPL 384-85301-2-3570

The determination that spacecraft equipment may require both ethylene oxide decontamination and thermal treatments for sterilization resulted in two JPL environmental test specifications for these treatments. Verification of the compatibility of electronic equipment with the sterilization procedures is thus an engineering requirement and includes sterilizable electronic equipment processes.

The materials applications and processes for the assembly and packaging of electronic equipment of the types expected to be used in Voyager were described in a statement of work divided into four subtasks. These were the embedment of welded modules, conformal coating of printed wiring board assemblies, adhesive bonding of metal and plastic surfaces, and strain relief of component leads for mounting. This statement of work as a part of an RFP also requested the proposals to furnish specimen descriptions and test methods to be used in evaluating the effects of ethylene oxide decontamination and heat sterilization treatments on the subtask equipment processes.

Responding proposals were received from several qualified companies. These were evaluated and as a result a cost-plus-fixed-fee contract was negotiated with Northrop Space Laboratories on June 1, 1965 for $24, 912. This contract has been let with funds from FY 1964 Work Unit 186-58-00-35, Ethylene Oxide – Sterilization and Material Effects. All of the FY 1965 funds from 186-58-13-03-55 are being used to support the multipin electrical connector portion of Work Unit 186-58-09-03-55, Effects of Sterilization on Electrical Connections.

To date, technical direction has been provided to the contractor in the planning and design of test specimens which represent the electronic equipment processes expected to be used. The application of appropriate test instrumentation to determine the effects of sterilization on these specimens is now being investigated. At present it appears that the most practical approach is the use of two parallel test methods. One method utilizes pressure indicating devices to measure the stresses on embedded or coated components and joints; the other method consists of electrical measurements of parts and joints by means of specimen external lead test points. The first method will compare the stresses imposed by the different materials and processes, whereas the second method will relate these effects in terms of operational degradation or failure.

Future activities will consist of testing the materials and related application processes that have passed the tests conducted by the Materials Section under Work Unit 186-58-13-02, Sterilizable Polymers. Materials suitable for use in electronic equipment processes will be tested using the test specimens and associated test instrumentation developed in FY 1965. Since the sterilizable polymers tests were conducted on discrete specimen types suitable for standard mechanical and electrical tests, these results provide a recommended materials list for further equipment process evaluation and testing. It is expected that in most cases more than one material will be qualified for each principal equipment process because of different requirements of various types of electronic equipment. Additional work will include the investigation of materials and processes, other than the four subtasks previously described, such as the potting of electrical connectors and additional types of

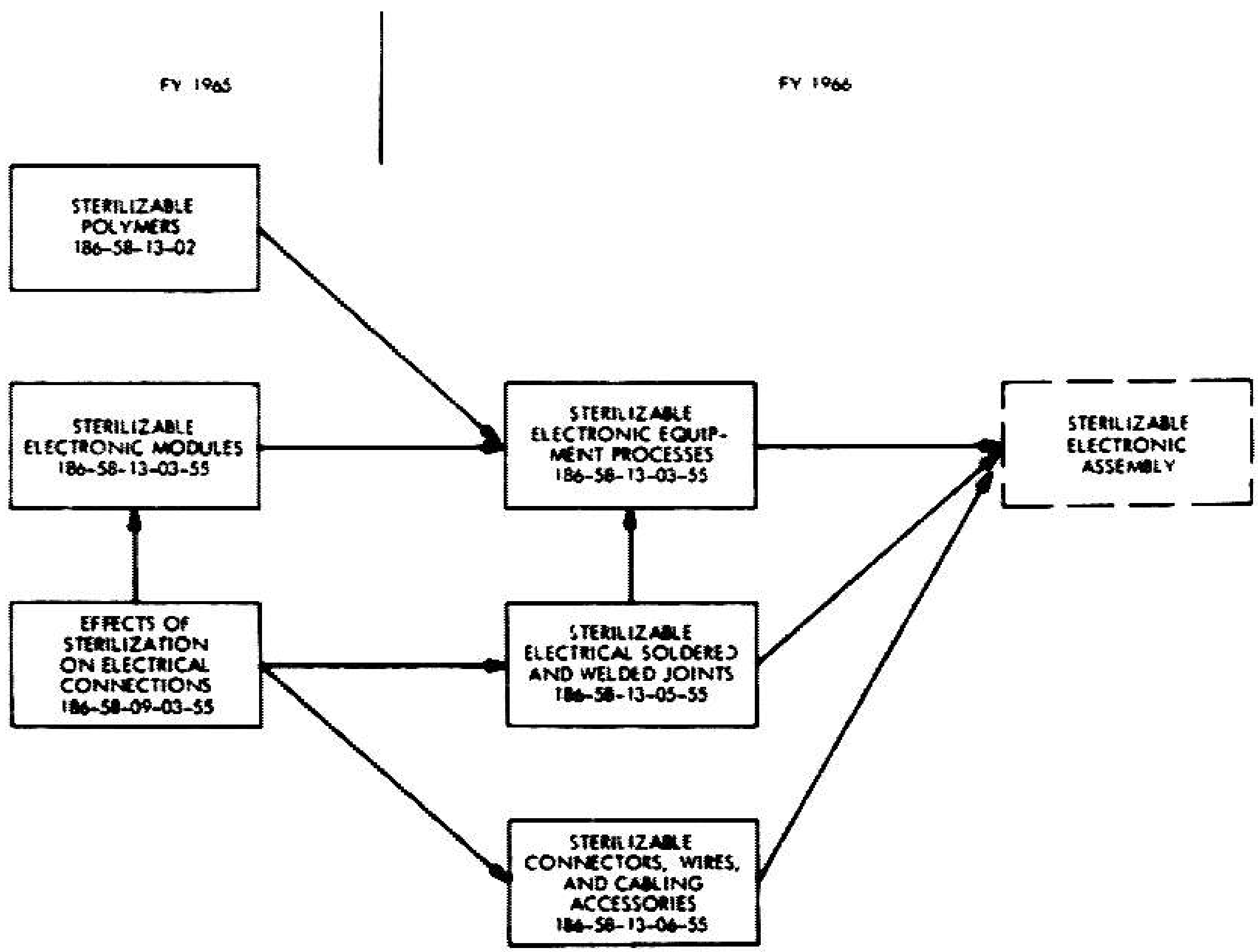


Fig. 1. Relationship of sterilizable electronic modules to other Division 35 sterilization work units

encapsulation and impregnation processes. Other processes will be added as their necessity for testing becomes evident from Voyager design planning. It is expected that these sterilizable process and material application tests will be added to the existing contractual work and supported with remaining FY 1964 funds and FY 1966 funding allocations. For this area of effort, the FY 1966 work unit title has been changed to Sterilizable Electronic Equipment Processes.

Some of the future effort will be devoted to an in-house investigation of methods of measuring embedment and coating stresses of polymeric materials on electronic components. A pressure test method using a laboratory type mercury bulb thermometer is now being evaluated, and additional or alternate methods and instrumentation for internal pressure measurement will also be considered. It is planned to introduce these pressure test method determinations into the contractor's testing of sterilizable equipment processes.

The goal of the FY 1965 and the FY 1966 work units is to provide data on a sufficient number of equipment processes, including material applications, so that preparations can be made for the fabrication of a fairly complex electronic assembly with a reasonable assurance of reliable operation after sterilization. The relationship of Sterilizable Electronic modules to other Division 35 sterilization work units is shown in Fig. 1.

BLANK PAGE

JPL Technical Memorandum No. 33-243, Vol. I

HIGH-IMPACT STERILIZABLE CRYSTAL DEVELOPMENT*
NASA Work Unit 186-68-10-01
JPL 384-62801-2-3550

JPL Contract 951080 with the Valpey Fisher Company is for the completion of the high-impact sterilizable crystal development. The contract provides for the fabrication of 20 crystals for sterilization tests. These tests will be performed by placing all of the crystals into a chamber provided with a dry nitrogen atmosphere, raising the temperature to 150°C (302°F) and maintaining it for 50 hr. At the end of this period the lot will be removed from the chamber and stabilized at 25°C for at least 24 hr. The sterilized crystals will be thoroughly checked before and after the heat cycle and compared with a control lot which will not be heated. The sterilization procedure will be repeated four times.

The materials in the crystal are alumina (which is cured at 1700°C), quartz (which can withstand repeated exposure to 500°C), kovar, deposited coatings for electrical conduction and solder-ceramic bonding, and solder. As yet, no prototype cyrstals have been exposed to the sterilization process. The only foreseeable problem is the seal. The quartz resonator is clamped between the body halves by loading the assembly prior to applying the solder seal. The clamping force is critical, as it affects the resonant frequency of the crystal. If the solder creeps sufficiently during the sterilization cycle to relax this clamping force, the crystal frequency could exceed the specified limits. Solder is being used in order to expedite development of the crystal, since the vendor is familiar with its use in this particular application. However, other sealing techniques have been investigated and appear adequate. Two of them are cold welding and the provision of a mechanical case. Development of these techniques will proceed in case the solder will not provide a sterilizable seal. Initial sterilization testing is expected to occur in December, 1965.

---

*This work is being carried out in conjunction with High Impact Electrical Technology, Work Unit 186-68-10-01 and is also reported in that section.

BLANK PAGE

SPACECRAFT AND CAPSULE EQUIPMENT DEVELOPMENT (186-68)

PLANETARY ENTRY AND LANDING STRUCTURES
NASA Work Unit 186-68-01-01
JPL 384-60101-2-3530

ENERGY DISSIPATIVE CAPACITY OF PHENOLIC HONEYCOMB

Test results obtained by the General Electric Company (JPL Contract 950564) indicate that phenolic honeycomb has energy dissipative properties comparable to those of balsa wood when loaded statically. (See Fig. 1.) However, when loaded dynamically (impact) the phenolic honeycomb fails interstitially in the cell walls, thereby dissipating less energy than predicted. Technical personnel have studied this failure problem and it appears to be soluble; thus, a followon contract was formulated to continue development in this area with the General Electric Co. Unfortunately, during the last quarter, progress with the technical problem was halted because of delays in contractual procedures, which should be resolved late in FY 1965.

ENERGY DISSIPATIVE PROPERTIES OF BALSA WOOD IN SIMULATED SPACE ENVIRONMENTS

Because of the delays encountered in formulating the contract with General Electric, work was initiated to evaluate the energy dissipative properties of balsa wood, when subjected to environments of high vacuum, sustained heat (300° F) or cold (-100° F), and/or controlled humidity. To perform these tests, an environment control chamber was needed. During the current quarter, a chamber was designed, built, proof-tested, and now is in use in actual tests. Application for a patent of this chamber has been made.

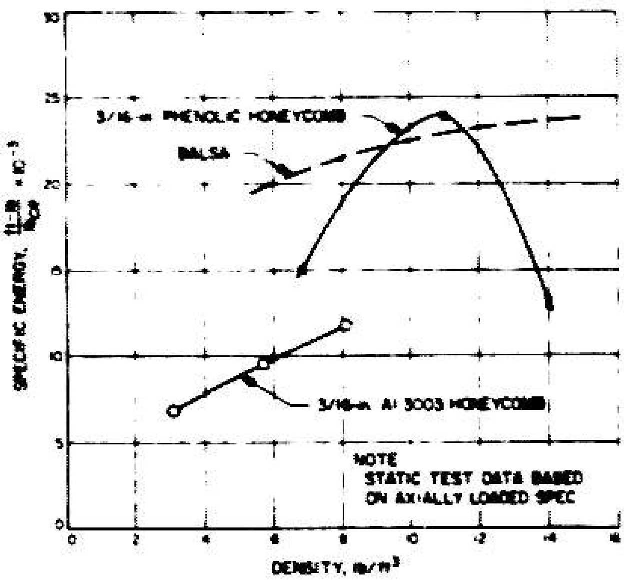


Fig. 1. Relation of energy dissipation capacity to material density

This test program will continue into FY 1966, with test results compiled and reported in the first or second quarter.

BALSA HIGH VELOCITY TEST RESULTS

The limited data obtained by the General Electric Co. (JPL Purchase Order AR4-331722) in testing balsa wood (density = 8 lb/ft^3) parallel to the grain at approximately 500 fps suggests an increase of 10 to 15% in the energy dissipative capacity of the wood above its static level. Additional testing is required to fully develop this relationship as a function of density and to validate the previous test procedures; however, because of manpower constraints, no testing is planned.

METAL CONICAL ARRAY ENERGY DISSIPATOR

In the process of formulating a work statement to contract the fabrication of a hemispherical array of truncated cones, it was determined that certain topological problems should be studied to establish rational means of optimizing the structure (weight vs energy dissipative capacity). Because this design concept is a primary factor in proposed landing capsule configurations, it was decided to initiate the study and delay the fabrication phase of the effort until the second or third quarter of FY 1966.

JPL Technical Memorandum No. 33-24? Vol. I

APPLICATION OF DIGITAL TECHNIQUES
NASA Work Unit 186-68-02-32
JPL 384-60301-2-3440

SURVEY OF DIGITAL TECHNIQUES

The use of digital techniques in attitude control and autopilot systems is being investigated. Methods of successfully using digital systems, their advantages and disadvantages, and new devices necessary for such systems are being studied

Since January 1965 a survey of the state of the art of the use of digital techniques has been conducted on a contract with TRW Systems (formerly STL). The general areas of this survey are:

1. Attitude control during thrusting flight.
2. Attitude control during nonthrusting flight.
3. Articulation control systems.

In each of these areas the contractor has investigated the state of the art of digital components. This includes inertial and optical sensors, angle measuring devices, and actuators. Systems considerations have also been studied. Block diagrams of possible and actual systems, analysis and simulation techniques, and a bibliography of applicable material have been tabulated. Six progress reports have been issued by the contractor. A final report is due August 2, 1965.

All in-house efforts, except minimal support for the contracted survey, were curtailed before January 1965 because of a cutback in funding.

FUTURE EFFORTS

This work unit will continue in FY 1966 under NASA Work Unit 125-19-03-02. Initial efforts will be directed toward using the results of the contracted survey to establish promising areas for detailed study. In addition, the use of digital techniques in control systems for pointing high-gain antennas will be started. This will be a tradeoff study between pointing accuracy and the complexity of the control system.

BLANK PAGE

ACTUATORS
NASA Work Unit 186-68-02-03
JPL 384-60401-2-3440

This work unit was undertaken to advance the state of the art of actuators used in spacecraft control systems. It includes investigations of the actuation devices as well as components required in these devices for attitude control, autopilots, and articulation control systems. Eight different items are reported in this report and are discussed in the order in which they appear on the NASA Form 1044 dated July 20, 1964.

MICROTHRUSTERS STUDY (MINIATURE ROCKET MOTOR)

This is a study effort to investigate the use of the solid propellant electrical thruster (SPET) as an attitude control actuator. A contract has been let to General Electric at Valley Forge for the study of the SPET as a detonation thruster. If the results of this study are favorable, the SPET may allow a considerable weight saving in future attitude control systems. The work under contract is divided into three tasks.

Task 1

This task is to be an analytical assessment of the feasibility of producing a SPET system with a specific impulse between 500 to 800 sec, and capable of delivering 0.01 lb thrust.

The studies will include a dynamic analysis of the chemical reactions in the combustion chamber, the determination of effects of chamber configuration on efficiency, an establishment of criteria for choosing propellants and chamber configurations, the tabulation of the physical and chemical requirments of suitable propellants, and a detailed analysis of the thruster with some of the most promising propellants.

Task 2

This task is a preliminary investigation of interface problems that might arise between the SPET and other spacecraft subsystems including:

1. The identification of interface considerations requiring further analysis.

2. The determination of any radio frequency interferences caused by the electrical discharge and/or the expulsion of plasmoids from the SPET.

Task 3

This task is the preparation of a final report that will supply all necessary criteria for design and development of a flight type SPET Thruster system prototype.

ACCOMPLISHMENTS

The major accomplishment has been in the determination and cancellation of the radio noise interference. With this task completed, one of the critical road blocks to the reduction of the proposed scheme to a useful space propulsion system has been overcome. Two major problems have been identified: (1) the analysis of wave formation and acceleration and the determination of the kinetic coefficients for the change of phase and chemical reactions may encounter limitations in present state of the art of analysis of nonequilibrium phase kinetics; and (2) reaction kinetics in the very-low-pressure range involves radiation couplings that are not well mastered in the current analytical state of the art, and it may thus be necessary to resort to an experimental effort. Other activities since January 1, 1965 are the initiation of the fluid dynamic and thermal chemistry analyses. Also, some promising propellants have been identified.

Two modifications to the contract with General Electric are planned. The first is a no-cost extension of the schedule and the second is an increase in scope to provide for experimental verification and flight-type system prototype development limited only by the funds available.

WARM GAS ATTITUDE CONTROL ACTUATOR

In this development, components of present day state of the art will be assembled into a mass expulsion attitude control actuator having an appreciable increase in total impulse capability for a given weight over a cold gas system having the same total impulse. Arrangements have been made with the Liquid Propulsion Section of the Propulsion Division of JPL to use their developments in the decomposition of hydrazine to gases in a catalyst bed. One test firing of their existing, nonportable hardware has been made. A distribution system has been fabricated in the configuration of a typical attitude-control gas system. A preliminary estimate of the hardware required to maintain cleanliness of the distribution system is complete.

Valves are available to mount at the ends of the distribution lines as soon as the equipment for maintaining pressure on the system is assembled. This work will be discussed in future reports. Before connecting the gas generating unit to the distribution system, evaluation of the cleanliness of the gas generated must be made and its temperature measured and compared to valve capabilities. A heat exchanger and filter may be necessary to permit use of existing valves.

ANTENNA ACTUATOR

New concepts and components are being investigated to reduce the weight and improve the efficiency of actuators suitable for movable antennas, instrument, sensor, or camera platforms.

The design approach of an experimental actuator around typical functional and environmental requirements has been made. A complete set of drawings have been produced completely describing this actuator in detail. The drawings have been fully checked and have been formally released.

The *Ranger* actuator is the basis from which this development is progressing. While the *Ranger* performed reliably as designed, improvements in theoretical reliability, reduced cost of fabrication, and reduced weight will be gained in this development for probable use on future spacecraft.

To achieve a self-locking characteristic desired at the actuator output, a new servomotor has been developed (under NASA Task 186-58-02-01-55 and will be separately reported) that has a capability of stopping immediately on the removal of power and holding the stopped position until power is again applied without the use of friction or mechanical interlocks. Application of this new detenting type servomotor allows the use of high efficiency spur gearing to minimize power consumption. It eliminates the requirement for a torque-limiting clutch and the use of self-locking worm gears from many applications. The quick stop capability will cause the actuator to stop within command limits without overshoot. The detenting function will hold it at its command position until a new updating command is received. The experimental actuator is now in construction in the JPL machine shop. One model is being made for evaluation by subjection to type approval test requirements, as well as sterilization requirements, in the coming year.

PASSIVE SOLAR VANE ACTUATOR

Experience in the development of the solar vane actuator for the Mariner Mars program indicated a spacecraft reliability advantage on advanced spacecraft by having the solar vane actuator independent of spacecraft power and the attitude control system.

The passive solar vane actuator, which would react to varying heat inputs to a bimetal element with spacecraft attitude change, has been brought to the point of layout design. Two serious problems remain: (1) how to make the operation of the actuator the same over the ambient temperature range, and (2) how to guarantee the null position of the actuator with the zero position of the spacecraft attitude control system.

All effort on the actuator has temporarily ceased because of manpower limitations. Based on Mariner Mars solar vane actuator experience, development effort is being used to improve and simplify the present design for advanced applications.

BRUSHLESS POTENTIOMETER

A potentiometer with no sliding contacts, adaptable to telemetry and control systems, immune to the effects of space vacuum, and with the ability to withstand sterilization would be a reliability advantage for use on the Voyager spacecraft. This potentiometer would not need a sealed case to carry an atmosphere inside.

To accomplish a brushless potentiometer, the method advanced used semiconductors which could not withstand the rigors of sterilization. To date, no commercial hardware has been uncovered worthy of recommendation for space flight. An awareness of industry capability will be maintained and should a promising design be found, engineering test samples would be purchased for further evaluation.

DIGITAL MOTOR

With the mounting interest in digital systems for use in advanced spacecraft control, an industry survey was conducted to improve the awareness of new developments and the latest thinking on digital motors for use in spacecraft actuators. Seventy-four companies were contacted; 37 companies responded. Twenty companies built digital motors. Eight of these companies built digital motors for use only on large power equipment. Of the 12 remaining, none demonstrated anything of particular interest. All effort on this task is held in abeyance until future specific spacecraft requirements are known.

NITROGEN GAS

Because cold gas attitude control actuators will still be required for select applications, a better understanding of the gas characteristics is required. The first step was to accumulate all known publications on the subject into a handbook.

Literature Search No. 655 titled, "Nitrogen Gas Physical Properties" of 125 pages of abstracts was completed in April 1965. It is quite general, but does have emphasis on thermodynamic properties, especially compressibility. Over 380 references are cited. The major quantity of listings is unclassified, but a classified supplement was made. Evaluation of the results is yet to be done, with subsequent compilation into handbook form if such a handbook is not uncovered by the search.

NOZZLE ANALYSIS

To increase the confidence in the accurate operation of the attitude control gas actuators on advanced spacecraft with long flight duration, better understanding of the pulse mode of thruster operation is needed. In association with the laboratory aerodynamicists, an analytical study is underway using computer techniques. A study of other known work in this area is being performed. Experiments will also be conducted in association with the analytical study to aid in obtaining accurate results.

The vacuum station in which the thruster testing will be done is undergoing the following changes:

1. A pier is being constructed to support the station free of ambient vibration.
2. The vacuum pump will be mounted away from the station to eliminate this source of vibration on the vacuum station.
3. A 50-ft^3/min pump is being purchased to replace the 15-ft^3/min pump to maintain better vacuum.

The air bearing table used in the force rebalance scheme of thruster testing is having a range of torque motors made to give the greatest sensitivity possible for each size of thruster tested.

An alternate method of testing, using strain gages in place of the air bearing table, is also under investigation. Attendance at a class at MIT in the use of strain gage techniques is scheduled.

It is expected that the vacuum station and the associated test equipment will be ready for operation by July 30, 1965.

JPL Technical Memorandum No. 33-243, Vol. I

LUNAR AND PLANETARY HORIZON SCANNER (LPHS)

NASA Work Unit 186-68-02-04
JPL 384-60501-2-3440

The LPHS program concerns the development of a long-life, infrared horizon sensor with no moving parts. This sensor would be useful on Voyager-type missions for providing information as to the direction of the local vertical of a planet from an orbiting spacecraft. The development is being made with the aid of an industrial contractor (Barnes Engineering Company) for design and fabrications, with JPL providing support in various design areas as well as detailed testing and evaluation.

PROGRESS

During the latter part of 1964 initial functional tests were performed at JPL. In the present period additional tests were performed and studies and designs for further improvements were made.

Contracted Effort

Contractor progress for this period has covered the following areas:

1. The present LPHS low level commutator for sampling the detector inputs, performs satisfactorily but it is quite bulky and requires high voltages on the order of 200 v. At JPL's direction, the contractor has made an intensive investigation of the suitability of the recently developed Metal-Oxide-Silicon (MOS) Field-Effect-Transistors (FETs) for use as a low level commutator. MOS FETs were procurred and designed into a breadboard commutator. Testing of the commutator over a temperature range of -50 to +90°C has shown signals to the level of 1μv can be successfully commutated. The limitation at 1μv was due to the thermal design of the breadboard set up and not inherent in the basic technique. The tests have demonstrated that this type commutator can be used in the LPHS and it is felt to be a very significant improvement in the LPHS design. The results of the commutator study and tests have been published in a report by Barnes Engineering Company titled "Low Level Commutation Using MOS FET Transistors" and is available from JPL Internal Document Control as report no. 65-360.

2. For the commutator application it would be highly desirable to use the MOS FET's in integrated circuits. In preliminary discussions with potential vendors, the contractor has been investigating the fabrication of a custom integrated circuit. The JPL Parts Reliability Group has participated in discussions regarding their providing support in the writing of a procurement specification and subsequent qualification and life testing of the circuit part.

3. A large portion of the logic processing of the signal subsequent to the commutator is basically of a digital nature. In addition, the switching drive circuitry for the commutator is digital. A study has been made of the application of standard digital integrated

circuits to provide these functions. The performance specifications of currently available integrated circuits elements, as well as the latest reliability information from the JPL parts testing program, have been reviewed by the contractor.

4. Contractor personnel have had preliminary discussions with the JPL Advanced Packaging Group. The use of the latest techniques for flight packaging of integrated circuits was reviewed. The implementation of these techniques into the design and fabrication at the contractor's facility was explored. A tentative decision was made that the contractor would obtain assistance from a subcontractor specializing in the design and flight packaging of electronic equipment. The JPL Advanced Packaging Group will provide consulting services and design review to the contractor and his subcontractor.

5. A theoretical analysis of detector responsivity by JPL[1] has indicated that the currently used LPHS detectors were a factor of 2.5 from achieving the calculated sensitivity. Later investigations by the contractor have shown that the assumed bulk Seebeck coefficient of the materials was not being realized in the thin film configuration of the detector. Further work has indicated that the purity of the materials used and the substrate temperature during the evaporation play an important part in the achievement of bulk properties. These discoveries should result in the ability to make more sensitive detectors in the future.

6. A paper giving LPHS design details and test results was presented by contractor personnel at the symposium for "Infrared Sensors for Spacecraft Guidance and Control," May 1965. The paper will appear in the published proceedings of the symposium.

A secondary benefit of the LPHS program has been the fallout of the state-of-the-art technology developed in this program. The MOS FET commutator and offset radiation source concepts are now being used in similar type instruments under development for NASA.

In-House Effort

JPL activities in the current period have covered the following areas:

1. Design and testing of a modified offset radiation source for the LPHS was conducted at JPL. Test results indicated that the radiation source was still emitting short-wave-length infrared energy and further modifications to the source structure will have to be made to eliminate the radiation at wave lengths shorter than 15 μ. With these modifications it is believed that the sensitivity of the LPHS will be sufficient to provide for operation capability against the dark side of the Moon. At present, the demonstrated capability is sufficient for planetary applications only.

[1] JPL Engineering Note 345-1

2. Procurement of an infrared spectrophotometer that can cover the range of 2.5 to 50 μ (Beckman IR-12) was initiated. The spectrophotometer will be used to measure the optical properties of the offset radiation source and the LPHS window. The effects of coatings, mounting methods, and high energy partical irradiation on the optical properties will be studied. In addition, modification will be made to the spectrophotometer to enable spectral tests of thermopile detectors to be performed.

3. The contract with Barnes Engineering Company was modified to provide for the extensive changes in the electronic design, packaging, detector studies for performance improvement, weight reduction, and other areas of design improvement.

FUTURE PLANS

Program plans for the second half of calendar year 1965 call for work emphasis in the following areas:

1. The contractor will complete the detailed design of a flight prototype LPHS incorporating all the latest design improvements.

2. An addition to the present LPHS Contract will be negotiated to provide for fabrication of a flight prototype unit based on the new design. $142,000 of FY 1966 funds have been budgeted for the prototype fabrication.

3. JPL will complete modifications to the offset radiation source and conduct further tests of the LPHS in the space vacuum simulator.

4. Modifications to the space vacuum simulation facility will be initiated to provide for Sun simulation.

5. Continued technical support will be provided to the contractor design effort by JPL in the areas of parts qualifications, circuit packaging and detector design.

In 1966 it is planned to complete the fabrication, functional testing, and preliminary flight qualification of a flight prototype LPHS. At this point of the program, the LPHS can essentially be considered a piece of off-the-shelf hardware. The LPHS can then be committed to a spacecraft program without the risks inherent in initiating development of an instrument under a fixed time schedule.

BLANK PAGE

IMAGE DISSECTOR
NASA Work Unit 186-68-02-05
JPL 384-60601-2-3440

This task is a continuing effort carried out in conjunction with CBS Laboratories, to improve the basic all-electrostatic image dissector. Our experience with applying the basic image dissector in the Mariner C Canopus Tracker is being fed back into the second generation electrostatic image dissector. Improved image tube characteristics are required for high performance star sensor and approach guidance planet sensor applications.

PROGRESS

A new specification has been written and released. This specification encompasses the appropriate requirements of all the previous documents and defines the requirements for null stability and maximum ratings.

The scope of the existing contract with CBS has been increased to cover improvements in the null stability. Null stability is to be improved by the incorporation of an improved Schlesinger deflection yoke that minimizes exposed dielectric surfaces and is integrated with the focusing anode. This part will be called a "drift-free integrated anode cone."

Analog field plotting techniques are being used to improve the electron optical resolution of the tube. Figure 1 compares the electrostatic field configuration in the basic tube with the most promising modification to the focus electrode.

CBS has made preliminary designs for the drift free integrated anode cone and is in the process of negotiating a subcontract for the development and fabrication of this part with a suitable ceramics company.

PLANNED EFFORT

Fabrication of the new design is to be completed by August. Two prototype tubes will be evaluated and delivered on this contract. Because the faceplate geometry has been changed, new fixturing is required to perform the evaluation. This equipment is being readied in-house and will be supplied to the contractor GFE.

A small in-house effort will also be undertaken to evaluate the off-axis resolution improvement that can be gained by coupling the focus voltage to the maximum deflection plate voltage.

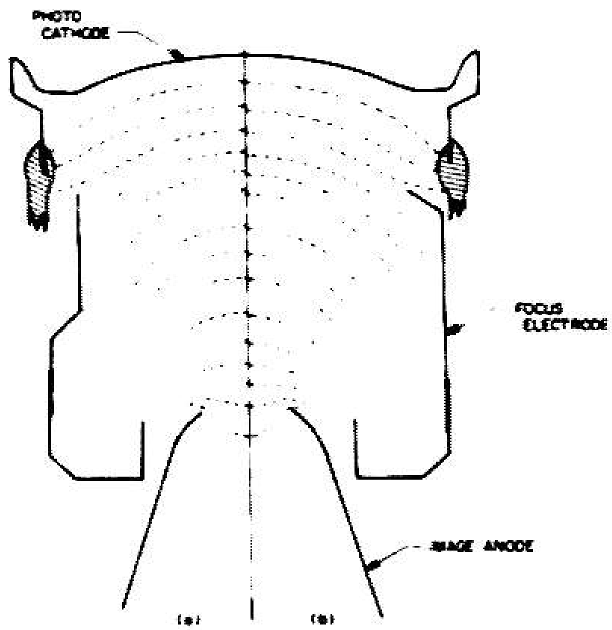


Fig. 1. Image section electrostatic field plots
a) Old electrode configuration
b) Most promising new configuration

LOW-LEVEL COMMUTATOR
NASA Work Unit 186-68-02-06
JPL 384-60701-2-3440

The switching and amplification of low-voltage dc signals have always presented design problems to the circuit engineer. An early solution to this problem was the chopper-stabilized amplifier. This technique mechanically chopped the signal of the input to the amplifier and referenced the signal to a known voltage level. After later amplification, in a highly stable ac amplifier, the dc level of the signal is restored by again passing the signal through a switch that is synchronized with the input switch. This method eliminates the problems associated with short- and long-term drift in dc amplifiers. The disadvantage is that it does use a mechanical switch (i.e., relay) and is not suitable when many signal channels must be switched because of the size and weight problem.

A more recent technique uses a photoconductor resistor as a circuit element. The resistance is caused to change by illuminating the photoconductor with light. This combination of light and photoconductor replaces the mechanical chopper and because these elements can be made smaller it is possible to commutate many low level dc signals in a medium size package. Several commercially available instruments now use this method of signal processing.

For some space applications the photoconductor still leaves much to be desired. Where there are a very large number of signals to be switched the lamp-conductor package again becomes large and bulky. What is more important the lamps that are best suited for the application are neon glow lamps which require a supply voltage of approximately 200 v for satisfactory operation. The switching circuitry for the high voltage to the large array of lamps (two for each photoconductor) is not compatible with high reliability requirements.

OBJECTIVE

The purpose of this program was to investigate other methods of low-level commutation that would be suitable for space applications. Preliminary studies were made of the use of electroluminescent sources and semiconductor injection sublasers as light sources for photoconductors. The electroluminescent source also required high voltages to achieve sufficient light and, in addition in the present state of their development, there is a gradual decrease in the light output with age. The injection sublasers are very inefficient sources from a power standpoint and, in the present state of their development, materials to achieve the best spectral match between the photoconductors and the source are not yet adequately developed.

PROGRESS AND CONCLUSIONS

The technology of making metal oxide silicon (MOS) type field effect transistor (FET) has recently been developed and the devices are now available commercially. The characteristics of this device appeared interesting for the commutator application. In the so-called enhanced mode of operation the device with no voltage applied to it has a very high impedance and is essentially an open switch. The application of voltage to the 'gate' results in a low resistance between the 'source' and 'drain' terminals of the device and these terminals now effectively represent a closed switch.

There is no offset voltage between the source and drain terminals, a problem that eliminates the use of conventional transistors from this type of application. Because of the apparent suitability of this device to the low-level commutator application on the Lunar and Planetary Horizon Scanner (LPHS), and the reduction in funding level of this low-level commutator effort, the LPHS contractor was directed to make an extensive investigation of the MOS FET as a commutator. The results of this investigation show that the MOS FET is admirably suited for this application. The MOS FET together with special circuit techniques developed by the LPHS contractor (Barnes Engineering Co.) is a significant advancement in the state of the art and should find wide application in this type of signal processing. The results of the work have been published in a report by Barnes Engineering Co., "Low Level Commutators Using MOS FET Transistors" and is available from JPL Internal Document Control as report No. 65-360.

REACTION CONTROLS FOR SPACECRAFT
NASA Work Unit 186-68-02-07
JPL 384-62901-2-3840

PROPELLANT SHUTOFF VALVE

Experimental tests of a small hydrazine monopropellant engine suitable for spacecraft attitude control systems have indicated that reliability of the propellant valve is one of the critical items of the system. Therefore, the present objective of this work unit is to evaluate the most advanced propellant shutoff valve design available for spacecraft applications. This encompasses the investigation of industry capability, the procurement of off-the-shelf type hardware, and an evaluation test program to determine performance and reliability characteristics. Because no specific spacecraft application is involved, general design and performance requirements are arbitrarily assumed with typical criteria as follows:

1. State of the art — The most advanced configuration available, which is assumed to be the Apollo project hardware.

2. Type valve — Electrically operated signal shutoff. The minimum size is limited to 1/4 in. line size and must be direct-operated; the maximum size may be 1/2 in. line size and may be either direct or pilot-operated.

3. Service — The propellant media may be either N_2H_4 or N_2O_4 or related compounds with operating line pressures ranging from 250 to 500 psi over the ambient temperature range of 0 to 170°F.

4. Performance — The areas of leakage and contamination are considered critical; conditions contributing to these specific problem areas will be scrutinized in detail.

On the basis of information obtained from the Apollo program and also NASA contract NAS 7-305, the hardware selected for this program is the Moog model 52 by 22 single propellant all-welded construction. Negotiation with this vendor, Moog Corporation, East Aurora, New York, has been initiated.

It is anticipated that the hardware will be available approximately December 1965. During the interim period, the necessary test planning for this in-house program will be completed. FY 1966 funding will be provided by NASA Code 128 from the Chemical Propulsion Division of OART.

BLANK PAGE

FLIGHT COMPUTERS AND SEQUENCERS ADVANCED DEVELOPMENT

NASA Work Unit 186-68-02-08
JPL 384-63701-2-3410

The progress for this reporting period, presented under the two major subtasks (logical organizations study, and circuits and component development), was substantially less than planned in December 1964. The reasons for the lack of progress are due to the extension of the Ranger project and the transfer of personnel to the Voyager project, which reduced the manpower planned for this work unit by approximately 1 man-year.

The major report prepared under this work is "Flight Computers and Sequencers, Advanced Development," JPL SPS 37-31 Vol. IV. Several unpublished internal reports have also been prepared.

LOGICAL ORGANIZATION

The CC&S logical organizations being evaluated may be classified as either timer-oriented or memory-oriented. The work during this report period has been concerned with evaluating the relative merits of these two types for Voyager type missions.

The arguments in support of the use of two basic sequencer types for future deep space missions are summarized as follows.

Case for Timer-Oriented Sequencer

1. More reliable (favorable ratio of partial failure modes to total failure modes).
2. Based on considerable space experience.
3. Smaller size, weight, and power.
4. Requires less alteration of support equipment.
5. Lower development cost.

Case for Memory-Oriented Sequencer

1. More versatile.
2. More mission independent.
3. May be mandatory on missions beyond Voyager.

Examination of the items listed indicates that the case for the timer-oriented (T-O) sequencer, at one time overwhelmingly convincing, now is growing more debatable. To illustrate this briefly, consider reliability, the major factor in the argument for the T-O system. The functional deployment in the T-O organization reduces the likelihood of forfeiting mission objectives because of failure of one of the CC&S components. This is illustrated by the reliability block shown in Fig. 1. Whereas, a component failure in a memory-oriented (M-O) system means complete reliance on ground commands for the remainder of a mission following the failure, as indicated by the reliability block diagram shown in Fig. 2.

The validity of the preceding argument diminishes when it is considered in terms of future mission requirements. As sophistication increases, the required event sequences become more numerous and complex. In response to demands for greater capability, the complexity of the T-O CC&S must increase approximately proportionally while that of the M-O system remains constant. This is particularly evident in situations calling for variable or a posteriori sequencing. Moreover, larger portions of a T-O system will be requisite to mission success in the future because complex maneuvers near the end of the mission will not be backed up.

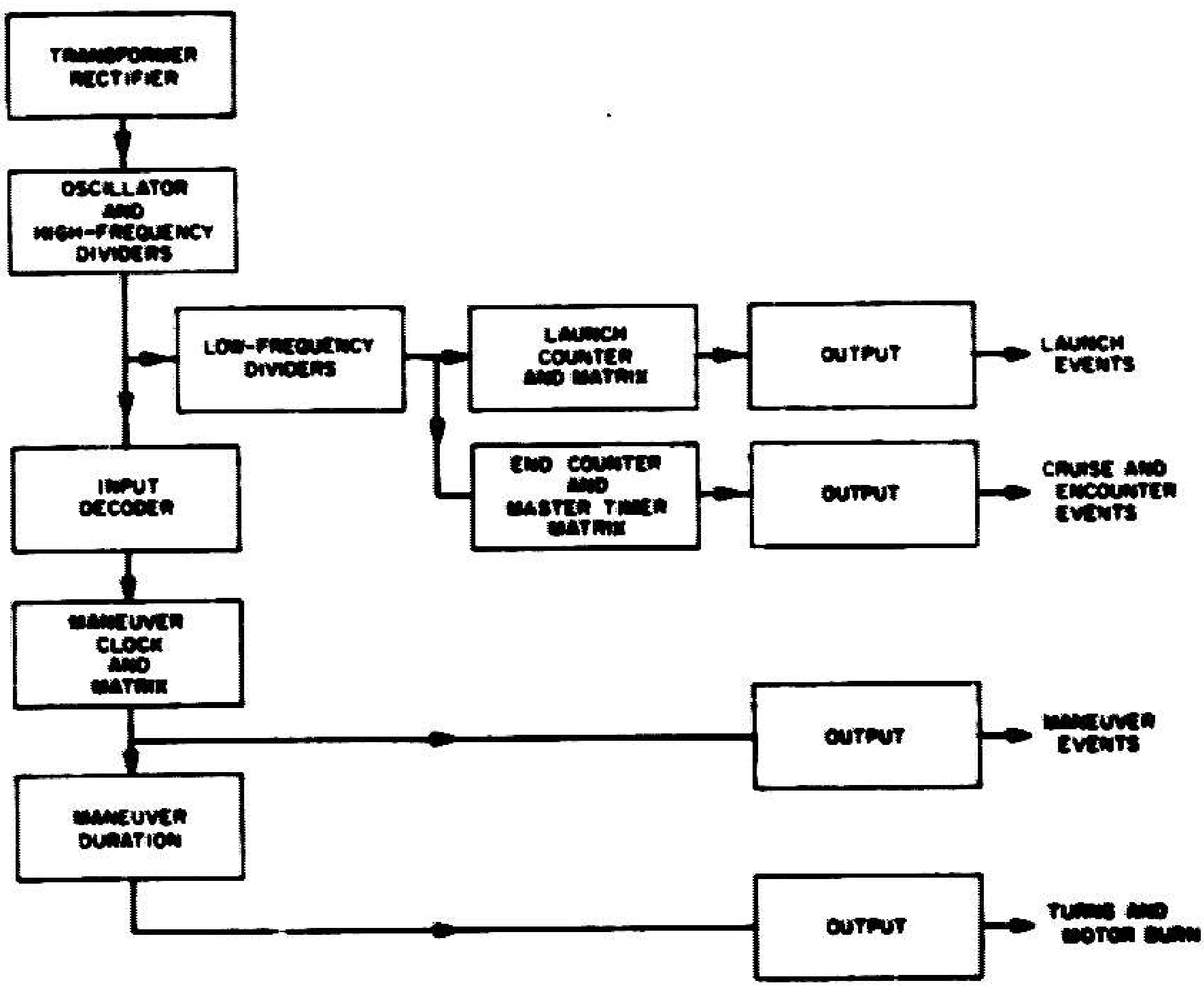


Fig. 1. Reliability block diagram, Mariner C sequencer

As an indication of the projected growth of CC&S equipment thought indispensable to overall success, the following observation is made. In the *Mariner C* spacecraft, 61% of the CC&S is vital to mission success for a period of about 1 to 2 wk (until after the midcourse maneuver) and operation of 33% is necessary for about 9 to 10 mo. in *Voyager*, on the other hand, an estimated 70% of a T-O CC&S will be required to operate flawlessly for about 9 to 12 mo. Although all of an M-O system would be needed for the same length of time, in the latter mission the amount of equipment involved in either case is comparable.

Future efforts under this subtask will be concerned with:

1. Relative comparison of:
   a. Failure modes that preclude corrective action.
   b. Simplicity and cost of applying redundancy.
   c. Improvements obtained from redundancy.
2. Determination of types of redundancy applicable to either system.
3. Derivation of more accurate reliability estimates.
4. Comparison of advantages of different M-O organizations in performing computing tasks.

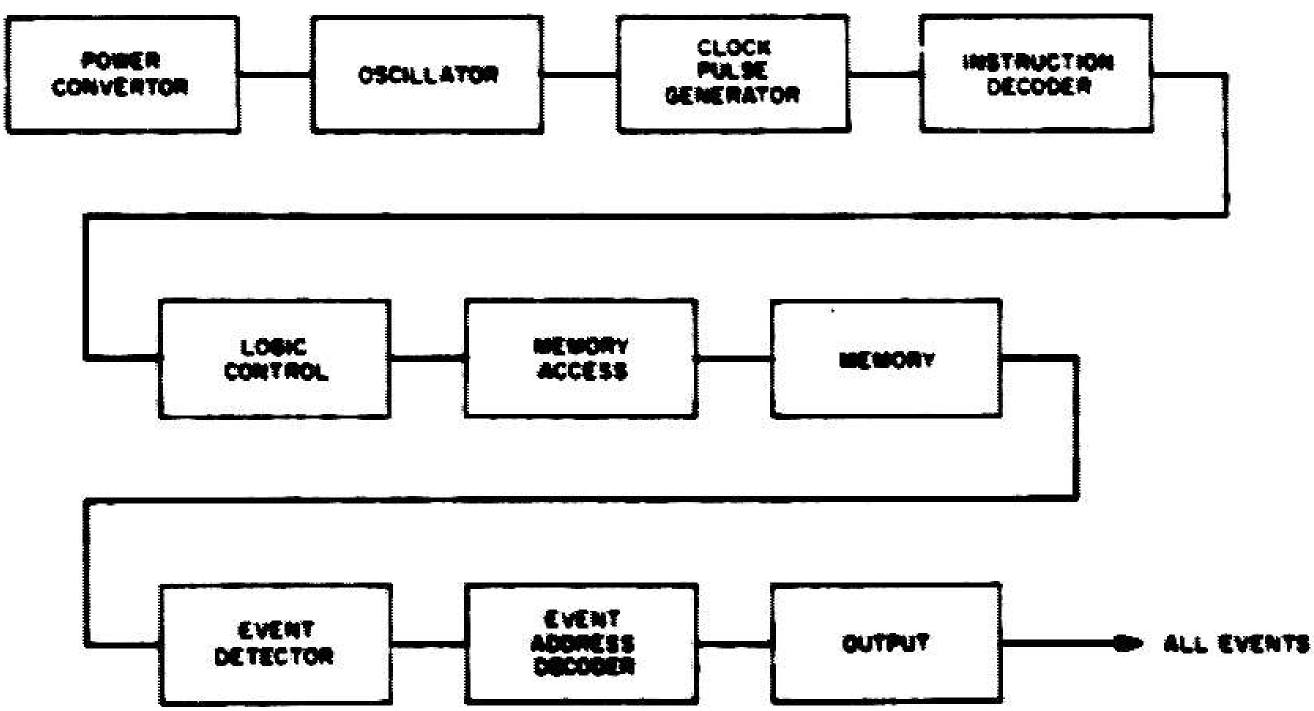


Fig. 2. Reliability block diagram, typical memory-oriented CC&S

COMPONENTS AND CIRCUITS

Hybrid Integrated Circuits

The RFQ for the hybrid integrated circuits (interstage coupling and readout circuit for a ferrite switch core counting stage, relay drivers, and diode matrix for readout of a magnetic counter) was released to Fairchild, Motorola, and Texas Instruments. The Fairchild quote was accepted and units ordered. The units were received in June.

These devices will be used to develop a 20-stage magnetic counter with 10 stages of readout. The system will be life-tested and subjected to voltage-temperature margin testing.

Standard Integrated Circuits

The standard integrated circuits of various manufacturers are being evaluated. Examples of individual component tests include the effect of voltage supply variations, transfer characteristics, and dc noise immunity. Also investigated was the effect of fan-out on noise immunity. Future tests on these same devices will include temperature effects on fan-out capabilities and power supply levels.

After the individual component testing, two functionally identical systems will be made using T^2L logic in one case and DTL logic for the other. Each system will be evaluated for combined voltage and temperature variations, and noise susceptibility.

Magnetic Wire Welding

Contract No. 951048, awarded to WEM's on September 11, 1964 to determine the feasibility of welding insulated magnet wire without prior removal of the insulation was completed. Two techniques were investigated. They were: (1) ultrasonic and (2) thermal-flow resistance weld.

The ultrasonic approach was abandoned after considerable effort had been expended. The largest single problem was the difference in the energy required to remove the insulation and that required to make the weld. Severe damage to the small copper wire occurred with each weld.

The thermal flow process was more rewarding. Feasibility was demonstrated although many refinements are still required in the process. The development of a low inertia head for the welding machines seems to be the answer to most of the remaining problems.

A survey of the welding industry indicated other processes exist that may be superior to thermal flow welds or machines exist that already have the low inertia heads.

Future activities in this area will be confined to the investigation of laser welding and thermal flow welds with machines having the low inertia heads. It is felt that one or both of the processes will produce repeatable, reliable welds without stripping the insulation. To this end, two contracts are being planned: one to Hughes for the evaluation of laser welding and a second to Sippican to develop the thermal flow process.

ADVANCED SCAN PLATFORM
NASA Work Unit 186-68-02-09
JPL 384-61901-2-3440

SYSTEM REQUIREMENTS

The goal of this effort is the development of scan platform systems that provide a mounting base for scientific instruments. A lightweight, low power, and high reliability scan system capable of search, acquisition, track, and/or scan is sought. As shown in Fig. 1, the platform subsystems shall be comprised of a planet sensor and/or a programmer, a controller, motor, and actuator. Its performance shall be optimized in terms of sensitivity, pointing accuracy, and ability to follow preprogrammed instructions.

The first iteration constraints placed on the scan platform are as follows:

1. The overall weight of the platform with the instruments is 480 lb.
2. The moment of inertia of the loaded platform is 265 lb-ft-sec^2.
3. The platform must have a capability of pointing to the planet vertical within 1 deg.
4. The platform must have a capability of pointing to an arbitrary inertial direction within 1 deg.
5. The subsystem must see a planet 4 to 160 deg continuously.

The structural specifications have been arrived at on the basis of the space science requirements as now envisioned. The scientific instruments provided for make use of the several frequency ranges of the planet emanating electromagnetic radiation. The pointing accuracy specifications and the field-of-view requirements have been arrived at by a compromise between system requirements and existing hardware.

SYSTEM MECHANIZATION

The sensor area was first investigated. Study has shown that the use of the infrared horizon in determining the local vertical is superior to other methods and that sensors using this principle have been built and flown. For the purpose of this study it is assumed that an infrared horizon scanner is available. Viewing this scanner as an input-output device, the output of the scanner shall be a signal proportional to the difference between the local vertical of the planet surveyed and the normal to the plane of the platform. The signal is updated every 100 millisec and may be available in either digital or analog form.

Two different means of mechanizing the subsystem are being studied. Figure 2a is a block diagram of one of the proposed methods of mechanization. The horizon scanner output is used to actuate a gate whose input is a clock. The gated clock is used to drive the stepper motor, which in turn (through appropriate gearing) drives the boom mounted platform. The transfer functions of the several blocks are shown in Fig. 2b. The horizon scanner is represented as a sampling switch followed by a zero order hold. It has been shown (in JPL Technical Report No. 32-206) that the

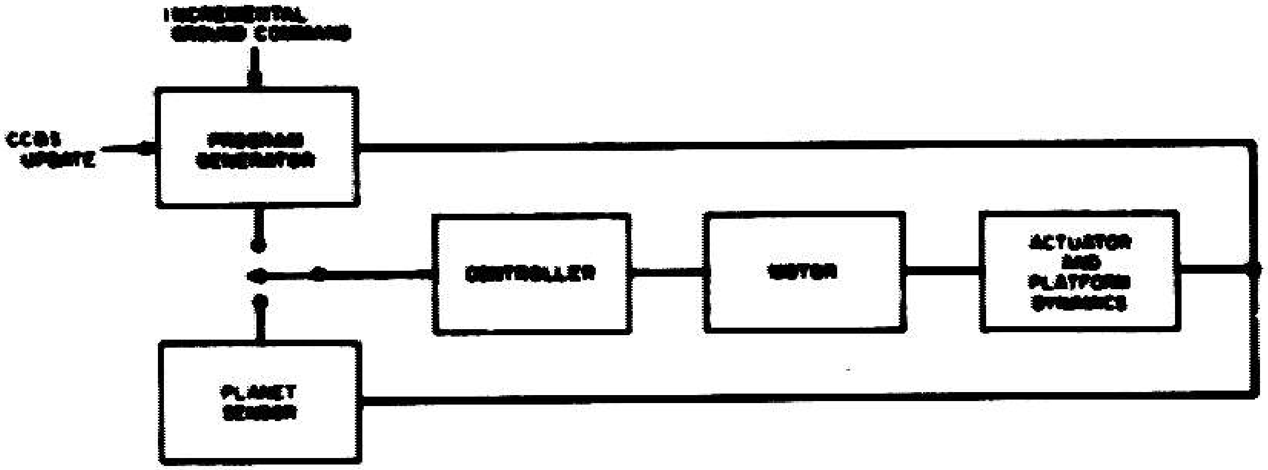


Fig. 1. Basic block diagram platform position control system

transfer function between the motor shaft output position and the platform position can be represented by a second order system where the natural frequency and the damping ratio are a function of the structural properties of the numbers used.

An alternate scheme considered is shown in Fig. 3. The main difference in the two methods lies in the motor being used. Here, instead of the stepper motor we use a two-phase induction motor. The controller mechanization is correspondingly different: a linear amplifier is driven by the sensor generated error signal, the amplifier drives the motor. The motor load is unchanged for the two methods.

The main advantage of the stepper motor over the induction motor configuration, based on a cursory examination, is the conservation of power for a stationary output shaft. The two systems are now being examined analytically for compatibility with the basic attitude control system, for realizable loop gain at a given gain margin, and for average offset errors with a ramp input under steady state operations. Also, the structural limitations on the support structure are being determined by the system performance.

FUTURE EFFORTS

An analog computer program simulating the two configurations will be generated. This will provide a verification to some of the analytical results and also will permit greater flexibility in the study of the systems as a function of the structural dynamics parameter variations.

The two systems shall be breadboarded and tested. Wherever possible the actual components shall be used. This includes the controller, motor, actuator, and (ultimately) sensor. The structural dynamics will be simulated through the use of inertial wheels and torsionally flexible rods. Work in this area has been started with a paper design of the necessary control electronics.

Once the advantages of one system over the other have been firmly established, the feasibility of using microelectronics shall be investigated.

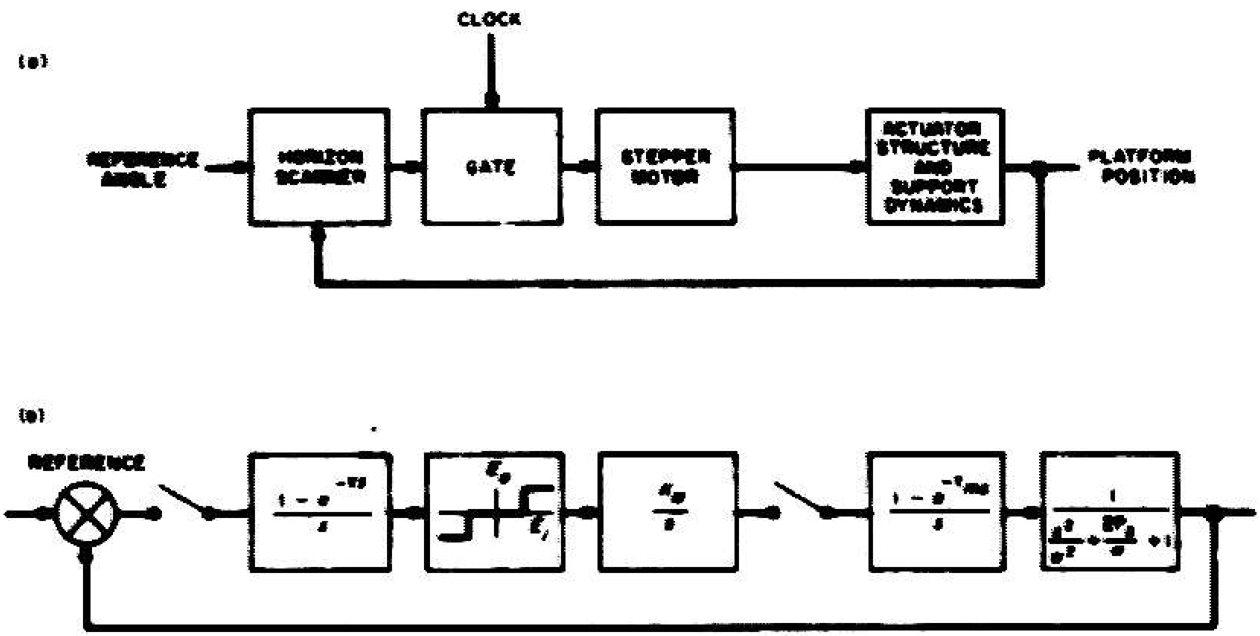


Fig. 2. Stepper motor driven scan platform
a) Functional block diagram
b) Analytic block diagram

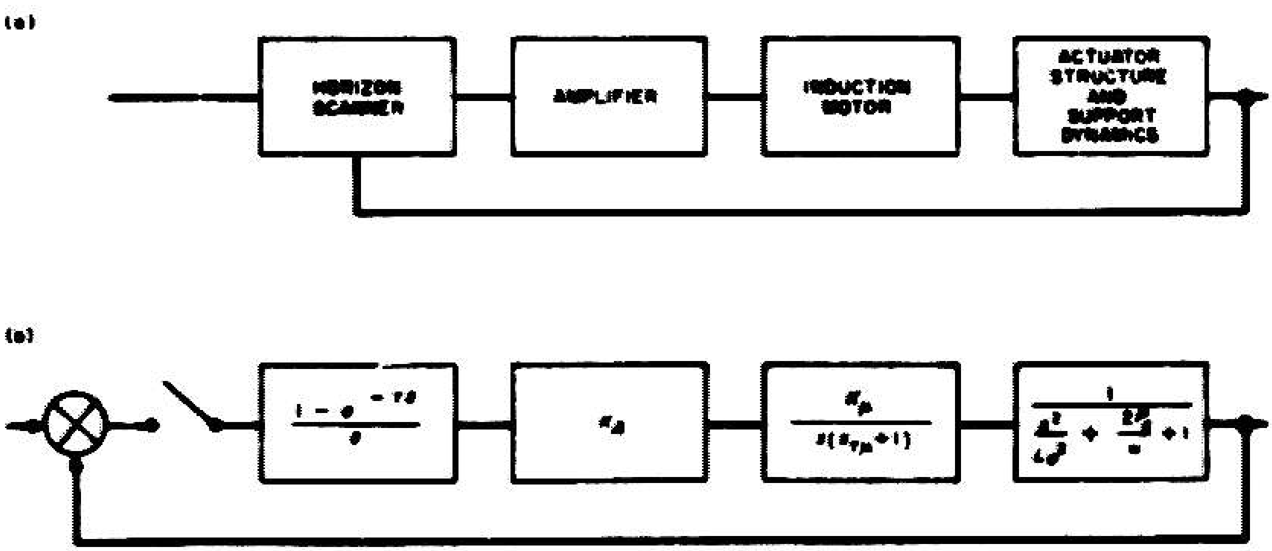


Fig. 3. Induction motor driven scan platform
a) Functional block diagram
b) Analytic block diagram

Component specifications for the sensor, controller, and actuator will be generated as an outgrowth of this program.

BLANK PAGE

ATTITUDE CONTROL OPTIMIZATION
NASA Work Unit 186-68-02-10
JPL 384-63901-2-3440

OPTIMIZATION STUDIES

Attitude control optimization studies were undertaken to develop advanced systems, to indicate new components requiring development, to support advanced technical study efforts, and to develop new analytical techniques for attitude control system analysis. These studies are being conducted both in-house and on a contracted basis.

The contract with the Purdue Research Foundation is divided into several areas. In one area a given attitude control system using derived rate stabilization is being optimized to give the best performance for parameters lying in a given range. One analytical technique being studied has worked successfully for some cases and its limitations are being investigated. Several other promising optimization techniques have been considered and are under further study.

In another phase of the contract, no attitude control mechanization was specified to give more freedom in system optimization. In this phase the specific optimal control (SOC) approach is being investigated. The solution to the SOC problem involving the application of quasilinearization to the resulting two-point boundary value problem has been under study. Because many of the difficulties are computational, practical techniques of computer solutions for these problems are being sought.

A preliminary investigation of a sequential state estimation technique has been completed. This is of value when all the state variables cannot be directly measured. In this technique, rate measurements about one spacecraft axis are used in conjunction with a computer model of the spacecraft to estimate the rates about the other axes. The technique was shown to be feasible, but further work must be done to simplify the computations required.

A study of how to determine the worst case initial conditions for an attitude control system has begun. Worst case here implies that the performance index takes on its maximum value. Initial studies show that the necessary computational problems can be formidable and a reasonable approach may be to try to determine suitable conditions on the system equations and the performance index for which the worst initial conditions will lie on the boundary of the state space being considered.

The first annual report was issued by Purdue in January 1965, and is available from JPL Document Services as Reorder No. 65-185. It is titled, "Investigation of Optimization of Attitude Control Systems." The fifth quarterly report was issued in April 1965.

SPINNING CAPSULE STUDY

As part of the overall problem of attitude control of spacecraft, an in-house study of spin-stabilized vehicles was begun. Because spin stabilization apparently offers the advantage of simplicity, some assessment of its capabilities is warranted.

The general case of the motion of a nonsymmetric torque-free rigid body has been considered. Computer programs have been written that allow the determination of the motion of such a vehicle if the initial conditions are known.

Another phase of this overall problem is that of vehicle spinup. Errors considered in this analysis were those caused by tumbling before and during spin up, and misalignment of the spin up rockets. Results of the study show that spin up errors introduce a fixed offset of the angular momentum vector and a coning about this vector.

Techniques of precessing the spinning vehicle by discrete pulses were also investigated. It was established that the precession errors were dependent on the body configuration, spin rate, precession torque, and the number of pulses applied to the system.

FUTURE PLANS

Future work on spin stabilization will be directed toward stability analysis of the spacecraft motion. While the rigid body stability requirements are clearly outlined, the problem of a torque-free spinning elastic body requires investigation. The requirement of spinning about the largest principal axis is absolute and not quantitative because the rate of error increase is not given. Further work needs to be done to define the characteristics of various body configurations and initial conditions to allow a complete description of long term stability. Another stability problem is that of the precessional control system. While the steady state performance has been analyzed, the operation of the control system as it approaches a limit cycle (or dead zone) needs further investigation.

This work will continue under NASA Work Unit 125-19-04-01.

STUDY OF ELECTROSTATIC GYRO APPLICATION
NASA Work Unit 186-68-02-11
JPL 384-64001-2-3440

OBJECTIVES

The system implications and data processing requirements encountered when electrostatic gyros (ESG) are used for advanced attitude control or autopilot purposes has been under study.

This study was conducted under a contract let to Honeywell, Inc. Their efforts were applied in two areas: (1) a parametric study of a strapped down attitude reference system and (2) a specific application. The study has been completed and the final report dated March 31, 1965, was issued. This report is available from JPL Document Services Reorder No. 65-191.

In the parametric study, the effects of accuracy requirements on the system complexity were investigated. Two accuracy requirements were considered: one that demanded that the computer include compensation for pickoff nonorthogonality, gyro misalignments, etc., and the other in which these effects could be neglected. Two readout rates were allowed, one fast enough for autopilot purposes and a slower rate sufficient only for attitude control reorientations, or acquisitions. Three ESG configurations, each using a cosine readout pattern, were included in the study. The first had no torquing or caging capability other than that required for spinup. The second included a caging capability and the third had both caging and torquing capabilities. For each of the 12 combinations that can be obtained with the above variations, the size, weight, power, and relative reliability versus accuracy were tabulated.

RESULTS

The results of the parametric study have had an influence on the component development program (NASA Work Unit 125-17-01-02). This study showed the desirability of having a readout channel for each of the three pickoffs. The original design was to use two channels and switch from one pickoff to another. The parametric study also showed that new methods for obtaining rate information from the ESG must be found. Because the velocity signal was obtained by differentiating position information, the noise component of the velocity signal was excessive. Further investigations for specific systems may indicate possible solutions to this problem area.

The second part of the Honeywell study was directed toward the application of the ESG to a landing capsule for use between separation and entry. A system configuration was selected and the size, weight, power, and reliability were estimated.

All in-house efforts except minimal support for the contracted study were curtailed before January 1965 because of a cutback in funding.

This work unit will not be continued in FY 1966.

BLANK PAGE

RANDOM STAR ANGULAR RATE AND POSITION SENSOR (RSARPS)
NASA Work Unit 186-68-02-12
JPL 384-64101-2-3440

The Random Star Angular Rate and Position Sensor (RSARPS) is an instrument designed to determine the angular rotational rate of a spacecraft, to which it is attached, by observing the motion of stars passing through its field of view. Other modes of operation could permit measurement of incremental angular changes in spacecraft attitude from an arbitrary star thus permitting attitude stabilization in any orientation.

PROGRESS

A breadboard RSARPS has been built using an image dissector for the detecting element. This breadboard has been tested in the laboratory and the field in several configurations.

A theoretical noise model has been developed for predicting the effects of parameter changes on the performance of the RSARPS and other instruments using a similar detector and scanning method.

This theoretical noise model has been experimentally verified over a wide range of system parameters.

The performance achieved during the testing was inadequate for spacecraft rate control functions. The problem areas limiting the RSARPS performance have been identified. Several modifications are possible, which were beyond the scope of this project, that have the potential of transforming the RSARPS into an instrument capable of performing all required spacecraft rate control functions.

TECHNICAL REPORTS

An interim report on the RSARPS appeared in JPL SPS 37-31, Vol. IV, Page 88.

A final report is in preparation and will appear in JPL SPS 37-34, Vol. IV.

This project terminates at the end of FY1965.

BLANK PAGE

CELESTIAL SENSORS - LENS DESIGN
NASA Work Unit 186-68-02-13
JPL 384-64201-2-3440

LENS DESIGN AND FABRICATION PROGRESS

The Sun simulator condensing optics were made and tested. As predicted by the program, the completed lens system produced an image having a blur circle radius of approximately 0.0053 in. This represents a resolution increase of nine times compared to that of the original condensor, which was designed and made by a competent optical company. The new design not only increased the simulator output significantly but also overcame a lens breakage problem caused by thermal stresses.

A collimating lens has been designed for the Sun simulator. It has slightly better resolution than the original one according to ray trace studies and will be 5 in. in diameter compared to 3 in. for the original lens. Because the new lens is a cemented doublet instead of an air spaced doublet, stray light will be reduced and the transmission will be increased. The fabrication of this lens is nearly complete and testing should be completed by July 15, 1965.

The Canopus tracker lens was designed starting from the configuration shown in Fig. 1a. The element shown on the right is the image dissector tube face, which becomes part of the optical system because the image is formed on its inner surface. Figure 1b illustrates the change in configuration after the initial computer design run. Figure 1c shows the configuration after still more design iterations. Note that two of the elements have become extremely thin, indicating that these elements might not be necessary. The two thin elements were eliminated and the design continued, which resulted in the final configuration shown by Fig. 2. This design phase resulted in a spot size reduction from 0.002 to 0.0015 in. proving the thin elements were unnecessary. This is important because it is generally thought that automatic lens design programs cannot indicate the type of system best suited to a particular requirement, but can only optimize a given lens system. If true, this would mean that two or more systems would have to be optimized individually and the results compared. In the tracker design, the computer output made it obvious that four elements would do the job instead of the original six.

The configuration shown in Fig. 2 was made and tested. Testing showed that the lens had color aberrations causing the blur circle radius to be nearly 0.06 in. compared to the predicted 0.015 in. This problem was found to be inherent in the design because of a misinterpretation of the computer data. The design was improved by additional computer runs until the chromic aberration was nearly eliminated. Instead of making this design, it was decided to modify it to provide an image that is smeared in one axis. This feature is desirable to smooth out the sensitivity response across the face of the image dissector. It is done by cylinderizing the lens surface adjacent to the tube face. This design modification is in progress and when completed, the lens will be made and tested. Some testing will be feasible using the tracker lens that has the chromic aberrations.

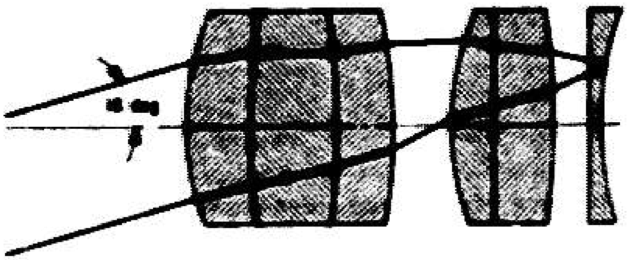


Fig. 1a. Six-element lens - initial prescription given computer, 0.035-in. rms spot size radius

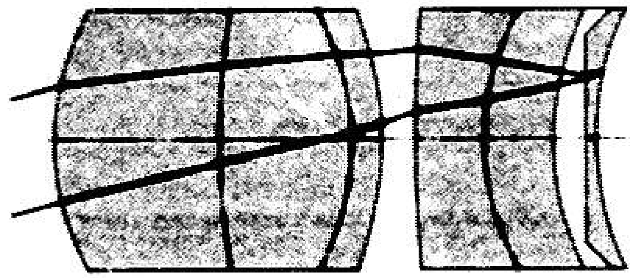


Fig. 1b. Six-element lens - prescription after initial design attempt, 0.0043-in. rms spot size radius

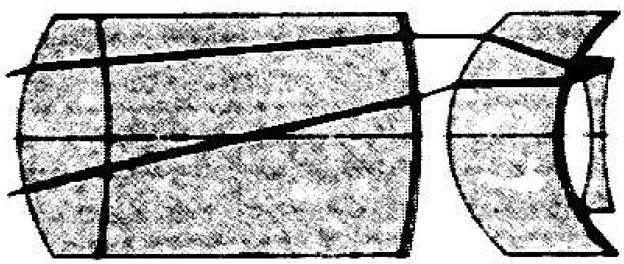


Fig. 1c. Six-element lens - allowed eight surface to become spherical instead of flat, 0.0027-in. rms spot size radius

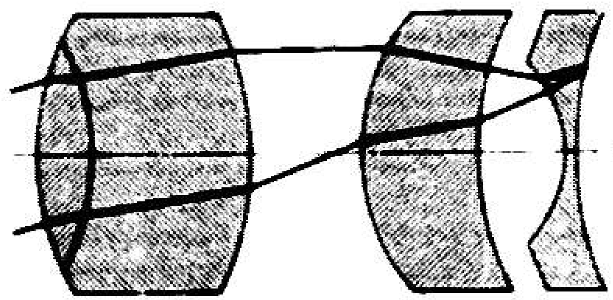


Fig. 2. Four-element lens with 0.0015-in. rms spot size radius. Restarted computer on previous prescriptions except elements 3 and 5 were omitted

LENS DESIGN REPORT

The complete lens design program report, covering operation and design techniques, will be published on JPL Technical Report No. 32-790. Recent changes to the program that have increased its flexibility are indicated and concern the following new features:

1. Capability of inserting rectangular aperatures in addition to circular ones.

2. Capability of specifying upper limits on lens element thicknesses and spaces between elements.

3. Capability of inserting vertical cylindrical surfaces; previously only horizontal ones could be used.

4. The user must specify in the program instructions the number of design iterations to be made. The program will not automatically skip any remaining design iterations if it cannot further improve the design. This saves computer time.

FUTURE OBJECTIVES

The computer program will be further changed to allow insertion of aspheric polynominal surfaces. An optional printout showing the relative sensitivity of the spot size in relation to each design variable will also be added.

Antireflection coating of fabricated lenses will be attempted at the sensor group facilities.

BLANK PAGE

CELESTIAL SENSORS – PLANET TRACKER
NASA Work Unit 186-68-02-14
JPL 384-64401-2-3440

PROTOTYPE PLANET TRACKER

A prototype planet tracker has been made and successfully tested. The tracker (Fig. 1) was designed and tested according to the requirements shown in Table 1. A detailed report published in JPL SPS 37-31, Vol. IV, page 82, describes the pertinent results.

The electronic block diagram and schematic for the planet tracker are shown in Fig. 2. For all tests to date the electronics were constructed breadboard fashion and mounted externally to the tracker housing.

The major problems encountered with the prototype planet tracker are the large scale factor variation vs apparent planet size and the absolute null stability vs temperature while operating at low illumination levels. The scale factor variation problem will be discussed later in this report. The null stability problem is now being looked at to obtain real values for null stability with the present cadmium sulfide photocells (Clairex CL-705L).

A contract with Autonetics is now under negotiation, partially funded from Planet Tracker, NASA 186-68-02-14 ($14,625), to provide fabrication and evaluation of cadmium sulfide photocells that will hopefully have superior null stability at low light levels. This contract should be completed by January 1, 1966.

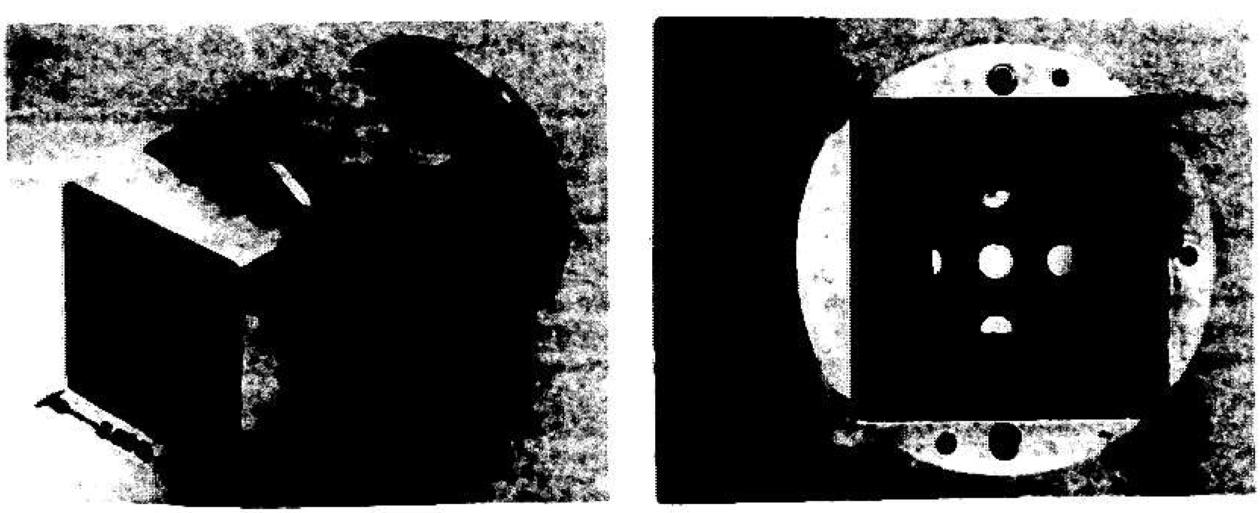


Fig. 1. Front and side views of planet tracker

Table 1. Wide-angle planet tracker requirements

Operational requirements	
Acquisition field of view	±25 deg total included angle
Scale factor	8 v/deg (not to fall off more than finite diameter of the planet would cause)
Sensitivity	Operate from 1.0 ft-cd to 150 ft-cd
Planet size	Operate from a 5-deg planet to a 60-deg planet
Sun protection	Should be able to withstand full solar illumination with no Sun shutter
Time constant	≤0.5 sec at 1.0 ft-cd illumination
Unit requirements	
Total power dissipation	≤0.5 w
Size	<45 in.^{3} (5.0 x 3.0 x 3.0 in. maximum)
Weight	<1.0 lb
Output requirements	
Error signal	Two axis (roll and hinge)
Intensity output	0.0 to 3.0 v (for inputs of 0.1 to 150 ft-cd)
Acquisition signal	Not acquired = ≤0.5 v; acquired = ≥7.0 v

VARIABLE GEOMETRY DEVICE

Conclusions drawn from tests conducted with the prototype planet tracker indicate the large scale factor change because of planet size can be minimized by optimizing lever arm and aperture size. A variable geometry device (Fig. 3) has been designed and made to empirically define these best parameters.

Tests have been concluded with the variable geometry device. Conclusions drawn indicate a lever arm of minimum practical length and an aperture half shadowing the photocell are best. Tests with the geometry device give a change of 11 to 1 in scale factor from a 5 deg planet to a 100 deg planet. This scale factor variation is still fairly large, but considering the large dynamic range of planet sizes covered, the scale factor variation is acceptable from a system standpoint.

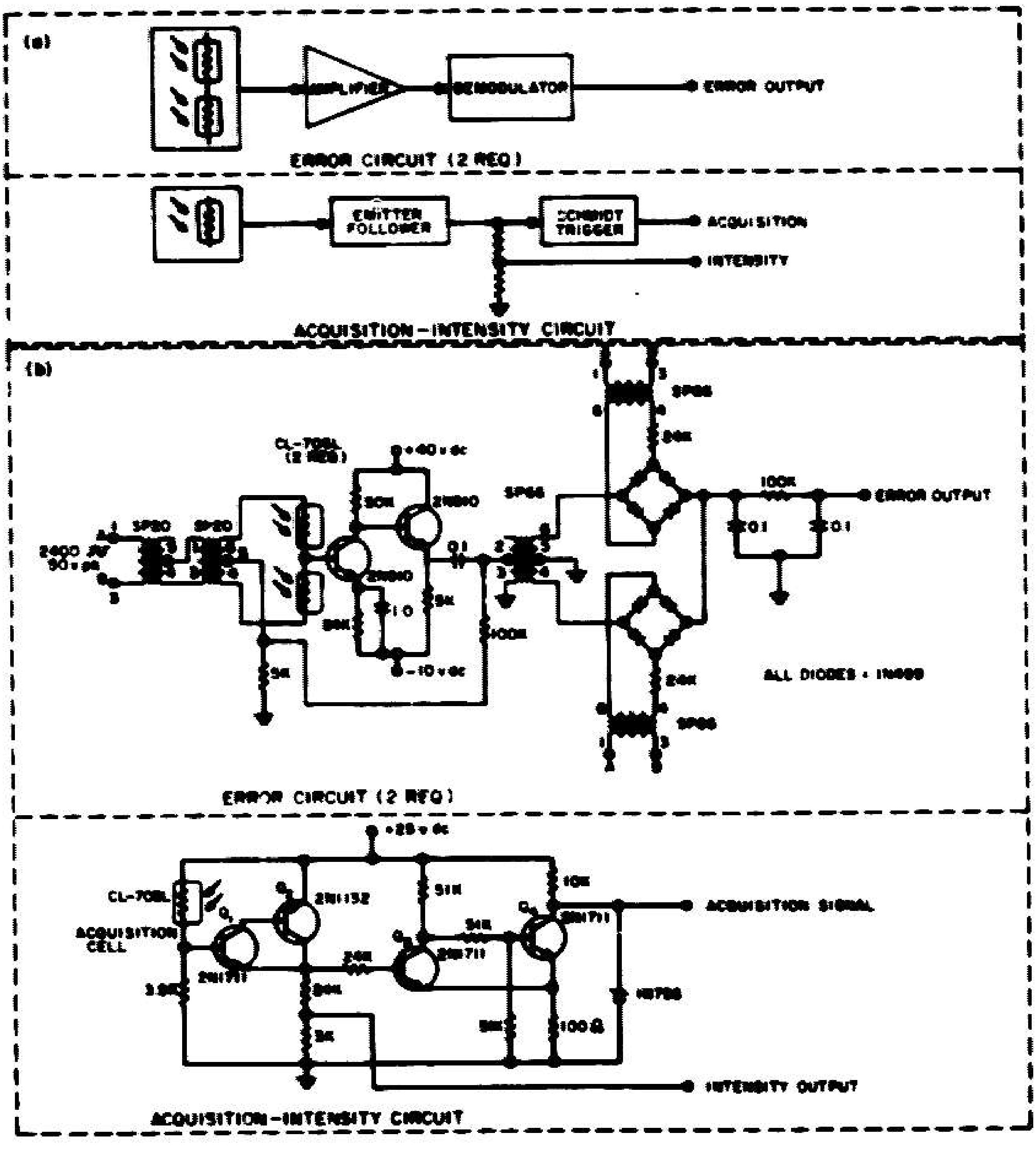


Fig. 2. Schematic and block diagrams of wide-angle planet tracker

PLANET TRACKER ENGINEERING EVALUATION MODEL

From the mechanical parameters obtained with the variable geometry device, a lever arm of 0.175 in. was chosen for the design of the engineering evaluation model (EEM). Design and fabrication of the EEM planet tracker are complete and the device is shown in Fig. 4.

Instead of the conventional method of placing side by side the two cells that make up one axis of rotation, the cells are stacked one over the other. The reason for this configuration is that simulation of a large planet using a flat disc causes geometry errors when the cells are side by side. By stacking the cells, these errors are effectively canceled; eliminating the need for a complex and costly optically collimated planet simulator.

An illuminated flat disc, 12 in. in diameter, has been constructed for the planet simulator. Preliminary tests of the simulator indicate satisfactory simulation of a planet as large as 100 deg subtended angle.

To plot tracker output as a function of angle, a special dividing table (Fig. 5) was constructed that would allow the tracker to be positioned close to the illuminated disc. This dividing table allows the tracker to be positioned within 5 in. of the flat disc simulator. This distance from tracker to disc is required to simulate a planet subtending an angle of 100 deg.

To date, no tests have been conducted with the planet tracker EEM because of manpower shortage. Testing should begin by July 1, 1965, however, with the following tests scheduled:

1. Field of view.
2. Scale factor (5 to 100 deg planet)
3. Null stability:
   a. Vs temperature.
   b. Vs light intensity.
4. Acquisition threshold.
5. Intensity output.
6. Hinge and roll characteristic curves.
7. Stray light tests:
   a. Planet-probe Sun angle.
8. Miscellaneous performance tests.

Cadmium sulfide photocells obtained from the Autonetics contract will be evaluated in the planet tracker EEM after completion of the above tests.

A detailed report will summarize the results of all evaluations.

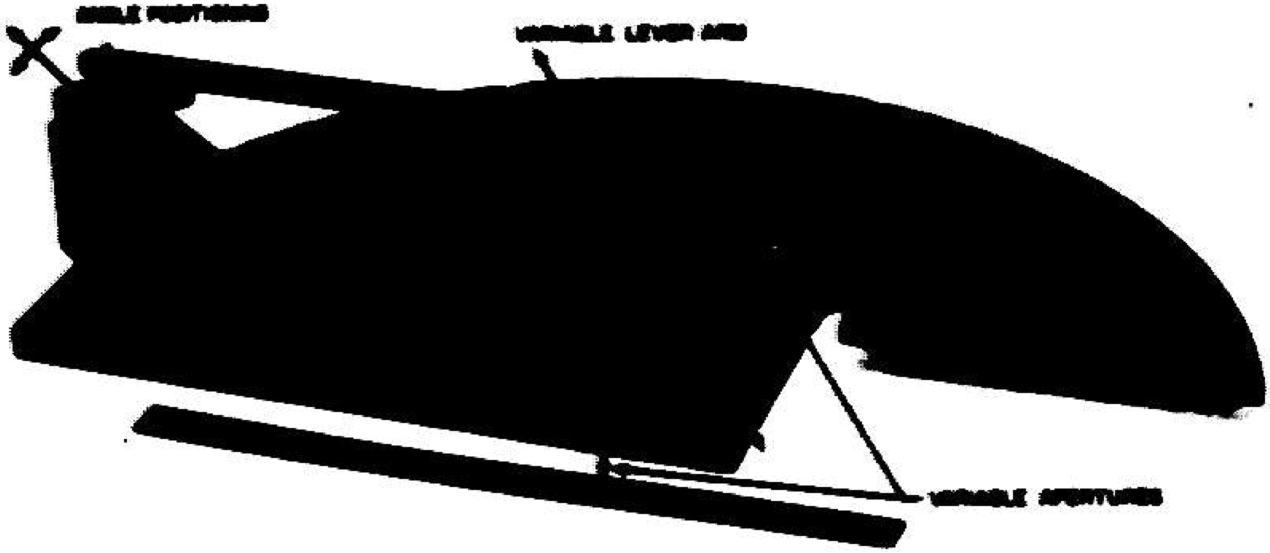


Fig. 3. Variable geometry device

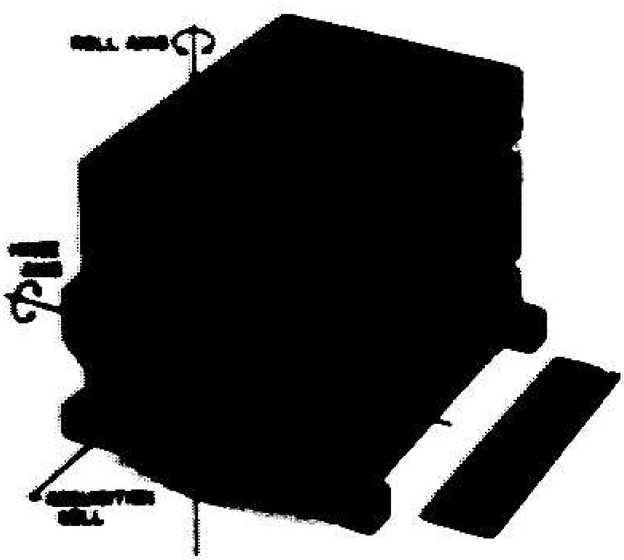


Fig. 4. Planet tracker engineering evaluation model

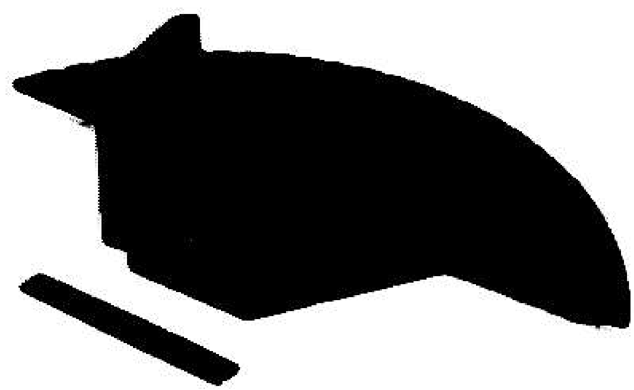


Fig. 5. Planet track dividing table

BLANK PAGE

CELESTIAL SENSORS - DETECTORS
NASA Work Unit 186-68-02-16
JPL 384-64501-2-3440

EVALUATION OF CADMIUM SULFIDE PHOTOCONDUCTORS

An in-house evaluation of 10 types of currently available cadmium sulfide photoconductors (Fig. 1) has been completed. This evaluation consisted of the following five types of tests:

1. Resistance vs intensity.
2. Light history.
3. Temperature.
4. Resistance vs voltage.
5. Ultraviolet radiation.

A detailed final report covering this evaluation has been completed and will be published.

No further work with commercially available cadmium sulfide photocells is planned for FY 1966.

VACUUM DEPOSITED CADMIUM SULFIDE PHOTOCONDUCTORS

A contract has been let to Autonetics for the fabrication and evaluation of vacuum deposited cadmium sulfide photocells. From this contract it is hoped a cell of greater dc stability and better uniformity will be developed.

The contract is partially funded ($8,399) by FY 1965 funds of NASA 186-68-02-16; results will be obtained during FY 1966. The vacuum deposition masks are scheduled for completion on June 29, 1965, with the first cell to be completed July 10, 1965. A total of 20 photocells are scheduled for completion July 31, 1965, along with preliminary test reports on the cells.

The second phase of this contract now under negotiation is for the evaluation of the previously fabricated photocells. The evaluation phase consists of the following tests:

1. Null stability vs temperature and illumination.
2. Maximum operating limits:
   a. Voltage.
   b. Power.
   c. Illumination.

3. Sterilization cycle survival.

4. Vacuum environment effects.

5. Time constants vs temperature and illumination.

6. Light memory effects.

This second phase of the Autonetics contract has also been funded from FY 1965 funds but from NASA 186-68-02-14 (Celestial Sensors - Planet Tracker). Total cost of the second phase is $14,625.

The contract should be completed by January 1, 1966, with final reports to follow.

THERMOELECTRIC INFRARED DETECTOR

A contract with Barnes Engineering Company is being negotiated for the development of an improved thermoelectric infrared detector to be used in the Lunar and Planetary Horizon Scanner (LPHS). This contract will be funded by FY 1965 funds of NASA 186-68-02-04 (LPHS) and FY 1966 funds of NASA 186-68-02-19 (Optical Sensor Techniques).

The infrared detector contract will be a level-of-effort type providing a 9-mo program. Investigations will be in the following four areas:

1. Improved thermoelectric output of the present bismuth - antimony detectors to achieve bulk thermoelectric properties.

2. Improved thermoelectric output through the use of new materials.

3. Improved thermoelectric output through lowering of heat losses from the hot junctions of the detectors.

4. Provide a detector capable of operation in the termperautre range of -40 to 160°F and capable of sterilization (145°C for 36 hr, three cycles) in an inoperable state.

IN-HOUSE DETECTOR VACUUM DEPOSITION

There have been no detectors fabricated in-house because of delays in chamber modifications and a temporary shift of manpower. However, vacuum deposition chamber modifications have been completed and fixtures made for work in detector fabrication. At this time there are no plans for detector vacuum deposition under NASA 186-68-02-19. The vacuum chamber and fixtures will be primarily used for vacuum deposition of optical coatings.

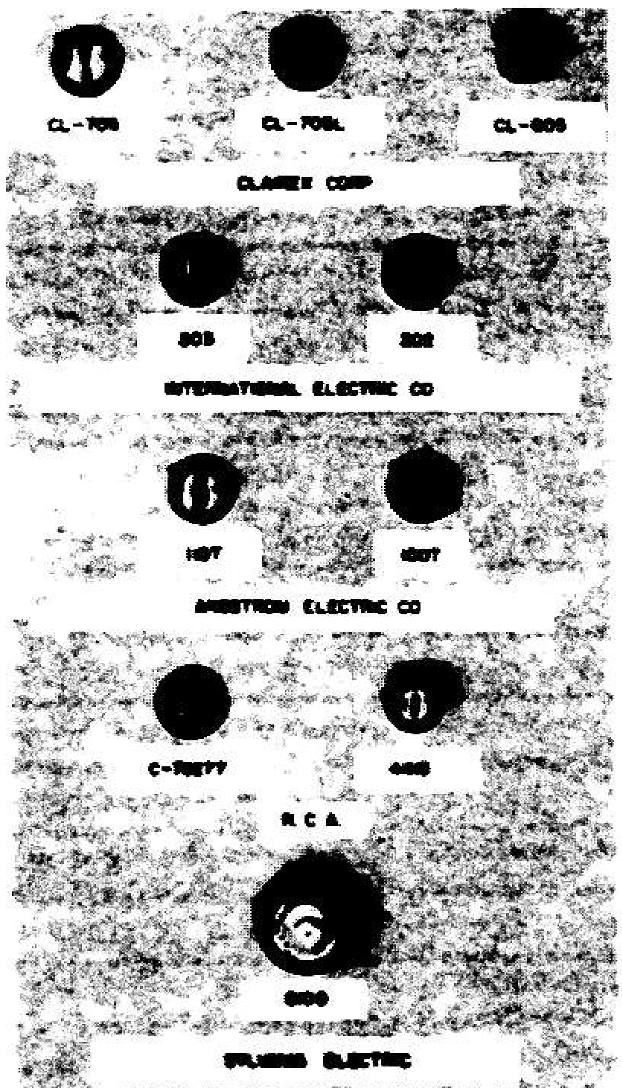


Fig. 1. Test samples of cadmium sulfide photoconductive detectors

BLANK PAGE

CELESTIAL SENSORS – TESTING AND EVALUATION
NASA Work Unit 186-68-02-19
JPL 384-64801-2-3440

The objective of this program is to procure, develop, and maintain equipment used in the testing and evaluation of various types of celestial sensors.

PROGRESS

During the present period, maintenance work was performed on the large heliostat and crane in the JPL 40-ft-diameter domed celestial simulation room (Celestarium).

Procurement of test instruments and accessories for existing equipment included the following main items:

1. Ion gauge for small vacuum test chamber
2. Bell jar for large vacuum evaporator
3. Clean mat for Celestarium
4. Optical test equipment for measurement of image quality and index of refraction of optical materials
5. Integrating digital voltmeter.

Other small procurements of miscellaneous supplies incidental to the operation of test equipment were made.

FUTURE ACTIVITIES

Besides the continued maintenance of existing equipment, the design and fabrication of the Sun simulator for the space-vacuum test chamber will be started.

The test and evaluation program for FY 1966 is being consolidated with other programs as "Optical Sensor Techniques" (NASA Work Unit 186-68-02-19-55). Lens design, detectors, and advanced signal processing techniques will be included in this Work Unit.

BLANK PAGE

THERMAL CAMERA
NASA Work Unit 186-68-02-20
JPL 384-64901-2-3440

THERMAL CAMERA USE

The use of the thermal camera (Fig. 1) has been restricted to the spacecraft control and spacecraft radio sections during the period January 1 to June 1, 1965. The spacecraft radio section had thermographs taken of the Mariner C radio power supply No. 2123; all components were found to be operating within their thermal tolerances.

The structures group inquired about measuring the emissivity of a complicated structural device with the thermal camera and it was concluded that the camera could be used for this purpose. Initial discussions were held on March 29, 1965, and photographs of a working spacecraft were also discussed at that time. This process requires the camera to photograph a spacecraft in the large vacuum chamber at the Laboratory; because of the lack of an infrared transparent window of adequate size, this subject was not pursued.

THERMAL PHOTOGRAPH OF OPERATING ELECTRONIC MODULE

The thermal camera has been successfully used to photograph working electronic modules. The thermograph in Fig. 2 shows warm transformers on the lower right, and warm transistors and heat sinks on the lower left. Other warm components are shown at the upper right. These units were operating from about 30°F (white) above room temperature down to room temperature (black to dark gray).

The thermal camera is most useful in determining the temperature of all the parts of a complicated structure with one thermal photograph.

The usefulness of the thermal camera in measuring the temperature difference between two objects at nearly the same temperature would be greatly enhanced by the addition of a cooled detector. The camera is now only capable of resolving about 1°F at room temperature.

THERMAL CAMERA FUNDING

The funding for the thermal camera has been closed out as of the end of FY 1965. Experiments are now being conducted with the thermal camera on advanced operational support equipment.

The final report on the use of the thermal camera titled Photography in the 3.5 to 15 Micron Region is in the process of completion and should be available by July 1, 1965 as Section Report 344-3.

INFRARED PHOTOGRAPHY IN THERMAL BALANCE OF SPACECRAFT

The measurement of the operating temperature of all visible surfaces of a spacecraft is an area where the camera could be well used. A large infrared window would be needed, because the camera was not built to be operated in a vacuum.

Fig. 1a. Thermal camera and electronic accessories – front view

Fig. 1b. Thermal camera and electronic accessories – rear view

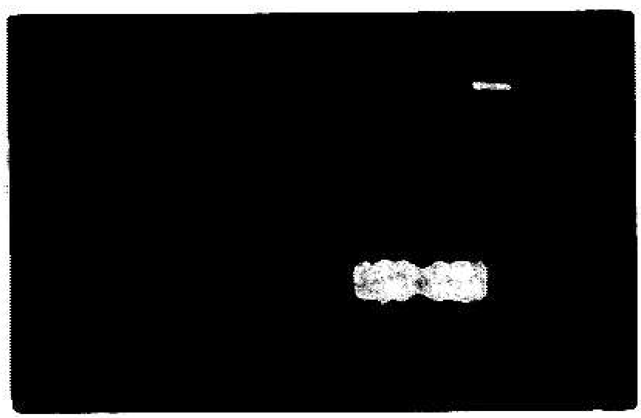


Fig. 2. Thermograph of an operating electronics module

If the spacecraft had a common type of surface or if the emissivities of all the surfaces are known, then the temperature of each part of the spacecraft could be directly read from the thermograph. This method could add to the accuracy of the thermal balance of the spacecraft as well as reduce the time required to make the thermal balance calculations.

BLANK PAGE

GUIDANCE AND CONTROL SUBSYSTEM INTEGRATION FOR FUTURE MISSIONS
NASA Work Unit 186-68-02-21
JPL 384-65201-1-3430

ON-BOARD COMPUTER PROGRAM

A program has been developed that can be used with a prototype on-board digital computer to enable a spacecraft to: (1) perform orbit determination using measurements from a planet sensor and (2) compute the retro maneuver required to insert the spacecraft into a desired elliptical orbit around the target planet. This program development was started to support the Magnetic Logic Computer development (NASA Work Unit 125-17-04-01, JPL 325-70201-2-3410) being performed by Section 341.

The program uses a simplified orbit determination procedure with weighting coefficients precomputed on the basis of the nominal orbit and fixed measurement times, and approximated by polynomials in time. A series of computer programs were developed to determine the measurement sensitivity coefficients, to determine the overall measurement weights, to determine the orbit parameter perturbations, and to fit the weighting coefficients with polynomials. The required maneuver is computed from the updated approach orbit parameters and ellipse parameters. This maneuver velocity vector is then transformed into spacecraft turn directions and velocity magnitude for controlling the maneuver execution.

The on-board computer program developed is a preliminary version and will probably require modifications and procedure changes to be made compatible with the magnetic logic computer and to operate efficiently. This effort will be continued in FY 1966. Other work planned for this effort is the generation of typical data to exercise the program and computer, the analysis of the accuracy of the computer results, and the evaluation of different approximation techniques that might be used.

HANDBOOK FOR SYSTEM RELIABILITY ASSESSMENT

The "Handbook for System Reliability Assessment" developed contains rules and procedures for organizing system functions and element reliabilities into standard forms, and for using this information to make quantitative estimates of system reliability. This handbook is to enable engineers with little background in reliability analysis to estimate system and subsystem reliabilities. The general approach taken makes the technique applicable to a wide range of problems. Final documentation has been delayed because of reassignment of manpower to flight programs. After the documentation is complete, the handbook procedures are to be evaluated using a sample problem and an engineer untrained in reliability analysis.

ORBIT TRIM GUIDANCE

In FY 1966, work will be started on a new phase of the analysis of accuracy with which an orbit around a planet can be trimmed or corrected to a more desirable orbit. This involves determining the effects of the individual error sources in the guidance and control subsystem on the overall accuracy of the maneuver and the resulting orbit. The on-board guidance and control subsystem may also contribute to the final orbit uncertainty if on-board sensors are used for orbit determination.

This aspect of the problem has been studied previously (reported in SPS 37-27, Vol. IV, pp. 20-24, "Satellite Orbit Determination Accuracy Using On-Board Instruments") but may require further analysis.

ADVANCED S/C DIGITAL MAGNETIC TAPE RECORDER DEVELOPMENT
NASA Work Unit 186-68-03-01
JPL 384-60901-2-3341

INCREMENTAL-MOTION TAPE-DRIVE DEVELOPMENT

The possibility and desirability of transporting magnetic tape with incremental motion to provide variable data rates during the record mode, the playback mode, or both, is being considered. Technical proposals were solicited for developing an incremental tape drive mechanism in accordance with JPL specification GMY-50384-DSN. A bidders' conference was conducted at JPL and attended by the eight following companies:

Ampex Corp.

Borg Warner

Consolidated Electrodynamics Corp.

Cook Electric

Leach Corp.

Precision Instruments Co.

Ralph M. Parsons Co.

Potter Instrument Co.

The three following companies responded with proposals:

Ampex Corp.

Borg Warner

Cook Electric

Following facility and proposal evaluation by JPL personnel, Ampex, and Cook were asked to submit cost proposals. On the basis of their technical proposal, facility capacity, and proposed cost, Ampex was selected. It is anticipated that a contract (for $44,884) will be placed and work started in July 1965. The first 4 mo of the contract will be devoted to a design study and motor-drive development.

HIGH IMPACT TAPE RECORDER DEVELOPMENT

During March, a formal request for information concerning state of the art high impact (1,000 to 10,000 g for periods of 1 to 5 msec tape recorder technology was submitted to industry (JPL RFI AT 5-152). Numerous responses were received, several of which indicated that the Sandia Corp. had sponsored significant work in this area. Two of the companies, Borg Warner and Raymond Engineering, were found to have existing contracts with Sandia for tape recorders to operate during a

3000 g shock. A visit to Sandia Corp. is scheduled for obtaining information and observing high impact tests.

ISOELASTIC TAPE-TRANSPORT EVALUATION

An isoelastic tape-transport developed on JPL subcontract 950850 (Fig. 1) was subjected to JPL Mariner C type-approval testing during the previous reporting period. During the present reporting period, further testing has been performed; most notably, flutter measurements that indicate operation of the transport may have deteriorated somewhat as a result of the type-approval stresses. To more precisely assess this deterioration, the unit has been completely disassembled and critical parts examined and measured. It will be reassembled (with new parts where required), retested, and evaluated during the next reporting period.

TAPE RECORDER ELECTRONICS MINIATURIZATION STUDY

This work consists primarily of an on-Laboratory study to determine the feasibility of replacing the Mariner C tape-recorder electronics with integrated circuits. The Mariner C tape recorder was chosen to provide a well documented starting point and an existing subsystem with which to measure progress.

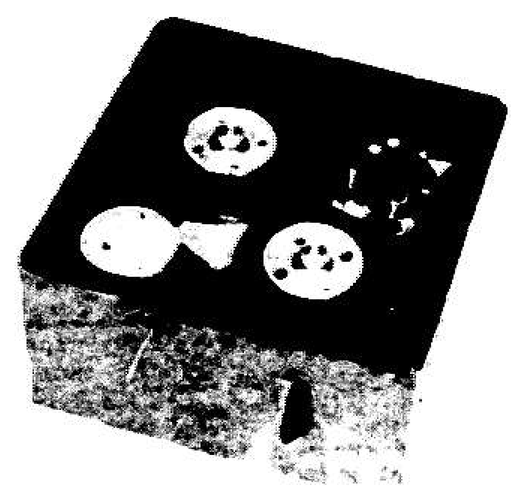


Fig. 1a. Isoelastic tape recorder (6 x 6 x 3.325 in.) Record to playback speed ratio = 1280:1 Top view

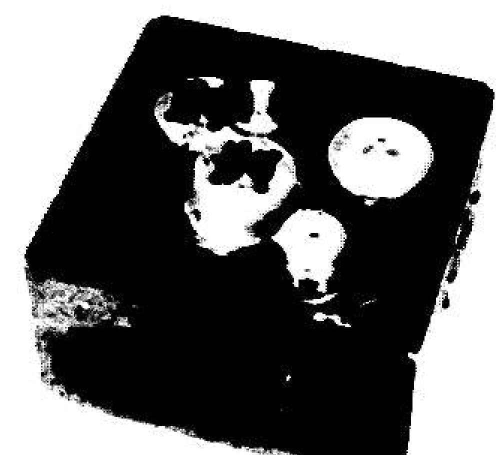


Fig. 1b. Isoelastic tape recorder (6 x 6 x 3.325 in.) Record to playback speed ratio = 1280:1 Bottom view

Discussions were held with Texas Instruments on the feasibility of integrating the several circuit sections. A listing of the discrete components which would have to be used in conjunction with the I/C networks, revealed capacitors to be the major item.

Two approaches to integration are being implemented. The first is to radically redesign the circuits so that large capacitors are eliminated; a contract to develop a photon-coupled switch to directly replace the present L P. switch will be placed soon. The second approach is an in-house effort to fabricate a system using off-the-shelf integrated circuits and discrete components as required. Two circuits, the playback amplifier and the differentiator, have been fabricated to date. In the following 6 mo, other sections of the tape recorder will be fabricated in the same manner. At the end of this period, a complete hybrid tape recorder electronics system should be completed.

MAGNETIC SPEED CHANGER DEVELOPMENT

Laboratory personnel were approached by the Magnavox Corp. with a (proprietary) device for speed changing in a torque transmission system. The advantages of such a device, if proven feasible, in a tape recorder include: (1) elimination of the drive belt, or belts, having the shortest life (lowest reliability) characteristics of all the belts used in a typical tape transport, and (2) the elimination of radial load on the motor bearings. S· ·h a device would also have the advantage of an infinite number of speed reduction ratios available by electrical switching.

Procurement proceedings for a design feasibility study were started in January. A fixed price contract for Phase I in the amount of $3,665 was written in May and work began in June. Some initial research on materials and magnetic circuit configurations has been made.

Test breadboards of the magnetic circuit will be developed and evaluated, and Phase I will be completed during the first quarter of FY 1966. Assuming a successful conclusion of this effort, Phase II (for the development of a prototype) will be attempted.

MAGNETIC BEARING DEVELOPMENT

From a reliability standpoint, one of the weaker elements of a tape transport is its motor bearings. The concept of a magnetic bearing that would have no mechanical contact seems attractive. Such a bearing would be especially compatible with the magnetic speed-reducer development now in progress. Therefore, an inhouse feasibility study is being conducted. The JPL library has been requested to make a literature search, and some useful information has resulted. A bearing has been optimally designed with the aid of the IBM 1620 computer and detail drawings are being prepared. During the next 6 mo, two versions will be constructed and tested. One will use only permanent magnets, while the other will use both permanent and electromagnets. Special equipment needed for the evaluation of the bearing has been purchased or is being designed.

BRUSHLESS DC MOTOR

Direct current motor characteristics have long been considered ideal for tape-drive applications. Many ground-station (serviceable) tape transports today use dc drive systems. The one major deterrent in applying such systems to spacecraft applications is limited brush-life; however, the advent of the brushless dc motor promises to eliminate this deterrent. Recent work at GSFC and motor companies in industry indicates that the major problems associated with brushless dc motors have been solved. Advantages in size, weight, and power are anticipated through the use of such motors in spacecraft tape recorders. Accordingly, a study is being made where two approaches are being pursued. First, the work being done by GSFC is being followed as closely as possible; secondly, procurement proceedings have started for an effort to develop a brushless motor for specific application to a spacecraft tape recorder. A contract for such a development should be awarded during the next 6 mo.

FLUX HEAD STUDY

The final report on contract 950850 for an evaluation of flux-responsive heads (Kinelogic Corp.) has been completed. The following information is extracted therefrom: all of the heads tested, both Hall-effect and modulator type, survived type-approval testing for shock and vibration without measureable degradation in performance. The signal-to-noise ratio for all heads was in excess of 40 db. Of the Hall-type heads, those with indium antimonide elements have the highest output but their use is limited to temperatures below 40°C. Those with indium arsenide elements are usable up to a temperature of 100°C but output is low. Flux-modulator types are usable up to a temperature of 80°C. The power requirements for both Hall-effect and flux modulator heads are about the same, approximately 100 mw/channel. No further work on flux-responsive heads is now contemplated.

DRIVE BELT STUDY

Work has been progressing on the program to evaluate creep and stress-relaxation of Mylar drive belts under various environmental and design situations. Speed of the driven pulley is measured by means of the G. R. Strobotac, while the output torque is measured by means of a calibrated pendulum coupled to the driven shaft through a magnetic clutch. From the data obtained, curves of speed vs torque are plotted for various pulley materials and configurations, belt tensions, and temperatures.

Repeated failures of the magnetic-particle brake, apparently because of magnetic particles getting into the bearings, resulted in the substitution of a magnetic-hysteresis brake that has performed satisfactorily. Four test units have been constructed and belt-stress relaxation tests are being implemented. These tests will determine the amount of torque transmitted as a function of time, temperature, and installed stress.

The present program for Mylar belts should be completed during the next reporting period. Following this, a similar evaluation of H-film belts is planned.

TRIPS, SYMPOSIA ATTENDED, ETC.

During the past 6 mo, personnel associated with the spacecraft tape recorder activity attended two mechanical-bearing symposia (one sponsored by the Industrial Tectonics Corp. and Design News, and the other sponsored by the American Ordnance Association); the IEEE Convention on Military Electronics; and the IEEE Intermag Conference. Two trips were made to GSFC to confer on spacecraft recorder problems, and a reciprocal visit was received at JPL from Goddard personnel. A visit was received at JPL from three members of the Canadian Department of National Defense Research Telecommunication Establishment for technical discussions concerning data storage on the ISIS-A satellite. Industrial companies visited during the past 6 mo by members of the JPL tape recorder activity, for the purpose of obtaining or exchanging technical information include:

General Kinetics, Inc.

Reed Instrument Bearing Div.

Kinelogic Corp.

Applied Magnetics Corp.

Borg Warner Controls Div.

Ampex Corporation

Cook Electric Company

United Shoe Machinery

Magnavox Corp.

Leach Corporation

Controls and Guidance Div. of Whittaker Corp.

Raymond Engineering Labs

Lockheed Electronics Company

Two visits were received from Lockheed Missiles and Space Company personnel to discuss satellite/spacecraft problems.

BLANK PAGE

JPL Technical Memorandum No. 33-243, Vol. I

ADVANCED S/C DATA HANDLING SYSTEMS DEVELOPMENT
NASA Work Unit 186-68-03-02
JPL 384-62101-2-3341

ENGINEERING DATA PROCESSING

The final report of the a posteriori redesign of the MA II data system was completed and informally published for Laboratory internal distribution on February 1, 1965. The report is titled "Some Considerations of Deep Space Data Compression Feasibility" by Philip Jewell and is some 430 pages in length. It is believed that the report quantitatively establishes the feasibility and desirability of data compression for certain classes of missions; namely, those to the planetoids and beyond. The desirability of data compression for more immediate missions was also evident in the results of the report, although this desirability can only be measured qualitatively in terms of better instrumentation for a given bit rate and not quantitatively in terms of such things as weight and power savings. Another report titled "Some Considerations in Establishing the Feasibility of Data Compression in Unmanned Spacecraft" by P. Jewell and D. G. Bourke was presented at the AAS Symposium on the Unmanned Exploration of the Solar System in Denver, Colorado on February 10, 1965 (also JPL Internal Technical Summary 3341-65-6) and summarizes the larger report mentioned previously.

Using the results of the feasibility study as a basis, it was decided to embark on the development of a breadboard engineering data handling system that uses data compression. The model chosen for this development was the Voyager Orbiter. Besides the immediate possibility of data compression being included in this mission, the choice of model was influenced by the need to do an a priori design process for a data compression system as a part of demonstrating feasibility, because previous work had modeled only past missions. Figure 1 is a simplified bar chart of the work plan for this development. A detailed explanation of the task areas in the bar chart and the approach is discussed later. A few salient points should be aired at this time. First, although Fig. 1 shows effort lasting through FY 1966 third quarter, it is envisioned that the effort will last for a considerably longer time. This time has significance because it is the time when a decision must be made to commit a system of this kind to the Voyager project and to proceed with flight prototype development. Second, it is not envisioned that a complete system will be built, only the essential and critical parts. The fabrication will be heavily supported by software simulation and verification studies. During the latter quarter of this year, all of the remaining procurement funds under this task were committed to contribute to the purchase of a Scientific Data Systems 930 computer system. As a result, most of the effort will be in-house.

At the time of this writing, the mission assumptions have been written and the measurement list has been compiled. Measurement processing requirements are in the process of being defined in detail.

The total measurements, which have been compiled through close liaison with the data user's, number some 736.

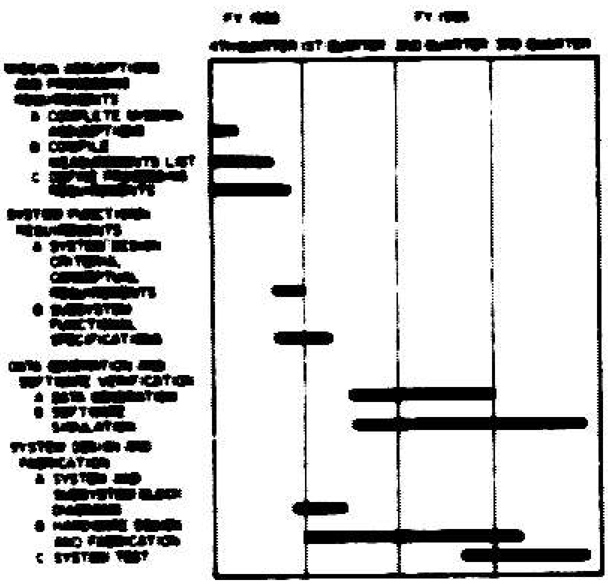


Fig. 1. Development work plan for engineering data compression system

DATA SYSTEM RELIABILITY

Two redundant multiplexer configurations have been designed and simulated on a computer. The simulation program has the capability for sequentially introducing random failures and checking for the correct functioning of the multiplexer until destruction. There is also provision for inducing failures statistically and consequently for deriving reliability figures for the multiplexer as a function of the element reliabilities. A report entitled "Reliable Multiplexing by Replacement" by J. R. Kinkel is in the process of being written. Another report titled "Data System Reliability" by J. F. Meyer is still in progress and is due for completion at the end of this quarter.

This subtask is being transferred to OART, NASA Work Unit 125-23-02-15-55, in FY 1966.

DEVELOPMENT WORK PLAN FOR ENGINEERING DATA COMPRESSION SYSTEM

Primary Objective

To demonstrate the feasibility of an Advanced Engineering Data Handling system that uses data compression and its attendant functions. Data compression is defined as being the process of removal of redundancy as defined by the data user from sensor signals. Functions attendant to data compression are confidence sampling (automatic and commanded), controlled redundancy introduction for operational measurements, data buffering, and priority selection during buffer overloading in addition to the standard functions of multiplexing, signal conditioning, and quantising. Feasibility will be demonstrated for:

1. Hardware.

    a. Design feasibility.

b. Reliability, weight, and power costs.

2. Efficiency of information transmission.

Secondary Objective

To provide meaningful information for later flight system development, design, and fabrication, if a decision to commit is made.

Methods

The hardware design feasibility objective will be pursued by the design and fabrication of a breadboard data compression system using modules that are as representative as possible of flight hardware, and by making flight reliability, weight, and power cost appraisals.

The hardware reliability, weight, and power costs objectives will be pursued in three basic steps:

1. Software implementation of the system transfer function in parallel with the system hardware design.

2. Showing agreement of outputs for identical input data to establish confidence in the software implementation.

3. Further using software simulation to derive other quantitative results from data that cannot easily be inputed to a hardware system (for example, actual telemetry data stored on magnetic tape is more suitable for input to a software simulation, realtime data generation on an individual source basis is more suitable for input to a hardware multiplexer).

The secondary objective acknowledges the importance of good information turnover in a development process. Data compression systems are more user oriented. Consequently, data requirements cannot be specified as in past systems and new methods must be established for carrying out this facet of design. The objective also recognizes that a data handling system input is probably the most variable interface on the spacecraft but, even though this interface will change, the design philosophy and certain desirable functional characteristics of the system must not be compromised during later development and flight design. In summary, information generated for the turnover process must allow for knowledgeable deviation from the specific system while ensuring that functional integrity is preserved. Accordingly, the secondary objective will be realized by:

1. The compilation of a specific set of system input measurements in consultation with engineering data users. The spacecraft model used will be the maximum case EPD 250 mission. Where EPD 250 is parametric in subsystem configuration or deficient in scope as compared to current Voyager considerations, resolutions will be made based on the most likely configurations for a Voyager mission or on the most diverse set of measurements if the former consideration does not bias a decision. The choice

of model was primarily made to parallel Voyager design activities and secondarily because an a priori design process must be carried out as a part of demonstrating feasibility.

2. The compilation and classification of data user processing requirements and the methods used to derive these requirements.

3. The outlining of a system design philosophy, design criteria, and functional specifications based on the compiled data processing requirements.

Work Plan Tasks (Refer to Fig. 1)

Mission Assumptions. The objective of this task is to specify the model to be used for input/output requirements and constraints on the data handling system. Work will consider the following mission factors in their potential effects on the data handling system:

1. Communication channel.
   a. DSIF availability.
   b. Spacecraft communication parameters and bit rates during availability of the channel.
   c. Interruption of the channel from occultation.
   d. Command availability and rates.
2. Mission modes.
3. Spacecraft subsystems.
   a. Firm up specific models for subsystems with attendant measurement lists.
      1) Propulsion.
      2) Capsule (bus source measurements only).
      3) Engineering mechanics.
      4) Power.
      5) Attitude control.
      6) Science and its relation to engineering design hardware.
      7) Video and storage and its relation to engineering design hardware.
      8) Communications.
      9) CC&S.

b. Derive a command list in conjunction with measurement lists.

Measurement Processing Requirements. The objective of this task is to determine measurement processing requirements to size system parameters and to determine the capability that the central processor of the system should have.

Work will proceed in three basic steps:

1. From the measurement lists, chart the information required to carry out the processing on the measurements.

2. Set up liaison with the data users to firm up processing techniques in quantitative terms.

3. Classify and decompose processing techniques to determine what capability should the central processor have. Compile quantitative figures such as number of channels, interrogation rates, etc.

Data Handling System Functional Requirements. The objective of this task is to outline system design criteria, system conceptual requirements, and specify design hardware subsystem functional requirements. The system will be designed to these specifications.

Data Generation. The objective of this task is to supply meaningful data to verify the integrity of the hardware system and software simulation programs.

This task will be performed in three basic steps:

1. User estimates of expected data characteristics vs their respective subsystem modes will be compiled.

2. Work will then proceed to find methods of generating simulated data that is parametrically similar to the expected data. After methods are found, any fabrication necessary to input this data to the hardware system and software programs will be done. Simulated data will be used to verify the integrity of the hardware system and the software simulation programs, and to verify that the two systems (hardware and software) perform identically.

3. Work will then emphasize the generation of what we will term "extrapolated data," which will be a combination of cleaned up or reconstructed nonreal-time *Mariner* data and user expected data. Some typical data profiles of modes envisioned for *Voyager* mission will be generated to input to the software simulation of the system.

Software Verification. The objective of this task is to derive figures of merit for the hardware system on data that is not easily inputed to the hardware system (such as actual stored telemetry data). Work in this task will parallel the design of the system in three basic steps:

1. Software requirements specifications will be completed shortly after subsystem block diagrams with interface diagrams have been completed.

2. Programming the central processor functions and then special processing functions to verify their operation. A strong iteration will be carried out with the system design and fabrication task.

3. Verification of system operation on simulated data and the derivation of system figures of merit using extrapolated data.

System Design and Fabrication. The objective of this task is to design and fabricate the hardware system in parallel with software development. The work will be carried out in four basic steps:

1. Conducting of preliminary hardware studies that strongly affect the establishing of system design criteria and subsystem functional requirements.

2. System design and fabrication, starting first on the central processor and next on the special processing. A strong iteration process will take place between this task and software verification.

3. System testing and verification with simulated data.

4. Appraisal of hardware costs (reliability, weight, and power) for an equivalent flight system.

SCIENCE SYSTEM DESIGN AND COMPUTER SIMULATION
NASA Work Unit 186-68-03-02
JPL 384-62102-X-3240

A system organization for science data handling (flight) was investigated (Fig. 1) for a first attempt at computer simulation and analysis at the detail level. The system design was abbreviated to process the output (two channels) of a single scientific instrument, an ultraviolet spectrometer.

The logical design of the (real time) timing and control signals was completed. The description of this design appeared in JPL SPS No. 37-32, Vol. IV and V.

Nonreal-time portions, including frame identification, frame count, data count, timing level generation, and control signal generation were logically designed. The Boolean equations that characterize the outputs of the memory elements in the synthesis of these subunits are discussed later. The logical diagram is shown in Fig. 2.

The use of a general-purpose computer as a design aid was demonstrated in the synthesis of a binary sequence detector (SPS No. 37-31, Vol. IV and V).

A statement of work was prepared and submitted with an RFP to six companies. Mesa Scientific Company was selected to carry out Task I. Mesa will prepare a computer program for the IBM 7094 that enables the computer to simulate the logical behavior of those subunits appearing in Fig. 2.

FUTURE WORK

Minor changes in the contract for a computer programming study will be incorporated. In the next quarter, a program will be written under JPL's supervision. In the following quarter, an analysis of the data flow and system organization will be undertaken.

BOOLEAN EQUATIONS

Boolean Equations Characterizing the Outputs of Memory Elements in the NRT Timing and Data Encoding

Scale of 8

$$A_1' = A_1\overline{A}_4 + \overline{A}_3\overline{A}_4$$

$$A_i' = A_{i-1} \quad i = 2, 3, 4$$

Input 416.64 kc clock

Output $Z_8 = \overline{A}_4$ 52.08 kc clock

Scale of 7

$B_1' = \bar{B}_1 B_2 B_3 + \bar{B}_2 \bar{B}_3$

$B_i' = B_{i-1} \quad i = 2, 3$

Input Z_8 52.08 kc clock

Output — internal states combined with $C_1, C_2, \ldots C_5$ provide (bit) timing levels $t_0, t_1, \ldots, t_{216}$ and scale of $7 \times 31 = 217$

Scale of 31 and Frame Identifier

$C_1' = (\overline{C_1 C_2 C_4})\, C_3 C_5 + \bar{C}_3 \bar{C}_5$

$C_i' = C_{i-1} \quad i = 2, 3, 4, 5$

Input Z_8 52.08 kc clock

Output — 31 bit pseudo-random sequence and timing levels described previously

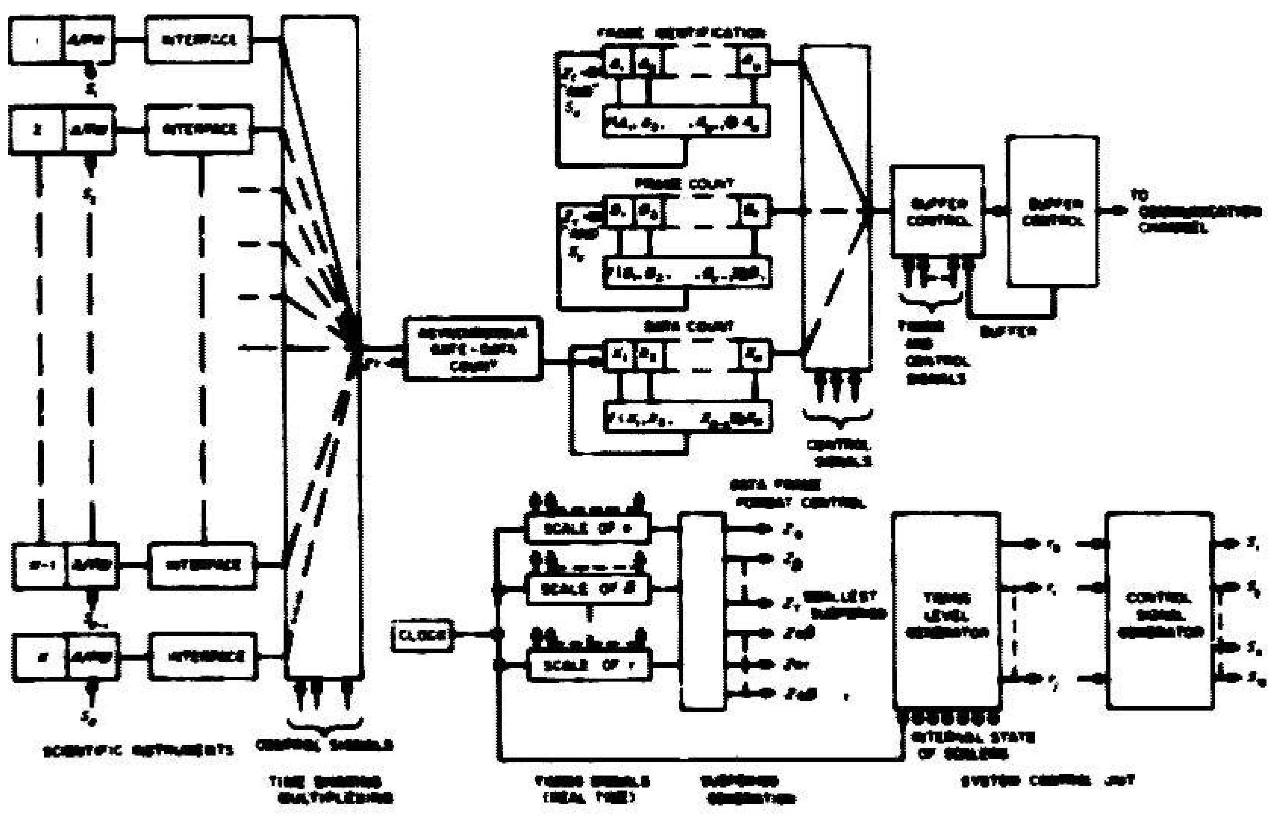


Fig. 1. System organization for science data handling (flight)

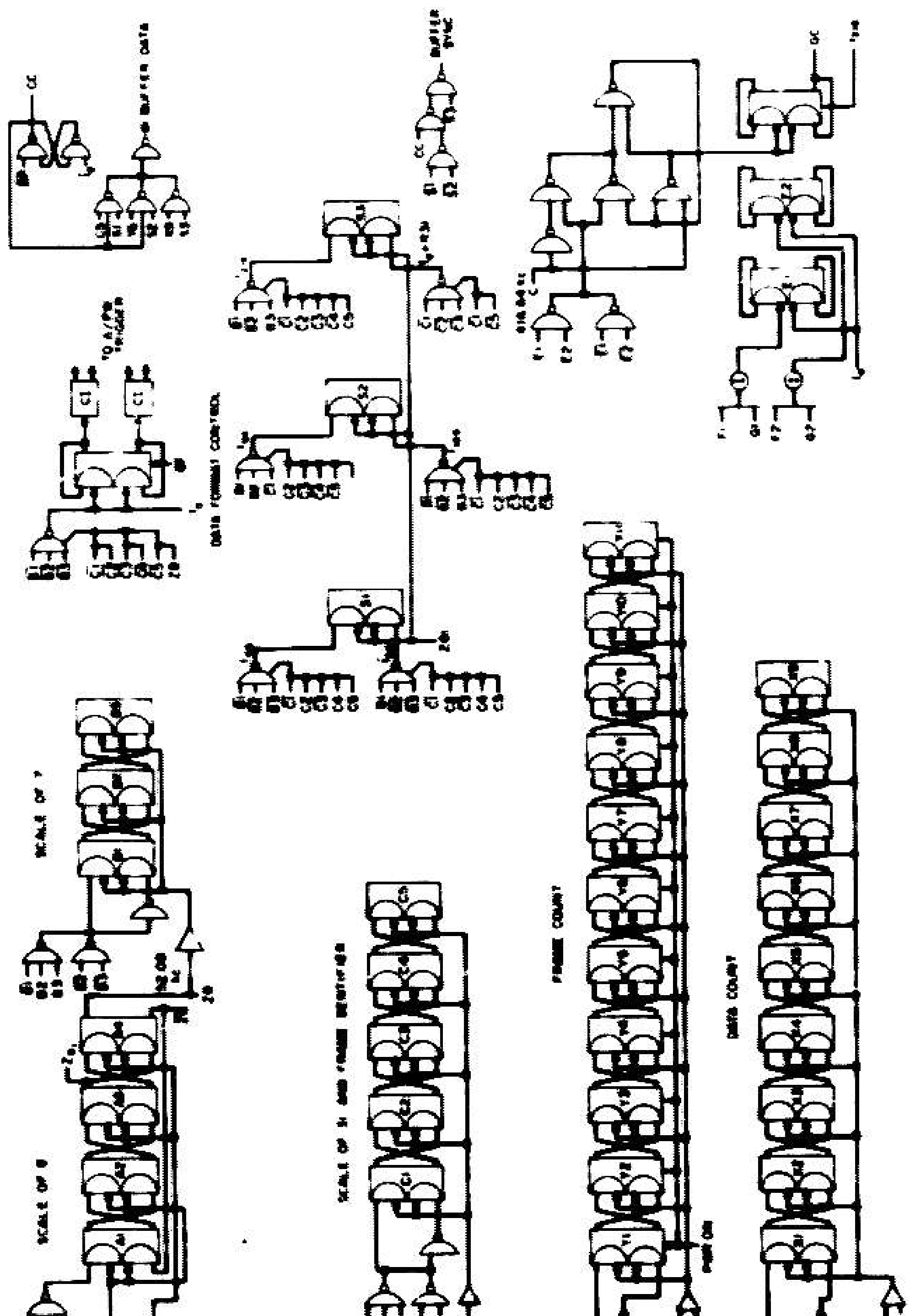


Fig. 2. Logical diagram for nonreal-time timing and data encoding

Frame Count

$Y_1' = \bar{S}_2\bar{Y}_9\bar{Y}_{11} + S_2Y_{11} + Y_9Y_{11}$

$Y_i' = Y_{i-1} \quad i = 2, 3, \ldots, 11$

Input $(\bar{Z}_{8_1} + S_2)BF$ gated clock

S_2 cycle right shift command

BF buffer full command

Data Count

$X_1' = \bar{S}_3\bar{X}_5\bar{X}_9 + \bar{S}_3X_5X_9$

$X_i' = X_{i-1} \quad i = 1, 2, \ldots, 9$

Input $(\bar{Z}_{8_1} + \bar{S}_3)\,GC$ gated pulse count

S_3 shift right and clear command

GC gate (data) pulse count

A/PW (analog-to-pulse width) Trigger

Input $\bar{t}_0$ 52.08 kc/217 = 240 cps

Output 120 cps

Data Format Control

$S_1' = t_{55} + \bar{t}_{86}\, S_1$

$S_2' = t_{94} + \bar{t}_{105}\, S_2$

$S_3' = t_{216} + \bar{t}_8 + K31\, S_3$

When S_1 is 31-bit frame identifier readout command

Asynchronous Gate-Data Count

$Q' = \bar{C}G + GQ + CQ$

Input $G = E_1\bar{E}_2 + \bar{E}_1E_2$ gate frame

C = 416. kc clock

Q present state of asychronous sequential circuit

Output, 208 kc gated clock

RADIO FREQUENCY TEST CONSOLE
NASA Work Unit 180-68-04-03
JPL 384-61201-2-3341

The Radio Frequency Test Console Phase I contract (JPL 950144) let to Westinghouse Corporation, Baltimore, Maryland on March 5, 1964 has been successfully completed. The primary goal of this contract was to build a precision 50 Mc signal-to-noise mixer and demonstrate that a signal-to-noise ratio could be set and maintained within a tolerance of ±0.3 db over a 4 hr period. In addition, Westinghouse was required to study practical methods of mechanizing an equivalent DSIF transmitter/receiver pair with an accuracy and precision at least an order of magnitude better than that obtainable from an operational DSIF transmitter receiver pair.

The significant results and the conclusions reached during the course of this contract are summarized in a final report. In addition, the detailed experimental and analytical work performed under this contract is available in the form of appendixes to the final report. For convenience, some of the more important results will be reported here.

The primary aim of the contract was to establish the accuracy with which average signal-to-noise ratios at 50 Mc could be set. Toward this end, a matrix of all possible signal-to-noise settings (25×10^4 of them) was arranged into four quadrants and 10 settings from each quadrant were selected at random plus the corner setting. The mean, variance, and standard deviation of each quadrant was calculated. By comparison, each quadrant was a subset of the total matrix population and a mean, variance, and standard deviation was calculated for all the readings. From these calculations a 95% confidence interval with 5% tolerance limits was applied and it was determined that no more than 5% of the readings would fall outside of ± 0.155 db. In addition, as a result of extensive testing, the noise power spectral density at the signal to noise mixer output was determined within ± 0.05 db by the frequency response of the mixer.

A design review of the contract was held at Westinghouse in Baltimore on March 10, 1965 with 10 JPL representatives (selected from Sections 331, 334, 336, and 339) in attendance. The design review consisted of a presentation of the significant results of the study effort including the proposed methods for building the RF (radio frequency) test console. In addition, a demonstration of the signal-to-noise mixer and the method of verifying the spectral uniformity of the noise at the mixer output, using an SDS 910, was presented. There was unanimous agreement among the JPL attendees that both the quality and quantity of the Westinghouse effort was well worth the money spent.

A follow-on contract (JPL 951140) was awarded to Westinghouse on June 29, 1965 to build the RF test console (the signal-to-noise mixer was built under JPL contract 950144) in accordance with the revised specification contained in the final report of contract 950144. It is anticipated that this followon contract will last 14 mo. Although this contract will not appear as a formal task in FY 1966, because it was completely funded in FY 1965, the progress of the RF test console will be reported in subsequent reviews.

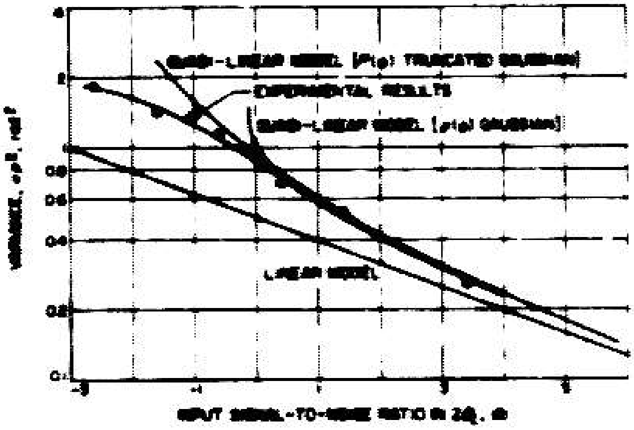


Fig. 1. Performance curves

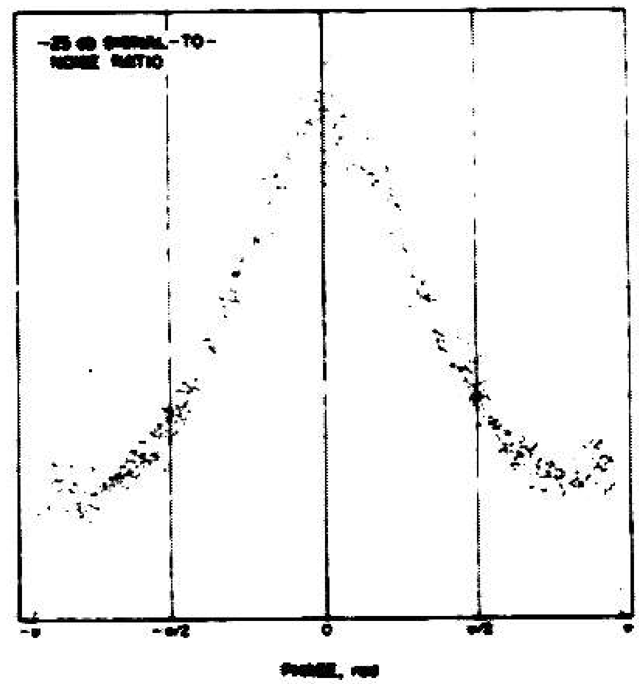


Fig. 2. Phase noise distribution, -25 db

PHASE LOCK ACTIVITY (IN-HOUSE)

This activity has been successfully completed and a summary of the results obtained is being prepared as a technical memorandum. In particular, during this reporting period, experimental probability densities of the phase error and the times between cycle slipping for a practical second order phase-locked loop have been measured. The performance of the loop as predicted by the familiar linear model and two different quasi-linear models is compared to the measured performance in Fig. 1. An example of the probability density plots obtained for the phase error and cycle slipping phenomena when the signal-to-noise ratio in the loop bandwidth is – 3 db is shown in Fig. 2 and Fig. 3 respectively.

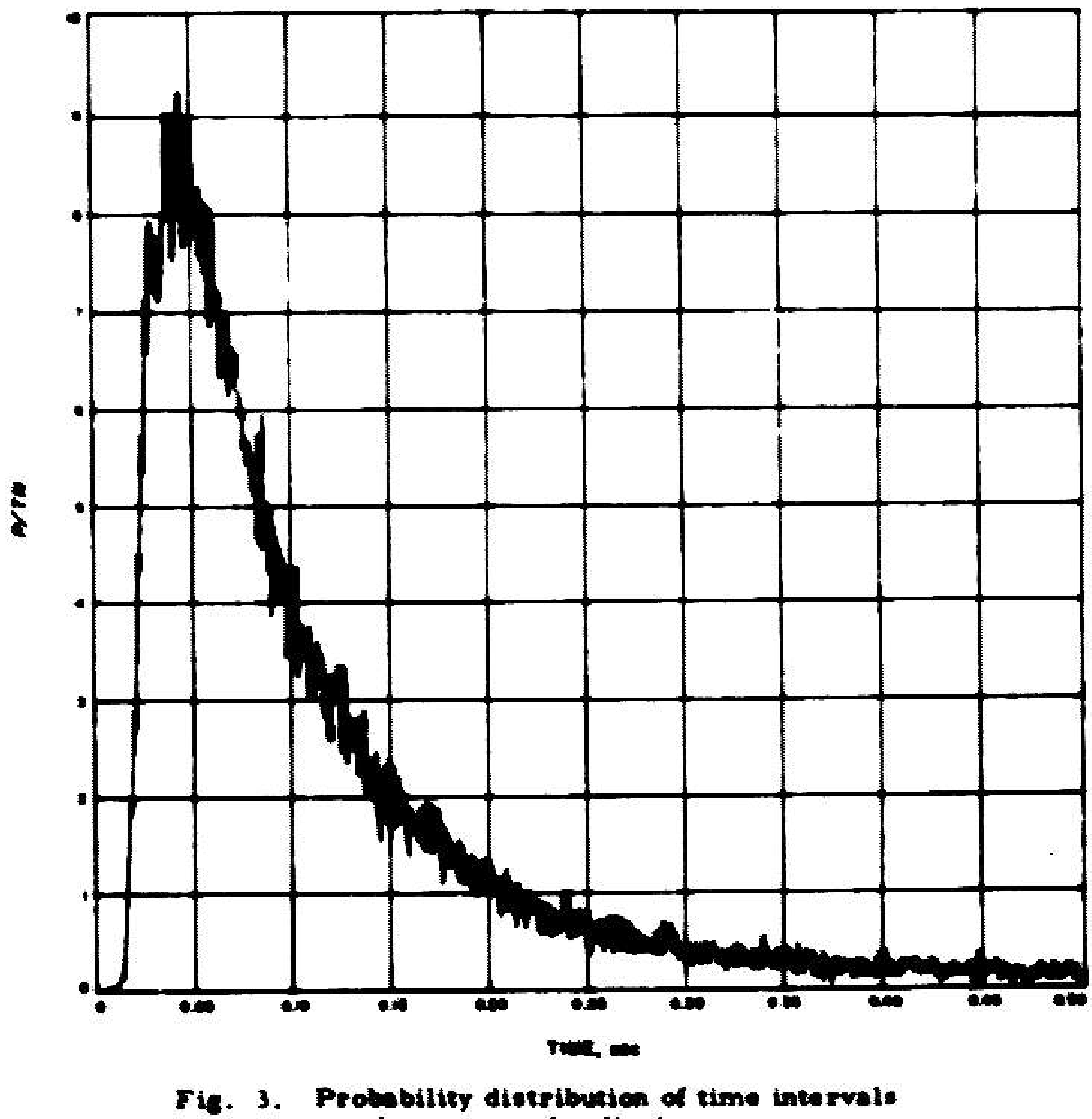


Fig. 3. Probability distribution of time intervals between cycle slipping

BLANK PAGE

CAPSULE TELEMETRY RELAY SYSTEM DEVELOPMENT
NASA WORK UNIT 186-68-04-04
JPL 384-61301-2-3341

No significant progress was made on this task until the third quarter of FY 1965, because of manpower limitations and more interest and activity on the direct link problems (NASA Work Unit 186-68-04-05). Since the third quarter, new emphasis has been given to relay link problems, and one engineer has spent approximately 40% of his time on this task.

GENERAL RELAY LINK STUDIES

In conjunction with studies pertaining to the advanced Voyager capsule missions, studies have been conducted on the general philosophy of relay link design given the constraints of transmitter power, antenna gains, acquisition times, etc. For the cases of spacecraft orbit or fly-by, the original work reported in JPL EPD 139, Vol. III still appears to be valid and should form the basis for future relay studies and design. The problem of communicating from a capsule during the planetary descent phase, after blackout and until impact occurs, appears to be quite formidable and further study is required before it can be determined if relay link techniques are applicable.

RELAY LINK MODULATION STUDIES

The majority of work to date has been for the design and analysis of coherent phase-modulated systems that use phase-locked-loop receivers aboard the spacecraft and some form of demodulation/detection before modulation of the spacecraft transmitter.

When a phase-lock-loop receiver is used in a relay link where the RF tracking bandwidth ($2B_{LO}$) is considerably less than the range of transmitter frequency uncertainty it is necessary to sweep the uncertainty range to attain carrier lock. As a result, it is mandatory to keep any sideband power, resulting from carrier modulation that may fall within the uncertainty range, at least 20 db down relative to the carrier to preclude false lock points. Because the uncertainty range is on the order of ±20 kc (relative to the nominal carrier frequency), subcarrier frequencies of 40 kc or greater must be used, requiring a very wide IF predetection bandwidth. This, in turn, complicates the RF receiver design because of large limiter suppression factors and/or phase detector thresholding, and could even require that the modulation be recovered before the final IF filter with a separate phase detector.

To alleviate these problems, the use of single-sideband angle modulation SSB/PM is being investigated; where the lower sideband is sufficiently suppressed to prevent false locks, and permitting sidebands relatively close to the carrier. Mathematically SSB/PM may be obtained from an equation of the form

$$y(t) = \exp\left[-\hat{X}(t)\right] \cos\left[\omega_c t + X(t)\right] \qquad (1)$$

or alternatively

$$y(t) = \exp\left[X(t)\right] \cos\left[\omega_o t + \hat{X}(t)\right] \qquad (2)$$

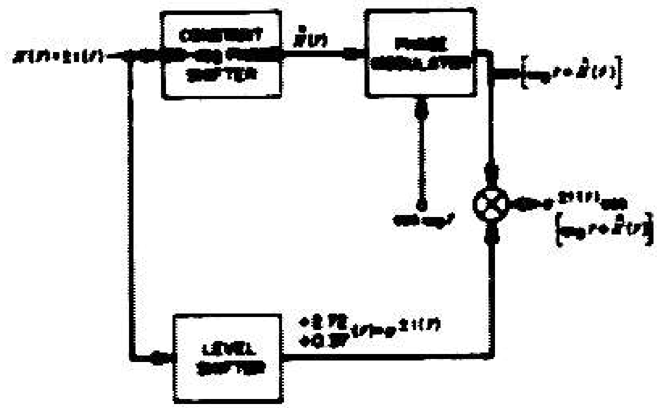


Fig. 1 Simplified SSB/PM system

where

$X(t)$ = the modulating signal

$\hat{X}(t)$ = its Hilbert transform.

When we deal with binary modulation, Eq (1) appears preferable from the standpoint of demodulation (phase demodulation after passing the signal through a limiter), while Eq (2) offers some simplification in amplitude modulation because exp [X(t)] is still binary. In any event, we are forced to obtain the Hilbert transform (or an approximation thereof) of the modulating signal. For binary modulation this might be satisfactorily done by shifting the waveform 1/2 bit in time and modifying its amplitude in some manner, or it may be possible to construct a constant 90 deg phase shift network over the frequency range of interest. In fact, if the modulation happened to be a square wave, a 90 deg shift of the waveform would be the exact Hilbert transform (because the Fourier cosine series representing the square wave would be shifted 90 deg) because $H\{\cos\omega t\} = \sin\omega t$. This, of course, is not true of the general Fourier series where $A_n \neq B_n \neq 0$; however, approximations of the nature already cited may be sufficient. Figure 1 shows a simplified block diagram of a modulator using Eq (2). Laboratory tests to further explore these processes are planned, and considerable emphasis will be given to the practicality of constructing such a system at RF.

SPACECRAFT DEMODULATION/DETECTION

Studies are in progress on the problems associated with spacecraft demodulation, detection, and synchronization. Double sideband PM or FM modulation would be recovered in the usual ways. If SSB/PM is used, the lower sideband must be restored before demodulation by a phase-coherent loop. This may be done by passing (at the IF frequency) the received carrier and upper sideband through a filter-limiter combination to remove the amplitude modulation.

After demodulation, the degree of detection performed may range from simply filtering and limiting the signal plus noise before modulation of the spacecraft transmitter (feedthrough system), to complete detection and synchronization systems that produce a binary output with some attendant bit error probability. Figure 2a shows the basic feedthrough approach and Fig. 2b the basic detection system.

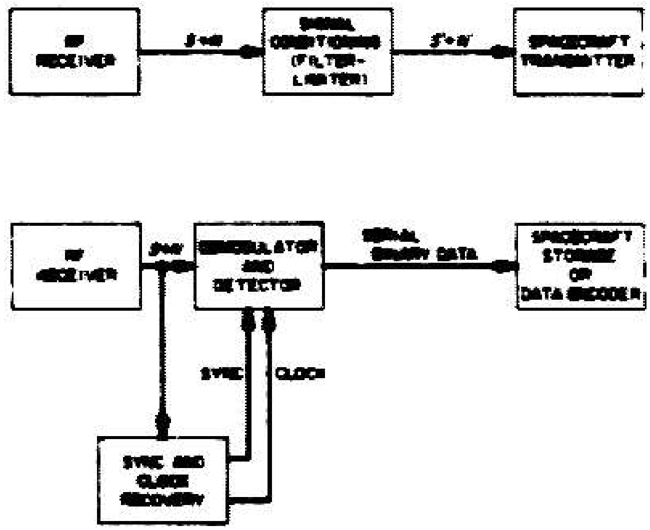


Fig. 2 Basic approaches
a) Feedthrough
b) Detection

The advantage of the feedthrough system is its simplicity, while the disadvantages are that: (1) the data rate, for a given bit error probability, is constrained by the link, capsule to spacecraft, or spacecraft to Earth (which thresholds first) and (2) a certain percentage of the available spacecraft transmitter power will be put into unwanted noise sidebands because of the noise modulation.

The advantages of the detection approaches are that: (1) the data rates on the capsule to spacecraft and spacecraft to Earth links do not have to be commensurate because buffer storage can be used, and (2) for a given signal-to-noise ratio at the output of the receiver, higher data rates may be obtained because of higher efficiency. The major disadvantages are those of complexity and the problems associated with sync and clock recovery.

It is planned to breadboard and test both feedthrough and detection systems in FY 1966.

LIMITER ANALYSIS

Filter-limiter combinations have been mentioned in conjunction with SSB/PM demodulation and feedthrough signal conditioning. Although limiters have been analysed many times in the past, a further understanding of the limiter problem is required; in particular, the signal-to-noise spectral density ratio $(S/N_0)_0$ at the first zone output of the limiter as a function of input signal-to-noise ratio (SNR). An analysis was made and is in the process of being published as a JPL internal Technical Summary, TS-3341-65-2, "Signal-to-Noise and Signal-to-Noise Spectral Density Ratios at the Output of Filter-Limiter Combinations."

The major results of the analysis are:

(1) $(S/N_c)_o$ as a function of $(S/N)_i$ was obtained (Fig. 3).

(2) It was proven that the total signal plus noise in any zone at the output remains constant independent of $(S/N)_i$.

(3) Using the results of item 2, the first zone $(S/N)_o$ was calculated and found to differ significantly from Davenport's[1] result over a rather wide range of input SNR (Fig. 3).

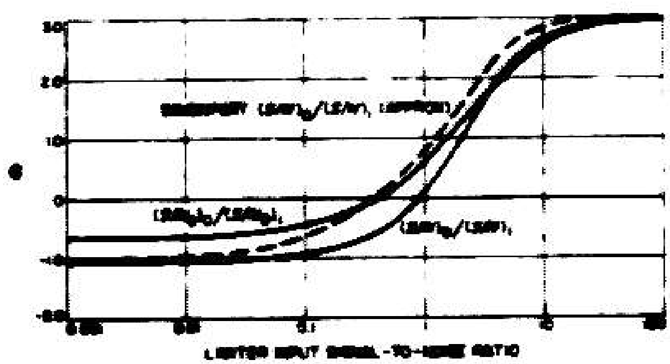


Fig. 3 First zone limiter

[1] W. B. Davenport, Jr., "Signal-to-Noise Ratios in Band-Pass Limiters," J. Appl. Phys. Vol. 24, No. 6, Jun. 1953

CAPSULE TELEMETRY DIRECT LINK DEVELOPMENT
NASA WORK UNIT 186-68-04-05
JPL 384-61401-2-3341

COHERENT 1 BPS DEMODULATOR

In the early part of the reporting period this task was transferred to the command task (186-68-04-10) to avoid duplication of effort and is consequently reported under that task.

DIRECT LINK NONCOHERENT TELEMETRY

Because the prime telemetry link from the early Voyager landed capsules will most likely be a direct capsule-to-Earth link, an investigation of the practical implementation of low bit rate noncoherent modulation/demodulation technique is necessary.

The major effort expended on this task during the reporting period has been directed towards a study of the more theoretical aspects of noncoherent detection systems to obtain a better understanding of the practical problems encountered in the design of these systems. Several well-known optimum implementations, i.e., configurations for which the error probability is a minimum, have been examined. In particular, a detection scheme that takes the form of a spectrum analyzer has been studied in detail. The practical realization of this system is best carried out by a digital computer. This necessarily involves sampling and quantization of the incoming signal and truncation of its autocorrelation function. Although several theoretical investigations of the harmful effects of these operations on the system performance have been made by various authors, the range of validity of their results has not been considered in enough detail. Consequently, an attempt is being made in the present study to obtain more realistic results than those now available. A technical memorandum summarizing this activity is in preparation.

The continuing effort under this task will be for a detailed study of the timing synchronization problem and the simulation of the entire system on a digital computer. This task is being transferred to OTDA (NASA Work Unit 150-22-05-12-55) in FY 1966.

BLANK PAGE

CAPSULE ANTENNA SYSTEMS STUDY
NASA Work Unit 186-68-04-06
JPL 384-61501-2-3360

SPINNING ORBITER CAPSULE ANTENNA STUDY

Objective

The objective of this study was to determine the best high gain antenna for a spinning orbiter type planetary capsule.

Summary

A high gain antenna that is compatible with a Sun-oriented, spin-stabilized capsule has been designed, and prototypes have been fabricated and tested. This in-house study was started in the second quarter of FY 1965 and completed in the third quarter of FY 1965. A final report was generated in the form of a personal memo. No further work is planned on this type capsule antenna implementation. The following is a description of the design requirements, the design evolution, and the test results.

Discussion

The design requirements for this particular implementation were that: (1) both type I and type II trajectories for a typical Mars mission be considered, (2) the minimum peak gain be greater than 10 db, (3) the peak of the beam be optimized in the cone 40 to 45 deg from the spin axis, and (4) the mechanization be highly reliable.

A prime decision made early in the study was to eliminate consideration of all types of implementations (phased and adaptive arrays and mechanically rotated devices) that require increased complexity, weight, and power if a simple mechanization, which meets the above requirements, was feasible.

The antenna that meets these requirements may be seen in photographic form in Fig. 1 and in graphical form in Fig. 2 where f is the focal point of a parabola a c b whose axis is rotated at an angle α to the axis of rotation to form a surface of revolution of two parts a' c a and b c b'.

Now, if the section of the surface a' c a is eliminated and the axis of rotation is considered colinear with the spin axis of the capsule, a single surface of revolution b c b' exists that will focus energy radiated from the focus into a conical beam whose axis is at an angle α to the spin axis.

The gain and beamwidth of the antenna may be calculated from the following relation:

$$G_p = \frac{k}{\theta_1 \theta_2}$$

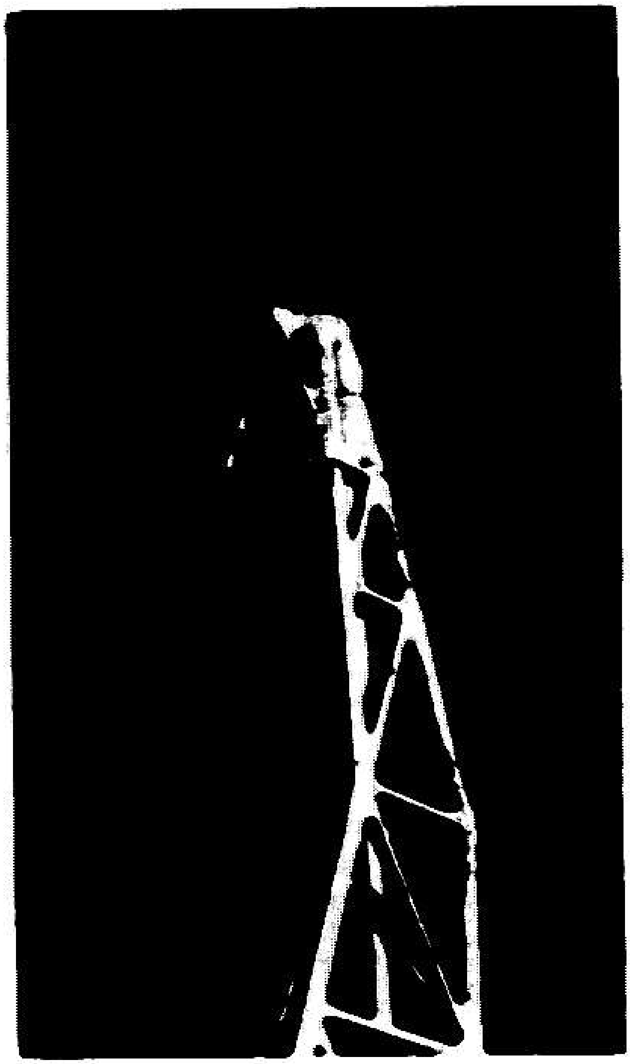


Fig. 1. Conical beam high gain antenna

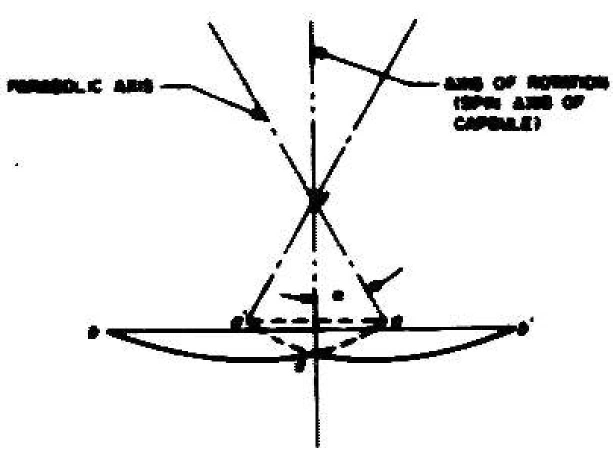


Fig. 2. Surface revolution of two parts

where G_p = power gain

k = an empirical constant

= 31,500 deg^2

θ_1 = full 3 db beamwidth in the cone plane, deg

θ_2 = 360 deg sin α that is beam position in the cone plane, deg

hence

$$G_p = \frac{31,500 \text{ deg}^2}{\theta_1 \times 360 \text{ deg} \sin \alpha}$$

For the antenna selected, which meets the look angle requirements for a Mars 1969 mission, θ_1 = 12.2 deg and α = 41.5 deg, hence the peak power gain

$$G_p = \frac{31,500 \text{ deg}^2}{12.2 \text{ deg} \times 360 \text{ deg} \sin 41.5 \text{ deg}}$$

$$G_p = 10.82$$

$$G = 10.34 \text{ db}$$

The above parameters were obtained empirically from design curves generated from measured data of prototype antennas of the same diameter, 65 in., but different α's, 39.5 and 45 deg. Hence, the scaling is very minor and there is a high confidence that the predicted performance parameters could be met.

Figure 3 shows a typical 360 deg cone-cut radiation pattern of the α = 39.5 deg antenna. The solid line is right-hand circular polarization, while the dashed curve shows the left-hand circular polarization.

Figure 1 shows that the reflector surface was constructed by joining two conical surfaces with a flat plate. Because the total depth of the reflector is only 3 in., it is practical to construct the reflector in this manner without deviating from the true parabolic curve by more than 0.3 in. This deviation represents a phase error of less than $\lambda/16$ and, hence, has a very small effect on gain or the peak of the beam radiation pattern.

HIGH-IMPACT SURVIVABLE LOW GAIN ANTENNA STUDY

Objective

The objective of this study is to obtain design information for the construction of low-gain capsule antennas with certain electrical characteristics

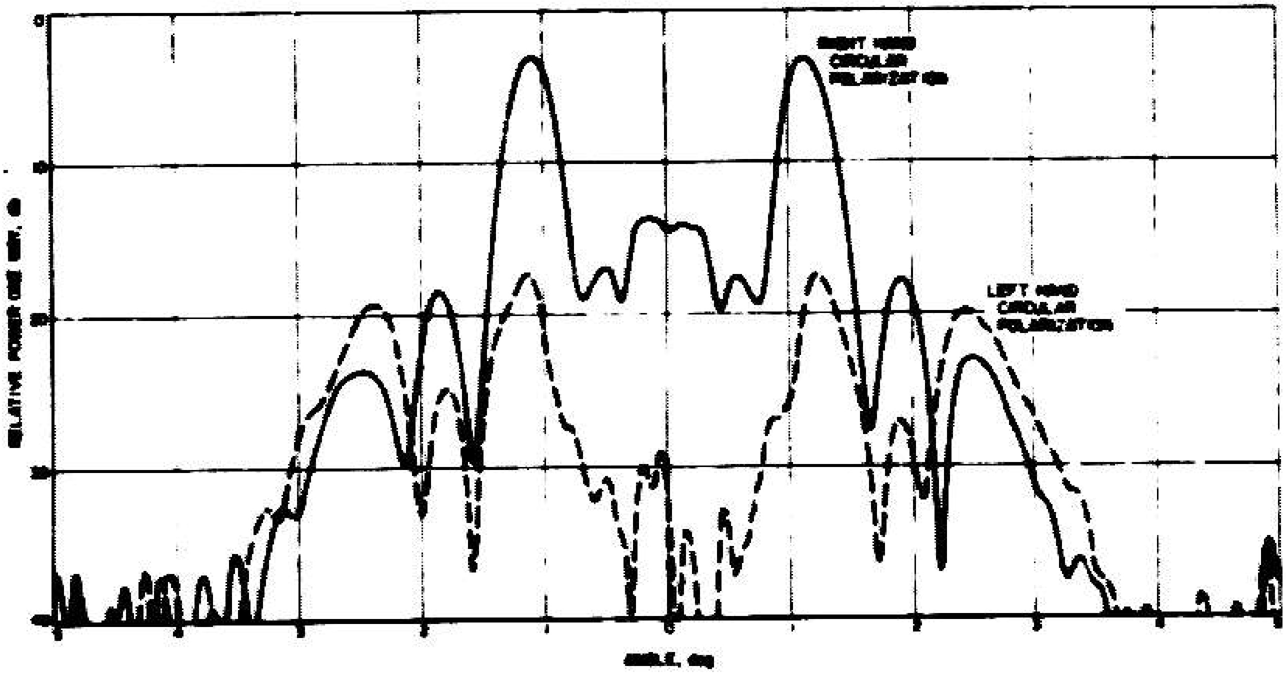


Fig. 3. 360 deg cone cut radiation pattern of θ = 39.5 deg. 65 in. diameter conical beam high gain antenna

that are capable of surviving the extremely high-impact loads predicted for the early planetary landed capsules.

Summary

A survey to determine the possible high-impact survivable types of low-gain antennas was conducted. Two types were chosen during the fourth quarter for further study. High-impact tests have been conducted on the split balun, cupped turnstile. Drawings for a ruggedized version have been completed and a second generation unit is being fabricated. Drawings for the second type chosen, an annular slot antenna, are in process. This study is continuing in FY 1966 with an out-of-house contract for approximately $50,000 to be let in the first quarter. Specifically the object of this contract is to produce design data for high-impact survivable low-gain antennas with specific electrical characteristics and to prove feasibility by actual tests on a series of prototype models. Duration of this contract shall be about 6 mo.

Discussion

To obtain preliminary design data for the ruggedized cupped turnstile, a *Mariner C* flight-type turnstile was high-impact tested. The tests were conducted on JPL's "sling shot" test facility. The antenna element survived two 3000 g shocks without any visible damage. These shocks were oriented along and orthogonal to the center column support. When the antenna was similarly shocked at 6000 g, no discernible affect was noted when shocked in the direction along the center column.

However, when shocked orthogonal to the center column at 6000 g, a small but permanent distortion of the center column occurred. Figure 4a shows the center column deformation. Figure 4b is a view at 45 deg of Fig. 4a. Electrically, this damage would have degraded performance by producing an asymmetric beam; yet, it would not have been catastrophic.

HIGH-IMPACT SURVIVABLE TRANSMISSION LINE HARDWARE

An out-of-house contract is scheduled to be let for a study and development contract to produce high-impact surviving transmission line components in the third quarter of FY 1966. The major effort here is to develop a coaxial switch capable of surviving high-impact and long term hard vacuum environment.

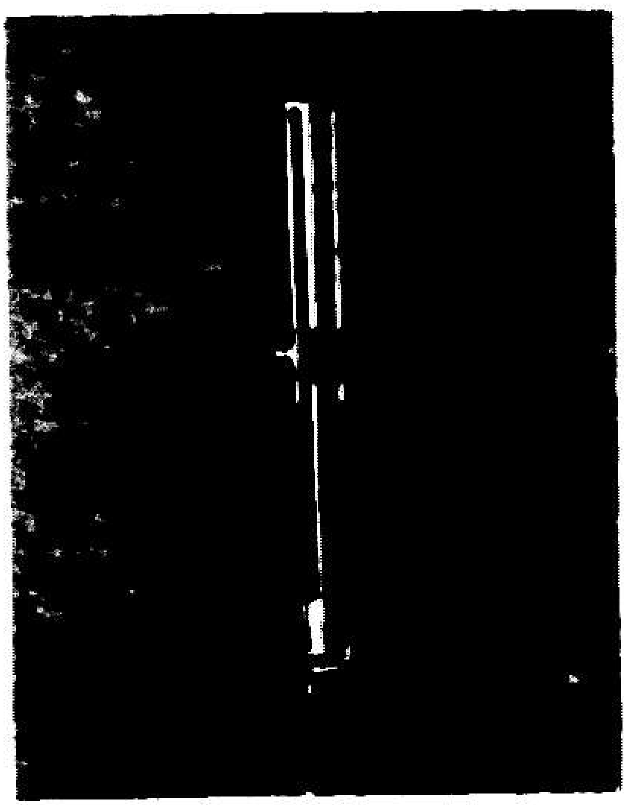


Fig. 4a. High impact tested turnstile antenna (regular view)

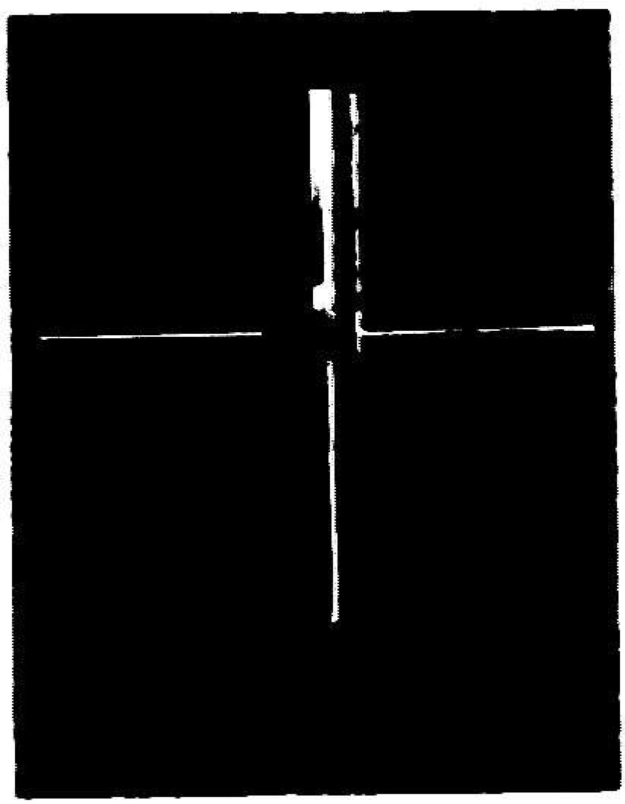


Fig. 4b. High impact tested turnstile antenna (viewed at 45 deg)

BLANK PAGE

CAPSULE DIRECT RADIO FREQUENCY SYSTEMS
NASA Work Unit 186-68-04-07
JPL 384-63001-2-3364

DEVELOPMENT CONTRACTS

An isolator is required to prevent instabilities in S-band solid state transmitters because of output impedence mismatch. The capsule environmental requirements, namely 10,000 g shock and high temperature sterilization (+145°C), pose a severe problem to magnetic materials such as those used in an isolator. Procurement for a high-impact, sterilizable isolator is in progress. The work statement is being finalized and RFQs will go out in July. The three phase contract will be divided into: (1) study effects of shock and heat on ferrites, permanent magnets, and magnetic shields; (2) develop materials and techniques to build an isolator; and (3) build a prototype. Funding in FY 1965 is $15,000 for Phase I. Funding for later phases will be in FY 1966.

TRAVELING-WAVE TUBE, 20W, STERILIZABLE, HIGH IMPACT, INTEGRAL AMPLIFIER

Requests for proposals for this development contract are being completed. Funding is (from FY 1965) $31,000 from Power Amplifier (NASA Work Unit 186-68-04-09), $53,000 from Capsule Direct RF Systems (NASA Work Unit 186-68-04-07), and $111,000 from Voyager (NASA Work Unit 818-01-07-01-02). This distribution is consistent with the charter of these three work units and the applicability of the amplifier to a Voyager capsule mission. This amplifier will contain the traveling-wave tube, power converter, and RF filter and will be designed to operate from a hard landed, sterilized capsule before and after impact.

SOLID STATE S-BAND TRANSMITTERS

A Conic 3 w solid-state S-band transmitter has been purchased ($9000) for evaluation. Similar units made by Monitor and STL will be available (Voyager procurements, NASA Work Unit 818-01-04-01-02) in August. Evaluation of these devices will aid us in our in-house developments, determine their applicability for future NASA programs, and advance our knowledge of vendors who may be selected to build prototype transmitters.

The solid-state 3 w S-band in-house development is about 50% completed. The VHF portion, which has a 20 w output at 191 Mc and is suitable for the capsule relay transmitter (see NASA Work Unit 186-68-04-08), has passed the 8200 g shock test in three planes and two planes of 10,000 g, 0.5 msec shock. The unit failed the third plane at 10,000 g because of a faulty power transistor mounting scheme. The high impact work is heavily supported by NASA Work Unit 186-68-10-01, High Impact Electrical Technology. The initial design of the high frequency varactor multiplier is about 50% complete. Previously available varactors were inadequate for power dissipation at the required frequencies and power levels. The latest varactors are on order for high power level and high impact evaluation. Also, lumped constant and coaxial cavity multipliers are being designed to contain two lower power varactors. The first results indicate reliable power dissipation levels are achieved. A 3-db loss is observed, however, while the single diode (lower power) multiplier exhibits a 2-db loss. A ruggedized strip line resonator is being examined as a possible means of improving efficiency. It is expected that the transmitter design will be completed and ready for a contract for a prototype in late FY 1966.

Two solid-state 1/2 w S-band transmitters are on life test at 55°C and atmospheric pressure. After 12,500 hr, neither unit shows a measurable change in output power.

S-BAND CAVITY AMPLIFIERS

An in-house development of 20 to 100 w cavity amplifiers was initiated during this period. These amplifiers are being designed for high efficiency, moderate life (1 to 2 mo), and medium impact capability (up to 1000 g). Five Siemans 2C39BA and five Eimac X483G triodes are on order ($6,800). Radial and 1/4 and 3/4 wave length coaxial cavities are being explored.

JPL Technical Memorandum No. 33-243, Vol. I

CAPSULE RELAY RADIO FREQUENCY SYSTEM
NASA Work Unit 186-68-04-08
JPL 384-63101-2-3364

CAPSULE TRANSMITTER

Previous studies conducted at JPL indicated that the best frequency for a capsule-spacecraft relay link was the region in the VHF band between 200 and 400 Mc. An engineering model of a solid-state transmitter with 20 w output at 190 to 220 Mc which is suitable for the VHF portion of the 3 watt S-band capsule direct transmitter (see NASA Work Unit 186-68-04-07), has passed 8200 g shock in three planes and two planes at 10,000 g, 0.5 msec shock. The unit failed the third plane at 10,000 g because of a faulty power transistor mounting scheme. The engineering model of the 190- to 220-Mc transmitter is scheduled for completion in September.

A relay frequency allocation is being requested. Should the frequency be 400 Mc, two approaches will be tried in parallel to determine which has the greater reliability and efficiency. One approach will be the addition of a doubler to the present 200-Mc transmitter. The alternate approach will be to generate 400 Mc at a lower power level and amplifier at 400 Mc to 15 w. Funds for the 400-Mc development are not now available. The high-impact work is heavily supported by NASA Work Unit 186-68-10-01, High-Impack Electrical Technology.

SPACECRAFT RECEIVER

A breadboard 200-Mc automatic acquisition phase lock loop receiver was completed in the first half of FY 1965. During the second half of FY 1965, this receiver has been modified to accommodate larger ranges of loop noise bandwidth (50 to 800 cps) loop gains (5×10^4 to 1.5×10^6 1/5 sec) and sweep rates (10 to 200,000 cps). Within these ranges, the experimental determination of acquisition probability is consistent with results of the GE study reported in IRE, SET-8; September, 1962; No. 3; p. 210.

Approximately 80% of the breadboard 200 Mc relay receiver is composed of slightly modified Mariner transponder circuitry. Development of the final 200 Mc receiver is about 60% complete, with an estimated date of completion of June 1966. Additional work is needed in the trigger and sweep circuitry and on a high gain VCO using a fundamental crystal.

Should a 400 Mc relay frequency become a requirement, approximately 60% of the spacecraft receiver will be composed of slightly modified Mariner transponder circuitry. A new RF amplifier and local oscillator multiplier chain will have to be built and the sweep range will have to be doubled over the present sweep range for the 200 Mc receiver.

BLANK PAGE

RADIO FREQUENCY POWER AMPLIFIER DEVELOPMENT
NASA Work Unit 186-68-04-09
JPL Task 384-63401-2-3364

DEVELOPMENT CONTRACTS

ESFA (20 to 100 and 100 to 500 w) Contract No. 951105

This contract was opened to six bidders. Only two responded because of the very difficult task requested (electrostatic focusing, heat radiation, and wide bandwidth presenting the major problems). Eitel McCullough was selected for their superior proposal and the four part contract was signed May 10, 1965. The four parts are:

1. Development of a 20 to 100 w tube.
2. Production of five 20 to 100 w tubes for life test.
3. Development of a 100 to 500 w tube.
4. Production of five 100 to 500 w tubes for life test.

Part 1 was funded from carryover FY 1964 OTDA (311-03-53-52) money ($206,000). Theoretical and experimental studies have begun on the focusing, electron gun, resonators, and power variability. Testing of tube hardware will begin in the next few weeks.

Part 3 (100 to 500 w development) will be started in FY 1966 from NASA Work Unit 186-68-04-15 money ($100,000 sufficient for only partial funding) provided sufficient progress is made in part 1.

Traveling-Wave Tube, 100 and 50 W (Contract Pending)

Nine vendors were requested to bid on this four phase development. Seven replied and a bidders conference was held on June 22, 1965. One contractor will be selected and the first phase will begin in September. Present funding (this work unit, $180,000) covers only the first phase of this effort. The four contract phases are:

1. Development of 100 w tube.
2. Production of five 100 w tubes for life test.
3. Development of a 50 w tube and.
4. Production of five 50 w tubes for life test.

Because it is easier to scale a tube down in power rather than up, the 100 w development will be started first. It is desired that the 50 w design require only slight modifications to the 100 w design.

Traveling-Wave Tube, 20 W, Sterilizable, High Impact, Integral Amplifier

Requests for proposals for this integral amplifier have been sent to 10 companies. Funding is (from FY 1965) $31,000 from Power Amplifier (NASA Work Unit 186-68-04-09), $53,000 from Capsule Direct RF Systems (NASA Work Unit 186-68-04-07), and $111,000 from Voyager (NASA Work Unit 818-01-07-01-02). This distribution is consistent with the charters of these three work units and the applicability of the amplifier to a Voyager capsule mission. This amplifier will contain the TWT, power converter, and RF filters and will be designed to operate from a hard landing, sterilized capsule before and after input.

AMPLIFIER EVALUATION

Test Equipment

All components (power supplies, generators, power monitors, RF hardware, etc.) have been purchased ($40,000) for an RF test set that will handle S-band tubes with over 500 w output. This test set will be used for evaluating the tubes produced during the tube development phases and the tubes produced for life test. The test set will be assembled in-house.

During FY 1966, the RF and dc support equipment for the life testing of the tubes produced on the development contracts will be designed and built.

Hardware Evaluation

A Litton 20 w E-FK ($11,800) and a Hughes 20 w TWT ($5,800) have been ordered. Three Watkins Johnson 20 w TWTs and power supplies have been ordered on Voyager (NASA Work Unit 818-01-04-01-02) money ($69,000). The evaluation of these amplifiers will serve two main purposes:

1. To advance our knowledge thus improving our capability both for in-house development and in directing the outside development contracts now underway.

2. To determine each amplifier's applicability to future NASA programs.

Raytheon is preparing a quote for five 22 w amplitrons and three solid-state power supplies. The lifetime and reproducibility of the amplitrons are the major interests in this evaluation. The funding will be primarily from the $67,000 remaining in the amplitron contract (OTDA funds from FY 1963, NASA Work Unit 311-03-53-52).

Life Tests

The status of life tests initiated during FY 1964 follows:

1. Three Siemens RH7C-C triodes (type used in MA-C) in cavity amplifiers with 10,000 hr on each. Two have dropped approximately 3 db and the other about 7 db in output.

2. Three Siemens V-251 triodes in cavity amplifiers each with about 9000 hr. Average decrease in power output is 2 db.

The status of life tests initiated during FY 1965 follows:

1. Two Siemens RH7C-C cavity amplifiers with flight power supplies have dropped 1.4 db in output after 2700 hr.

2. Two Machlett EE10P triodes have dropped 0.7 db after 2000 hr.

3. Two 10 w TWTs (Hughes 216H, MA-C type) with flight power supplies show no measurable drop in power output after 3500 hr.

MSC/LEM AMPLITRON CONFERENCE

L. J. Derr, JPL engineer, attended an LEM Amplitron Conference at MSC January 11, 1965 at the request of C. Riddick. The status of the amplitron was discussed and it appeared that many of the problems with which JPL is familiar still remain. JPL recommended a Watkins Johnson 20 w TWT as a backup amplifier.

BLANK PAGE

ADVANCED SPACECRAFT COMMAND SYSTEM DEVELOPMENT
NASA Work Unit 186-68-04-10
JPL 384-62201-2-3341

SINGLE-CHANNEL COMMAND DETECTOR

The development of a 1 bit/sec single-channel command detector was started in FY 1963, the prime motivation being a predicted 6 db performance increase over that obtainable with the Mariner R and Mariner C two channel detectors. After the delivery of a breadboard and flight prototype to JPL in 1964, a series of tests were begun to assess system performance. As reported in previous quarterly summaries it was found that:

1. A strong extraneous signal component was being generated in the sync loop because of correlated inputs to the cross-multiplier.

2. The phase-locked loop error signal was more nonlinear than had been anticipated.

3. The bandwidth of the filters preceeding the cross-multiplier was approximately 3 cycles wider than had been originally specified.

The cause of the extraneous signal component was analyzed and reported in JPL internal technical memorandum No. 3341-65-9, "Single-Channel Cross-Multiplier Spectrum Due to Input Noise." Effects of the error signal nonlinearities were minimized by changing the input signal to the detector to PN ⊕ $2f_s$ rather than PN ⊕ $f_s \times f_s \angle 90$ deg. In addition, the filter bandwidths were narrowed to conform to specifications.

After making the necessary design modifications, tests were performed during the third quarter of FY 1965. The results showed that nearly satisfactory bit error performance could be obtained for a detector input S/N_0 of 15.5 db. However, when acquisition tests were performed it was discovered that the acquisition properties were inadequate. Further investigations showed that to achieve satisfactory acquisition properties, the bandwidth of the loop must be increased to the point where comparable performance to the two-channel detectors resulted in a net system improvement of approximately 1 db. It became apparent, that to obtain good acquisition properties and still meet the desired threshold improvement, some form of adaptable loop bandwidth would have to be used.

As a result of the above difficulties, and the growing awareness of the desirability of an automatic acquisition system, work was ceased on further development of the 1 bit/sec single channel detector during the third quarter.

THREE BIT/SEC AUTOMATIC ACQUISITION

The 3-bit/sec automatic acquisition detector (followon development to the single channel detector development) is a coherent PSK deep space command detector intended to provide better communication performance than the Mariner C command detector. The primary reasons for investigating this system are to achieve improved communications efficiency, greater confidence in the acquisition process, and decreased acquisition time. The 3-bit/sec direct link coherent telemetry development (NASA Work Unit 186-68-04-05) has been integrated with this task because of the essential similarity in the techniques required to execute both the telemetry and command functions. The functional requirements of the detector are:

1. Data rate = 3 bits/sec.
2. Probability of bit error = 10^{-5}.
3. Threshold input signal-to-noise spectral density = 16.5 db cps.
4. Probability of acquisition at first trial ≥ 0.95.
5. Acquisition time normally less than 50 sec.
6. Complexity commensurate with that of the Mariner C command detector.

The basic block diagram of the system is given in Fig. 1. This diagram may be separated into two parts:

1. Clock phase acquisition.
2. Code phase acquisition and data detection.

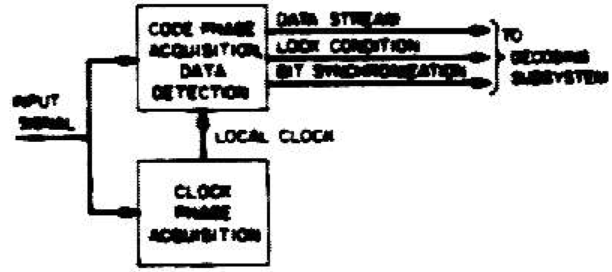
The purpose of the clock phase acquisition block is to reconstruct a local receiver model of the basic system clock. Two methods are being considered to execute this function. The first involves square law detection of the input signal to isolate a clock frequency component and then locking to this component with a phase locked loop (PLL). The second involves directly locking a PLL to a CW clock frequency present in the input signal. The first method enables the sync and data information to be extracted from the same signal (thus conserving power) while the second requires that the sync and data information be transmitted as separate signals (summed). In either case, the PLL noise bandwidth may be quite small (1/4 cps) so that the clock tracking performance is good compared with a Mariner detector (noise bandwidth = 2 cps).

The purpose of the code phase acquisition and data detection block is to acquire synchronization of the phases of the local and received pseudo noise (PN) codes and, once having acquired synchronization, to decide whether the later transmitted data bits are one or zero. Again two possible techniques are being considered for the detection of PN sync.

1. Maximum likelihood detection.
2. Threshold detection.

With maximum likelihood detection, the correlation of each possible phase of the PN codes is examined before deciding the correct phase. With threshold detection, the correlation of the PN codes is compared with a preselected threshold. The maximum likelihood technique provides a higher probability of correct acquisition, but requires greater mechanization complexity.

Fig. 1. Basic automatic acquisition detector block diagram



The functional behavior for the detector specified above has been verified experimentally with a detector configuration using a clock acquisition scheme that locks directly to the transmitted CW clock and threshold detection for the PN code acquisition. The experimental configuration consisted of a modulator, signal-noise mixer, and the detector, and thus involved no conversion to S-band. Tests are now in progress to verify the detector performance in the flight configuration with the modulator detector mated to an actual Mariner C transponder S-band receiver and DSIF equivalent transmitter.

Planned future activities include completion of receiver interface testing, investigation of the other detector configurations mentioned above, and documentation of the final test results and analysis so that this automatic acquisition system may be released to the Voyager project.

CVE AND DSN GROUND COMMAND

The procurement of a prototype command verification equipment (CVE) was initiated during the first half of FY 1965 but was halted until the completion of the design of the DSN standard ground digital logic family. Meanwhile, an in-house team design effort (the DSN Monitoring A Team) was begun with the objective of evolving a plan for the development of the DSIF digital data system and the DSIF station monitoring system valid through the period of FY 1967. This team effort was supported by the SR&AD group.

The results of the DSN Monitoring A Team effort are documented in the Data System Development Plan (DSDP) to be published July 1, 1965. These results indicate a Scientific Data Systems (SDS) 900 series type computer will be used to satisfy the requirements of mission independent telemetry and command functions. Simultaneously with the monitoring effort, the Voyager project command group has obtained an SDS 920 computer that will be used to gain experience in computerized ground command techniques and to develop a prototype Voyager ground command system. Therefore, the need for a CVE procurement has abated, and the CVE will no longer appear as a prime objective in this task. SR&AD surveillance of the computerized ground command area will continue on a consulting basis.

BLANK PAGE

ADVANCED SPACECRAFT TELECOMMUNICATIONS SYSTEM
NASA Work Unit 186-68-04-11
JPL 384-63201-2-3360

The primary objective of this work unit is to bridge the Advanced Mission Studies and Telecommunications Advanced Development work units by coordinating their technical aspects and organizing new efforts. This objective was not fully realized during the second half of FY 1965 because of manpower shifts to higher priority projects resulting in curtailed in-house activity. However, effort was maintained to carry activities in process to a logical suspension, monitor a reliability contract, redefine the work unit for greater clarification, plan future activities, and organize new activities. (See Fig. 1a.)

SUSPENSION OF ACTIVITIES IN PROCESS

A low bit rate telemetry system has been proposed as part of this work unit during the first half of the fiscal year for use in a high impact Mars lander mission. Analysis of this problem was under way at the time of the reduction of manpower, but minor effort and documentation in the form of notes continued until a convenient point was reached to suspend analysis for future continuation with minimum loss of effort.

RELIABILITY CONTRACT

Part of the available manpower was expended in monitoring a contract for reliability analysis with Tam Research Associates, Pasadena, California.

Two internal reports concerning FY 1965 effort were issued during the second half of the fiscal year.

The first report, "A Study on the Uncertainty of Reliability Predictions," is concerned with the uncertainty associated with reliability estimates that frequently arise in the process of obtaining improvement in reliability by various means such as redundancy, dormancy, system synthesis, simplicity, and selection. It is not unusual for these studies to show differential changes of reliability in the second and third decimal place and criticism invaribly centers on the knowledge or lack of knowledge of the parameters and on the methods of analysis. An attempt to clarify this difficulty is made by associating probabilities to the values for the reliability parameters (mean time before failure). This results in a probability function on the predicted reliability for various improvement techniques. By this method, a measure of significance can be attached to improvements by competing systems.

The second report, "Reliability Improvement and Added Economic Burdens," basically discusses the problem of allocations of money, weight, power, and manpower as a function of the various means of reliability improvements.

REDEFINITION OF THE WORK UNIT

A redefinition of this work unit was made for greater clarity. The new definition makes this work unit the center of the spacecraft telecommunications advanced development effort by bridging the gap between the Advanced Mission

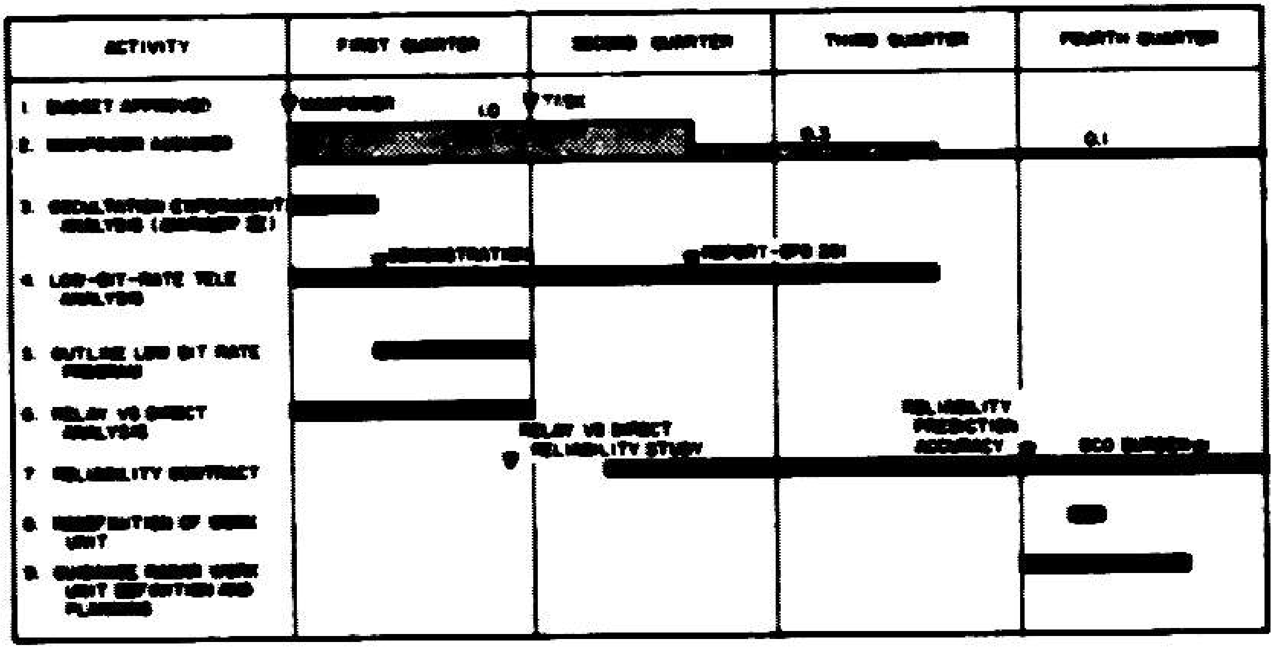


Fig. 1a. Advanced spacecraft telecommunications system activities FY 1965

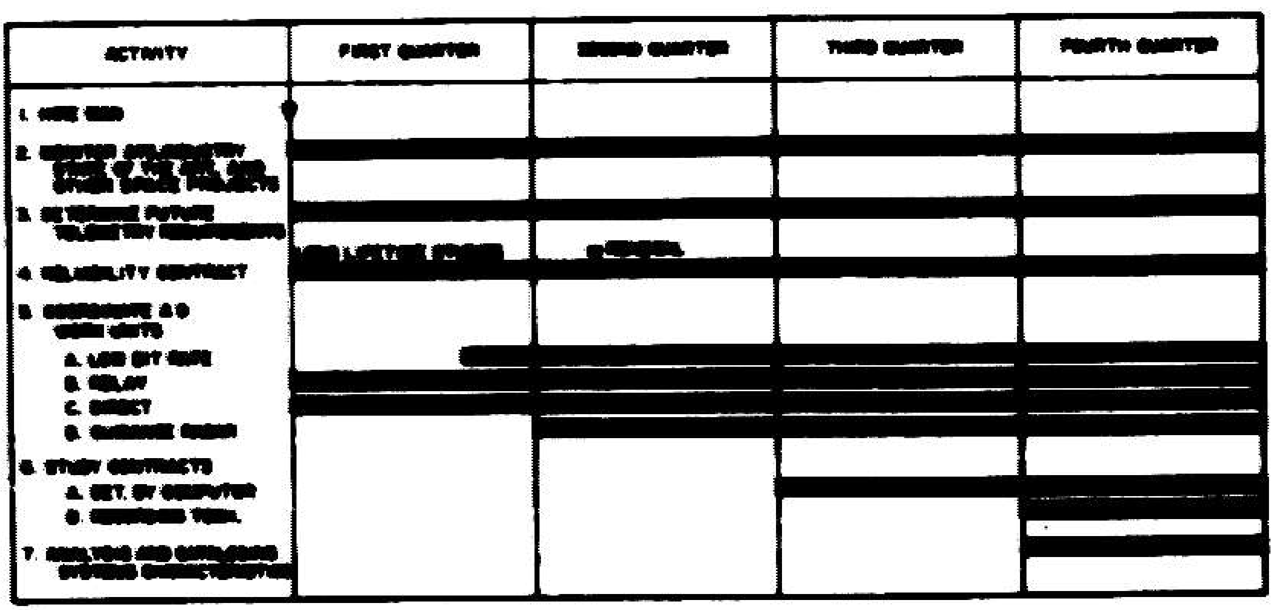


Fig. 1b. Advanced spacecraft telecommunications system activities FY 1966

Studies and the various telecommunications Advanced Development work units. This not only coordinates the existing work units but plans and organizes new work units as the need arises.

ORGANIZING AND PLANNING OF NEW WORK UNITS

Under the redefinition of this work unit, new work units are to be organized and planned as needed. Analysis of the various Advanced Mission Studies has shown the need for a new work unit in the area of Spacecraft Guidance Radars. A new work unit was organized and planned during the second half of this fiscal year and is described under Research and Technical Resume, NASA Form 1122, NASA Work Unit 186-68-02-14-55, JPL 384-61001-2-3360. This work unit will become active in FY 1966.

Future Plans

Full activities to be resumed during FY 1966 are summarized in Fig. 1b. The greatest concentration of effort will be on items 4, 5, and 6 that are most urgently required for the *Voyager* Project.

BLANK PAGE

JPL Technical Memorandum No. 33-243, Vol. I

APPLICATIONS OF COMPUTER TECHNIQUES TO WORST-CASE CIRCUIT DESIGN
NASA Work Unit 186-68-04-12
JPL 384-65001-2-3341

ADVANCED DEVELOPMENT

The advanced development phase of this task will be terminated at the end of FY 1965. This is primarily because the degree to which these computer techniques have been developed indicate that a continued development effort at this time on the remaining subtle problems will only yield diminishing returns. Nevertheless, continuation of the application of worst-case circuit design techniques to space programs in FY 1966 is planned under the Voyager Program, in agreement with the original task outline suggested to the NASA JPL Office of Research and Advanced Development.

CIRCS LINEAR CIRCUIT ANALYSIS PROGRAM

The CIRCS Program is a linear circuit analysis program that is now fully operational on the IBM 1620 computer (20K version with 1311 Disk Storage Drive). During the reporting period, the AC and TRANSIENT portions of this program were successfully used by JPL Division 34 for improving the design of several circuits contained in the Mariner C Canopus Sensor. A user's manual for this program is available as an internal JPL Section Report titled, A Linear Circuit Analysis Program For The IBM 1620/1311, 20K Data Processing System (CIRCS), May 1964, by J. N. Hatfield, Section Report 317-1.

TAG NONLINEAR CIRCUIT ANALYSIS PROGRAM

The TAG program is a general nonlinear circuit analysis program that is now fully operational on the IBM 7090/7094 computer. A rough draft copy of the revised user's manual for the TAG Program has been prepared and is now available for reference. This preliminary manual contains user instructions and the results from several typical transient analysis problems.

During the reporting period, a major attempt was made to incorporate (into the TAG program) a piecewise linear transistor model whose parameter values are relatively easy to obtain or estimate. However, while testing this scheme, an anomaly became apparent. It was basically a result of numerical round-off and was experienced only on very large problems (24 nodes) in which the emitters of the transistor model were not connected to ground. Although further investigation of this anomaly continues, the results to date are still negative.

The main problem occurs within one of the computer subroutines when the analysis of large circuit problems is attempted. Although the piecewise linear modeling procedure works well on small circuit problems, it will not be very useful as such. It was primarily intended for use in the analysis of complex feedback transistor circuits with response time constants orders of magnitude greater than the smallest time constant in the circuit. A failure to find a satisfactory solution to the anomaly will in no way jeopardize the basic utility of the TAG program. A satisfactory solution, however, would definitely improve it.

Also, during the reporting period, the TAG program was modified to decrease the compilation time by a factor of four. Now, a typically large problem of 20 nodes and 50 or 60 branches requires only about 6 to 8 min of 7094 time for compilation.

TAG is now being used by a contractor to perform a worst-case analysis on a family of digital circuits designed in JPL Division 32. In the course of their analysis, the contractor has made several improvements in the TAG program. The analysis is still in progress, and the results to date are very satisfactory.

TRACKING ANTENNAS FOR SPACECRAFT (ADVANCED STUDIES)

NASA Work Unit 186-68-04-13
JPL 384-65101-2-3362

ANALYTICAL STUDY

The start of the Tracking Antenna Study program was slightly delayed because of an earlier commitment to another program. This report covers work done during the last quarter of FY 1965 with a 50% man-hour work load.

The first task started was a study to determine which of the two most common monopulse sensing techniques (amplitude-sensing and phase-sensing) would be most feasible for spaceflight operations. It was determined from this study that phase-sensing would be most inferior for spacecraft operations compared to amplitude-sensing. The selection of amplitude-sensing over phase-sensing was because phase-sensing requires two or more apertures spaced several wavelengths apart, and it is very difficult to compensate for any off-axis boresight shifts and reductions in difference pattern null depths. However, amplitude-sensing requires only one aperture and the system is such that any errors in off-axis boresight shifts or reductions in the null depth can easily be compensated for.

Using the amplitude-sensing system as the desired goal, an investigation was carried out to determine the criteria that the tracking antenna should meet. The criteria was determined by computing the secondary error beam squint angles that are a function of focus and the aperture illumination. Group patterns of two point sources were computed on a computer for various phase spacings. The results of these computations will also be used to determine ideal antenna patterns that will assist in making predictions of various pattern shapes without having to go through laborious and time consuming range measurements. The computations will also be used for determining the mutual coupling between the various elements in the array.

After establishing the criteria of the system, an analytical study was carried out on the factors that may degrade the ideal conditions. Most of the factors were found to be caused by precomparator phase shifts and voltage unbalances. The mathematical details of this particular phase are beyond the scope of this report.

FUTURE ACTIVITIES

Because of a lack of manpower and funding for the next fiscal year (FY 1966), the Tracking Antenna Study has been postponed until FY 1967. The postponement came at a time when actual physical models were about to go into the experimental stage.

BLANK PAGE

NEW CIRCUIT DEVELOPMENT
NASA Work Unit 186-68-06-04
JPL 384-63301-2-3220

The new circuit development account has been used primarily for the development of automatic range switching electrometers. These electrometers have potential application in gas chromatographs, mass spectrometers, solar plasma analyzers, and other low current measuring instruments requiring long term stability.

An electrometer using an electrostatically driven dynamic capacitor was developed, tested, and later substituted for an earlier electrometer in a gas chromatograph breadboard. In addition, an automatic resonance tracking oscillator was developed to drive the dynamic capacitor. The capacitor, which had been developed and reported earlier under this account, provides the capability of measuring currents as low as 10^{-15} amp.

Concurrent with the effort on the dynamic capacitor electrometer, an extensive evaluation of the new metal oxide silicon (MOS) transistors was started to determine their suitability for use in high quality flight electrometers. As a result of these investigations, an electrometer was developed using one of the MOS transistors. The advantages offered by this electrometer over the dynamic capacitor type are: (1) greater reliability, (2) lower power consumption, and (3) lower weight. Its limitation is that its current measuring threshold is somewhat higher (on the order of 10^{-13} amp) than that of the dynamic capacitor electrometer. An MOS electrometer is now under development for possible use in an atmospheric mass spectrometer. A report is being prepared that will describe the application of MOS transistors in electrometer design.

In addition to the electrometer development, a paper on unipolar and bipolar logarithmic compressors is being prepared for submission to the Review of Scientific Instruments. A paper titled "Electrometers for Scientific Instruments in Space Exploration" was submitted to the IEEE Transactions, SET, for publication.

BLANK PAGE

JPL Technical Memorandum No. 33-243, Vol. I

ENGINEERING MECHANICS STUDIES – CAPSULE ENTRY
NASA Work Unit 186-68-09-04
JPL 384-62301-2-3550

HEAT SHIELD MATERIALS

Past studies of heat shield materials have indicated: (1) that design thicknesses for a Mars entry body heat shield may be determined by bonding and fabrication requirements rather than by heating and (2) that uncertainties in radiant heat inputs have a potentially much larger affect on heat shield thicknesses than uncertainties in convective heat inputs.

During the past 6 mo, the materials aspects of the Engineering Mechanics Studies operation have been centered on the usefulness of present radiative heat transfer data and theory for real material analysis, and on the analysis of measurements of the properties of key materials in the ablation and insulation process.

Radiative Heat Transfer and Material Analysis

The available radiative heat transfer data for typical Mars atmospheres from the Ames free-flight facility and from the JPL and General Electric high-energy shock tube facilities were gathered and analyzed in a least-squares sense, and the results matched with the available empirical equations derived in part or whole from theory. The equation fitted in a least-squares sense was

$$\dot{q}_r / R_n = A \rho_\infty^m V_\infty^n$$

where

$\dot{q}_r$ = the radiative heating rate in Btu/ft^2 sec

R_n = nose radius of vehicle

ρ_∞ = free stream density

V_∞ = free stream velocity

A, m, n = constants

Only data at velocities below 26,000 ft/sec were used in the calculations; the data showed anomalies at velocities above this because of a breakdown in the key cyanogen radiators. Figure 1 shows one way of plotting the available data. Tentatively, the following observations can be made:

1. There is too little experimental data at velocities below 26,000 ft/sec.

2. The few data points near 16,000 ft/sec are very important and tend to influence the rest of the curve significantly when moved about within the bounds of their probable accuracy.

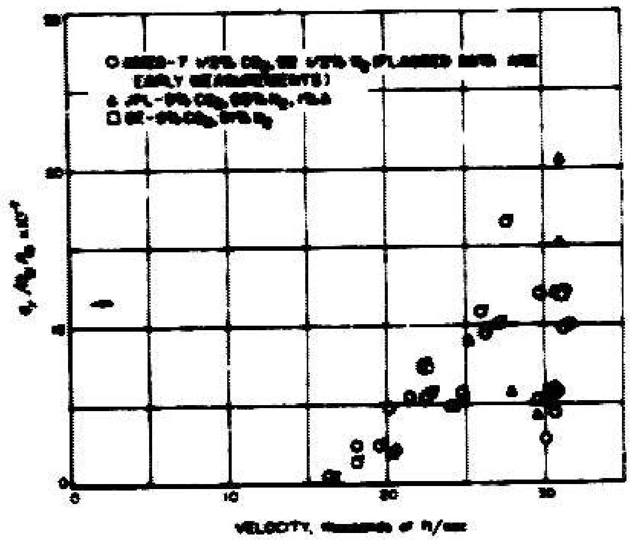


Fig. 1a. Normalized radiant heating rate for Mars atmosphere model with 7.5 to 9% carbon dioxide

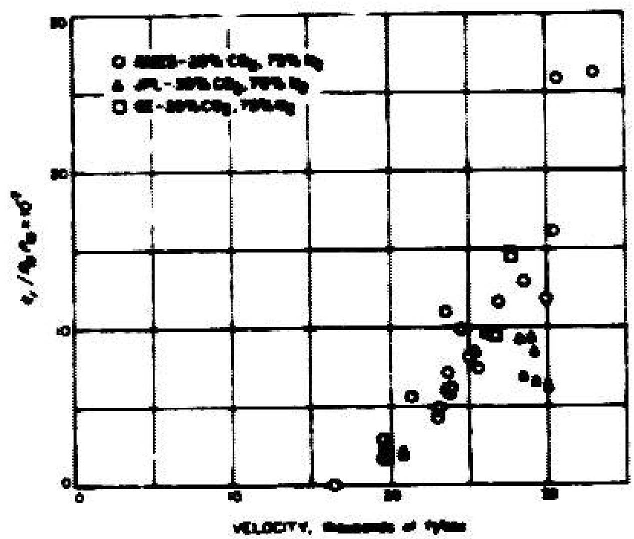


Fig. 1b. Normalized radiant heating rate for Mars atmosphere model with 25 to 30% carbon dioxide

3. The normalization exponent for density is a key calculation. The data tend to indicate that the exponent (-1.0) is lower than the lower limit predicted theoretically for the atmospheres studied (-1.3). The use of a density exponent of 1.0 rather than 1.3 tends to double or triple the total radiant heat to an entry body during a typical Mars entry trajectory. Under certain circumstances this could as much as double the weight of the heat shield required at the stagnation point of the entry vehicle. However, the correct density exponent has not been verified.

A report concerning more extensive investigations of the problem is being prepared.

Thermal Conductivity of Phenolic Nylon Chars

In this and the following effort, the actual contract funds came from Advanced Development Tasks; however, the interpretation of the results is part of the Engineering Mechanics Studies activity.

The final report on JPL contract 950868 titled "Thermal Conductance of Polymer Chars" was received from Lockheed Missiles and Space Company in March 1965. The conductance of phenolic nylon chars was measured by laser pulsing techniques. The chars were varied in their nylon fiber and powder diameter and in their method of preparation. Each char was identified by its density, porosity, degree of molecular ordering, etc., before and after testing. The following tentative observations can be made:

1. The natural variation of conductance because of inhomogeneity disguises any trend in conductance because of most of the parameters studied in this contract.

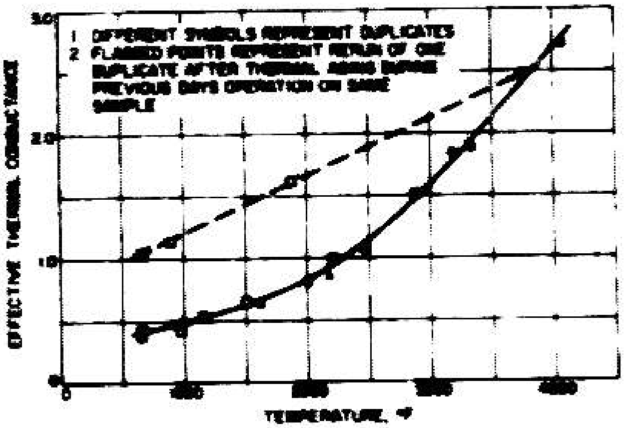


Fig. 2. Example of the effect of temperature history on the effective thermal conductance of one type of phenolic nylon char

2. The rise in conductance with temperature is greater than that predicted from steady state methods used elsewhere.

3. The degree of ordering in the char microstructure appears to dominate the conductance. This ordering is a function of the thermal history of the char (see Fig. 2). The major implication in this observation is that the chars on restartable ablative rocket nozzles and liners could have conductivities in the initial stages of the restart that may be as much as an order of magnitude larger than that used on the original ignition. This decreases the actual life of the nozzle or liner below that which might normally have been predicted.

Reflectance of Graphites and Phenolic Nylon Chars at High Temperatures

JPL Contract 950867 titled "High Temperature Spectral Emittance and Reflectance Measurements" is proceeding at Arthur D. Little, Inc. This contract is establishing the techniques for measuring the reflectance of graphite materials at high temperatures (to 4500°F) as a function of spectral wave-length and angle of incidence. Chars representing a wide range of char surface conditions are to be investigated as well as several graphites. Three major accomplishments are expected from the contract:

1. An apparatus that can measure reflectance accurately at high temperatures without the limitations of the arc imaging techniques now used elsewhere.

2. The range of reflectances possible for the maximum probable variation in the surface properties of phenolic nylon chars.

3. A reduction in the radiant heat transfer predictions to entry bodies because of new measurements that will incorporate the effects of angle of incidence on reflectance for use in integrating the total boundary layer radiation to a surface point.

The contract will end in October 1965.

TRANSPORT PROPERTIES AND CONVECTIVE HEAT TRANSFER

During the investigation of uncertainties in heat shield design, the literature yielded considerable evidence of uncertainties in predicting cold wall stagnation point heat transfer. While it can be argued that the cold wall problem is somewhat academic to heat shield design, a careful assessment of the problem of heat transfer to an ablating surface will reveal that many questions are common to both. Among these are the following questions: (1) what are the proper assumptions for simplifying the fluid mechanics problem (2) what are the proper procedures for calculating the high temperature thermodynamic and transport properties, (3) what numerical technique should be used in obtaining solutions? In face of these questions common to both the cold and ablating wall situations, the ageless maxim of research "investigate the simple situation first" seemed to justify a thorough investigation of the cold-wall stagnation point convective heat transfer problem.

In surveying the literature, one first becomes aware of the variety of "theories" for predicting cold-wall stagnation point heat transfer. These "theories" are actually correlation equations that represent empirical fits to the data points resulting from "numerical experiments" i.e., solving the stagnation point boundary layer problem using a digital computer. The use of "theories" to arrive at an understanding of stagnation point convective heat transfer in a planetary atmosphere is rather questionable as illustrated by Fig. 3. This figure presents heat transfer rates in argon given by investigators who used the "Fay-Riddell Theory." This comparison attests to the caution that should be exercised in the use of such correlation equations. These equations should be used only with the thermodyanic and transport properties that were used in originally generating them.

Consideration of the fundamental questions mentioned earlier: (1) fluid mechanics, (2) transport properties, and (3) numerical solution techniques reveal that a great deal of attention has been directed to the first and third questions. For example, there have been at least three, Ref. (1), (2), (3), different approaches to the solution of the stagnation point boundary layer problem using the same transport properties (Hansen). These approaches show only a slight variation in calculated heating rate with the fluid mechanics assumptions and solution technique. An excellent summary of approaches to the stagnation point convection heat transfer problem is given by Donovan in Ref. (4).

The question of the effect of high temperature transport properties on convective heat transfer does not seem to have been as systematically investigated as the other two questions. However, the following evidence seems to indicate that high temperature properties play an important role:

1. The well-known disagreement between GE and Avco, shown in Fig. 4, has definitely been shown by Pallone and Van Tassell, Ref. 5, to be due to a difference in high-temperature transport properties. In this investigation, the same fluid mechanics assumptions and solution technique were used with two different sets of transport properties, those of Yos (Avco) and of Scala (GE). Thus, the large discrepancy between Scala's work and that of others is because of the large difference in high temperature transport properties

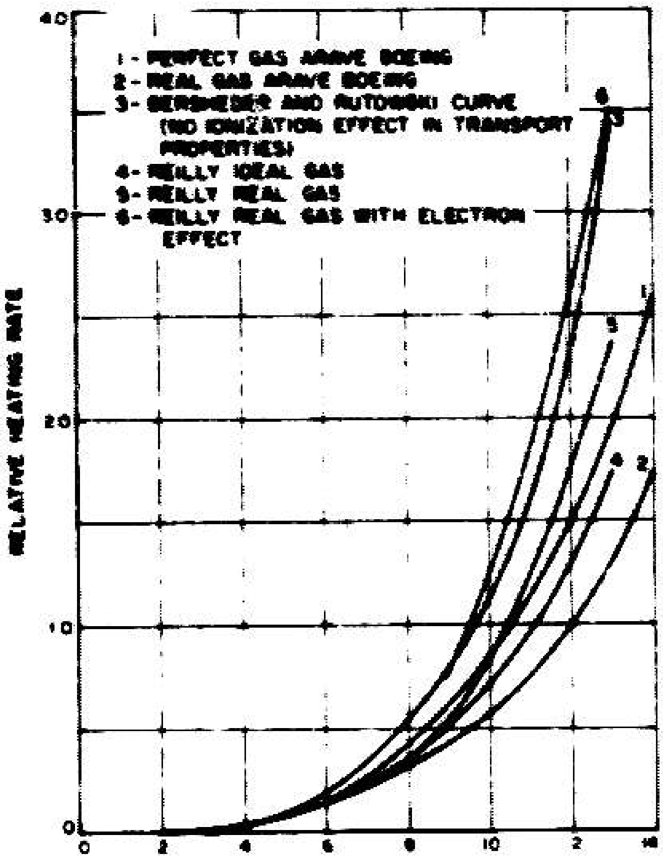


Fig. 3. Shock tube test conditions (stagnation point, air)

2. The disagreement between the results of analyses by Hoshizaki, Ref. (1), and by Van Tassell, Ref. (6), shown in Fig. 5 is primarily because of transport properties. The intent of these two investigations was to examine the affect of gas composition on heat transfer. Hoshizaki obtained solutions for the stagnation point heat transfer using transport properties for air and carbon dioxide that were calculated by the technique outlined in Hansen's report. The work of Van Tassell uses a different procedure for solving the boundary layer problem and uses transport properties for carbon dioxide-nitrogen mixtures calculated by a procedure similar to that of Yos. (It is interesting to note that the properties used by Van Tassell for a mixture of 10% carbon dioxide -90% nitrogen, which is chemically similar to air, differs markedly from Yos's properties for air.) The interesting point of Fig. 5 is that these two investigators, each of which has systematically analysed the affect of gas composition, differ so greatly for the same gas mixture. One concludes from this comparison that the differences resulting from the technique used to calculate transport properties are greater than the differences in transport properties because of the variation of gas composition.

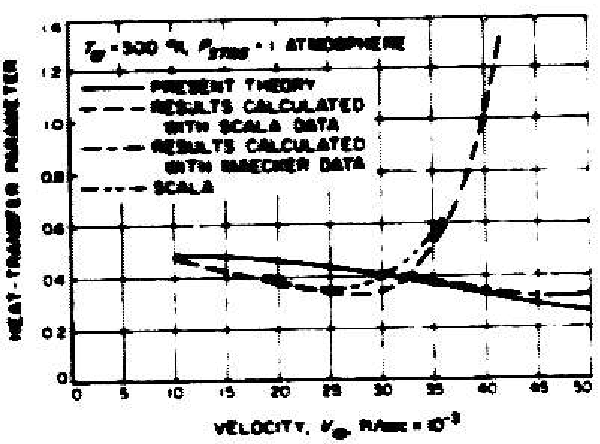


Fig. 4. Comparison of heat-transfer calculations

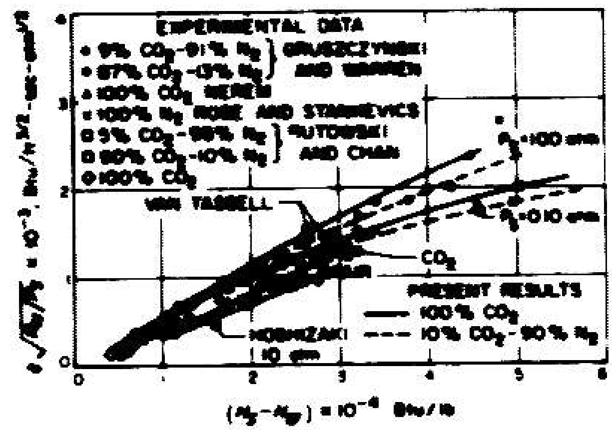


Fig. 5. Comparison of analytical and experimental results for stagnation-point heating in carbon dioxide-nitrogen mixtures

An examination of the high-temperature transport properties in the literature shows considerable disagreement; see Fig. 6. In fact, in comparing the viscosity of air and carbon dioxide, we find that the disagreement between the carbon dioxide curve for Van Tassell and Thomas is greater than the difference between Van Tassell's air and carbon dioxide or between Thomas' carbon dioxide and Hansen's air. The differences in transport properties are reflected in the differences in heat transfer rates.

The sources of the discrepancy between the data are two-fold. First, the collision cross-sections for the various particles are not well known and different techniques for estimating the cross-sections have been used by the various investigators. The question of proper collision cross-section seems to be the real problem area in calculating transport properties. The other source of discrepancy the proper equations for predicting the transport properties of gas mixtures, seems to be well developed but not yet used by any of the investigators reviewed.

Because the existing analyses of stagnation point heat transfer differ not only from differences in transport properties but also because of the variety of assumptions and numerical techniques that were used, calculations should be performed applying one fluid mechanics approach and numerical technique while using the various literature values for the high temperature transport properties of a gas such as air. Preliminary work for such an investigation has been completed (JPL SPS No. 37-31, Vol. IV, Feb. 28, 1965, p. 115). The major conclusion of the study is that there is a 20% variation in convective heating at 25,000 ft/sec in air depending on what set of transport properties are adopted.

Future study effort will be performed to determine the affect of ablation products released from the heat shield on radiative heating to the forebody and aft body of a Mars entry capsule.

STRUCTURAL MECHANICS EFFORT

The structural mechanics effort of Engineering Mechanics Studies (EMS) has been directed toward providing the tools for analysis of thin-walled shell structures. These tools have later been used effectively in support of entry capsule studies.

The most important contribution is the development of a digital computer program for the geometrically nonlinear analysis of axisymmetrically loaded thin shells of revolution. This program was developed by Dynamic Science Corporation (Dynamic Science Corporation Report No. SN-38-5). The computer checkout and technical monitoring of the contract during the period of developing the program was funded by EMS. The main use of this program will be to determine whether the loading on the shell is such that axisymmetric buckling may be critical. The program uses the proportional loading method and solves the nonlinear equations for displacements, rotations, and internal forces at each load step. The process is repeated until the shell is in unstable equilibrium. The difference between theory and experiment is such that even with this nonlinear analysis a reduction factor should be used.

A subroutine has been written to simplify the input to both the A. D. Little thin-shell program (linear) and the nonlinear program. This routine may be used if the generator of the shell is made up of circular arcs and tangents. This subroutine (AUX) is being used in production with the A. D. Little program.

A proposal has been received from Philco WDL to include a conical element in the structural analysis system (SAS). This addition will allow the analysis of axisymmetric shells using a reasonable number of elements. The loading may be axisymmetric or asymmetric and is expanded into a sine and cosine series in the hoop direction. The required stiffness and mass matrices for this element were formulated in a paper by J. H. Percy, T. H. H. Pian, S. Klein and have been checked and put in a form suitable for programming at JPL. This effort to incorporate asymmetric loads of axisymmetric bodies will be performed in FY 1966.

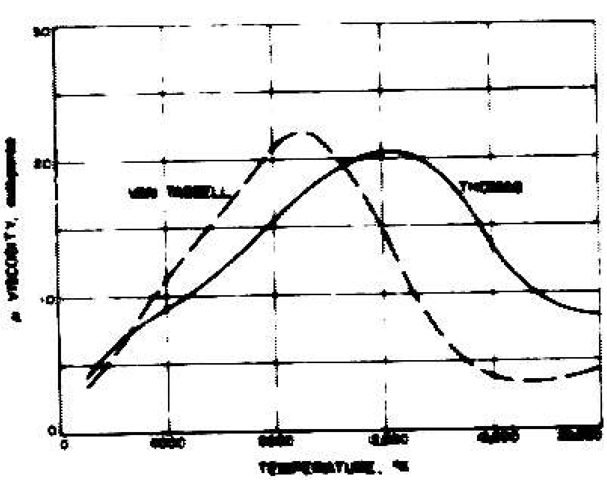


Fig. 6a. High-temperature transport properties - air at 1 atmosphere

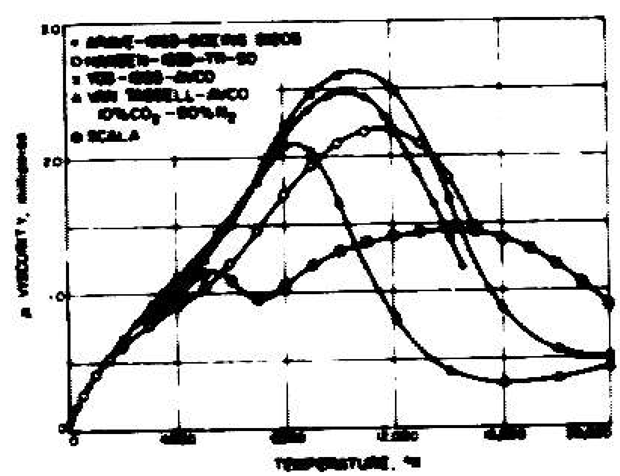


Fig. 6b. High-temperature transport properties - carbon dioxide at 1 atmosphere

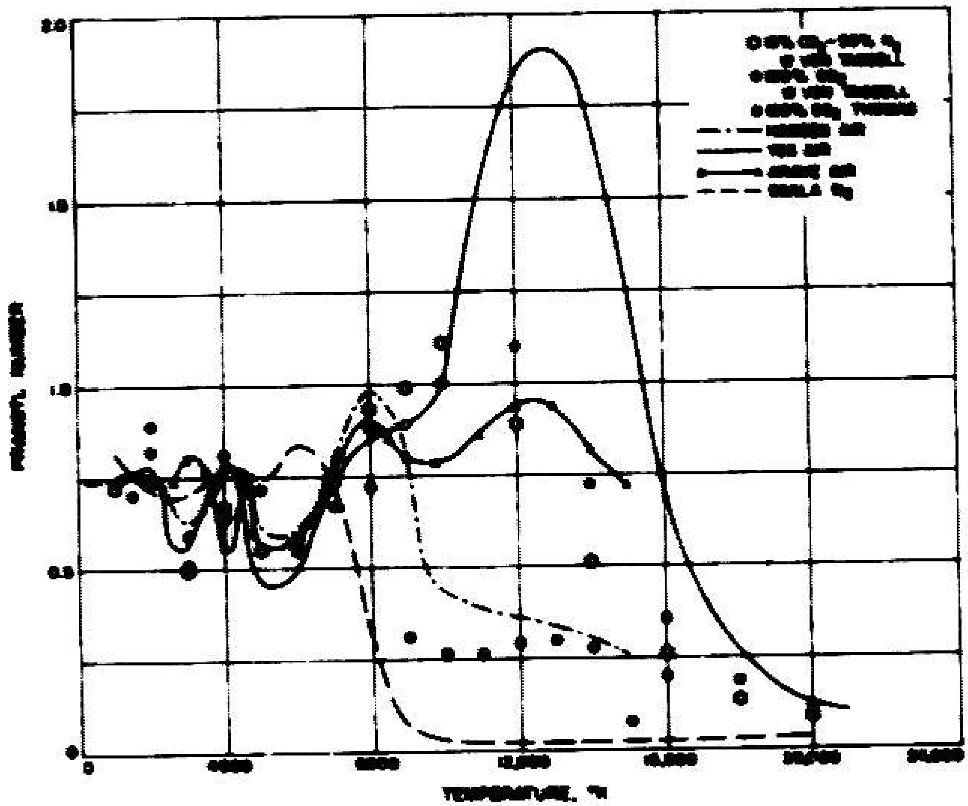


Fig. 6c. High temperature transport properties - Prandtl number (with reaction effects)

REFERENCES

1. H. Hoshizaki. Heat Transfer in Planetary Atmospheres at Supersatellite Speeds. ARS Preprint 2173-61.

2. I. E. Beckwith and N. B. Cohen. Application of Similar Solutions to Calculation of Laminar Heat Transfer on Bodies with Yaw and Large Pressure Gradients in High Speed Flow. NASA TN D-625. Jan 1961.

3. J. Marvin and G. Deiwert. Convective Heat Transfer in Planetary Gases. Prospective NASA Report.

4. M. B. Donovan. A Survey of Stagnation Point Heating. Report D2-22050. The Boeing Company. Jan 1963.

5. A. Pallone and W. Van Tassell. The Effects of Ionization on Stagnation Point Heat Transfer in Air and in Nitrogen. TM-62-75. AVCO RAD. Sept 1962.

6. W. Van Tassell. Convective Heating in Planetary Atmospheres. TM 63072. AVCO RAD. Oct 1963.

SPACECRAFT DESIGN TECHNOLOGY
NASA Work Unit 186-68-09-06
JPL 384-63801-2-2920

The approach used in this study is directed at extending the functional analysis technique now used in system study and system design efforts at JPL. By means of this technique, the objectives of a mission are converted into the functional performance requirements that must be met by the system. Various combinations of the possible subsystem mechanisations capable of performing these functions are formed, yielding a number of systems potentially capable of carrying out the mission objectives and illustrating a variety of overall system philosophies. These combinations are then examined for performance level, systems integration problems, probability of mission success, state-of-the-art, and relevant parameters.

The scope of planned effort for FY 1965 consisted of two major subtasks: (1) the creation of a design data information system and (2) a significant spacecraft design technology study. Original funding for the task was $227,000 and was to be supported by 4 man-years in-house effort and supporting contractor effort.

Early in November 1964, when OART determined that a mission planning and evaluation study could no longer be supported, this effort was continued by OSSA under this work unit by an addendum to the original scope of effort. An additional $50,000 was added to the total funding. During budgetary review in May 1965, a reduction of $145,000 reduced total funding to $132,000. This reduction resulted in the dropping of two procurement actions in process at the time.

Effort during this report period has been concentrated on: (1) in-house data collection and contract planning for a design data information system, (2) several in-house advanced technology studies and contract planning for a data handling, control, sequencing, and malfunction detection system conceptual design and trade-off study, and (3) a mission planning and evaluation study. The progress during this report period and the status of each segment of the work unit follows.

DESIGN DATA INFORMATION SYSTEM

This subtask requires the formulation of a design data information system (DDIS) and the compilation of relevant design data of past and current spacecraft projects in a suitable form for use in future design and mission planning activities. The system has been envisioned as a volume of design books indexed to reflect the various functional design of spacecraft systems. Data content and format were established during the first part of FY 1965. To test the system, data collection on *Ranger* Block III and *Mariner* IV was made during this report period. A prototype portion of the planned DDIS is scheduled for reproduction at the close of the fiscal year. The prototype system is composed of approximately 30 data sets of each *Ranger* and *Mariner* system, subsystem, and scientific experiment.

Contract planning in support of this subtask included an industry survey for appropriate talent and interest in data collection systems, review of this capability, and the preparation of a statement of work and procurement requisition. Budget reviews in May reduced total funding of the task and precluded carrying the contract effort to the planned level. Late in June, a revised statement of work was prepared for an effort level reduced to the limit of available funds. The initial contract will be funded to approximately $30,000, which will permit testing of a contractor's capability, identification of problems associated with the effort, and determining (later in FY 1966) the merit of proceeding with plans to complete up to 35 spacecraft systems for DDIS.

IN-HOUSE SPACECRAFT DESIGN TECHNOLOGY STUDIES

This portion of the work unit is concerned with the identification of spacecraft design technology problems from current spacecraft or future mission study projects as likely candidates for intensive technology study. The candidate problems are then considered and selection for further study is based on their criticality to future project effort. The following studies were initiated in FY 1965 and will be completed early in FY 1966.

Studies in Progress

Redundancy Optimization Approach to Mission Planning Models. The purpose of this study is to develop a model that will present a decision-maker with a surface that shows the probability of success of a spacecraft as a function of cost and weight. The allocation of resources is optimized for each functional subsystem. The final surface is then obtained by the optimization, for a number of fixed values of cost and weight, of the total spacecraft for the optimized subsystems and to the systems effort. Machine programs have been developed for the computations, and data have been collected for the *Mariner* Mars 1964 spacecraft to test the model and to serve as a basis for its application to future missions. As one input to this model, the effect of best use of redundancy on reliability and weight has been calculated for each electronic subsystem of the *Mariner* Mars 1964 spacecraft. The results of this in-house effort will be published in a JPL report.

Simple Redundancy Reliability Estimation Techniques. Prior work in this area, which produced an upper limit to the reliability attainable in a given system of sequential components by the use of active parallel redundancy, has been extended in several directions. Asymptotic forms of the previously derived limit have been developed; these forms are much simpler and generally provide just as good an approximation to the exact, discrete solution. A "mixed" form of the solution, partially discrete and partially continuous, has been devised to deal with a type of system where the straight continuous approximation fails markedly. A start has been made on the much more difficult problem of obtaining similar results for the more realistic standby redundancy. Results of this study will be summarized in a JPL report early in FY 1966.

Optimal Control of Planetary Entry. The purpose of this study was to investigate the nature and performance characteristics of an optimal feedback entry control system. The effort in this area has recently been divided in two tasks: the construction of both analog and digital computer models of the proposed system and the preparation of descriptive material suitable for publication as a JPL report. This material includes discussions of the value of controlled lifting planetary entry and the additional gains achieved by an optimal control system. While it was hoped that this report would be completed in FY 1965, several programming difficulties have prevented the necessary data from being available at this time. Although it is expected that these difficulties will soon be overcome, the usefulness of the parametric expansion method of optimal control system synthesis is being questioned because of the many computational problems that have been encountered.

Deep Space Mission Attitude Control and System Tradeoffs. An analysis of problems that will probably be encountered when using a spin stabilized attitude control system instead of other stabilization techniques for deep space missions was initiated. Progress consisted of the following:

1. A report of a typical mission sequence and a list of the pros and cons of the two systems.

2. The mathematical background and derivation of the equations for a spinning vehicle were obtained. In addition, an analysis involving the simple case (i.e. I_{xy}, etc. = 0) and the progression to the nonlinear analysis were made.

3. Two computer simulations were performed. Results will be published in a JPL report early in FY 1966.

Study of the Relationships of Electronic System Complexity with Other Spacecraft System Parameters. This study, performed under contract (No. 950798) with Space Craft, Incorporated, under FY 1964 funding, was an extension of a previous contract. The unsolicited proposal sought to extend and verify trends of the relationship of cost, reliability, manufacturing mode, countable parameters, and performance to the spacecraft subsystem integration effort by consideration of additional spacecraft systems. The contractor concluded that collection of data at the electronic components level was too frustrating and time-consuming for the level of results obtained. Electronic countable parameter data collected on several spacecraft systems did not validate the contractor's initial hypothesis presented at the completion of the first contract. Results tend to increase the validity of a top-to-bottom approach. A more significant countable parameter may be "direct project manhours" in lieu of basic electronic components. A final report was received on May 31, 1965 and is now under evaluation.

Data Handling, Control, Sequencing, and Malfunction Detection. A significant spacecraft design technology study was planned for contracted effort during FY 1965. The problems associated with the centralization of the data handling, control, sequencing, and malfunction detection function of spacecraft design were to be studied. The proposed study was also to require a comparison of the effectiveness of these functions that range in centralization from a Mariner 1964 type system to fully integrated digital computer-based systems. The study was to include system aspects and the effects of the possible means of implementing these functions on the rest of the system. The statement of work and supporting documentation and procurement requisition were prepared for contract solicitation. However, budgetary reviews in May reduced the total funds to a level that precludes contract efforts at this time. In the early part of FY 1966, it is planned to review this study plan with the intention of contracting during FY 1966.

Potential Studies

Other study candidates that were examined during this report period for possible intensive study are as follows.

Hibernating Spacecraft Reliability and System Design Implications for Outer Planet Missions. The objectives of this study are to determine the affect on the probability of mission success and the effects of system performance of spacecraft systems operated in an intermittent mode where parts, or all the system, is deenergized for periods during its mission life. This study is divided in two phases. Phase I will ascertain the availability of applicable data on which an analysis may be based. Phase II is intended to develop the analytic means, system reliability models, and system performance implications of such a mode of operation if Phase I provides adequate quantity and quality of data from which valid results may be predicted.

Aerobraking Mars Orbiter (AMO). The mass associated with the use of retro rockets to inject an interplanetary probe into a stable orbit about Mars is quite large; usually more than half of the original probe weight must be allocated to the propulsion system and related equipment. A mass penalty of this magnitude invites the system designer to cast about for alternate means of achieving a planetary orbit.

One possible method is to use an aerobraking - retro fire sequence that would result in greater total payload in orbit. To achieve this end, the vehicle must pass by Mars in a grazing trajectory: close enough to reduce its velocity below escape and far enough to prevent capture and impact. Once the vehicle has left the atmosphere on a satellite orbit, a retro maneuver may be performed to raise the periapsis above the atmosphere.

It was proposed that a study be performed to investigate the true feasibility of such a scheme and to determine the system implications of such an injection sequence.

Design Reliability. System design aspects of achieving high reliability particularly on long life missions is required. A fair amount of literature exists on the methods of reliability calculation and modeling; however, there are many questions of actual implementation that have yet to be fully answered. Typical questions arising in design and reliability analysis concern:

1. The feasible levels and techniques of using switching logic for standby redundancy.

2. The methods and problems of tight control of component environment to reduce stress levels that lead to higher probability of failure. Increases in reliability through environment control would be compared to redundancy required to achieve comparable gains.

A study is proposed to investigate these and other questions relative to design reliability in which the *Mariner* Mars 1964 spacecraft will be used as a representative system on which the analysis will be based.

Best Entry and Landing Sequence. The problem of bringing a payload to a soft landing on the surface of Mars may be interpreted as a multistage decision process in which weight is expended to achieve velocity reduction. Considering the use of all possible techniques, a complete sequence would be:

1. Approach retro fire; jettison empty tankage.

2. Atmospheric entry.

3. Deploy drag device.

4. Deploy parachute.

5. Terminal retrofire.

6. Crushup landing.

It would be useful to perform a study to determine the best emphasis to place on each of these operations. Mathematically, it could be attacked by:

1. Formulating a model of the process in which at each stage the velocity reduction achieved is a function of the present velocity, mass, and mass expended.

2. Determining the best sequence of mass expenditures to maximize the landed payload.

It is proposed that a study be performed to develop such a model and solution and to investigate the feasibility of actually implementing the solution obtained. The system implications of the best entry sequence would be fully investigated.

MISSION PLANNING AND EVALUATION

This study task is planned to extend JPL's ability to plan for advanced space projects by developing a generalized methodology for the quantitative evaluation of advanced space projects. Such a methodology treats reliability, spacecraft performance, scientific data acquisition, costs, and time of performance. The interrelationships of these factors at a generalized level of consideration will be defined. A definite goal is to improve JPL's ability to predict (approximately) the nature and costs of advanced projects and thus to plan more efficiently and effectively.

Review of this task with NASA/OART continued throughout October 1964. Early in November, it was decided that OART could no longer provide budgetary support for this effort, and work under NASA Work Unit No. 124-06-01-03 was stopped. Effort in the general area was continued by OSSA as an addendum to Spacecraft Design Technology, NASA Work Unit No. 186-68-09-06-55.

During the first quarter of FY 1965, efforts were limited to in-house activities because the budget was under review with NASA Headquarters during that period. These activities, which have continued throughout the year, were largely devoted to the technical direction of the Lockheed contract, to a continuing effort to collect, analyze, and interpret historical JPL data with the aim of defining relationships between cost, performance, reliability, and project organization for achieving the ultimate goal of developing models useful in planning and evaluation; and to an in-house study.

The in-house study was started with the aim of developing a partial mission planning model that will predict the maximum probability of success obtainable for various levels of funding and of spacecraft weight. In this model, a mission is divided into functions that must be performed. For each function, reliability is estimated as a function of cost and weight on the basis of previous experience and of engineering judgment. Factors influencing the reliability of a function include redundancy, use of improved parts, design effort, and subsystem testing. The probability of mission success is also influenced by system design effort and systems testing, which are treated as elements of cost. These relationships will be used to determine, by the use of dynamic programming, the "maximum" probability of success for various levels of cost and weight. A second portion of the computer program will be developed for the purpose of retrieving the corresponding cost and weight data by functional area and systems effort for a particular mission; e.g., for a particular point in the performance probability of success, cost, and weight "policy space" previously developed. The current status of this planning model is as follows:

1. A method of approach has been worked out for the calculation of reliability/cost/weight relationships.

2. The feasibility of this approach has been tested by programming a simplified problem for an IBM 1620 computer. The problem selected was an analysis of the affect of weight on reliability for the Mariner C subsystems, with the machine program being used to compute the best allocation of redundant weight among the subassemblies of the subsystem.

3. The results of the Lockheed study have been applied to current project cost estimating and used in the evaluation of technical tradeoffs.

On February 15, 1965, Lockheed concluded the study under JPL contract 950851, and delivered a final report, "Advanced Mission Planning and Evaluation Methodology" to JPL. During an oral review of accomplishments presented to JPL, a case example of a Jupiter mission was used to illustrate the principles derived from the study.

Since the conclusion of the Lockheed contract, the material presented by the study has been under review at JPL. Based on this review, a continuation effort was planned for FY 1966. This plan would have been directed toward the collection of technical data, establishing indicators for assessing each technical category, determining the sensitivity of the methodology to variance, and establishing confidence levels on results of the evaluations. However, because budgetary support for the continuation effort is not available, this task is terminated at the close of FY 1965.

ENGINEERING MECHANICS STUDIES - CRUISE PHASE
NASA Work Unit 186-68-09-07
JPL 384-65301-2-3550

VOYAGER BUS MODULES

Voyager bus modules can be thermally controlled with techniques similar to those used on Mariner IV.

ADVANCED TECHNOLOGY ELECTRONIC PACKAGING STUDIES

The objectives of the advanced technology electronic packaging studies are to develop packaging concepts that will provide substantial reliability improvements in future spacecraft and to provide the detailed spacecraft study activity and the support required for advanced technical and project studies.

A major part of this effort is in the technical direction and evaluation of in-house development of advanced packaging and cabling concepts. Advanced concepts that were engaged in during FY 1965 were:

1. The development of a printed conductor (P.C.) ring harness for the Mariner spacecraft.

2. The development of a new packaging concept for integrated circuit (I.C.) devices.

A printed conductor ring harness was designed and developed to determine the feasibility of replacing the two upper ring harnesses and through assembly in the Mariner IV proof test model. In April 1965, the assembly was tested on the Mariner proof test model and the electrical performance was excellent; in fact, it was considered flight acceptable.

The advantages of the P.C. configuration when compared to conventional harnesses are:

1. Lower weight.

2. Lower manufacturing cost.

3. Better rejection of high frequency electrical noise.

Based on the April proof test model test, a few modifications are being made on the P.C. assembly to improve the electrical performance. The modified assembly will be retested in August, and the resultant information will permit relative evaluation of the conventional wiring harness compared to the P.C. configuration.

A unique configuration for I.C. packaging has been developed. This design is now being used in the packaging of approximately 300 integrated circuit devices for the programmer subassembly of a plasma experiment that will be carried by an OGO-E satellite. In FY 1966, this integrated circuit packaging configuration will be further developed and refined for Voyager.

Classically, high density modular assemblies have been developed with one common point of conceptional design that is questionable when the best design is required. There have been three dimensional interconnection requirements for both the discrete modules (welded cordwood, etc.) and the associated mother board interconnect assembly (welded wire matrix, multilayer circuit board, etc.). This dual requirement for planned 3D interconnection has resulted in larger numbers of joints than would be required by the best configuration for a given functional electronics assembly. Also, the 3D mother boards are difficult to reliably rework if required by a circuit change.

A stick module design concept was developed that decreased the numbers of total assembly interconnections and eliminated the requirement for a 3D mother board in high density modular assemblies. This concept was reported in SPS No. 37-26, Vol. 4. Basically, the concept that allows this improvement is a simple one. The 3D module concept was determined to be a vital feature from detailed study of all the tradeoffs. However, study always showed that the mother board interconnections could be reduced to single dimension parallel conductors. This simplification was developed by examining the total modular assembly in 3D and designing to obtain two dimensions of assembly level interconnections within each module thereby leaving only a single dimension requirement to interconnect the modules at the assembly level.

Some of the more unique features of the I.C. stick module concept are as follows:

1. Use of insulated magnet wire for multilayer interconnections at the discrete module level.
2. Nonmagnetic weldable and solderable terminals for high reliability repairable interconnections.
3. Minimum design and fabrication time requirements.
4. Assembly level interconnections are one dimensional coplanar conductors.

Future effort in advanced packaging studies will include a continuous review and collation of data on integrated circuitry and connector techniques mainly from a reliability standpoint.

ENGINEERING MECHANICS STUDIES – TERMINAL DESCENT AND IMPACT
NASA Work Unit 186-68-09-08
JPL 384-65401-2-3550

TERMINAL DECELERATION

As planned, an industry competition was held for a study of aerodynamic terminal decelerators other than parachutes. The contract has been awarded to the Goodyear Aircraft Corporation, Akron, Ohio. This contract has the objective of conducting a parametric design study of auxiliary balloon-type devices and expandable entry vehicle structures for possible use as auxiliary aerodynamic decelerators and stabilizers for a ballistic entry vehicle during terminal descent in the Mars atmosphere. The contract is funded by $30,000 from this work unit and by $40,000 from Planetary Entry Aerodynamic Deceleration, NASA Code OSSA 186-68-13-01.

SENSING FOR AUXILIARY DECELERATOR INITIATION

A JPL study in this very important area was completed and the information was used as a basis for an industry competition under NASA Work Unit OSSA 186-68-13-01, Planetary Entry Aerodynamic Deceleration. In the JPL study, eight existing sensing-system concepts and their combinations were reviewed using the extremes of Kaplan and Schilling atmospheric models and entry-path angles. The study analyzed the system performance in defining and sensing appropriate initiation conditions with least loss of attitude from the allowable design limits of the auxiliary decelerator. Also the quantities that limited the allowable design were established as being the material temperature, the Mach number (related to the temperature and actuation dynamics), the dynamic pressure, and possibly the Reynolds number in the order of decreasing significance.

In general, it was established that the more critical limiting quantities, material temperature, and Mach number, cannot be sensed directly by available means. Hence, indirect systems must be used that all incur undesirable altitude losses for the critical atmospheric model and 90 deg entry. The reduction of the altitude losses by systems combining two or more sensible conditions introduces complexities that tend to reduce the reliability. Hence, recommendation to contract for a more detailed study of the subject resulted.

DYNAMIC TRAJECTORY RUNS

Six-degree-of-freedom dynamic trajectory runs were made for Apollo type, sphere cone, and Langley tension shell Mars entry capsule shapes to compare their drag and dynamic performance characteristics. The Langley tension shell and sphere cone showed superior aerodynamic damping over the Apollo type capsule at a capsule diameter of 10 ft and weights of approximately 500 to 1,000 lb. More recent results for a 16 ft diameter, 1500 lb capsule indicate that there may be significantly higher effective drag (integrated over the entry trajectory) for a 60 deg sphere cone and tension shell than for the Apollo type, assuming backward entry conditions. The impact velocities for the Langley tension shell and sphere cone are approximately 100 ft/sec less than the Apollo type capsule for backward entry at 90 deg entry angle in a 14 mb surface pressure, 300°K atmospheric surface temperature Mars model.

ACTIVE TEMPERATURE CONTROL SYSTEMS FOR LUNAR AND MARS LANDER PAYLOADS

This study is a new task to evaluate and define (1) the type of thermal control needed (variable absorptance, variable internal conduction or connection, etc.), (2) thermal requirements for power, and (3) the micro-climate (diurnal environment) that the payload may be subjected to for planetary and lunar landed payloads.

JPL Technical Memorandum No. 33-243, Vol. I

HIGH IMPACT ELECTRICAL TECHNOLOGY
NASA Work Unit 186-68-10-01
JPL 384-62801-2-3550

For FY 1966, this work unit will be divided into High Impact Battery Technology and High Impact Communications Subsystem Technology.

HIGH-IMPACT-BATTERY TECHNOLOGY

The high-impact-battery effort (performed in conjunction with the JPL Guidance and Control Division) during this report period has consisted mainly of testing standard silver-zinc and silver-cadmium cells under impact in order to learn more about failure modes and levels. The cells have in all cases been supported by potting them into rigid (typically 3/8 in. aluminum) fixtures. The effort has been centered around the investigation of the plates and separators, since these are essential to the battery and less susceptible to various structural approaches than cases.

Table 1 summarizes battery tests performed during the report period. Figure 1 explains the impact directions referred to in Table 1. Discharged batteries are much less rugged than charged batteries because the anode is in the oxidized condition. Only one cell (the Whittaker P. S. D. CD-3 sealed silver-cadmium cell) has survived 10,000 g impacts in all principal directions with no detectable electrical degradation. Figure 2 shows one of these cells cut open after a 10,000 g impact in direction A. As can be seen, some rippling of the plates and separators occurred. However, the separator effectively prevents shorting between plates.

As yet, no sterilizable materials or components have been included in batteries tested under high impact. It is planned to include these materials and components as soon as they become available. It is planned to continue testing various types of cells in various stages of discharge in order to gain more knowledge about failure modes and levels. It is also planned to begin fabricating prototype cells or portions of cells in order to examine various techniques of improving internal and external cell structure. Plate and separator stacks are surprisingly rugged if closely constrained between rigid walls and potted into the case. Rigid cases which will not crack under impact are, therefore, important to high-impact batteries. Work will be initiated on the development and investigation of such cases.

HIGH IMPACT COMMUNICATIONS SUBSYSTEM TECHNOLOGY

The high impact communications effort is carried out in cooperation with the JPL Telecommunications Division (Capsule Direct R. F. Systems. NASA Work Unit 186-68-04-07, JPL 384-63001-2-3364). A 3-watt, S-band, solid state, high-impact (10,000 g from 500 fps) resistant transmitter is presently under development. Figure 3 shows one of the units as contrasted with one module of the S-band transmitter from a Mariner spacecraft. The total weight of the completed high impact transmitter will be about 2 lb and the size of each module is approximately 1.5 x 2 x 4 in. The first two units in prototype form are under high impact test. The second stage has survived 10,000 g impacts. The third stage is being breadboarded. The first stage as it presently exists should survive 10,000 g as soon as the high impact crystal development is completed.

Table 1. Battery tests summaries

Battery	Condition	Potting	Direction	g Level	ΔV, fps	Comments
Yardney LR20-3X-1	25% cap.	Silastic	A	1,800	50	
	25% cap.	Silastic	B	1,800	50	No detectable degradation
	25% cap.	Silastic	C	1,800	50	
	25% cap.	Silastic	A	4,100	135	Buckled leads & plates - gave to Div. 34 for X-ray
Yardney LR20-3X-1	25% cap.	Silastic	A	1,400	52	No detectable degradation
	25% cap.	Silastic	D	3,500	120	Would not charge to capacity
Yardney LR20-3X-1	25% cap.	Silastic	C	3,400	117	Capacity slightly degraded
Recased Yardney	25% cap.	Silastic	C	4,200	108	No detectable degradation
	25% cap.	Silastic	A	7,300	175	Battery destroyed - zinc plates failed - silver plates cracked. Separator looks o.k.
	25% cap.	Silastic	B	7,300	175	
	25% cap.	Silastic	C	7,300	175	
Eagle Picher Model #25-65 Silver Zinc	Uncharged	Silastic	C	4,800	145	Slight visible plate damage. No shorting.
	Uncharged	Silastic	D	4,800	145	Plates buckled.
Eagle picher Model #25-65	Charged	Silastic	C	3,900	130	
	Charged	Silastic	C	4,600	152	
	Charged	Silastic	C	5,750	148	No de' ectable degradation.
	Charged	Silastic	C	6,220	149	
	Charged	Silastic	B	3,700	135	
	Charged	Silastic	B	5,700	150	Case split, one plate buckled. Discharge cycle showed almost full capacity.
Eagle Picher Model #25-65	Charged	Epon 815	B	7,000	148	No detectable degradation
	Charged	Epon 815	B	8,600	143	Case cracked and separated from potting, plates crushed, internal short.
Yardney YS 20 Silver Cad Cell	Charged	Silastic	C	7,400	166	No detectable degradation.
	Charged	Silastic	B	7,200	167	No detectable degradation.
	Charged	Silastic	B	10,800	169	Case cracked. Electrically o.k.
Yardney YS 20 Silver cad cell	Charged	Silastic	B	7,600	174	Case cracked. Electrically o.k.
Whittaker P.S.D. P/N 201171 sealed silver cad cells 2 potted in fixture	Charged	Epon 815	B	8,400	161	Case cracked. Electrically o.k.
MA-C ES5 cell	Charged		D	5,400	158	Case cracked. Gross internal shorting.
Whittaker P.S.D. CD-3 sealed silver cad cells 2 potted in fixture	Charged	Epon 815	B	10,800	174	No detectable degradation.
	Charged	Epon 815	D	10,400	170	No detectable degradation.
	Charged	Epon 815	C	10,000	166	No detectable degradation.
Whittaker P.S.D. CD-3 sealed silver cad cells 2 potted in fixture	Charged	Epon 815	A	10,800	176	No electrical degratation Potting and one case cracked.
	Charged	Epon 815	A	10,000	164	No electrical degradation Potting and one case cracked.
Ranger ES8 cell	Charged	Epon 815	D	6,000	165	Case cracked - internal shorting.
	Charged	Epon 815	A	6,800	170	Potting and case cracked, plates shifted.

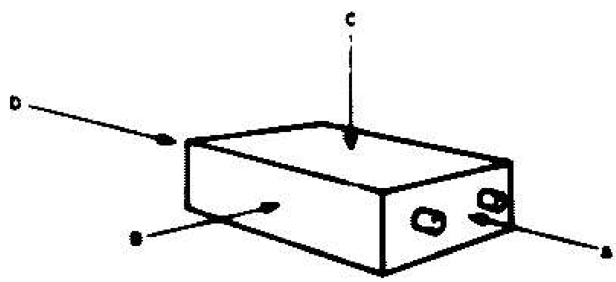


Fig. 1. Battery impact directions

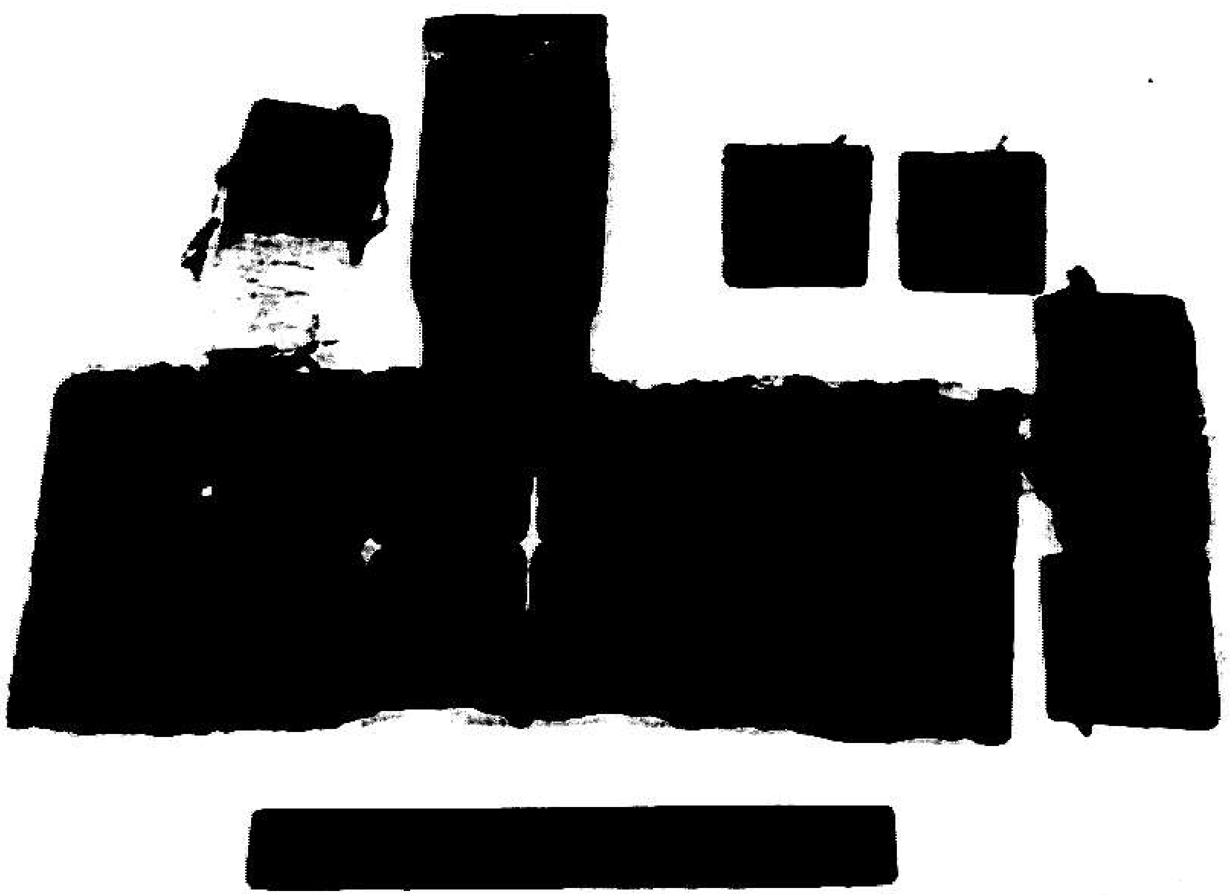


Fig. 2. Dissected P. S. D. CD-3 silver cadmium cell after 10,000 g impact

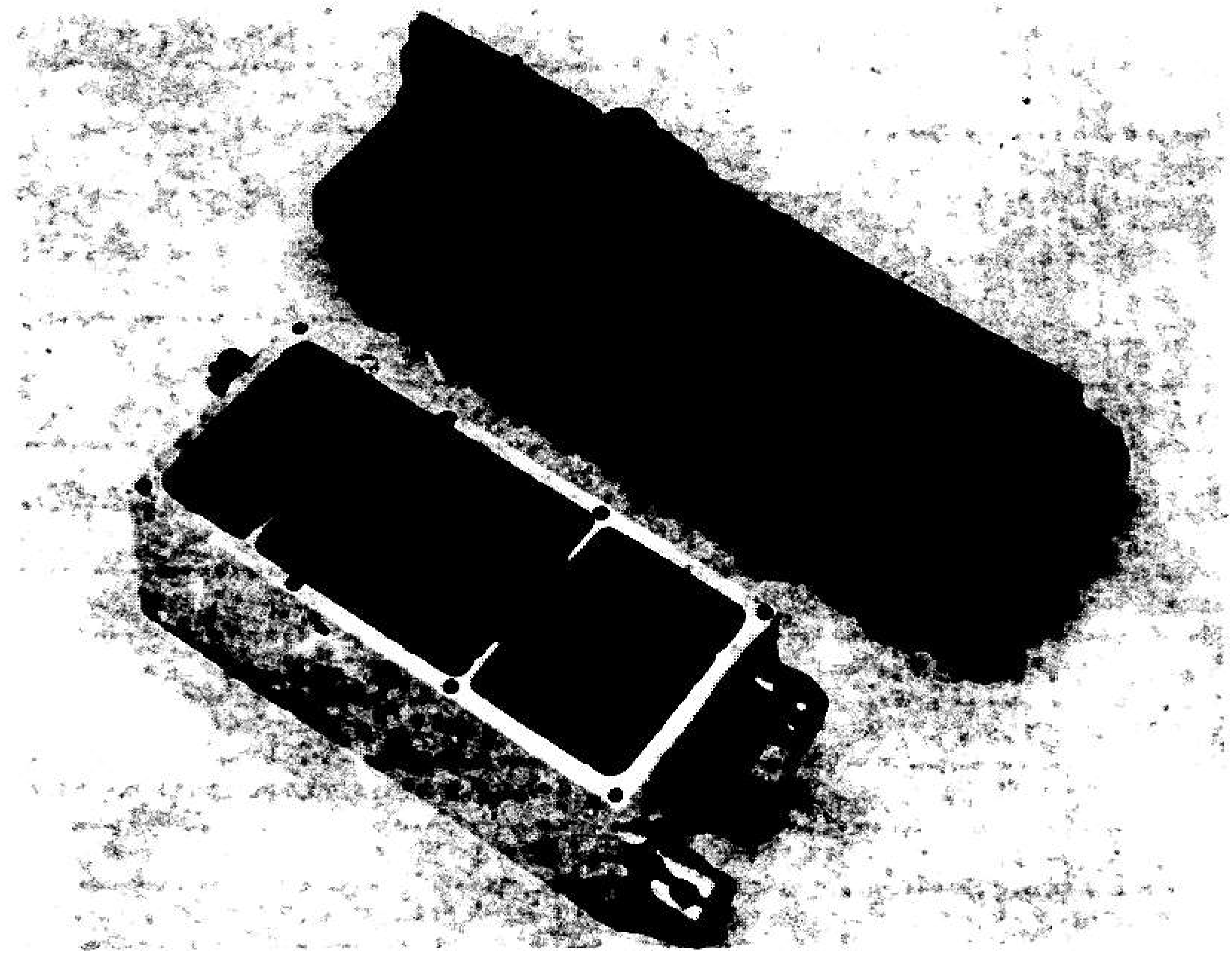


Fig. 3. High-Impact S-band transmitter module

HIGH-IMPACT STERILIZABLE CRYSTALS

JPL Contract 951080 with the Valpey Fisher Company is for the completion of the high-impact sterilizable crystal development. The contract was let on January 28, 1965 and is scheduled to be completed about March 1, 1966. The contract calls for an engineering investigation of aspects of the crystal such as cut angle, resonator plate design, package design, sealing technique, unit mounting technique, and so forth. The contractor will fabricate 20 crystals for electrical tests before and after impact, 20 crystals for sterilization testing, and 20 crystals for aging tests. The final product will utilize a quartz resonator in an alumina case. The case will allow the quartz freedom to resonate, but will not allow it to deflect to failure under impact. The specifications call for the crystal to have a nominal frequency of 19.125 Mc ±0.001 % at 25°C and for design techniques to be applicable over the frequency range of 15 to 50 Mc. The impedance value to be less than 30 ohms at 25°C, the capacitance is to be less than 7μμf, and the frequency is not to deviate more than ±0.001 % over the temperature range of -10 to 75°C. The phase error is not to be more than

0.05 ±0.01 deg peak measured in a phase lock-loop receiver with a 12-cps noise bandwidth and the incidental phase error is not to exceed 0.01 deg peak per g of acceleration.

Several prototype specimens have been delivered to JPL. Figure 4 shows one of these units. Impact tests have been performed to check case integrity and adequacy of various sealing methods. One operating crystal has been impacted in all principal directions at 10,000 g from 200 fps. The resulting frequency shift was well within specification. The biggest difficulty at present is with phase jitter before and after impact. However, mounting refinements presently underway should solve this problem. The present sealing method makes use of eutectic solder applied to vacuum deposited chrome-silver surfaces. The seal must not only withstand impact and prevent crystal contamination, but it must also sustain a tensile load as the resonator is held by edge clamping. The only presently foreseeable sterilization problem is relaxation of this clamping force due to solder creep under high temperature. However, other sealing methods exist which should prove adequate under both high impact and sterilization.

TECHNICAL CONTACTS

During the report periods, technical contacts were made with Langley Research Center, Harry Diamond Laboratories, Sandia Corporation, several battery manufacturers, and various manufacturers of components and devices. Additional reports on this work unit can be found in SPS 37-31, Vol. IV and V, SPS 37-32, Vol. IV and V, and SPS 37-33, Vol. IV and V.

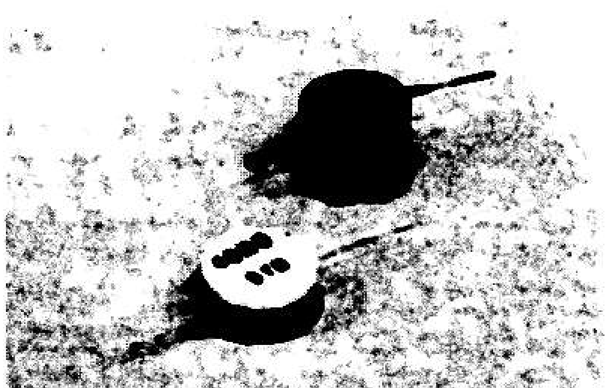


Fig. 4. Prototype high-impact crystals

BLANK PAGE

HIGH IMPACT MECHANICAL TECHNOLOGY
NASA Work Unit 186-68-10-03
JPL 384-65601-2-3550

The purpose of this work unit is to investigate various mechanism elements and devices under high (10,000 g from 500 fps) impacts. Additional reports on this work can be found in SPS 37-33, Vol. IV and V.

BEARINGS

Various bearings have been tested under impact. Table 1 shows typical data from such tests. The bearings were mounted in pairs in an aluminum block and mounted with shafts weighing 1.25 oz each. The shock loads were applied in radial and in axial directions. The shafts were not turning during impact. The ball bearings were 0.25 in. ID, 0.625 in. OD, phenolic separator, flanged deep-groove Barden bearings. The bushings were machined from a Westinghouse sintered copper, lead, Teflon compound. In general, rolling element bearings with normal rotating masses are not capable of taking the loads encountered under 10,000 g shocks without significant damage. This is, of course, due to very high brinelling loads between the balls and the races.

Since rolling element bearings are very attractive for use in space, an investigation was made of methods of supporting bearings so that impact loads would not be transmitted through the rolling elements. Figure 1 shows a prototype spring mount for a rotating element bearing. This mount is a six-deg-of-freedom spring which is stiff enough (approximately 25,000 lb/in. axially and radially) to maintain alignment, yet soft enough to deflect during an impact so that bearing loads will not become high enough to damage the bearing. A 4-oz rotating mass with a 0.002-in. clearance with its housing was supported between two lightweight ball bearings (Microtech MC814SSR 25L10) in these spring mounts. The unit survived impacts of 10,000 g from 200 fps with no detectable damage. The major loads, of course, were absorbed by bottoming between the rotating mass and the housing.

ELECTRIC MOTORS

A series of small electric motors incorporating spring-mounted bearings was developed and tested. Figure 2 is an exploded view of one of these motors. This is a rebuilt Gaylord-Rives size-8, synchronous motor and has successfully survived 10,000 g impacts from 200 fps in both radial and axial directions. The motor was not operating during impact. It was rigidly clamped to the carriage of the testing machine. Acoustic techniques were used to compare preshock and postshock performance as well as torque measurements. Pickups were attached to the motor which was operated in a soundproof chamber. The resulting noise spectrum was then analyzed. By looking at the energy content of various frequencies it was possible to detect extremely small changes in motor performance.

TURBINE

One possible use of bearings in a high-impact situation would be in a hard-landed turbo-alternator secondary power source. In this situation it is conceivable that the turbo-alternator would be operating during impact. In an attempt

Table 1. Impact test of ball bearings and bushings

Impact		Direct.	Ball Bearings			Bushings		
Velocity	Peak		Radial Play	End Play	Torque, oz	Radial Play	End Play	Torque, oz
50	300 g	radial	neg.	0.000	0.50	neg.	0.001	0.75
		axial	neg.	0.000	0.50	neg.	0.001	0.75
50	700 g	radial	neg.	0.000	0.50	neg.	0.001	0.85
		axial	neg.	0.000	0.50	neg.	0.006	0.75
50	1500 g	radial	neg.	0.000	0.50	0.001	0.0075	0.85
		axial	neg.	0.000	0.50	0.001	0.008	0.85
50	3000 g	radial	neg.	very rough races	0.75	0.0015	0.008	0.75
		axial	neg.	very rough races	0.75	Bushing locked		
50	6000 g	radial axial	Bearing brinelled so severely races locked					

to investigate this situation, a mocked-up turbine was fabricated and tested. The turbine was similar to the test specimen for the bearing spring-mounts referred to above. Turbine buckets were milled into the circumference of the rotating mass and an air jet was provided to power the turbine. By providing air through flexible tubing, it was possible to power the turbine continuously before, during, and after impact. The unit was impacted radially at 13,000 g from 173 fps. Although the rotating speed changed slightly during impact, the device regained its preimpact rotating speed (about 30,000 gpm) and operated successfully for a 3 - 5 hr period before it was shut down. Examination showed that some race brinelling had taken place. Damage to the turbine and housing was small. An improved version is under fabrication which should survive impact with no bearing damage.

TAPE RECORDER

A Westrex ruggedized track tape recorder and a Kinelogic nonruggedized spacecraft tape recorder have been under impact investigation. Development of a JPL high-impact tape recorder has been initiated. This development is more of an attempt to investigate mechanism elements in subassemblies than an attempt to develop a

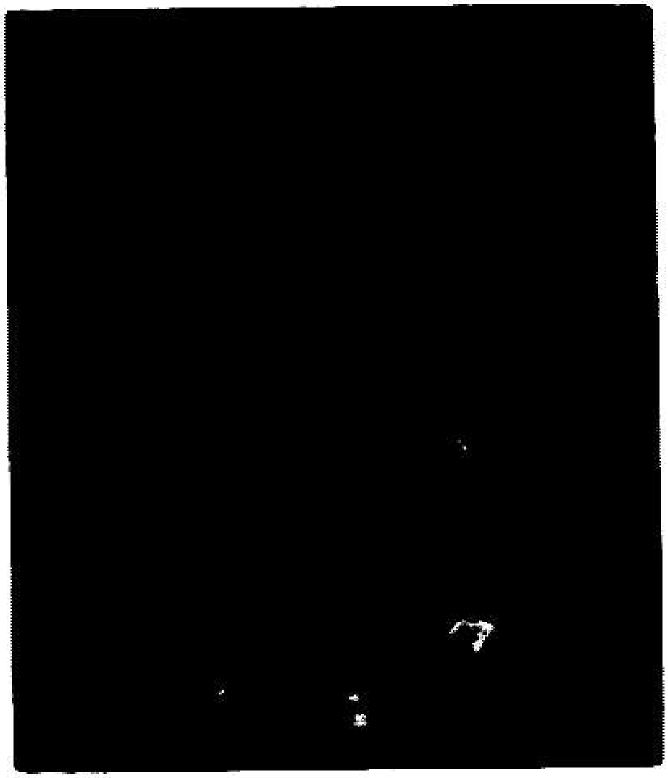


Fig. 1. Six deg of freedom high-impact bearing mount

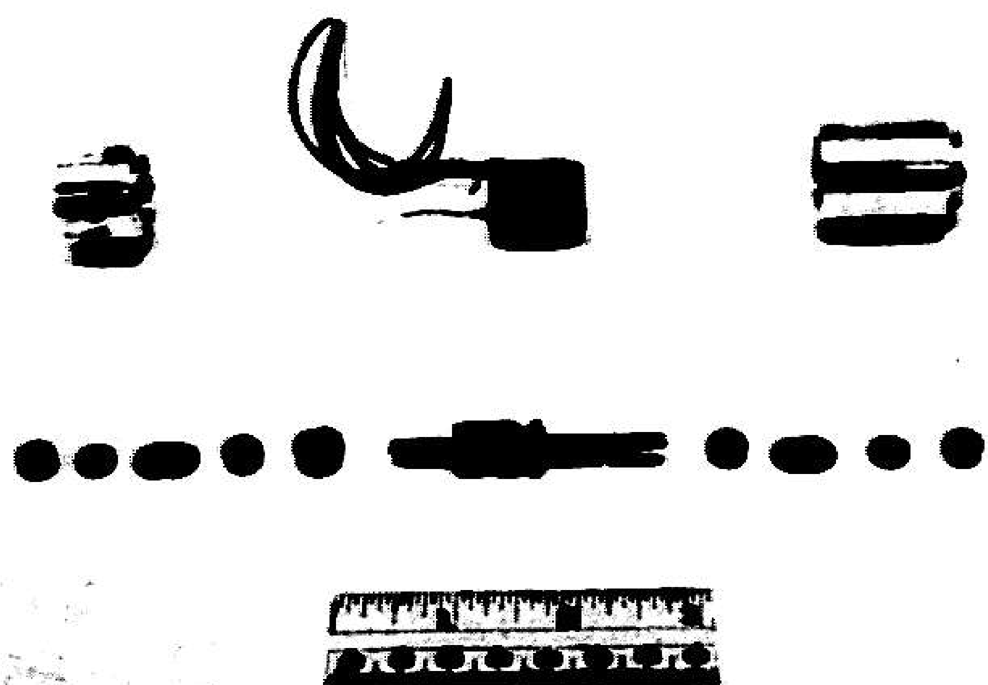


Fig. 2. Exploded view of high-impact motor

tape recorder. The problems of interest are the use of belt drives in high impact mechanisms, the attainment of precisely regulated motions after impact, and the support of heavily loaded rotating shafts (tape spindles). In conjunction with this development, progress in similar projects for Sandia Corporation and other users of high-impact resistant recorders are being followed closely.

GEARS

Gears have been investigated under impact in order to evaluate their usefulness under high impacts. As yet no conclusions have been reached. Preliminary tests indicated that damage is difficult to avoid at 10,000 g. However, the extent of damage is less than that predicted by gearing theory. For instance, a series of 5 tests was performed as part of the gear investigation. In each test, two 96-tooth, 1/8-in. wide gears were meshed, one rigidly fixed to the testing fixture and the other eccentrically weighted so as to produce approximately 0.65 in.-oz of torque in one g field. The direction of impact was such that torque value would be approximately equal to the g loading times the 0.65 in.-oz value. In the first test, both gears were stainless steel and the impact level was 5800 g from 170 fps. Fellows Red-Line tests showed no detectable damage to the rotating gear and a maximum tooth-to-tooth error of 0.0006 in. in the fixed gear. Test 2 duplicated test 1 and resulted in no detectable damage to the rotating gear and a maximum tooth-to-tooth error of 0.0005 in. in the fixed gear. Test 3 was run with a fixed 2024 aluminum gear and a rotating 2024 aluminum gear. At an impact of 5900 g from 165 fps, the fixed gear showed a maximum tooth-to-tooth error of 0.0022 in. and the rotating gear a maximum tooth error of 0.0022 in. In test 4, a rotating stainless steel gear was meshed with a fixed aluminum gear and impacted at 6000 g from 170 fps. Red-Line results showed no detectable damage to the stainless steel gear, and 0.002 in. maximum tooth-to-tooth error in the aluminum gear. Test 5 meshed a rotating aluminum gear with a fixed stainless steel gear. No damage could be detected to the steel gear and a maximum tooth-to-tooth error of 0.003 in. appeared in the rotating aluminum gear. The impact level was 6,000 g from 170 fps. These test results are inconsistent both in theory and among themselves. Further test and analysis is being performed.

HIGH IMPACT ELECTRO-MECHANICAL HARDWARE INTEGRATION TECHNOLOGY
NASA Work Unit 186-68-10-02
JPL 384-65501-2-3550

The major portion of the effort expended on this task during the report period has been directed toward the development of a high-impact resistant gas chromatograph. This instrument is being developed in conjunction with the JPL Space Sciences Division, using the Mars atmospheric scientific feasibility gas chromatograph breadboard as a basis. Figure 1 shows the design of the instrument. The components which have been tested in all principal planes and which have been tested in conjunction with the development of the instrument are listed as follows:

1. Gas chromatograph columns filled with molecular sieve 5A.
2. Gas chromatograph columns filled with silica gel.
3. Rotary gas sample valves.
4. Pressure regulators.
5. Ionization detectors.
6. Plumbing techniques.
7. Packaging techniques.
8. Dynamic capacitors.
9. Victoreen hi-meg resistors.
10. Texas Instruments 1% glass-carbon resistors.
11. Sprague solid slug tantalum capacitors.
12. Goodall Mylar capacitors.
13. Hamlin Reed switches.
14. Transistors (Texas Instrument 2N930, 2N2605, 2N3350, 2N3609, 2N2432, 2N3329, Fairchild 2N3117, SSP 2N2843).

At the present time, all electrical components suspected of being incapable of surviving high impact have been tested and ruggedized where necessary. The sample valve, columns, detectors, jet pump, and manifolding techniques have been designed and fabricated and are under test. The pressure regulator has been designed and is under fabrication. The electronic packaging design has been completed, circuit boards have been fabricated, and the electrical system is operating in prototype form. The first complete gas chromatograph assembly should be ready for testing within two months.

The design goal for the gas chromatograph is the capability of surviving a 10,000 g impact from 500 fps. Components have been tested to 10,000 g from 200 fps.

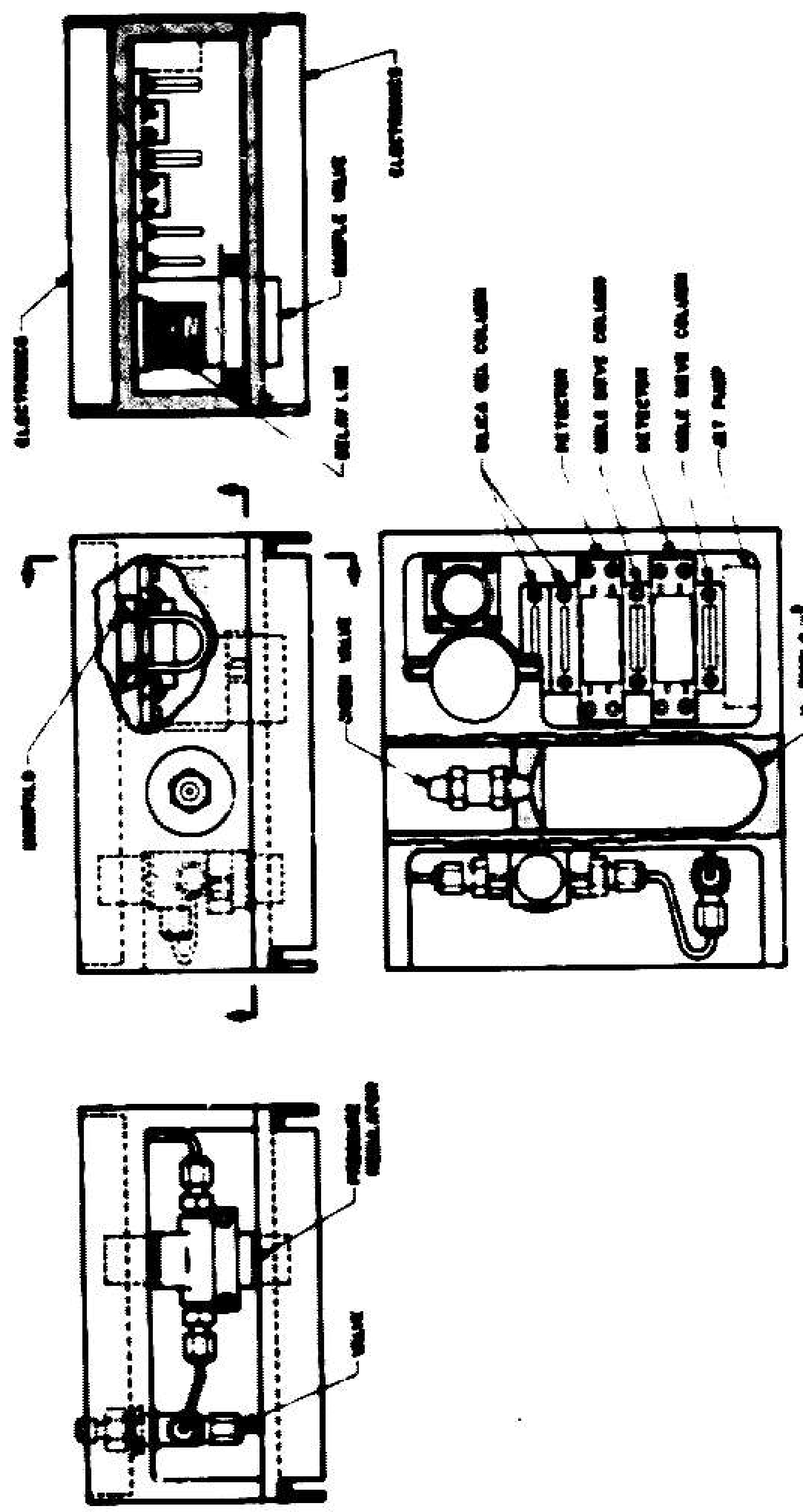


Fig. 1. Gas chromatograph configuration

Most of them should be capable of withstanding the 500-fps im- Testing is now underway in order to qualify the components for this higher im, energy level. The gas chromatograph makes use of rigid construction, internal gas piping, and securely mounted components. The finished package will occupy a volume 4x4x7 in and weigh approximately 8 lb.

This work unit will be divided into two portions in FY 1966. One of the portions will be "High Impact Scientific Instrument Technology" and will be concerned with completing and testing the gas chromatograph and initiating development on another instrument of interest both to planetary landers and the high-impact technology effort. The other portion will be entitled "High Impact Demonstration Landing Payload" and will be concerned with the development of a demonstration hard landing payload. The purpose of the effort will be to investigate electrical and mechanical integration problems due to high impact and to provide a vehicle for structural investigations. The payload will include the gas chromatograph, temperature and pressure sensors, batteries, a transmitter, and associated electronics.

A contract for the evaluation of balsa wood impact limiters under velocities up to 500 fps is in process. RFP's have been sent out, proposals have been received, and evaluation is under way The contract should be awarded by August 1, 1966, and will include the design, development, and testing of representative hardware. The intent is to extend the balsa wood technology acquired during the Ranger hard-lander efforts to cover the higher approach speeds and differing environments of planetary hard landings. The funding for the contract was reprogrammed from NASA FY 1965 Work Unit 186-68-09-0 (JPL 384-65401-2-3550) "Terminal Descent and Impact."

BLANK PAGE

JPL Technical Memorandum No. 33-243, Vol. I

HIGH IMPACT TESTING
NASA Work Unit 186-68-10-04
JPL 384-65701-2-3550

During this report period, 235 high-impact tests were performed at JPL. These tests supported various high-impact development efforts as shown below:

Ruggedized gas chromatograph	62 tests
Ruggedized S-band transmitter	21 tests
Ruggedized crystal	23 tests
High-impact battery investigation	35 tests
High-impact packaging investigation	33 tests
High-impact mechanical elements	43 tests
Miscellaneous component investigations	18 tests

The majority of the tests were performed on the horizontal impact machine (sling shot) at accelerations ranging from 3,000 to 15,000 g with preimpact velocities ranging from 100 to 200 fps. The drop tower was used in the testing of obviously delicate components. A few items were tested using the 6-in. diameter air gun. However, this gun has only recently become operational, so that most of the firings during the report period were for the purpose of de-bugging the gun itself.

Figure 1 is a photograph of the 6-in. compressed air gun Figure 2 is a schematic of the device. The gun itself consists of a 2-ft diameter x 9-ft long storage chamber, two 6-in.-diameter barrels 18-ft long, and various pipe fittings. The projectiles are loaded into the barrels and held under slight tension against O-ring seals. Tension is provided by rods which are fitted with turn buckles and connect the two projectiles by means of a clevis, a yoke, and a shear pin. The storage chamber is pressurized until the shear pin fails. Various velocities can be achieved by controlling the shear area.

The impact is obtained by decelerating the projectile after it leaves the barrel. The simplest method used for this purpose employs blocks of wood. The velocity of the projectile prior to impact is measured by means of break-wires. An accelerometer is carried on board the projectile and data is obtained by means of a trailing cable. The projectiles are hollow and test specimens are secured to the back of the projectile nose. Projectiles can also be used to test the energy absorption capability of various materials. Figure 3 shows two blocks of balsa wood which were impacted with 25-lb projectiles traveling at approximately 500 fps.

A 22-in.-diameter compressed air gun is under development. Figure 4 shows the gun in its present state. Its operation is identical to that of the 6-in. gun except that the gun has only one barrel. It should be capable of accelerating 500 lb to 500 fps. The gun will be used both to accelerate projectiles containing test specimens to impact velocities for subsequent deceleration against a crushable material (identical to the 6-in. gun mode of operation) or with a piston to allow the testing of

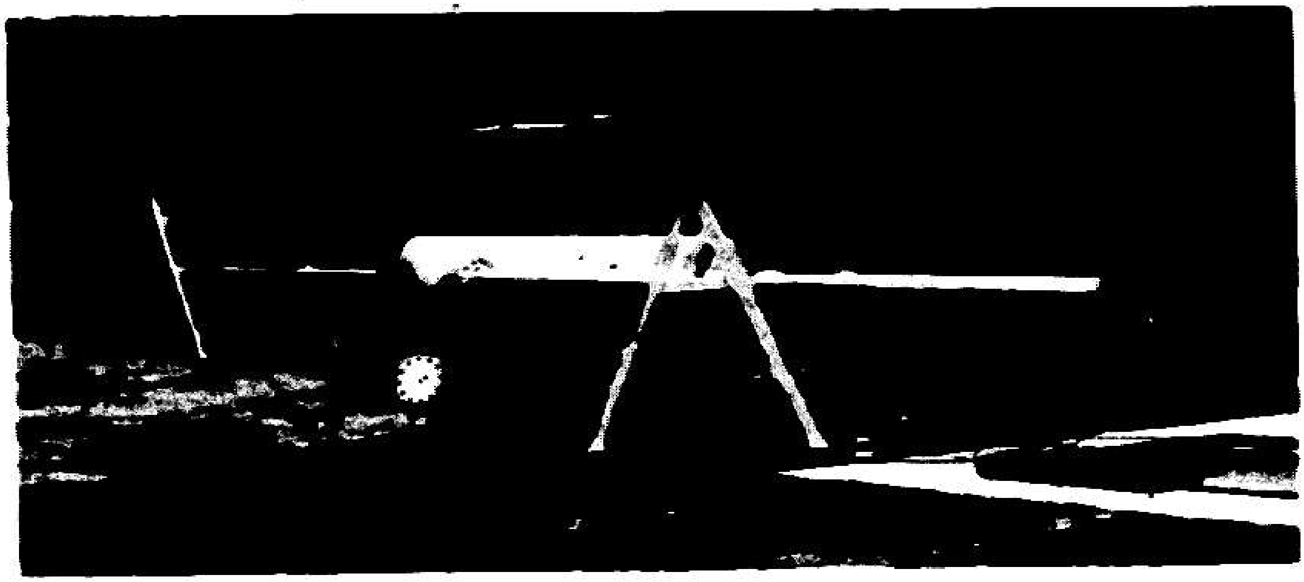


Fig. 1. 6-in. diameter compressed-air gun

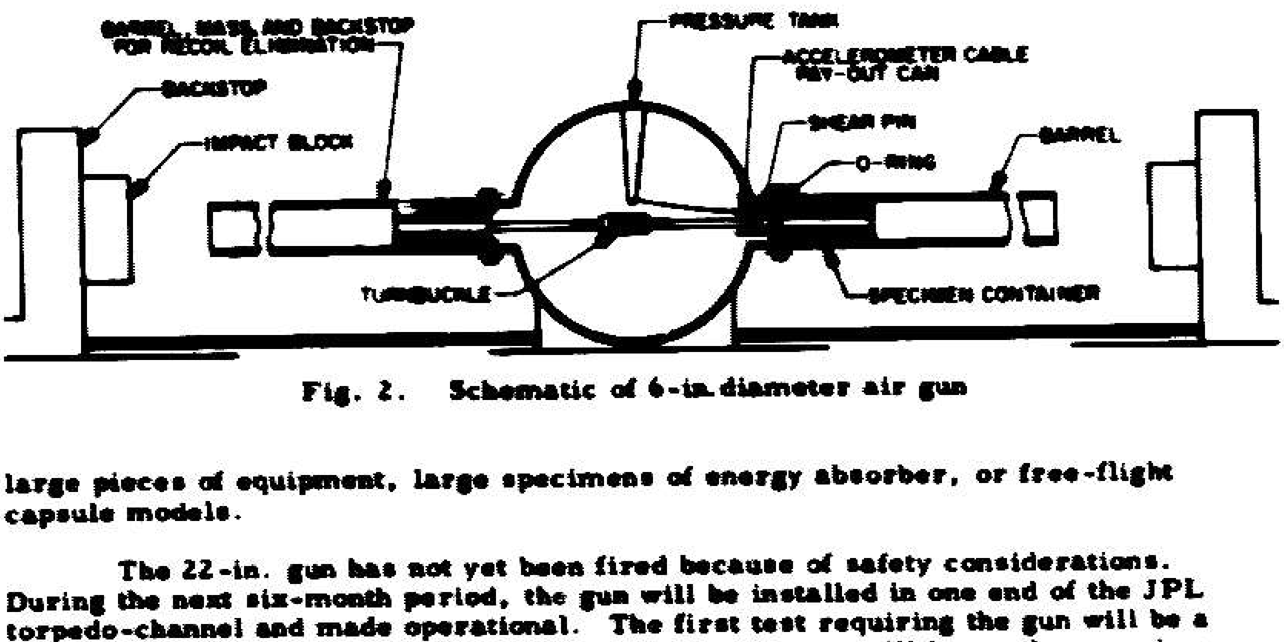


Fig. 2. Schematic of 6-in. diameter air gun

large pieces of equipment, large specimens of energy absorber, or free-flight capsule models.

The 22-in. gun has not yet been fired because of safety considerations. During the next six-month period, the gun will be installed in one end of the JPL torpedo-channel and made operational. The first test requiring the gun will be a test of an air-bag capsule deceleration system. The gun will be used as a prime mover for a piston which will accelerate the test item and then be stopped to allow the test item to impact in free flight. During FY 1966, all high-impact test facilities and the associated shop and laboratory will be moved into the torpedo channel. This will allow centralization of instrumentation, installation of the facilities, better environment control, and more efficient operation.

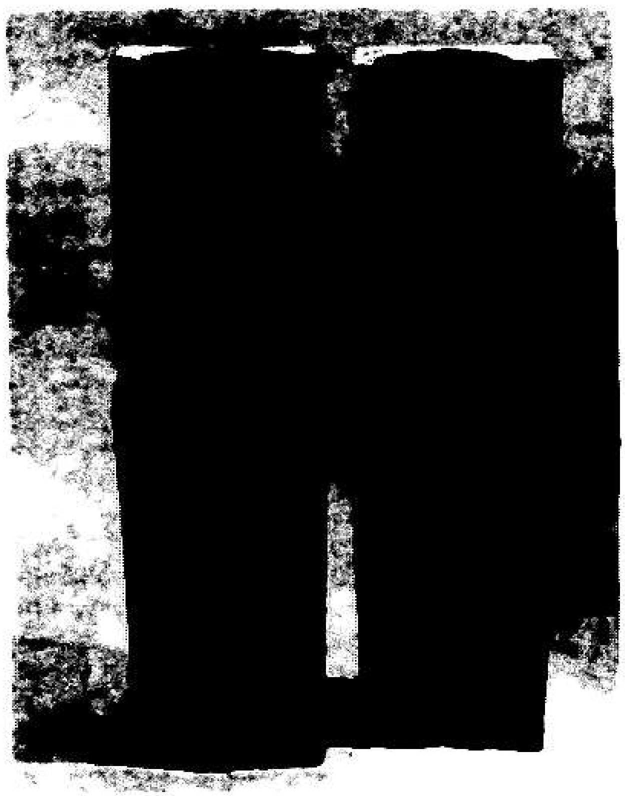


Fig. 3. Balsa blocks impacted by 6-in. diameter 25-lb projectiles at 500 fps

Additional reports on high impact testing can be found in SPS 37-31, Vol. IV and V, SPS 37-32, Vol. IV and V, and SPS 37-33, Vol. IV and V. During the reporting period, technical contacts were made with Langley Research Center, Harry Diamond Laboratories, Sandia Corporation, Aeronutronic Division of Philco, Space General Corporation, and various manufacturers of components and devices. Detailed information about the JPL sling-shot and drop tower was given to Space General Corporation. As a result, they were able to build similar facilities with a minimum of cost and delay.

Fig. 4. 22-in. diameter compressed-air gun

JPL Technical Memorandum No. 33-243, Vol. I

ADVANCED MECHANISMS - PIN PULLERS AND LATCHES
NASA Work Unit 186-68-12-01
JPL 384-62401-2-3550

Figure 1 shows a test unit developed for the investigation of various film lubricants for possible use in spacecraft. There are many such lubricants available with potential advantages for spacecraft application (stability in vacuum, cleanliness, operational convenience). However, many of them are unknown quantities as far as lubrication is concerned. The test unit is for the purpose of running long term tests on such lubricants in air. A similar device can perform tests in a simulated space environment. Table 1 shows some of the results obtained with the test unit. It is planned to keep this unit continuously in operation screening various film lubricants as they become available.

The operation of the test unit is quite simple. Shafts of various materials can be supported between bearings and driven by the constant speed motors. Bushings of various materials are placed upon the shafts and loaded by hanging weights which bear upon a crank. The shafts and bearings are treated with the various test lubricants. Friction torque is counterbalanced by rotation of the crank, which results in a direct reading of torque upon a calibrated dial. Dampers are attached to the crank member to prevent dynamic oscillations The machine contains automatic timers and limit switches which terminate the tests automatically if the torque exceeds a certain limit.

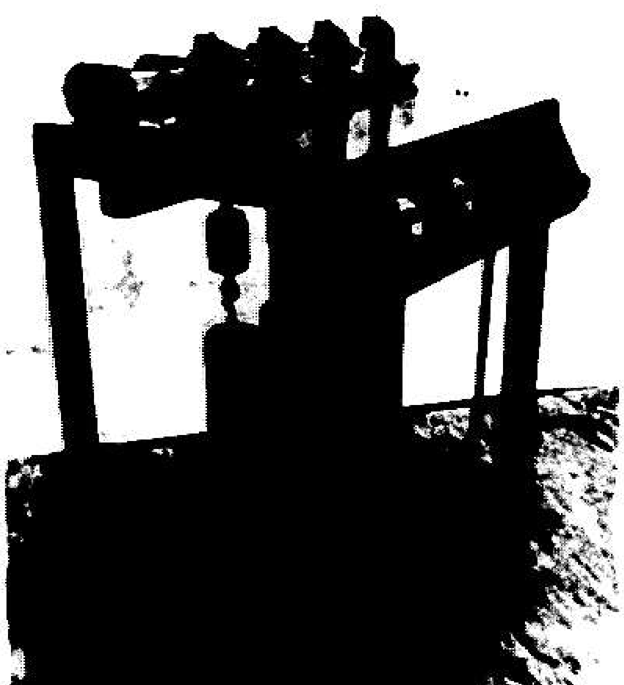


Fig. 1. Film lubrication tester

Table 1. Film lubricant test results[a]

Sleeve material	Dry lube	Radial load, lb	Speed, rpm	Time to failure
303 S.S.	Everlube 811	40	100	4 hr
303 S.S.	Dri-Lube 805	40	100	1 hr
2024 Al.	Electrofilm 1005	40	100	6 min
303 S.S.	Electrofilm 1005	40	100	1 min
2024 Al.	Electrofilm 4306	40	100	191 hr
2024 Al.	Electrofilm 811	40	100	159 hr[b]
2024 Al.	Dri-Lube 811	40	100	187 hr
303 S.S.	Electrofilm 2007	4	100	54.5 hr
303 S.S.	Everlube 811	4	100	55.7 hr
2024 Al.	Everlube 811	4	100	529.8 hr[b]
303 S.S.	Electrofilm 4306	4	100	82.3 hr

[a]A 321 stainless steel ground shaft was used in each case; the unit loading was 160 lb/in.^{2} for 40 lb loading and 16 lb/in.^{2} for 4 lb loading.

[b]These two data points are not valid since metal-to-metal contact was experienced prior to the times listed. This was not detected since the friction coefficient of 321 stainless steel on 2024 aluminum is not greatly different than the metal to metal situation.

Figure 2 is an exploded view of a spring operated rotary gas valve. This valve was developed for use as the sample valve in the high-impact gas chromatograph. However, since it has potential application in a variety of instruments, it was developed as an advanced mechanism. The valve as shown is a three-position valve which interconnects the gas chromatograph sample source, the carrier gas, the vacuum line from the jet pump, the sample loop, and the analysis line. However, by changing the porting and the escapement the valve can perform a multitude of switching functions. The valve is powered by a spirator spring which stores sufficient energy for 45 cycles (15 revolutions). The unit weighs 1/2 lb and can be triggered by any small mechanical input. It has successfully survived impacts of 10,000 g from velocities in excess of 100 fps.

During this report period, the effort has been lower than anticipated due to diversion of manpower. The mechanism specialists who were expected to work in

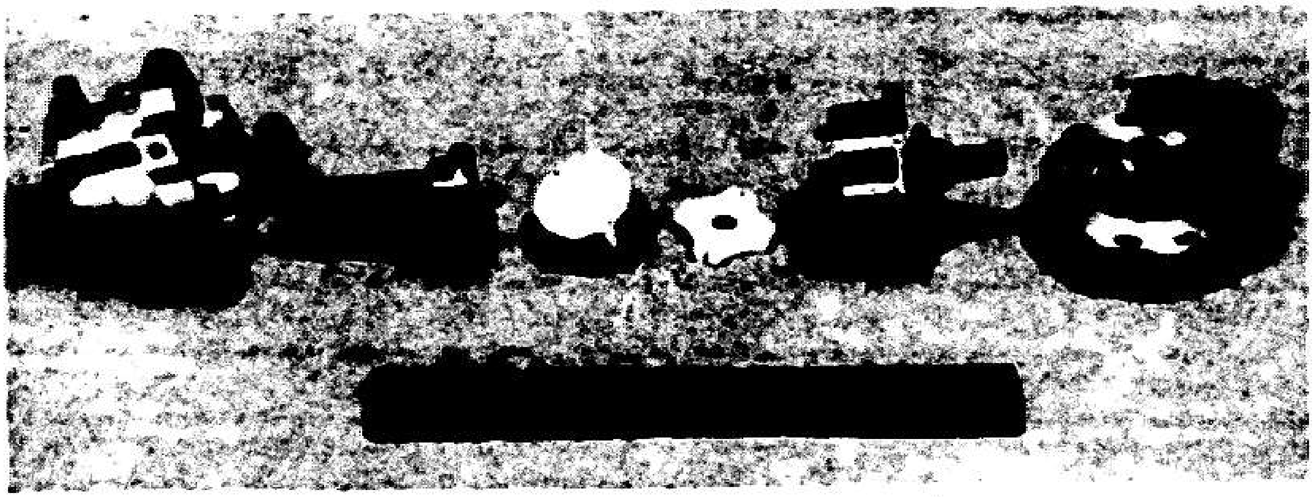


Fig. 2. Gas chromatograph sample valve

this area have been assigned to the Surveyor or Voyager projects. On the basis of a projected continuation of the manpower and billet shortage, the pin-puller and latches effort is being terminated as of the end of FY 1965

BLANK PAGE

ADVANCED MECHANISMS - SEPARATION
NASA Work Unit 186-68-12-02
JPL 384-63501-2-3550

During this report period, the separation effort has been lower than anticipated due to diversion of manpower. The mechanism specialists who were expected to work in this area have been assigned to the Surveyor or Voyager projects. On the basis of an expected continuation of a manpower and billet shortage, the separation effort is being terminated as of the end of FY 1965. This report contains a summary of the work performed during FY 1965. It was not all performed during the reporting period, but is included because of project termination.

A simulator was developed at JPL to allow the testing of spinup and despin systems, nutation dampers, precession attitude control devices, and other equipment needed for separation of spin-stabilized capsules and payloads. The simulator is shown in Fig. 1. It consists of a toroidal tank which serves both as the capsule mass and the pressure vessel for any cold gas systems being tested. The tank can be mounted either to a modified automobile universal joint or to an air bearing made from a bowling ball and a concave pad. The air bearing is used in applications where very low friction is desired. The universal joint is used for less sensitive applications as it is less subject to contamination and mechanical damage.

The simulated capsule has a weight of 300 lb, a moment of inertia of approximately 25 slug-ft^2 about its other axes, and a moment of inertia of 50 slug-ft^2 about its principal spin axis. During the development of the simulator, it was fitted with a

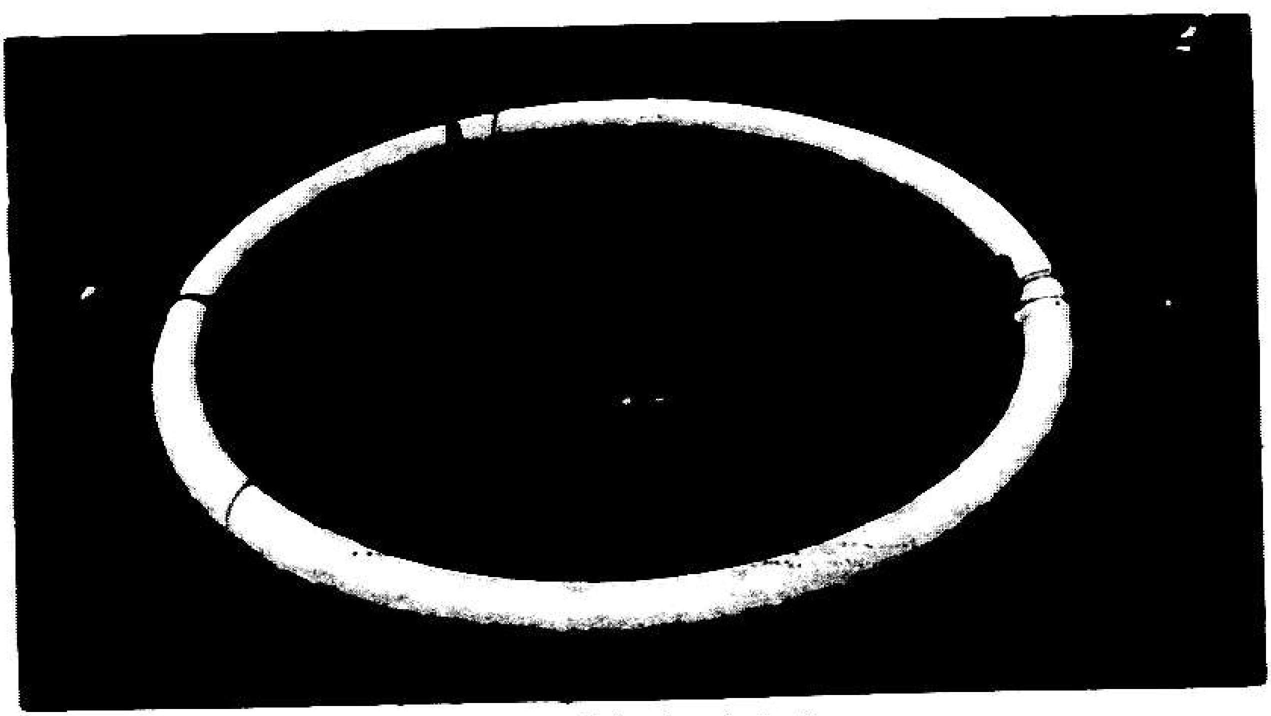


Fig. 1. Spin-despin tester

cold-gas spinup system and a yo-yo despin system. The spinup system could accelerate the rotating mass to 90 rpm in 5 sec or 135 rpm in 15 sec. Solenoid valves were used for actuation and the rate of spinup was controlled by metering the gas. The despin system utilized a nichrome heating loop which cut a nylon line to release the weights. All instrumentation was accomplished with calibrated motion picture cameras.

An interesting portion of the development program was the provision of a barrier to stop the despin weights. These weights can weigh several lb and travel at several hundred fps. It was desired not only to stop them but to stop them gently enough so that they could be re-used. After studying many combinations of materials, it was found that the cheapest and functionally most satisfactory solution was to use baled waxed paper containers. These bales were 30x36x72 in. and weighed approximately 100 lb each. The total cost for a complete enclosure (40 ft ID, 9 ft high) was under $100.00.

A pendulum separation simulator (Fig. 2) was developed for use in evaluating various separation techniques. This device consists of a fixed vertical separation surface and a simulated (mass and moment of inertia) capsule suspended by a cable which is attached to bearings at the capsule c.g. The simulated capsule is free to pitch, yaw, and translate on the end of the cable. In its present form it is constrained in roll. Capsule pitch, yaw, and position as a function of time as recorded by means of calibrated motion picture cameras.

A large part of the experience gained through this development, the instrumentation techniques and equipment, and the people who had developed the pendulum

Fig. 2. Pendulum separation device

separation simulator were used during the Mariner Mars shroud problem. During the shroud work at JPL, between the firings of Mariner III and Mariner IV, it became necessary to perform separation tests on a metal shroud in a short period of time. Because of the advanced development effort which had taken place, it was possible to design, develop, and fabricate a test facility and to perform the required tests within a few days.

BLANK PAGE

separation simulator were used during the Mariner Mars shroud problem. During the shroud work at JPL, between the firings of Mariner III and Mariner IV, it became necessary to perform separation tests on a metal shroud in a short period of time. Because of the advanced development effort which had taken place, it was possible to design, develop, and fabricate a test facility and to perform the required tests within a few days.

BLANK PAGE

JPL Technical Memorandum No 33-243 Vol. I

ADVANCED MECHANISMS – DAMPERS
NASA Work Unit 186-68-12-03
JPL 384-63601-2-3550

During this report period, the damper effort has been lower than anticipated due to diversion of manpower. The mechanism specialists who were expected to work in this area have been assigned to the Surveyor or Voyager projects. On the basis of a projected continuation of the manpower and billet shortage, the damper effort is being terminated as of the end of FY 1965.

The bellows damper evaluation has been completed. Figure 1 shows the bellows damper in both partially disassembled and assembled configuration. JPL Section Report No. 355-7, "Development of a point damper for the Ranger Solar Panels," contains a discussion of the damper and test results compared with test results for the Ranger flight dampers. The performance of the bellows damper was adequate and the original goal of achieving a flyable, leak-proof damper was achieved. The bellows damper information will be included in a JPL Technical Report to be released within a few months.

JPL Contract 951099 was let to the Dynamic Science Corporation to perform a design study of visco-elasto-plastic dampers. Funding was with FY 1964 money originally allocated under NASA Work Unit 124-08-01-01, JPL 324-00804-2-3550.

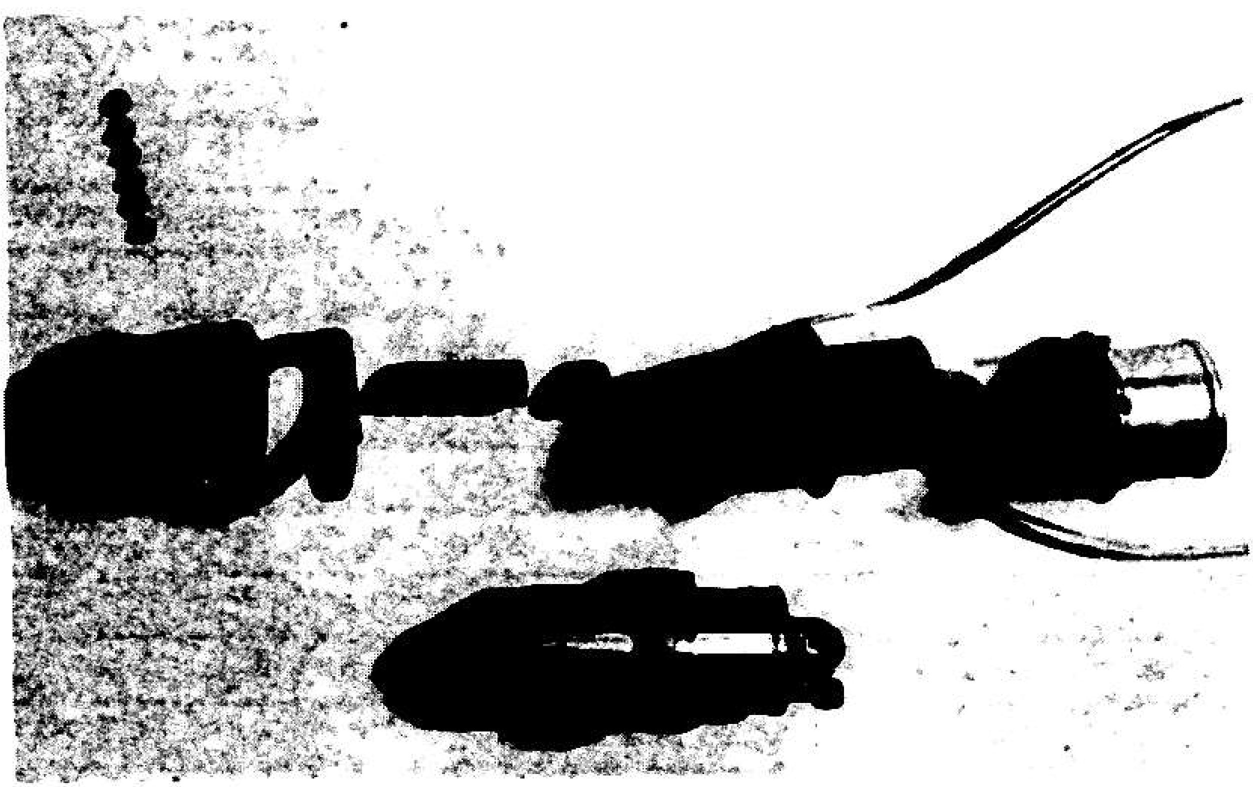


Fig. 1. Bellows damper

The contract calls for a mathematical analysis of the steady state vibration response of idealized nonlinear damper models, a design analysis to choose specific configurations for a damper, a fatigue property and temperature/pressure investigation, the determination of design procedures and curves, and the design of a specific example. The work under the contract is presently 50% complete.

PLANETARY ENTRY AERODYNAMIC DECELERATION
NASA Work Unit 186-68-13-01
JPL 384-62501-2-3530

Effort in this work unit for the second half of FY 1965 has been directed toward: (1) establishing a basis for selection of an aerodynamic decelerator and (2) selection of a system to sense conditions for release of a terminal decelerator.

BASIS FOR SELECTION OF AN AERODYNAMIC DECELERATOR

The planning of a development program for the auxiliary decelerator(s) to be used in a Mars landing requires first that the type of device and its design be circumscribed to some extent.

Choice of type and design of the device are dictated by the operational flight regime of the decelerator, and on the decelerative properties of the parent entry vehicle and initial (entry) conditions. In order to determine the constraining deployment conditions, such as velocity, altitude, density, and pitching oscillation, a systematic series of entry trajectories were computed at JPL. These trajectories utilized varied representative aerodynamic entry vehicle shapes, sizes, ballistic coefficients, initial conditions and atmospheric models. Continual updating of these trajectories has been necessary because of revisions to mission plans and to atmospheric estimates.

Evaluation of the low-altitude (deployment) flight conditions obtained in these trajectories indicated that only a single subsonic decelerator is needed if an entry vehicle (capsule) can be constructed with a ballistic coefficient below approximately 0.25 slugs-ft^2. Moreover, a supersonic decelerator stage should be added if a higher capsule ballistic coefficient is necessary for structural reasons. Capsule intrinsic aerodynamic stability appears to keep pitching amplitude and frequency within reasonable limits at decelerator deployment, even for the large sizes considered.

The decelerator system is also constrained by the payload requirement for landing impact alleviation. Tradeoff studies to optimize payload by suitably combining an impact-absorbing crushable structure with a parachute-drag capability have resulted in selection of a preferred terminal descent velocity range.

In addition, consideration of a Mars horizontal wind would require a multidirectional capability and consequently a heavier impact absorber. This consideration, however, does not appreciably increase the total energy to be absorbed, since the wind is estimated to have about the same maximum velocity as that of descent.

An in-house study of the general dynamic relationships between payload and towed decelerator has been started. In the present phase a linearized treatment identifies these combinations of system parameters where incipient instability could be expected. In-house wind tunnel support is providing experimental checks on the free-flight behavior of payload-plus-towed rigid-drogue configurations.

Continuing discussions with other government agencies and industry personnel, experienced with decelerators, have identified the types of devices most applicable to the flight regimes disclosed by the trajectory studies. For a low speed or preimpact-terminal decelerator, the type of parachute used on meteorological or sounding rocket payloads appears most promising. Further investigation with the congnizant agencies to find a means for developing this type to meet the significantly different Mars descent requirements is being pursued. For a high-speed first stage or supersonic-deployment decelerator, both balloons and specialized parachutes have shown acceptable performance in limited USAF tests at Mars density altitudes.

Earlier contract studies by Cook Electric Co., funded under this work unit title, have outlined the essentials of parachute system capability for use in Mars landing. In order to obtain comparable information on the possibly competitive balloon type, a contracted study has been initiated. Industry competition for procurement of a design study of balloon and expandable first-stage decelerators has been completed and award made to Goodyear Aerospace Corp. The contract is funded by $40,000 from this work unit and $30,000 from Engineering Mechanics Studies, NASA Work Unit 186-68-09-04. The objective is to describe the weight, stability, fabricability, packageability, and actuation characteristics of inflatable types for Mars landing use. Such information will enable a choice to be made between balloon-type devices and parachutes for first stage use.

SENSING SYSTEMS FOR DECELERATOR RELEASE

The in-house phase of this work was done under NASA Work Unit 186-68-09-04 and the results are described under that work unit.

The objective in this work unit was to let a contract to conduct an engineering study directed toward the development of a practical system which is capable of sensing entry conditions requisite to the initiation of a two-stage or one-stage auxiliary decelerator for a Martian entry vehicle. The study is expected to result in a conceptual design and engineering specifications of a sensing system that will maximize the initiation altitude for each decelerator stage, consistent with design limits, model atmospheres, trajectories and sterilization requirements specified by JPL.

An industry competition resulted in a contract being let to Northrop-Ventura, Newberry Park, Calif. Final negotiations are in progress.

POLYMERS FOR SPACECRAFT HARDWARE
NASA Work Unit 186-68-13-02
JPL 384-62601-2-3510

SPACE ENVIRONMENTAL EFFECTS ON POLYMERIC MATERIALS

During the latter half of the third and the entire fourth quarter, work continued at Stanford Research Institute under a 22K supplement, issued in February 1965, to the original contract. Work continued during the first two months of the report period under an earlier supplement, FY 1964 NASA Task 186-58-00-18. In addition to monthly informal letter reports, the contractor has issued two formal reports as follows:

1. Whittick, J. S., Effects of Spacecraft Environment on Polymeric Materials, Special Bibliography dated January 15, 1965 (JPL Contract No. 950324).

2. Muraca, R. F., et al, Space Environment Effects on Polymeric Materials, August 1964 to May 1965, Interim Technical Report No. 2 dated May 30, 1965 (JPL Contract No. 950324).

Negotiations have continued concerning renewing the contract with changes in scope. This work will be combined with the polymer specifications work in one contract, as discussed in the Future Work section.

The work during the report period was designed: (1) to ascertain the extent to which warm polymers release substances in a vacuum which condense at temperatures in the vicinity of 25 C; (2) to determine if polymers undergo gross skeletal degradation in a vacuum at temperatures in the vicinity of 125 C;[1] (3) to determine changes in pertinent physical properties of selected polymers in a vacuum-thermal environment. The commercial polymers, all elastomers, selected for study during the report period were Vitons, Nordels, and Hypalons. These materials show good behavior characteristics at moderately elevated temperatures in air and are logical space grade candidate materials.

Outgassing Studies of the Elastomers, Nordel, and Hypalon

The two elastomers Nordel, an ethylene-propylene terpolymer with a diene, and Hypalon, a chlorosulfonated polyethylene, were studied by means of the volatile condensable materials (VCM) technique and by analyzing the volatile species employing a mass spectrometer. The temperature employed (143°C) was higher than the nominal maximum (125°C) at the request of JPL in order to provide an independent crosscheck of some suspected results being obtained for Nordel on an in-house screening program using a different version of the VCM test.

---

[1] 125°C is considered to be an "average" maximum temperature during a planetary mission. 25°C is considered typical of equipment aboard a planetary spacecraft not in the immediate vicinity of an internal heat source.

The equipment used by Stanford is shown in Fig. 1, 2, 3, 4, 5, 6, and 7. The VCM results obtained are plotted in Fig. 8 and 9. Mass spectrometer results are summarized in Tables 1 and 2. The appearance of one of the Nordels after vacuum-thermal exposure is shown in Fig. 10. The appearance of the Hypalons was not changed, although they (and the Nordel of Fig. 10) exhibited a marked increase in stiffness as a result of 336 hr exposure to high vacuum at 145°C in the VCM apparatus. The appearance of the VCM plugs showing the condensate from both Nordel and Hypalon after almost 100 hr exposure is shown in Fig. 11.

The results of this work and a discussion of their significance is reported in detail in Ref. 2. General, if somewhat over-simplified, conclusions from this work are as follows:

1. The Nordels studied may be considered unsuitable for spacecraft service where they will be exposed to pressures much below Earth atmospheric in combination with temperatures approaching 140°C. The oil contained in the Nordels, while of sufficiently low vapor pressure to remain in the material at relatively high temperatures in a near-earth-atmospheric-pressure environment, volatilizes quite readily at pressures approaching those encountered in space (see also Fig. 12 and Table 1).

   It is of interest and perhaps considerable significance with regard to future studies of polymers that the VCM curve for the high oil content Nordel (-113) of Fig. 8 shows a definite peak at about 50 hr with a second peak occuring in excess of 320 hr. The first peak is caused by the lower molecular weight polymer fraction (Sun Oil). The decreasing VCM values occuring between 50 and 100 hr results from volatilization of the lower molecular weight fractions from the 25°C collector. Note that the ultimate VCM value is much higher than the first peak value. It is the latter part of the curve which is of greatest interest for long time space missions.

2. The Hypalons studied, like the Nordels, showed steadily increasing VCM values out to the maximum time, in excess of 320 hr, tested. The changes in properties noted are not unexpected in view of the relatively high temperature, for Hypalon, of the test. At such a temperature, there is breakdown of either the polymer skeleton or of low molecular weight polymeric material, as indicated by the data of Table 2 (note especially the increasing carbon dioxide content of the outgassed products with increasing time).

Mechanical Properties of Elastomers

Mechanical property measurements (continuous and intermittent stress relaxation) were made in a thermal-vacuum environment on samples of Viton, Hypalon, and Nordel at a temperature of 125°C and a pressure of approximately 10^{-6} torr.

The equipment used for the tests is shown in Fig. 13 and 14. Results of the stress relaxation tests are presented in Tables 3 and 4. Table 5 gives the weight

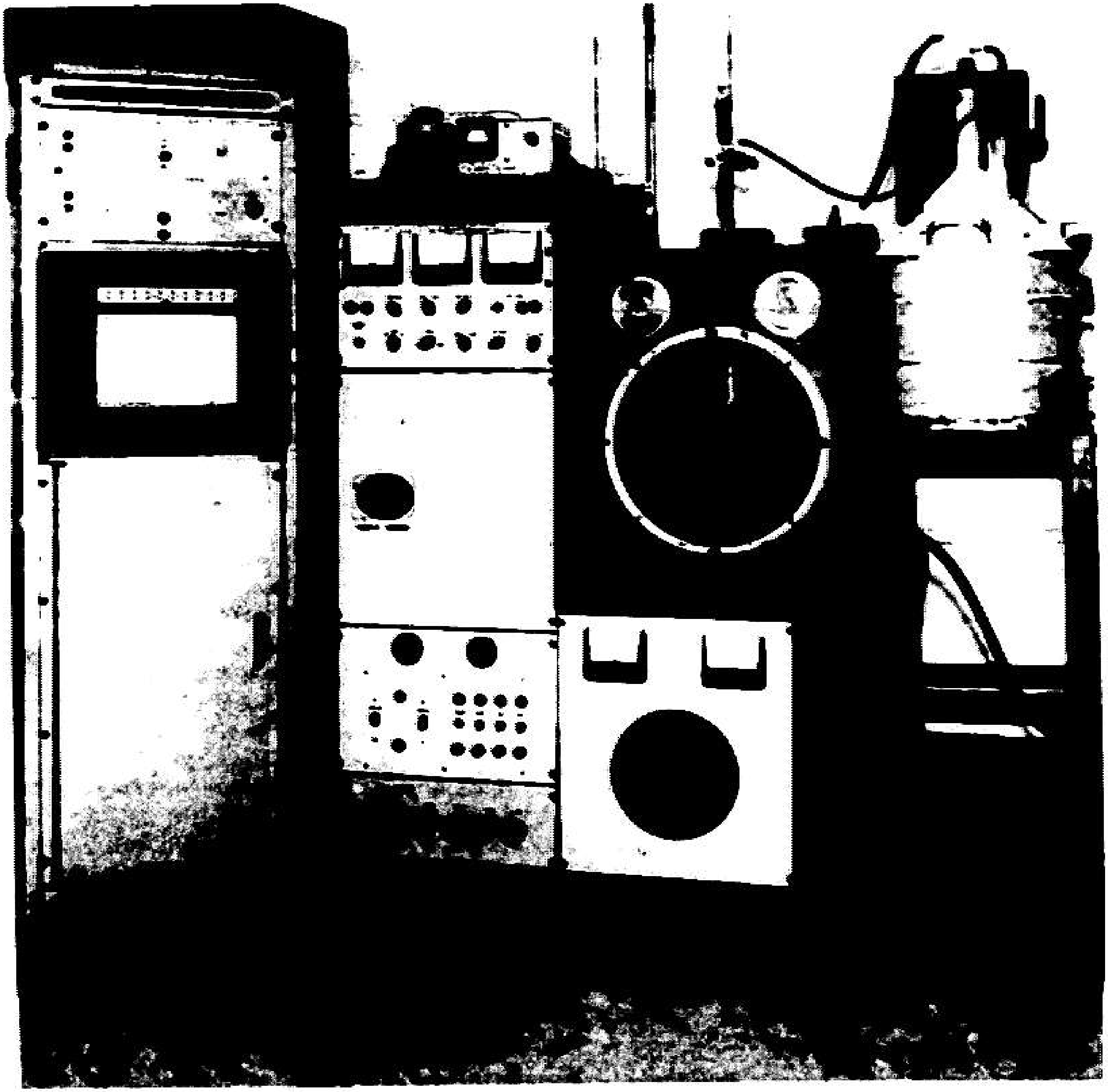


Fig. 1. Complete apparatus for VCM determination

Fig. 2. Internal view of VCM apparatus showing arrangement of heater-collector assemblies and shields

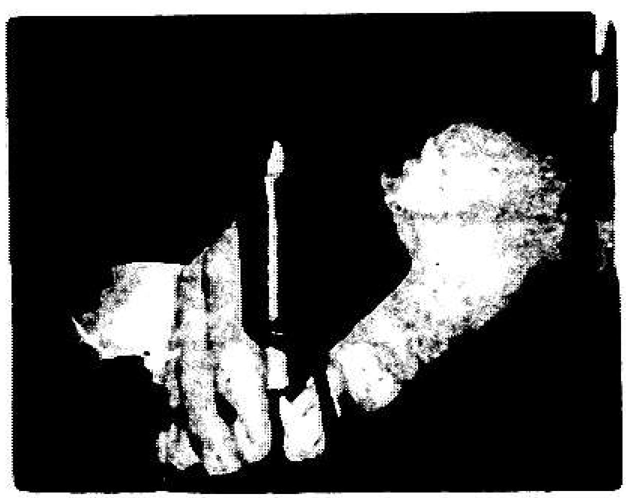


Fig. 3. Heater and shield assembly for VCM

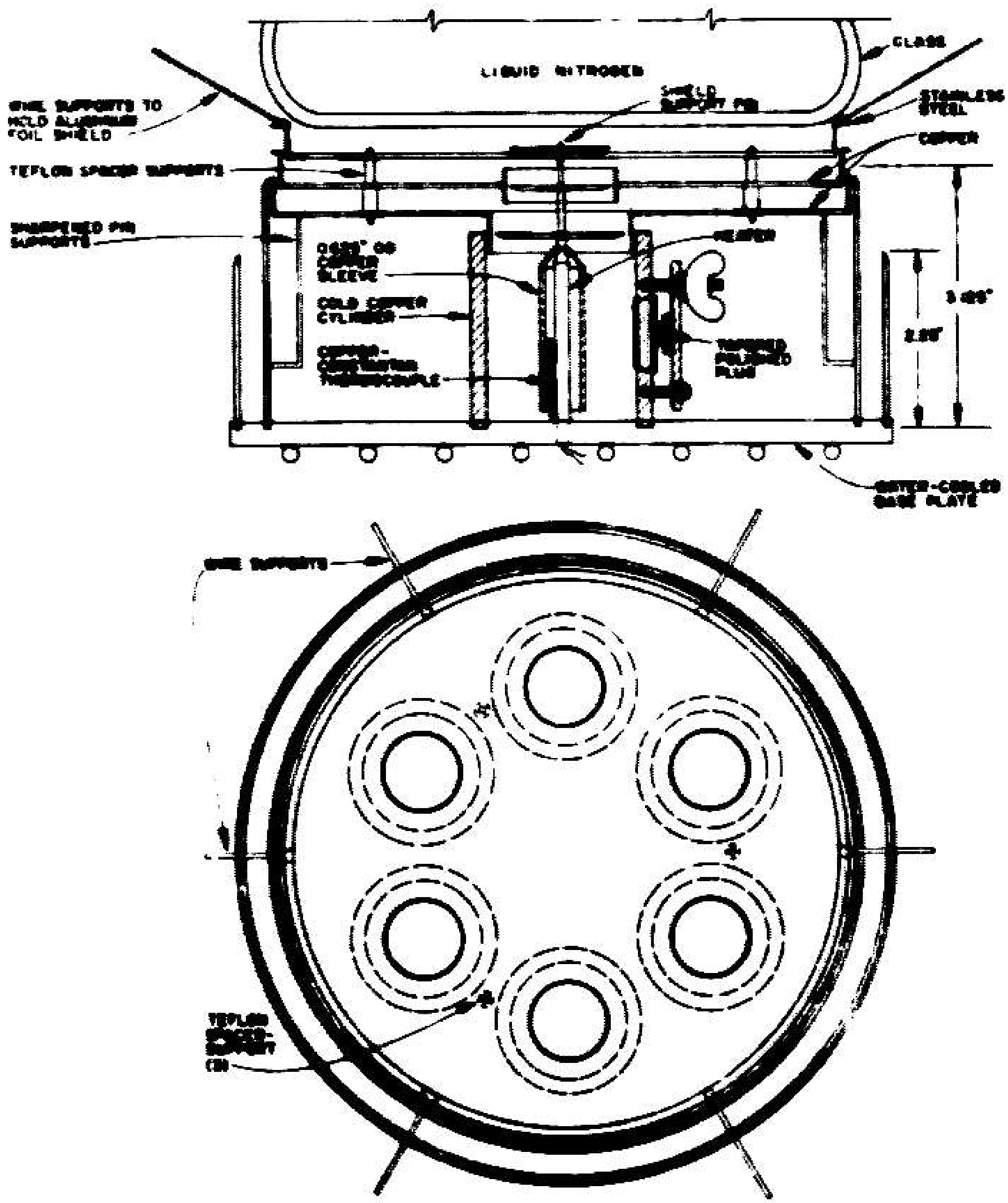


Fig. 4. Schematic diagram of a single VCM unit and arrangement of a cluster of six units

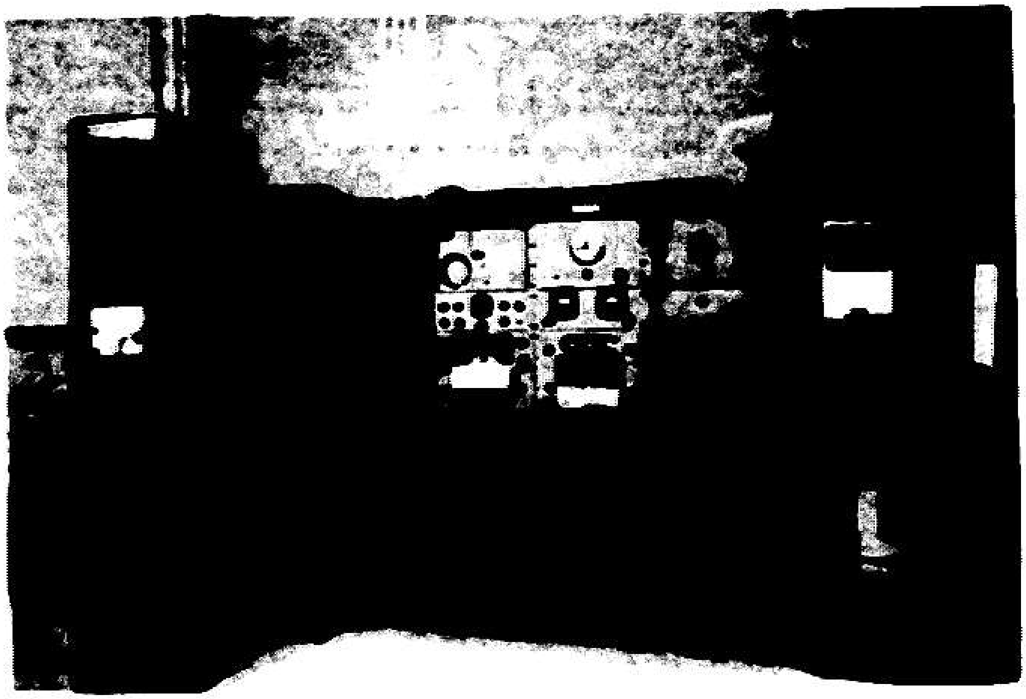


Fig. 5. Over-all view of mass spectrometer

Fig. 6. Mass spectrometer sample probe for polymers shown in place

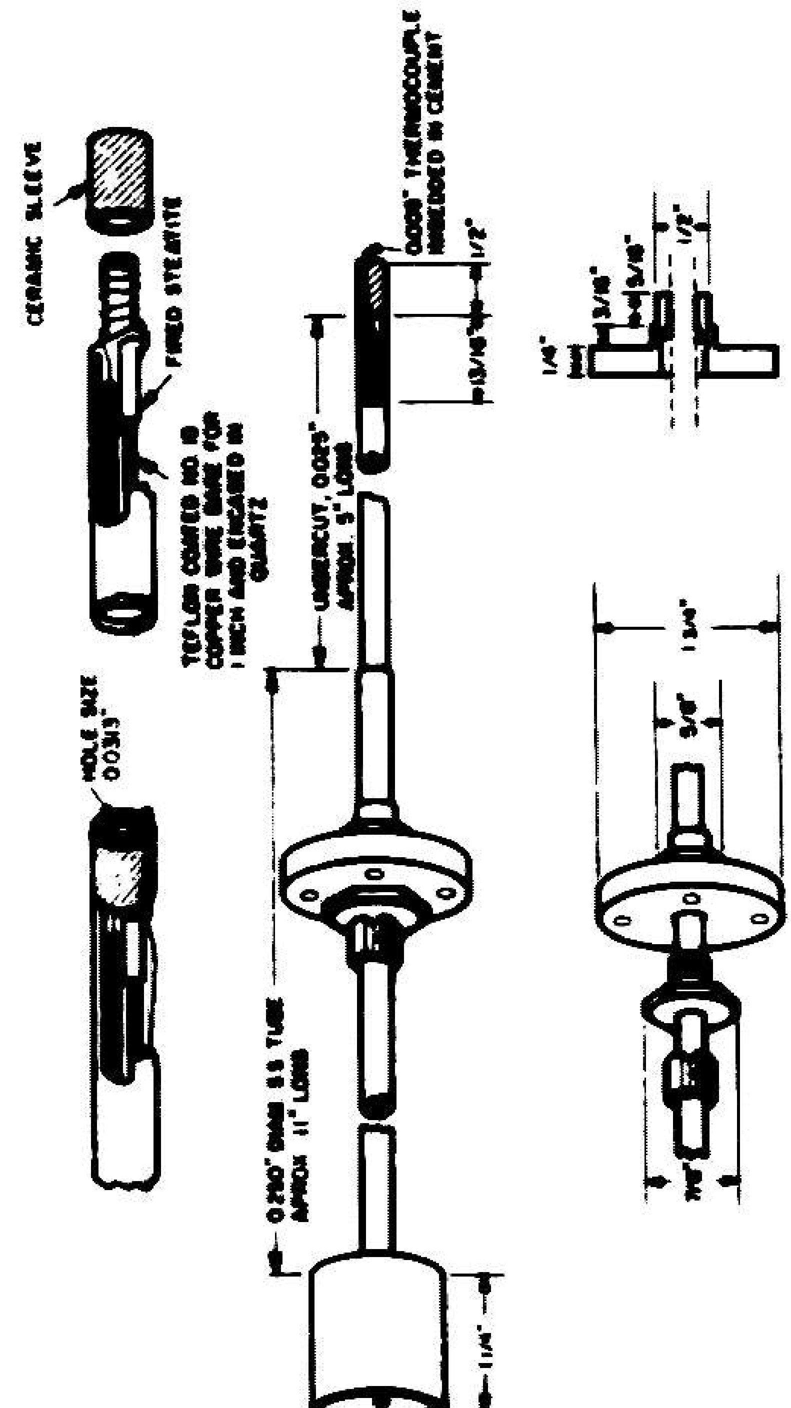
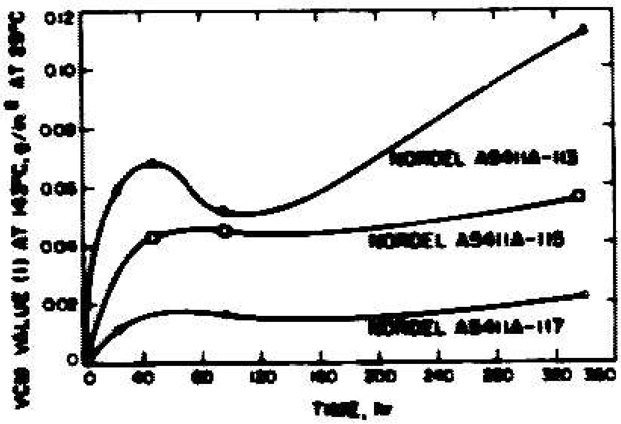


Fig. 7. Sectional view of mass spectrometer sample probe for polymers



(1) VCM value - weight of material deposited on the collec. - in grams/in^2 of emitter surface. The higher temperature is emitter temperature, lower is collector temperature.

NOTES:

Formulations (Parts by Weight)

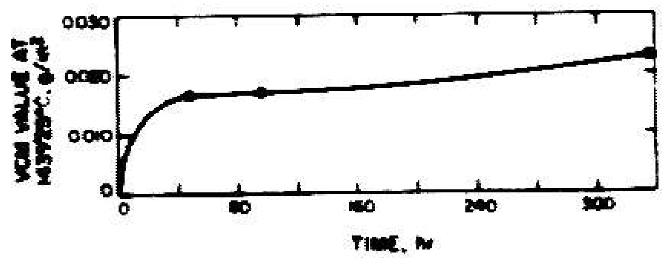
A5411A-	113	115	117
Nordel 1070	100	-	-
Nordel 1040	-	100	100
Zinc oxide	20	20	20
SRF[2] black	70	70	70
Sun Oil 5150	30	10	1
Thionex[3]	1.5	1	1
MBT[4]	2	2	2
Sulfur	0.8	0.8	0.8
Hypalon-40	-	5	5
Cure:	30'/307°F	30'/307°F	30'/307°F

(2) Semi-reinforcing furnace grade carbon black

(3) Tetramethylthiuram monosulfide

(4) 2-mercaptobenzothiazole

Fig. 8. VCM values at 143°C/25°C with respect to time for Nordel samples



NOTES:

Formulations (Parts by Weight)

Hypalon-40	100
Sublimed litharge	20
Maglite D[(1)]	
MBTS[(2)]	0.5
Tetrone A[(3)]	0.75
NBC[(4)]	3
SRF Black	25

(1) MgO

(2) Mercapto 2-benzothiazyl disulfide

(3) Dipenta methylenethiuram tetrasulfide

(4) Nickel dibutyldithiacarbamate

(5) Semi-reinforcing furnace grade carbon black

Fig. 9. VCM values at 143°C/25°C with respect to time for Hypalon A-2411A2717

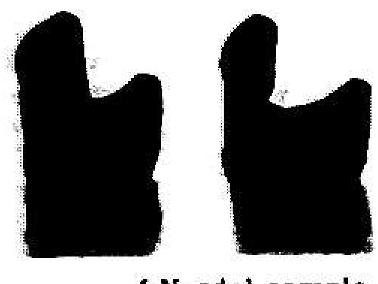


Fig. 10. Appearance of Nordel sample A5411A-117*
after 340-hr VCM run
*see Fig. 8

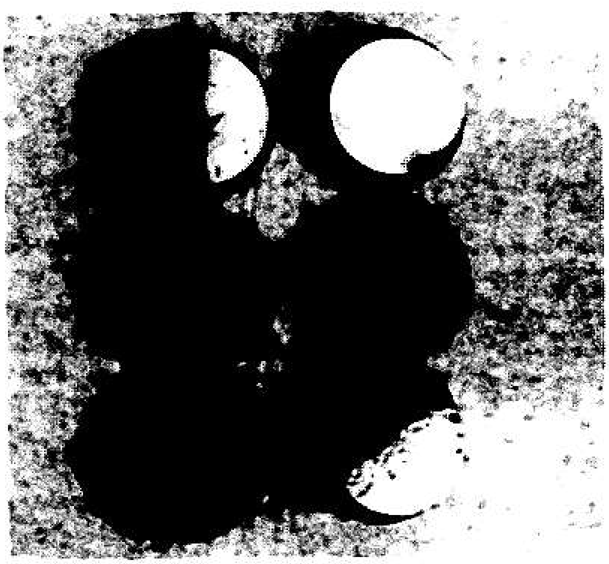


Fig. 11. View of plugs after 96-hr run

Top: Blank plugs.

Middle: Plugs showing discoloration from Hypalon A-2411A-2717; in actual appearance, the color is a green-yellow.

Bottom: Plugs showing condensate of oil from Nordel A-5411A-115.

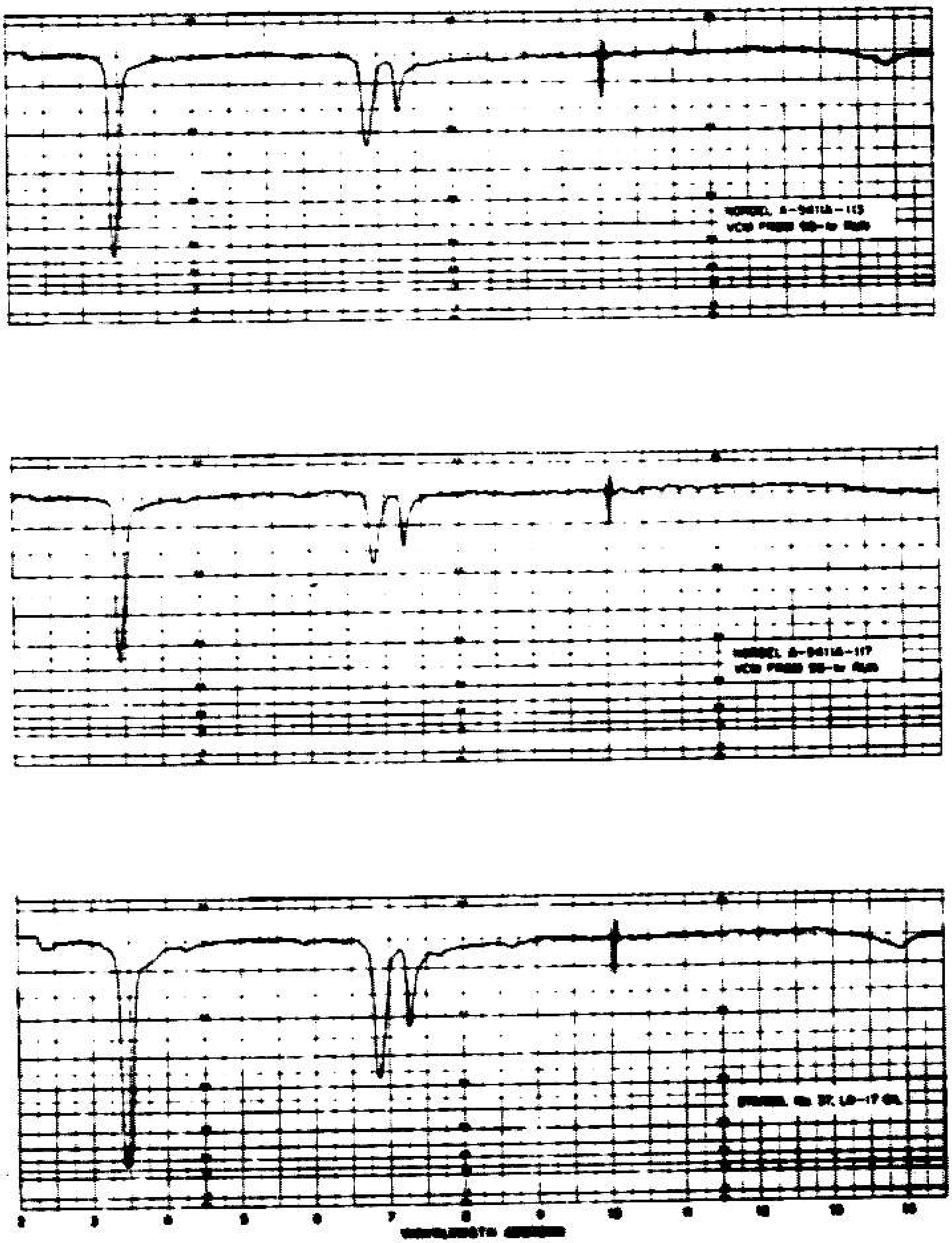


Fig. 12. Infrared absorbance of VCM from two Nordel samples compared with an instrument lubricating oil

Table I. Mass spectrometric analysis of outgassing characteristics of Nordel A-5411A-113[a]

Temperature, °C	Time at Temperature, hr	Vacuum, torr	Identification of products (estimated mol-%)	
150[b]	0.1	6×10^{-7}	H_2O	50
			saturated hydrocarbons to C_{27}	40
			terpene, to C_{15}	7
			CO_2	2
			aliphatic carboxylic acid to C_{18}	1
150	16	7×10^{-8}	same as above	

[a]1.8-mgm sample, post cured at 177°C in air.

[b]Sample was outgassed for 24 hr at 25°C and then raised to 150°C within one hour.

Note: Nordel A-5411A-113 in the as-received condition was also analyzed mass spectrometrically; the same products were identified.

loss measurements made in conjunction with the mechanical property tests, and Tables 6 and 7 show changes in tensile properties in the vacuum-thermal environment. A comparison of the stress-relaxation characteristics of Hypalon in air and in vacuum is shown in Fig. 15 and 16.

A discussion of the above results and significant conclusions is reported in detail in Ref. 2. A brief summary of the highlights follows:

1. The Nordels are not catastrophically altered in mechanical properties. However, they are not suited for the space environment because of excessive outgassing (see Table 5 and Fig. 8).

2. The Vitons appear to be the best of the materials evaluated, and based on the mechanical property data obtained to date[2], should perform satisfactorily in the space environment within the limits of their physical capabilities.

3. Hypalon, if used at lower temperatures, possibly would be suitable for use in the space environment.

[2]The outgassing behavior needs to be better understood before it can be considered entirely suitable, however.

Table 2. Mass spectrometric analysis of outgassing characteristics of Hypalon A-2411A-2717

Temperature, °C	Time at Temperature, hr	Vacuum, torr	Identification of products (estimated mol-%)	
143	0.1	7×10^{-6}	H_2O	82
			saturated hydrocarbons	14
			CO_2	3
			hydrocarbons containing Cl^-	0.5
			unsaturated hydrocarbons	0.3
143	22	8×10^{-8}	H_2O	62
			CO_2	30
			saturated hydrocarbons	3
			SO_2	2
			hydrocarbons containing Cl^-	1
			CS_2	1
			HCl	1

4. Hypalon behaves quite differently in vacuum as compared with air. Figure 15 illustrates how the tensile properties in vacuum increase with longer times during the intermittent test, while in air (Fig. 16) there is a trend indicating decreasing properties with longer times.

5. From an examination of the stress relaxation data, it is quite apparent that it should be considered how the elastomers are to be used in the space environment. For example, if a material is to be applied under a constant tensile strain, then results from the continuous tests are of greater importance than are those from the intermittent test.

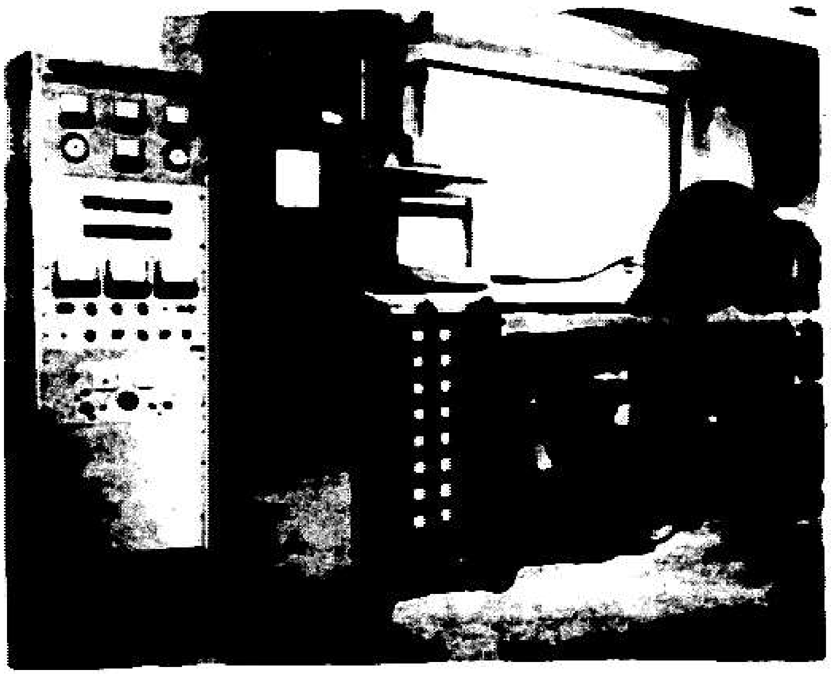


Fig. 13. Vacuum chamber and associated instrumentation used for mechanical property studies

Fig. 14. Stress relaxation assembly mounted on chamber door

Table 3. Effect of vacuum-thermal environment on stress relaxation behavior of Viton, Nordel, and Hypalon

Material	Intermittent			Continuous		
	Approx. time to f(t)/f(o) > 1.0, hr	f(t)/f(o) at 20 hr	f(t)/f(o) at 500 hr	Approx. time to f(t)/f(o) [illegible] 0.8, hr	f(t)/f(o) at 20 hr	f(t)/f(o) at 500 hr
Viton A 4411A-990[a]	20	1.01	1.27	20	0.74	0.66
Viton A 4411A-991[a]	3	1.11	1.46	70	0.83	0.76
Nordel A-5411A-113[b]	70	1.0	1.11	1	0.51	0.40
Nordel A-5411A-117[b]	5	1.20	2.48	1	0.65	0.55
Hypalon A-2411A-2717[b]	100	1.0	1.26	0.5	0.48	0.21
Hypalon A-2411AV2717[b]	250	1.0	1.07	0.8	0.52	0.25

[a] These compounds are identical except a different armine curing agent was used.

[b] See Fig. 8 and 9 for formulations.

Notes:

1. All tests conducted at strains of approximately 0.25.
2. Data obtained from best curves drawn through duplicate test results.
3. Exposure conditions consisted of two stages:

   Viton - (a) 325 hr at 50°C and average pressures of from 2×10^{-5} to 7.5×10^{-6} torr (b) up to about 800 hr at 125°C and average pressures of from 2×10^{-5} to 7.5×10^{-6} torr.

   Nordel - (a) 425 hr at 50°C and an average pressure of about 7.5×10^{-6} torr (b) up to about 600 hr of 125°C and an average pressure of about 4.5×10^{-6} torr.

   Hypalon - (a) 168 hr at 50°C and an average pressure of about 5×10^{-6} torr (b) up to about 800 hr at 125°C and average pressures of from 6×10^{-6} to 3.5×10^{-6} torr.

4. The function f(t)/f(o) is the ratio of the force at time t to the force at time o (the starting time).

Table 4. Effect of thermal environment on stress relaxation behavior of Nordel and Hypalon

Material	Intermittent		Continuous	
	Approx. time to f(t)/f(o) > 1.0, hr	f(t)/f(o) at 20 hr	Approx. time to f(t)/f(o) = 0.8, hr	f(t)/f(o) at 20 hr
Nordel A 5411A-113	1	1.2	0.8	0.52
Nordel A 5411A-117	1	1.44	0.8	0.52
Hypalon A-2411A-2717	1 (< 1.0)	0.91	0.8	0.44

Notes:

1. All tests conducted at strains of approximately 0.25.
2. Data obtained from tests of single specimens.
3. Environment consisted of one atmosphere of air at 125°C.
4. The function f(t)/f(o) is the ratio of the force at time t to the force at time o (the starting time).

Polyurethane Degradatio Studies

Study of a synthesized polyurethane has indicated that no skeletal degradation of this polymer system takes place at temperatures below about 225°C in vacuo. Because of limited immediate interest in such high temperatures for interplanetary spacecraft service, this work was suspended early in the report period. The work is summarized in Ref. 2. It will be interesting to compare the results of this work with those for commercially available polyurethane, to be studied during the next contract year.

DEVELOPMENT OF POLYMERIC MATERIAL SPECIFICATIONS FOR SPACECRAFT

Work continued during the last half of the fiscal year at the Stanford Research Institute under a contract issued in June, 1964 ($67,000 one year, NASA Task 186-58-00-18). The major emphasis from a testing standpoint was placed on the development of vacuum weight loss criteria and the qualification of selected product to these criteria. Effort during the report period was concerned with three catego of materials: epoxy-based structural adhesives, RTV silicone rubbers and fluorocarbons.

Table 5. Weight loss of rings used for stress relaxation tests

Material	50°C Exposure		125°C Exposure		Total Weight Loss, %, average of four rings
	Time, hr	Ave. pressure, torr	Time, hr	Ave. pressure, torr	
Viton A-4411A-990	325	2×10^{-5} to 7.5×10^{-6}	800	2×10^{-5} to 7.5×10^{-6}	0.075
Viton A-4411A-991	325	2×10^{-5} to 7.5×10^{-6}	800	2×10^{-5} to 7.5×10^{-6}	0.12
Nordel A-5411A-113	425	7.5×10^{-6}	600	4.5×10^{-6}	10.5
Nordel A-5411A-117	425	7.5×10^{-6}	600	4.5×10^{-6}	3.0
Hypalon A-2411A-2717	168	5×10^{-6}	800	6×10^{-6} to 3.5×10^{-6}	3.5
Hypalon A-2411A-2718	168	5×10^{-6}	800	6×10^{-6} to 3.5×10^{-6}	2.5
Nordel A-5411A-113	0		54	760 (air)	1.1[a]
Nordel A-5411A-117	0		30	760 (air)	0.95[a]

[a]Average of two rings

Table 6. Effect of vacuum-thermal environment on tensile properties of Viton

Batch No.	History	Test temperature, °C	Stress at strain of 0.25, psi	Stress at rupture, psi	Strain at rupture, in./in.
A-4411A-990	Control	2[illegible]	127	1495	4.65
	Exposed	25	130	1940	4.85
	Control	125	79	338	2.10
	Exposed	125	102	402	1.64
A-4411A-991	Control	25	116	2180	4.32
	Exposed	25	118	2025	3.92
	Control	125	88	453	1.78
	Exposed	125	115	449	1.37

Notes:

1. All data points are averages of measurements on duplicate specimens.
2. Tests were conducted at an extension rate of 0.1 in./min.
3. Control specimens were stored at normal room conditions for the entire period from specimen preparation to final testing.
4. Exposure conditions consisted of two stages: (a) 325 hr at 50°C and average pressures of from 2×10^{-5} to 7.5×10^{-6} torr, (b) 820 hr at 125°C and average pressures of from 2×10^{-5} to 7.5×10^{-6} torr.

Epoxy-Based Adhesives

Work is nearing completion on the preparation of materials specifications based on the following products, all manufactured by the Shell Chemical Company: Epon 901, 903, 914, 917, 931, and 422J. Vacuum weight loss data are summarized in Table 8.

A draft of the first material specification is being readied for release. The approach taken is summarized in Table 9. The specification contains a series of qualification criteria, used to qualify a given product (place it on an approved list) and a set of acceptance tests which will be used as receiving inspection criteria for each lot of material received. The first product tentatively qualified under this specification is Shell's Epon 901 with curing agent B-3. As the need for multiple sources develops, other producer's products will be qualified under the specification.

Table 7. Effect of vacuum-thermal environment on tensile properties of Nordel

Batch No.	History	Test temperature, °C	Stress at strain of 0.25, psi	Stress at rupture, psi	Strain at rupture, in./in.
A-5411A-113	Control	25	63	1395	9.31
	Exposed	25	90	1630	7.39
	Control	125	60	305	2.77
	Exposed	125	79	477	2.77
A-5411A-117	Control	25	142	1425	5.09
	Exposed	25	382	1468	3.37
	Control	125	110	632	2.73
	Exposed	125	258	619	1.48

Notes:

1. All data points are averages of measurements on duplicate specimens.
2. Tests were conducted at an extension rate of 0.1 in./min.
3. Control specimens were stored at normal room conditions for the entire period from specimen preparation to final testing.
4. Exposure conditions consisted of two stages: (a) 405 hr at 50°C and an average pressure of about 7.5×10^{-6} torr, (b) 605 hr at 125°C and an average pressure of about 4.5×10^{-6} torr.

RTV SILICONE RUBBERS

Vacuum weight loss data were obtained on the following products, all manufactured by the General Electric Company, Silicone Products Department: RTV-11, 60, 511, 560, 615, 102, 106, 108, and 112. All of the materials evolved large quantities of condensable oil during the testing. In an attempt to find a simple solution to the volatile oil problem, several variations in the cure of five of the materials: RTV-11, 60, 511, 560, and 615 were tried. Use of a larger proportion of curing agent was essentially ineffective; postcuring for 24 hr at 150°C was partially successful; postcuring at 150°C in a vacuum of 10^{-4} torr was successful in virtually eliminating the outgassing of objectionable[3] condensable oil. Data are summarized in Table 10.

Work is continuing on obtaining data on the remaining RTV silicone rubbers listed and to prepare material specifications for all nine materials.

[3] These results will be rechecked on a new, recently constructed apparatus (see section on Vacuum Weight Loss Determination).

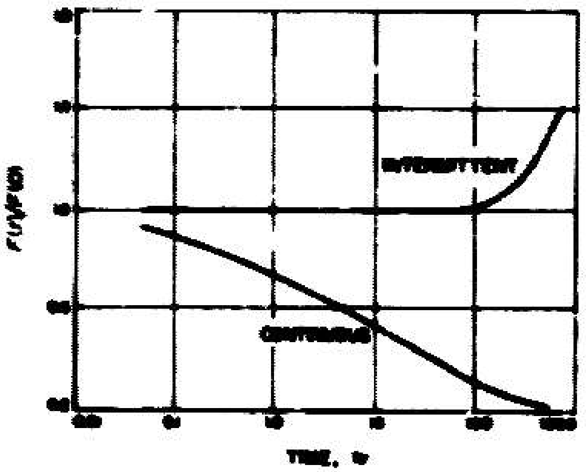


Fig. 15. Continuous and intermittent stress relaxation results of Hypalon A2411A-2717 in vacuum at 125°C

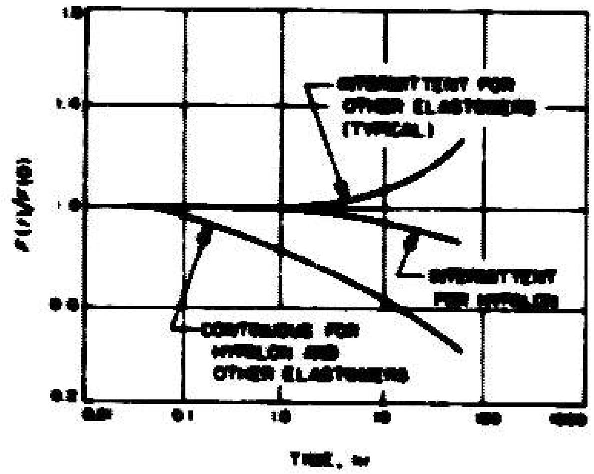


Fig. 16. Continuous and intermittent stress relaxation results of Hypalon A2411A-2717 in air at 125°C compared with other elastomers

Table 8. Vacuum weight loss of epoxy-based adhesives

Epoxy Adhesive	Cure (in air)	24-hr weight loss (%)		200-hr weight loss (%)	
		150°C	200°C	150°C	200°C
901/B-3	1/2 hr @ 116°C + 1-1/2 hr @ 177°C	0.79	0.51	0.81	1.4
903	2 hr @ 177°C	0.78	1.8	0.95	3.2
914	1/2 hr @ 204°C	0.49	1.8	0.49	2.0
917	2 hr @ 177°C	0.80	---	1.01	---
931	1 hr @ 121°C	0.61	2.2	0.61	3.8
422J	1/2 hr @ 166°C + 6 hr @ 177°C	0.95	1.7	1.13	2.1

Notes: Test pressure was 10^{-5} torr maximum.

Test method described in a JPL Test Specification.

Data extracted from an interim report on epoxy adhesives to be published in the near future by the Stanford Research Institute under JPL Contract No. 950745.

Table 9. Material specification - two part structural adhesive, elevated temperature, aromatic amine cured (diglycidyl ether of Bisphenol A type)

	Qualification	Acceptance (each lot)
Base	Resin structure[a] Epoxy equivalent Hologen content Filler type[a] Filler content Non-volatile content Viscosity Density Infrared spectrum	 Viscosity Density infrared spectrum
Curing agent	Chemical species[a] Amine value Halogen Non-volatile content Viscosity Density	 Viscosity Densiry
Mixed and cured adhesive	Vacuum weight loss[b] Tensile shear Creep rupture	Vacuum weight loss[b] Tensile shear

a. No test defined or required.

b. Test method described in separate JPL test spec.

Notes: All tests except those marked with an a or b are defined in the specification (utilizing existing ASTM specifications where applicable).

Fluorocarbons

Preliminary outgassing studies on selected polyfluorocarbon films have been completed. Five types of film, four Tedlar® and one Teflon FEP were subjected to thermal vacuum treatment at 150°C and 10^{-6} mm Hg for over 200 hr. Weight losses for all these materials were quite low, ranging from zero to about 0.5%. The outgassing characteristics of the samples tested are summarized in Table 11. No condensable oils were evolved from the test specimens. No analysis of volatiles was made because it was felt that the outgassed materials could consist only of water and gases desorbed from the surface of the test specimens. All Tedlar samples underwent very slight darkening during thermal vacuum treatment; the Teflon FEP samples remained unchanged.

Table 10. Vacuum weight loss of RTV silicone rubbers

RTV silicone rubber (G. E. number)	Weight loss in 200 hr (%)			
	0.1% Thermolite-12 no postcure	0.5% Thermolite-12 no postcure	0.1% Thermolite-12 postcured for 24 hr @ 150°C in air	0.1% Thermolite-12 postcured for 24 hr @ 150°C and 10^{-4} torr pressure
11	3.0	2.5	1.5	0.7[a]
60	1.7	1.5	0.9	0.4[a]
511	4.6	4.3	2.1	---
560	3.5	3.5	1.8	0.5[a]
615	2.2	---	---	0.9[a]
102	6.0	---	---	---
106	5.5	---	---	---
108	6.0	---	---	---
112	6.1	---	---	---

a. No evolution of condensable oil.

Notes:

Test pressure was 10^{-5} torr maximum.

Data extracted from an interim report on RTV silicone rubbers to be published in the near future by the Stanford Research Institute under JPL Contract No. 950745.

Vacuum Weight Loss Determinations

A test specification covering a method for measuring vacuum weight loss of polymers (all) has been drafted. Release is planned simultaneously with the release of the first polymer materials (adhesives) specification. Remaining to be resolved are the effects of equipment orifice size and specimen geometry on outgassing rate.

Table 11. Outgassing characteristics of fluorocarbon films ($150^\circ C$, 10^{-6} mm Hg)

Material	Code[a]	Weight loss after 24 hr (%)	Weight loss after 200 hr (%)
Tedlar	200 SG 40 TR	0.14	0.14
	200 AG 30 WH	0.39	0.54
	200 BG 30 WH	0.35	0.50
	50 AG 20 TR	0-0.05	0-0.05
Teflon	500 A FEP/a	0.004	0.075
	500 A FEP/b	0.003	0.05

[a]Key to DuPont film code identifications:

1. Film thickness
   - 200 = 2 mil
   - 50 = 0.5 mil
2. Surface characteristics
   - A - One side adherable for use with adhesive inks or coatings; the other side is nonadherable and can be heat sealed
   - B - Both sides are adherable, but not heat-sealable
   - S - Both sides are strippable and both can be heat sealed
3. Degree of surface gloss
   - G - Highly glossy surface
4. Film type
   - 40 - Film with low shrinkage and good formability
   - 30 - Film having medium tensile strength
   - 20 - Film with high tensile strength
5. Color
   - TR - Transparent
   - WH - White

Tests aimed to resolve these questions are proceeding at this writing. The test specification will cover the vacuum test system and associated equipment, preparation of test specimens, test procedure, and preparation and reporting of test data.

The research apparatus on which initial vacuum weight loss tests were run and on which the test methods and criteria were established is shown in Fig. 17, 18, and 19. A simplified apparatus for more rapid testing of materials, which should eliminate any problems with possible "Knudsen cell effects," is shown in Fig. 20 and 21.

FUTURE WORK

Contract negotiations leading to continuing the work with Stanford are proceeding, and it is hoped that a new one-year contract for approximately 160K will be placed within the foreseeable future. The new contract is funded entirely with FY 1965 186-68-13-02 funds. The Voyager project plans to fund subsequent contracts.

The new contract, entitled "Polymers for Spacecraft Hardware," continues the work reported in earlier sections of this report with some changes in scope, as summarized below, and will be divided into two phases under the titles, "Materials Specifications" and "Engineering Information."

The intent of the Material Specifications phase is to complete the work already begun on preliminary materials specifications for the RTV silicones and the fluorocarbons. New work is planned to be begun on testing and preparing preliminary specifications for conformal and other protective coatings, elastomers other than the RTV silicones, wire enamels, and non-structural adhesives. Depending on the types of problems encountered in the foregoing as it affects the rate of effort, work may also be begun on foams and sleeving materials. In addition, approximately fifty materials in other use categories are planned to be tested for outgassing characteristics using somewhat more sophisticated and meaningful techniques than in JPL's in-house screening programs.

The Engineering Information phase of the contract will be aimed to obtain long-time data on outgassing behavior and physical and mechanical properties of carefully characterized materials most of which will be considered spaceworthy based on the preliminary testing to be conducted in the Specifications phase. In the event unexplainable results are obtained, carefully selected base-line materials will be studied to give clues for likely approaches for modifying materials (on other contracts).

It must be emphasized that development of truly spacecraft-quality materials is outside the scope and funding structure of the new contract. It is felt that the state of the art is such that it is better to concentrate on utilization of existing commercially available materials and to define the most serious problems (inadequacies of available materials) on a broad basis rather than to expend the meager funding available at this time by proceeding with serious materials development work. There seems to be little question that such inadequacies will be revealed by the work at Stanford, although as yet not enough is known to pinpoint the areas where development work is most urgently needed. For example, from the relatively small amount of work done to date it is apparent that none of the elastomers studied on either of the Stanford contracts (with the possible exception of the Vitons, where outgassing information is inadequate) can be considered truly space-grade materials.

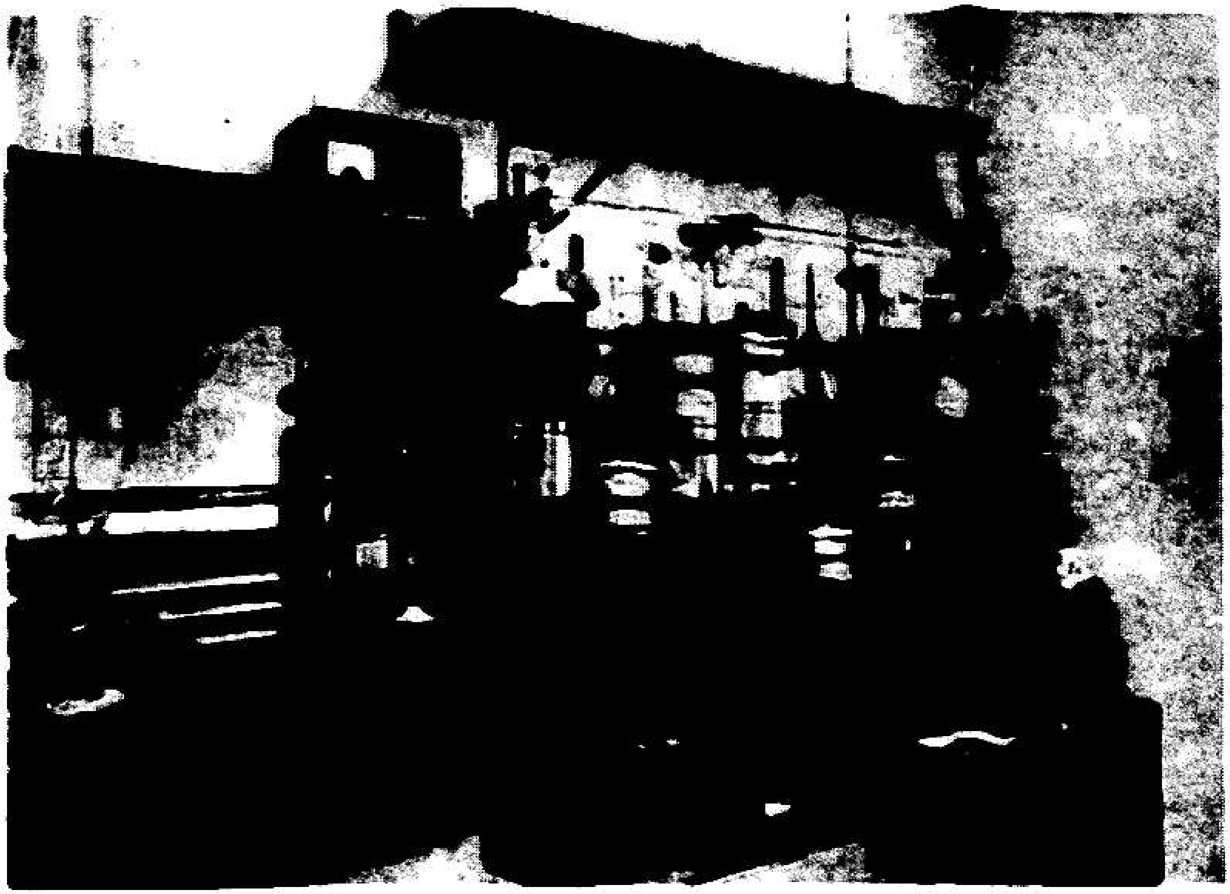


Fig. 17. Vacuum weight loss research apparatus

The vacuum post cure that must be employed for the RTV silicone rubbers virtually rules out these materials for many spacecraft applications.[4] If the millable silicones, to be studied shortly, make as poor a showing as have the Nordels and RTV silicones, it may be necessary to develop some space-grade multipurpose elastomers – millable types, usable where the Vitons and Hypalons are inadequate, and cured-in-place types, usable where the processing restraints required for the RTV silicones are too restrictive.

[4]For example, many of the electronic parts that will be used on the Voyager spacecraft will not be able to withstand the cure temperature, thus eliminating the RTV silicones from consideration where the rubbers are intimately associated with the parts. On the other hand, paradoxically, the problem from the standpoint of using the silicones on the Voyager capsule may not be so serious since the capsule sterilization requirement dictates the use of high temperature-resistant electronic parts.

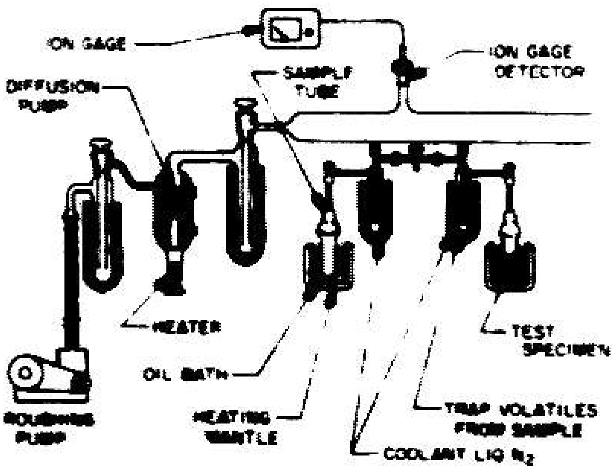


Fig. 18. Schematic of vacuum weight loss research apparatus

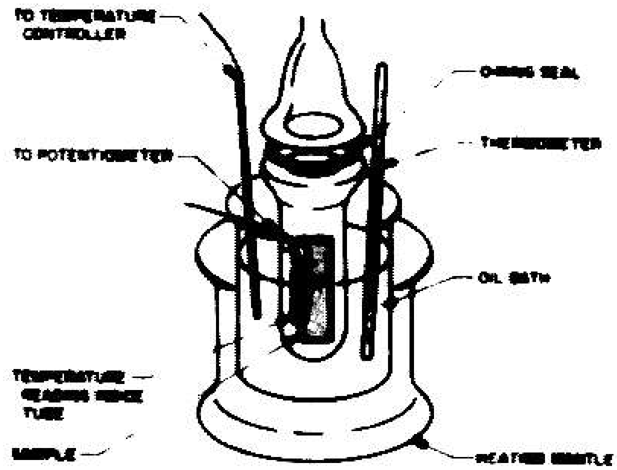


Fig. 19. Detailed drawing of sample cell assembly for vacuum weight loss research apparatus

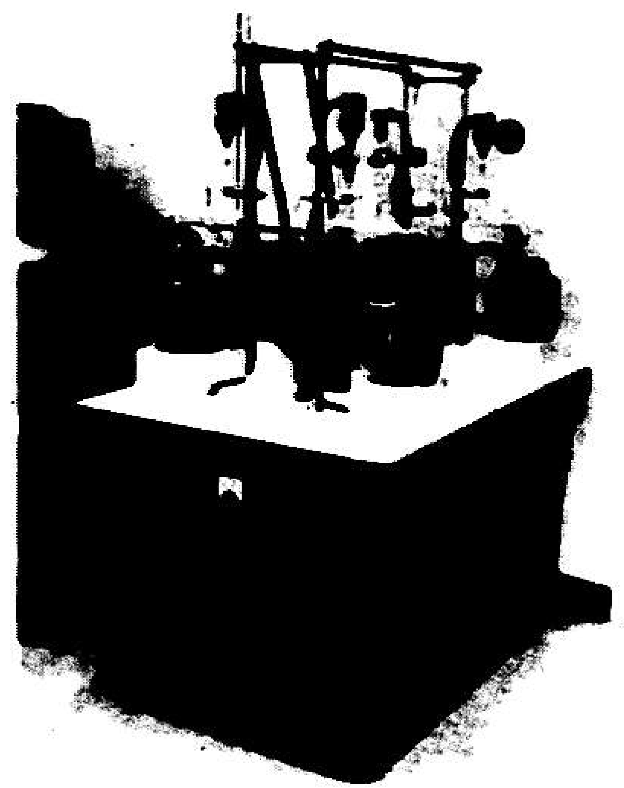


Fig. 20. Photograph of vacuum weight loss – simplified apparatus

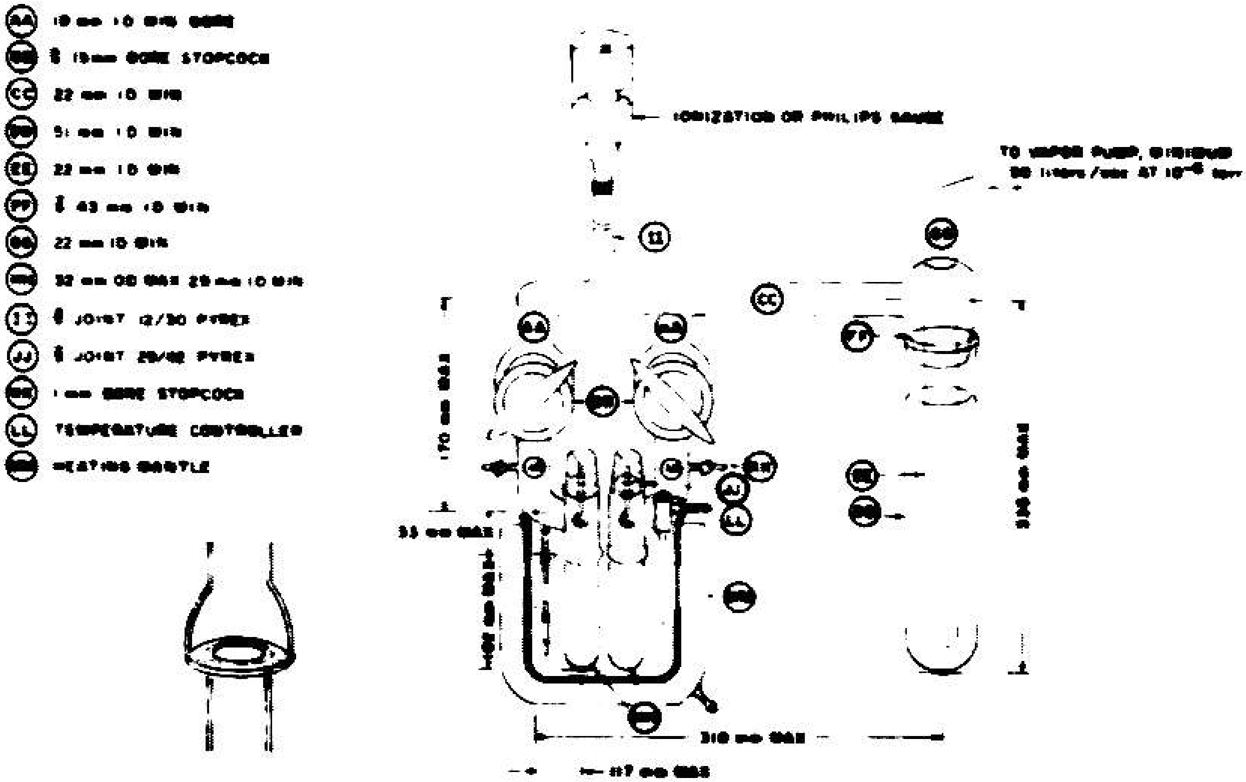


Fig. 21. Schematic of vacuum weight loss – simplified apparatus

BLANK PAGE

SPACECRAFT MATERIALS EVALUATION
NASA Work Unit 186-68-13-03
JPL 384-62701-1-3820

The decision to eliminate polymeric foams from the list of approved encapsulants for high voltage spacecraft components was made because of the lack of information on (a) pressure decay times for blowing gas, and (b) factors affecting corona discharge such as pressure, nature of the blowing gas, or dielectric properties of the foam.

For the first phase of the program, diffusion rates for carbon dioxide were determined on closed-cell polyurethane foams of varying densities by monitoring, for two to three weeks, the loss of weight of specimens suspended in a vacuum of 10^{-7} mm Hg. The experimental data were used to calculate diffusion coefficients for these materials, and were found to be of the order of 10^{-6} cm^2/sec at 22°C.

The solution of the diffusion equation for an idealized model for a foam yielded the following expression for the diffusion coefficient:

$$D^{o} = kp_{e}\left(\frac{\rho_{o}}{\rho}\right)\left[\frac{1}{\left(1-\rho/\rho_{o}\right)^{1/3}} + 1 + \left(1-\rho/\rho_{o}\right)^{1/3}\right]$$

where D^{o} is the diffusion constant for foam, p_e permeation constant for bulk polymer, ρ_o density of bulk polymer, ρ density of foam, and k a constant. Thus, by use of this equation the diffusion coefficient of a foam can be calculated from permeation data on the bulk polymer and the foam density. This equation gave reasonable estimates for the density dependence of the diffusion coefficient for the polyurethane foams studied so far.

This investigation is being extended to other foams. A Cahn vacuum balance for measurements at higher temperatures was rented pending the procurement of a similar balance for work at ultra high vacuum (10^{-8}mm Hg).

A report on this work is to appear in SPS 37-34, and will be presented to the Canadian High Polymer Forum, Ottawa, Canada, September 22-24, 1965.

Foam test specimens with encapsulated electrodes are being prepared for the investigation of the time it takes for the pressure within the foam cells to reach the ionization region for the gas. These results will be compared with the times calculated from diffusion data.

BLANK PAGE

SPACECRAFT OPERATIONS (186-69)

MESA ANTENNA RANGE
NASA Work Unit 186-69-04-01
JPL 384-90101-1-3331

This work unit funds instrumentation for the new JPL anechoic chamber facility in the amount of $60,000.00. The equipment involved is commercial antenna range equipment. The chamber building and the absorber lining is funded as a facility; the building has been completed and absorber sample evaluation tests are presently in progress prior to ordering the lining. The facility is expected to be operational in the first half of FY 1966.

Table 1 lists the items which are funded by this task. All items have been ordered except the second signal generator and the modulator, both of which are pending a more detailed review of requirements. These items and also item 10 will be separately funded in FY 1966. The apparent surplus of $11,000.00 was taken by item 3 which resulted in an actual expenditure of $17,000.00 rather than $6,000.00.

Table 1. FY 1965 equipment purchases for anechoic chamber facility

Item	No. of Units	Description	Total Cost
1.	2	Antenna positioners, with ancillaries	$16,000.00
2.	2	Pattern recorders	13,000.00
3.	2	Illuminator positioners	6,000.00
4.	2	Equipment racks	2,000.00
5.	2	Signal generators	4,000.00
6.	1	Modulator	1,000.00
7.	2	Power meters	1,000.00
8.	2	VSWR meters	1,000.00
9.	--	Minor supplies	8,000.00
10.	--	Minor equipment modifications	8,000.00
		Total	$60,000.00

BLANK PAGE

SPACECRAFT RELIABILITY (186-70)

PARTS RELIABILITY - SCREENING METHODOLOGY
NASA Work Unit 186-70-01-04
JPL 384-00401-2-1520

INVESTIGATION OF TRANSISTOR BACK BIAS VERSUS POWER LIFE TEST

A detailed test procedure has been prepared and an RFP submitted to potential contractors. The procedure defines a test using 770 PNP transistors in a series matrix. The matrix, having parameters and voltage, will be used to determine life effects for both back bias and linear power operation. The test is designed to provide comparative data for the two operating modes as well as data on the effects of temperature and voltage on each.

The parts for the test have been purchased and are undergoing extensive quality assurance examination to assure homogeneity of the test sample. This data will also be utilized for surveillance checks of the test contractor.

Negotiation of the test contract and implementation of the test is anticipated by September 1965. Program completion will be approximately December 1965.

Severe curtailment in the original budget allocation prohibited, or at least delayed into FY 1966, all other items on the previously submitted budget plan.

BLANK PAGE

JPL Technical Memorandum No. 33-243, Vol. I

PARTS RELIABILITY - LONG LIFE STUDIES
NASA Work Unit 186-70-01-05
JPL 384-00501-2-1520

TESTING AND INVESTIGATION

This portion of the task is concerned with performing tests to investigate part failure rates as a function of applied stress and continuing the investigation of the reliability of electronic parts in a combined radiation and thermal-vacuum environment.

Capacitor Matrix Test (Test Procedure 152.20-03)

Pan Technical Systems of Montrose, California has been awarded fixed price Contract 951125 for $11,586.00 to perform this test. Initial electrical tests and electrical/thermal screening tests have been completed and the samples have entered the various cells of the life test matrix. The test is running approximately two months behind the original schedule due to late delivery of materials needed for completion of the life test set up. The contractor has also encountered a problem in the measurement of capacitor leakage current. The leakage current of these devices is typically in the range of 10 to 100 picoamps. However, a number of the devices has indicated a negative value of leakage current. This is believed to be due strictly to problems involved in instrumenting this measurement for high K dielectric capacitors but improved shielding and instrumentation analysis have not yet provided a solution. Discussions with the capacitor manufacturer and others have indicated that this is a common, but usually unrecognized, problem because insulation resistance, a less sensitive parameter, is normally measured instead of leakage current. On a typical insulation resistance bridge, a negative leakage current results in an insulation resistance reading greater than infinity. However, in the analysis of insulation resistance data, values above some preset limit are often all lumped together. Hence, the negative leakage current may not be recognized as such.

Efforts to resolve the leakage current measurement problem will continue. If a simple solution can be found, it is believed that leakage current may be a much more sensitive indicator of device reliability than insulation resistance.

Semiconductor Test (Test Procedure 741.00-03)

Test Procedure 741.00-03 has been completed and submitted for bid. A contract award for performance of this test is expected to be accomplished during the first quarter of FY 1966. In this test, several groups of diodes of two different types will each be initially subjected to different electrical/thermal stresses. All groups of a given diode type will then be subjected to identical life test conditions. The resulting data will allow establishment of relationships between the response of each group to the initial stress and the subsequent life test behavior. Comparisons of parameter stability and reliability during life test will be made between groups.

Laboratory Equipment

An IR microscope which was to be used in correlation of part thermal behavior with life test behavior was not purchased due to a budget cut.

Continuation of Radiation Thermal-Vacuum Effects Study

The radiation thermal vacuum life test has been completed through 5,000 hr with electrical parameter measurements having been completed at the 2,000-, 3,000-, 4,000-, and 5,000-hr measurement points. The task to prepare and publish details of the test procedure used in the test program was completed. The document is entitled The Revised Test Procedure for JPL Test No. 617, Phase II, dated January 25, 1965. The conversion of data cards to the format requirements of JPL Specification No. ZPP-2090-GEN, which was negotiated in the previous report period, has been completed for all cards through the 4,000 hr measurements. Submittals to JPL have included the converted data cards through 4,000 hr and listings of catastrophic failures together with their apparent failure modes. Significant publications have included the eighth and ninth quarterly progress reports which were received from the contractor and a summary of the program published in SPS 37-30. Contractual activity included the negotiation with CEIR for a cost of $3,671.00 additional refinements in requirements of data reduction to include program changes and additional analyses. Total cost for data reduction is now $7,646.00. Data reduction has been delayed until the contract has been executed to incorporate the additional requirements.

During the next report period, the radiation exposures and operational life tests will continue. This will include measurements at the 6,000-, 7,000-, 8,000-, and 9,000-hr measurement points. Data cards will be converted and the data will be reduced inclusive to 5,000 hr and again inclusive to 8,000 hr. JPL has been notified that a major shutdown of the reactor may occur in October 1965. Should this take place, a delay will occur in the test program. Depending on the extent of the shutdown and the completeness of the information gained by that time, it may be advisable to discontinue further testing if the problems introduced outweigh the utility of further information.

COMPARISON OF LIFE TEST BEHAVIOR

This portion of the task consists of comparing the long term life test behavior of unscreened parts with that of parts subjected to particular types of initial screens.

Capacitor Screening Evaluation Test Program

In June 1964, Preston Scientific of Anaheim, California was awarded fixed price Contract 950864 to perform a 5000-hr life test per Test Procedure 152.20-01. The basic purpose of the test program was to compare differences in life test behavior of screened and unscreened capacitors. Test Report No. 152.20-01 reports the result of this work and indicates that no basic differences existed in the behavior of the two groups. To investigate long-term life behavior, the life test was extended for an additional 5000 hr. The extension was accomplished in April 1965 by modification of Contract 950864. This modification increased the contracted amount by $6,546.00 to a total of $16,020.00. The test is progressing satisfactorily and has accumulated 7029 hr of test time. No catastrophic failures have been recorded to date. All testing and the final test report will be completed during the second quarter of FY 1966.

Diode Screening Evaluation Program

This test is being performed per Test Procedure 741.10-01 by the Boeing Company of Huntsville, Alabama. The test is being performed under fixed price Contract 950863 for $27,996.00. Basically, the test is designed to compare the life test behavior of three groups of diodes representing three different levels of initial screening. The test is replicated for two diode types. Progress has been satisfactory and 3519 hr of test time have been accumulated. Interim Test Report 741.10-01 covering the results through 2000 hr is currently in rough draft form. The current test effort and final test report will be completed by the second quarter of FY 1966.

Resistor Screening Evaluation Test Program

This test is being performed per Test Procedure 651.20-01 by the Boeing Company of Huntsville, Alabama under fixed price Contract 950869 for $10,182.00. The test is designed to compare the life test behavior of two groups of resistors representing different levels of initial screening. Progress has been satisfactory and 3490 hr of test time have been accumulated. Interim Test Report 651.20-01 covering the results through 2000 hr is presently in rough draft form. The present test effort and final test report will be completed by the second quarter of FY 1966.

Transistor Screening Evaluation Program

This test is to be performed per Test Procedure 742.10-02 by the Boeing Company of Huntsville, Alabama. The original fixed price Contract 950862 for performance of this test was for $38,595.00. At the outset of this test it was determined that a number of the test specimens were defective and would prevent performance of a worthwhile test. Hence, a stop-work order was issued to the contractor and efforts were initiated to obtain proper test samples. Due to an extended delivery date for these samples, it appears that work cannot be reinitiated until approximately November 15, 1965. The stop-work order and the work which must necessarily be repeated will result in a contract increase of approximately $5,700.00.

BLANK PAGE

PARTS RELIABILITY - FAILURE MECHANISM
NASA Work Unit 186-70-01-07
JPL 384-00701-2-1520

X-RADIATION EFFECTS TESTS

The object of this task is to perform special studies and tests to determine the effects of X-radiation on semiconductor devices, statistically determine the distribution of major part parameters, and establish improved methods of screening by relating reliability and the physics of devices.

Test Procedures 742.10-17 and 742.20-04, respectively, for transistors and diodes were submitted for proposals during the fourth quarter. The proposals have been received and reviewed, and negotiations are currently in progress. A contract award for performance of these tests is expected to be accomplished during the first quarter of FY 1966. These tests have been designed to investigate any degradation effects which may be produced by radiographic inspection of semiconductor devices. In this investigation, devices will be subjected to radiation dosages which are both representative and in excess of those normally experienced in radiographic inspection.

PARAMETER DISTRIBUTION STUDY

Statements of work defining the data necessary for this study were completed and issued with RFQ's during the fourth quarter FY 1965. The part types [illegible] data is desired include diodes, transistors, metal film, carbon film, and wir[illegible] resistors, and ceramic, tantalum and glass capacitors. The only quote which has been received was for glass capacitor data. All the quotes are now overdue.

Preliminary efforts have been made to determine the reasons for the lack of response. The primary cause of this reticence in the parts manufacturers appears to result from a fear of disclosing information pertaining to product yields. The data necessary to establish true parameter distributions must be gathered from production lots prior to multiple truncation resulting from the sorting and classification techniques employed by most manufacturers. Therefore, even though the purpose of this study is not to investigate product yields, some yield information would result as a by-product.

Additional discussions will be held with parts manufacturers to determine possible ways of obtaining this data. Since the primary purpose of the study is to determine the shapes of the various parameter distributions, the manufacturers may be agreeable with providing data normalized in some fashion instead of actual numerical measurements. This problem is expected to be resolved during the first quarter of FY 1966.

ESTABLISH IMPROVED METHODS OF SCREENING BY RELATING RELIABILITY AND THE PHYSICS OF DEVICES

No work was done due to a budget cut. For the same reason, a leakage plotter which was to have been used in this study was not purchased.

BLANK PAGE

SPACECRAFT TESTING EQUIPMENT AND TECHNIQUES (186-71)

ADVANCED SOLAR SIMULATOR DEVELOPMENT
NASA Work Unit 186-71-01-01
JPL 384-10101-2-3750

ACTIVITIES DURING REPORT PERIOD

Experiments were concluded proving the possibility of increasing the size of the beam in the 10-ft space simulator from 6 to 8 ft in diameter and reducing the field angle (sun diameter) from 4-1/2 to 3 deg. These improvements have been incorporated into the simulator by the Surveyor project.

The high-flux, all-quartz, lens unit (mixer) development was successful and a 19 lens version was used in the above improvements.

System parameters for the 25-ft space simulator current modification to a 15-ft diameter beam were established.

The albedo simulator study contract was concluded with excellent results. Information gathered thereby is currently being used in the preparation of the Preliminary Engineering Report required in the C of F funding cycle.

Due to a vendor's failure to perform, a crash program was initiated and successfully concluded to develop a technique for aluminizing large (10-ft diameter) mirrors. This technique was used and was instrumental in maintaining the schedule of the 10-ft space simulator.

FUTURE ACTIVITIES PLANNED

Activities planned for the next 6-mo period are as follows:

1. Investigate high power lamp and collector units now on hand for 25-ft space simulator application. Preliminary results are very encouraging.

2. Investigate and/or develop methods of applying an adequate reflecting surface to mirrors greater than 20 ft in diameter. This would be applicable to the 25-ft space simulator.

3. Perform experiments aimed at further improving the efficiency of solar simulation systems.

4. Investigate techniques for simulating albedo and planetary radiation with a high degree of accuracy.

BLANK PAGE

SUPPORTING STUDIES (187)

BLANK PAGE

TOUCHDOWN STABILITY STUDY
NASA Work Unit 187-06-12-06
JPL 387-62401-2-3500

A request for proposal (337109) for Surveyor lunar touchdown stability study was prepared and sent to six potential vendors. Three vendors were responsive to this request and three were nonresponsive. The proposals were technically evaluated and personal visits were made to each of the responsive bidders.

As a result of this evaluation a two-phase contract totaling $73,690.00 was awarded to Bendix Products Aerospace Division. The first phase will entail the designing and compiling of an analytical computer program appropriate to study the Surveyor landing dynamics on a hard lunar surface. The second phase will entail the use of the computer program to determine the stability of the spacecraft as a function of eleven initial conditions.

At the oral presentation on May 3, 1965, the question of soft surface effects was raised by the representatives from OSSA. A further investigation by JPL showed that a soft surface could be more critical than a hard surface. Therefore the phase one computer program will be written in such a fashion that soft surface landings may be studied by the same program after the direct addition of a subroutine. The complete study of the soft surface will involve both analytical and experimental approaches and will constitute the third phase of this study support which has been requested in FY 1966.

BLANK PAGE

ADVANCED STUDIES ([illegible])

BLANK PAGE

PLANETARY AND INTERPLANETARY (684-30)

ADVANCED PLANETARY MISSION STUDIES
NASA Work Unit 684-30-01-05
JPL 388-50101-2-2920

Two conceptual design and feasibility study contracts for *Mariner*-class comets and asteroid missions, initiated at the close of FY 1964 were completed during this report period. These studies were: (1) comets and close-approach asterioids mission study, performed by Philco Corporation-WDL, and (2) asteroid belt and Jupiter flyby mission study, performed by Lockheed-Sunnyvale. The emphasis was placed upon lower-energy missions to comets and asteroids in the Philco study and upon the higher-energy missions to the asteroid belt and growth to a Jupiter flyby for the Lockheed study. Broad scientific objectives were established for each study which permitted the development of design concepts with the greatest flexibility to meet future requirements. The study framework provided for: (1) establishing the spacecraft functional requirements to accomplish selected missions, (2) a forecast of the applicable state-of-the-art required, (3) performance of design tradeoffs as a basis for design selections, (4) synthesis of appropriate system concepts, and (5) comparison of the design technology required to perform the missions with *Mariner* Mars 1964 design technology.

COMETS AND CLOSE-APPROACH ASTEROID MISSION STUDY

Missions to comets and close-approach asteroids that could be performed with an *Atlas*/*Agena D*, or *Atlas*/*Centaur* launch vehicle in the time period 1967 to 1978 were studied. Five comets and one asteroid were selected as being appropriate within launch energy, closing velocities, and time constraints for this study. The five comets were: Tempel (2), 1967; Pons-Winnecke, 1969-70; Kopff, 1970; Tuttle-Giacobini, 1973; and Brooks (2), 1974. The one asteroid was Eros, 1974. Other comet targets found not to be appropriate for study within the launch energy constraints during this time period, were classified according to energy requirements.

The mission and system requirements were established for the above targets and design concepts were developed which are essentially identical to the *Mariner* Mars 1964 spacecraft design. Principle *Mariner* design changes for comet missions were relevant to the higher guidance requirements for comet intercept, higher communications capability for increased data rates, and consideration of radio-isotope thermo electric generators for power sources.

Major design problems that were found to be unique to the comet missions are relevent to spacecraft guidance. The uncertainty in the comets orbital elements from all available data infers either (1) a need to establish the orbital elements of comets more precisely from earth observations, or (2) require over-design of the guidance capability to allow for the positional uncertainties. Other problems associated with guidance were relevant to the range of comet intensity variation and uncertainty in their levels which presents problems in acquiring and tracking comets through encounter. A comet tracker and a number of alternate operational modes were given as possible solutions to this problem.

Final study reports were received in February and pertinent data was reported in the Space Program Summary No. 37-32 Volume II, January 1 to February 28, 1965.

ASTEROID BELT AND JUPITER FLYBY MISSION STUDY

Asteroid belt flythrough missions in the time period 1967 to 1975, investigation of two major asteroids, Ceres and Vesta, and development of the concepts for a Jupiter flyby in the time period 1970 to 1980 were studied. Flythrough missions of the asteroid belt would measure particle distributions and physical and chemical properties of the particles in the belt. Two trajectories were studied which essentially lie in the plane of the ecliptic with aphelia at 3.2 and 4 AU to provide long-term measurements of specific regions of the belt. A third trajectory with aphelia at 6.7 AU was examined which could provide a relatively rapid survey of the whole region to beyond the orbit of Jupiter. Two major asteroids, Ceres and Vesta were studied as being suitable for observing gross surface features of asteroids. The concepts developed for asteroid missions were studied for their suitability for a Jupiter flyby.

The mission and system requirements were established for the above targets, and a range of design concepts were developed for asteroid belt flythrough missions with a 346-lb minimum weight and a 1,049-lb maximum weight spacecraft. Similarly, two design concepts were developed for the major asteroid missions with a 605-lb minimum weight and a 1,149-lb maximum weight spacecraft. The maximum asteroid design concept was adapted for a Jupiter flyby mission spacecraft weighing 1,289 lb. The missions studied were based on the use of an Atlas/Agena D or an Atlas/Centaur and a Lockheed proposed third kick stage.

The major problems indicated by the study were the high-energy requirements, necessitating a high-energy kick stage and the long trip durations.

Final study reports were received in February, and pertinent data was reported in JPL Space Program Summary, SPS No. 37-33, Volume II, March 1, 1965 to April 30, 1965.

The results of each study are being reviewed by JPL, and critiques are in preparation. It is planned that data furnished by these studies will be used as the basis of in-house advanced technical study activities through FY 1966.

PROPULSION (JPL 388-30180-2-3804)

The following studies have been made in support of the propulsion aspects of the advanced technical studies work unit:

1969 Variable-Orbit Mars Atmosphere Probe

The study of a Mars spinning orbiter was finished in early 1965 and the propulsion aspects were documented in an informal report on February 17. The orbiter discussed was to be spin stabilized and sterilized so the periapsis altitude of a highly elliptical orbit could be decreased to measure upper atmosphere drag. The drag would perturb the orbit and the perturbation could be measured. Propulsion systems included were a solid retro motor, a pair of solid spinup rockets, and a pulsed hydrazine system for precession and orbit variation.

ADVANCED TECHNICAL STUDIES
NASA Work Unit 684-30-03-01
JPL 388-301 xx-x-xxxx

VOYAGER CAPSULE

During this report period, the effort in this task was concentrated on alternate Voyager capsule studies. Propulsion studies are presented separately in the subsequent section of this work unit report.

Previous studies, both by JPL and industrial contractors, have determined the gross feasibility and capabilities of Voyager-class Mars landing capsules. The purpose of the studies described below is to examine those specific detailed problems which previous studies have shown require early attention and advanced development support, prior to the initiation of formal capsule design and procurement processes by the Voyager Project Office, in order that the capsule portion of the Voyager program's 1971 mission may be successfully implemented within schedule.

The studies were composed of six separate efforts. The objectives and preliminary results are shown below. In all cases, studies are in the final weeks of completion with effort scheduled for completion during August 1965.

Capsule Bus Deflection

The general goals of this study include:

1. Bus deflection to extend the mission profile, abort system mechanization, and probability of impact analysis beyond that considered in earlier studies.

2. Capsule deflection to study a wide range of attitude and thrust vector control options from the points of view of accuracy, reliability, sterilizability, weight, and power requirements.

3. Comparison phase to perform comparison within and between alternate deflection modes.

The general conclusions of the study are as follows:

1. There are solutions to the competing trajectory design constraints on orbit selection, landing site location, relay link geometry, and guidance accuracy.

2. The resulting capsule guidance accuracies are quite stringent by previous standards.

3. Such guidance accuracies are achievable with the bus deflection mode.

4. The guidance policy related to the control of nonsterile objects should meet mathematical constraints based on a proposed interpretation of the non-contamination constraint.

5. Further analysis of the necessary and achievable reliability of the bus deflection mode indicates that it can meet the noncontamination constraint. However, it will be difficult to demonstrate the required reliability.

6. For the capsule deflection mode, it appears that the guidance accuracy of the spin-stabilized and active attitude-controlled capsules is comparable and that there will be some difficulty with either method in meeting the accuracy goal.

Relay Direct Communications

This study includes the following areas of effort:

1. Descent relay-link: Analysis of the acquisition problem, telemetry modulation and detection schemes, transmitter and receiver requirements, and capsule and bus antenna requirements.

2. Postlanding direct link:

   a. Low bit-rate FSK system

   b. Direct link high-gain steerable antenna considerations

3. A systems analysis comparison of postlanding direct and relay (via orbiter) communication links for an eventual ("mature" Voyager) long-life Mars surface mission.

Preliminary conclusions of the descent phase relay link (terminal descent relay study) are as follows:

1. From the system performance standpoint (commensurate with the study assumptions), communications using an automatic phase control relay receiver with an automatic acquisition capability and PCM/PSK/PM modulation technique are possible under realizable trajectory constraints for 1971 missions.

2. An investigation of the equipment required to implement the systems revealed that a suitable capsule transmitter and bus receiver has not been demonstrated at this time. A suitable spacecraft bus and capsule antennas would have to be developed.

3. In addition to these equipment developmental tasks associated with the subsystems that comprise a relay communication system, there exists the difficult task of integrating these subsystems. This integration would have to include the spacecraft communication system and result in an overall system that is of sufficient quality and reliability to allow a reasonable probability of achieving the mission goals.

Capsule Shape

This study is considering six technical areas:

1. Dynamics of entry to compare three shape families (Apollo-type, sphere-cone, and smooth-flare) on the basis of velocity-at-altitude and angle of attack envelope for a fixed vehicle size (diameter).

2. Aft-body configuration to examine aft-body shape requirements for achieving directional stability at various entry angles-of-attack and to consider the relationship of aft body shapes to auxiliary decelerator ejection.

3. Auxiliary decelerators for terminal descent to make a preliminary assessment of the aerodynamic performance of an expandable skirt.

4. Low-altitude gusts to assess the effect of low-altitude wind gusts on the capsule dynamics near impact.

5. Structural deformations to assess effects on aerodynamic characteristics.

6. Heat shield and structural weights for sphere-cone shape family to make a parametric study of the variation of these weight components with nose radius and cone angle using the JPL (AVCO) computer program.

This study has not yet reached the point where significant results can be listed.

Descent and Landing Operations

The objectives of this study are to:

1. Extend the earlier ballistic mode study to consider effect of employing large capsule diameters (16 to 19 ft).

2. Determine whether the capability exists in a large-diameter ballistic capsule to carry a parachute engineering experiment.

3. Consider various terminal deceleration subsystems to trade off increased lander performance with increased operational complexity.

4. Examine a Saturn-size Mars entry capsule from an aerodynamic stability standpoint.

5. Determine the extents and requirements of the lander from an operations standpoint (orientation, erection, deployment requirements, etc.).

In addition, there is currently under way a re-examination of:

1. Critical temperature profile for ballistic and decelerator modes.

2. Mean surface winds, vertical wind gradients, and gust wind conditions.

3. Development of engineering Mars surface terrain model.

This study was conducted for the Apollo-type shape only and several guidelines were adopted which, if changed, could modify the conclusions given.

Preliminary results (complementing the objectives) are as follows:

1. Ballistic mode.

   a. Shell structure weight is a large percentage of the entry weight.

   b. Fabrication techniques for a lightweight, reliable shell requires extension of current practice.

   c. Consistent with the M69-5 Mars atmosphere (TM 33-234), no payload capability exists for the ballistic mode with backward entry because the impact velocity is too high. Little, if any, payload exists for entry angles 90 deg or less.

   d. Trajectory study shows that for large diameters, the oscillations during entry decrease in frequency and increase in amplitude. The impact velocity for the ballistic mode increases and there is a decrease in the altitude at which the maximum velocity for parachute deployment occurs.

   e. Current SIB shroud envelope constrains the capsule size to 16 ft (Apollo-type) with the spacecraft on bottom configuration. However, space vehicle weight allocation to capsule may be overriding limitation.

   f. Heat shield requirements are predominantly insulative rather than ablative. Heat shield unit weight estimates are insensitive to initial entry angle and angle-of-attack. The most significant variations result from changes in ballistic coefficient.

2. There is insufficient payload in the ballistic mode to support a parachute experiment.

3. Parachute mode and ballistic descent were considered. Shell and payload joints, separation operations, chute deployment problems leave many problems needing further analysis. Increased landed payload capability is obtained at the expense of additional operational complexity.

4. Entry trajectory analyses show that the *Apollo*-type body will right itself and become stable after entering in a backward attitude. Oscillations have a diversion trend after the vehicle passes through peak deceleration. Stability of a vehicle with the aft cone jettisoned prior to parachute deployment, and also the low speed stability of the *Apollo* shape needs further study.

5. Several payload configurations were studied, each of which integrated the requirements of the scientific experiments and the engineering support. The landed payload operations are very complex and the complexity increases with the sophistication of science requirements.

6. Approaches have been developed for solving the problems ranging from impact survival and jettisoning of attenuation material, to antenna orientation and science deployment, but further study is required.

7. A preliminary investigation was made for using a balloon-type gas bag, with the payload suspended into center, as a combined decelerator and impact attenuator. Sufficient advantages were found to warrant some experimental investigations which are being undertaken.

Lander Power

The purpose of this effort has been to:

1. Determine the most likely limits of the capsule operational power profile in order to specify power subsystem requirements.

2. Examine various candidate systems for capsule power sources and determine their available systems that can be made applicable to lander systems operations, the power systems that can be eliminated by recognition of obvious defects or deviations from lander requirements, and the system or systems that are best suited for capsule applications based on the mission load profile, requirements, and system characteristics.

The following preliminary conclusions have been obtained:

1. Solar cells, primary and secondary batteries, monopropellant fueled turboalternators, and radioisotope systems are the most promising for use on the *Voyager* capsule. The selection of any one or a combination of these systems is dependent on the mission requirements.

2. No system is available now which will meet all the requirements of a capsule system.

3. In order to provide a system or systems for capsule and lander operation, intensive development on all the above systems should be started immediately to make them state of the art by January 1967.

1971 Lander Science Sample Payload

The purpose of this study is to develop capsule science instrument requirements which would be typical of a 1971 lander; this information is required to make the previous five studies meaningful. These requirements include:

Weight	Field of view
Power	Atmospheric access
Volume	Radiation tolerance
Data Rates	Temperature tolerance
Lifetime	

At present, requirements are being developed for the following representative payload:

1. Atmospheric water vapor analysis.
2. Atmospheric composition analysis.
3. Ground gas analysis.
4. Atmospheric pressure.
5. Atmospheric temperature.
6. Wind velocity.

After the completion of the above studies, in-house effort at JPL will be concentrated on two studies: (1) active Mars landers and (2) advanced planetary probe mission.

The active Mars lander study consists of an extension of current Voyager-sponsored studies concerning ballistic vs. parachute landing systems to consider the potential feasibility of active landing systems (propulsion systems such as in Surveyor). The objective of the study is the determination of whether active landing systems should be considered in the development of ultimate Mars landers.

The advanced planetary probe study will be an in-house study of deep space missions similar to the contracted study defined in Work Unit 684-30-08-01.

PROPULSION (JPL 388-30180-2-3804)

The following studies have been made in support of the propulsion aspects of the advanced technical studies work unit:

1969 Variable-Orbit Mars Atmosphere Probe

The study of a Mars spinning orbiter was finished in early 1965 and the propulsion aspects were documented in an informal report on February 17. The orbiter discussed was to be spin stabilized and sterilized so the periapsis altitude of a highly elliptical orbit could be decreased to measure upper atmosphere drag. The drag would perturb the orbit and the perturbation could be measured. Propulsion systems included were a solid retro motor, a pair of solid spinup rockets, and a pulsed hydrazine system for precession and orbit variation.

Lander Power Study

One of the committees supporting Voyager capsule studies considered power sources for a landed capsule. The propulsion division supported this effort in the consideration of a hydrazine powered turbo-alternator system. Information was gathered from a seminar with Garrett AiResearch on March 8 from JPL-TM-33-180 and other sources. The results of the turbo-alternator study were presented to the committee in an informal report on April 30, concluding that such a sterilized system could be built and that it would be lighter than batteries. Systems for 40 and 300 watts output were considered and weights estimated.

Capsule Flight Test Study

The propulsion aspects of the capsule flight test study were considered and conclusions were documented in an informal report on May 4. The conclusions were that a flight test is not required for either propulsion or pyrotechnic systems, but that both should participate in any flight test made.

Exhaust Plume Considerations

Studies of the Voyager capsule have produced a number of questions concerning rocket exhaust plume interactions with proximate spacecraft, such as forces, torques produced, heating and particle impingement. JPL does not have a plume calculation computer program so an approximate program was written for the IBM 1620 computer which has given rough numbers for values of force, torque and heating. Preliminary results were included in an informal report on June 24. Additional work is being done on this problem.

Liquid Capsule Deflection Rocket

As a part of the capsule deflection study a liquid deflection rocket, similar to the Mariner midcourse motor, was considered and a preliminary design outlined. The results were published on June 4 in an informal report.

Meeting Attendance

The propulsion division representative to the advanced technical studies committee attended two AAS meetings during the reporting period, one in Denver on unmanned exploration of the solar system and the other in Chicago on post Apollo space exploration. While in Denver a presentation by the Martin Company on Titan III was attended also.

During FY 1965, analytical support in the area of propulsion system analysis will be continued at approximately the same level of effort. Specific studies to be considered include advanced Voyager and other interplanetary missions

BLANK PAGE

JPL Technical Memorandum No. 33-243, Vol. I

COMET AND ASTEROID MISSION STUDY
NASA Work Unit 684-30-05-00
JPL 388-50101-2-1610

This effort concentrated on the monitoring of the final phases of Philco and Lockheed comet and asteroid study contracts. The objectives and results of these two studies are as follows:

ASTEROID BELT AND JUPITER FLYBY MISSION STUDY

The final report of this study, conducted by Lockheed Missiles and Space Company under JPL Contract 950871, was received during February 1965. A summary of the objectives and results of the study is presented below.

Study Objectives

The prime objective of the study was to determine alternate ways of reliably accomplishing the following scientific objectives separately, utilizing unmanned spacecraft.

1. Measurement of the particle distribution encountered in traversing the asteroid belt within a corridor comparable in diameter with that of the spacecraft and over a region 100 times the spacecraft diameter.

2. Measurement of the physical and chemical surface properties of a statistically significant sample of asteroidal material.

3. Observation of the gross surface features of one of the major asteroids within the belt.

An additional objective was to use the results of the asteroid belt study as growth potential to formulate a Jupiter flyby mission to obtain the following planetary environmental data: magnetic field, radiation, atmospheric pressure, temperature and composition, surface temperature, and visual.

The following tasks were to be performed in support of the objectives:

1. Define functional requirements for accomplishing each of the mission objectives.

2. Examine alternate system and subsystem concepts, perform trade-off analyses, and suggest concepts most suitable for fulfilling mission requirements.

3. Perform failure mode and reliability analyses and apply the results to the selection of system concepts and the estimation of the probability of mission success and meeting partial objectives.

4. Provide descriptions of each system concept together with functional specifications to ensure meeting mission requirements.

5. Prepare development plans for all system concepts and provide preliminary cost estimates; cost and schedule data to include further study, design, development, manufacture, testing, and flight operations.

6. Define study concepts in sufficient detail to allow comparison with the *Mariner* Mars 1964 spacecraft.

Study Constraints

The following guidelines were used in the study: The mission period for the particle distribution and composition mission will be 1967 to 1975. The major asteroid and Jupiter missions will be during the 1970 to 1980 period. Mission energy requirements are to be compatible with Atlas/Agena D and Atlas/Centaur vehicles. A third stage is to be used, if required. The full deep space instrumentation facilities are to be used.

Methods of Approach

Definition of the major functional requirements for successful accomplishment of the scientific objectives of each mission evolved from two basic and related areas: (1) mission concepts and flight trajectories and (2) system concepts, associated subsystems, and application to spacecraft design.

Mission concepts. Flythrough missions to measure particle distributions and physical and chemical properties of the particles have the simplest mission profiles. The trajectories lie essentially in the plane of the ecliptic, and a launch can be made on any day. An infinite number of trajectories are possible but, for the purposes of the study, trajectories with aphelia at 3.2, 4.0, and 6.7 AU were examined. The first two provide long-term measurements of specific regions of the belt, and the 6.7 AU mission represents a relatively rapid survey of the whole region to beyond the orbit of Jupiter.

Two major asteroids, Ceres and Vesta, were chosen as suitable targets for observing gross surface features. The choice of two asteroids provides a greater degree of flexibility in planning the eventual missions, since the requirements are similar and the launch opportunities are interspersed. A miss distance of about 1000 km from the target is desirable for scientific observation.

A flyby of Jupiter represents a fairly conventional mission concept. The main variables are concerned with the encounter phase when various approach trajectories can be used to give the required coverage of the planet. Because of Jupiter's large mass, an approach to about 2 radii of the planet's center results in a dark-side passage for trips of moderate duration.

System concepts. A range of possible system concepts exists for each mission depending on the depth of scientific investigations attempted and the degree of sophistication adopted in the subsystem design. For the asteroid missions, the upper and lower ends of this range were examined. Minimum missions were defined for which simple system concepts could be envisaged that would deliver small scientific packages with minimal demands on the subsystems. More refined system concepts, at least comparable in complexity to *Mariner C*, were also developed to give a capability of more comprehensive scientific observations to fulfill the requirements of maximum missions. System concepts for the performance of a Jupiter flyby were developed from those suitable for the maximum asteroid missions. Table 1 summaries the alternate concepts studied. Table 2 gives the range of typical science packages for asteroid missions.

A more detailed summary of the results of this study is included in JPL SPS 37-33, Vol. II, pages 22 through 41.

COMET AND CLOSE-APPROACH ASTEROID MISSION STUDY

The final report on the project study, conducted by the Philco Corporation's Western Development Laboratory was received during February, 1965.

The objectives of the study were as follows:

1. Develop conceptual spacecraft designs for missions to selected comets and close-approach asteroids during the mission period of interest, 1967-1975.

2. Determine tradeoffs among mission parameters, instrument requirements, and subsystem performance.

3. Forecast the state of the art and apply the new technology to conceptual designs of comet and asteroid probes.

4. Specify the feasibility of adaptable spacecraft designs for missions to a number of comets and close-approach asteroids.

5. Compare comet and asteroid spacecraft system concepts with the Mariner Mars 1964 (Mariner C) system design.

6. Estimate mission schedule, cost, and probability of success.

Some of the pertinent results of the study are discussed in the following paragraphs.

Objectives

Astrophysicists believe that a definitive insight into the origin and formation of comets and planets will be gained by exploring comets and asteroids with space probes. A large amount of data must be collected in order to refine or to reject extant theories about the evolution of the solar system, about the physics of cometary and asteroidal bodies themselves, and about the dynamics of the interplanetary medium. There appears to be agreement within the scientific community that, as is the case with the Moon and planets, the true nature of comets can be revealed only by a direct probing of the coma and tail and by observations and eventual sampling of the nucleus by a space probe. In the meantime, photometric and spectroscopic identification of cometary materials in the laboratory and from ground observations will be continued.

Table 1. Alternate system concepts

Mission	Control mode	Typical science package[a]		Science payload, lb	Data transmission, bit/sec	Average total power requirement, w	Spacecraft weight, lb
		Distribution	Composition				
Asteroid Belt flythrough (Particle distribution)							
A1 Minimum	1 Spin stabilization only	Aa	Ba	18	1 (at 3.5 AU)	110	366
A2 Intermediate	2 Intermittent all-axis	Ab	Ba	20	9.8 (at 5 AU)	138	485
A3 Maximum	3 Continuous all-axis	Ad	Bb	65	30 (at 5 AU)	194	1,049
Major Asteroid Flyby							
C1 Minimum	1 No stabilization to target All-axis stabilization for maneuvers, encounter, and data playback	Ca		6	17 (at 3.7 AU)	200	605
C2 Maximum	2 Continuous all-axis stabilization	Cc		75	56 (at 3.7 AU)	285	1,140

[a] Defined in Table 2.

Table 2. Range of typical science packages for asteroid missions

Mission	Package No.	Instrumentation	Weight, lb	Power, w	Control mode	Evaluation
Particle Distribution A1	Aa	12 Impact gages for flux measurement (direction and number) spacecraft diameter	[illegible]	[illegible]	Spin*	Wide field-of-view, low angular resolution, reduced [illegible] rate
A2	Ab	6 Impact gages, flux [illegible] spacecraft diameter; Optical meteoroid detector flux [illegible] 100 spacecraft diameter	[illegible]	[illegible]	Intermittent all-axis	All-axis stabilization for optical detector
	Ac	Multiple film meteoroid monitor, flux [illegible] spacecraft diameter	10	5.0	Spin	Wide field-of-view, reduced sample rate
A3	Ad	Multiple film meteoroid monitor, optical meteoroid detector, impact gages, interplanetary instrumentation	65	17.5	Continuous all-axis	Continuous observation, maximum useful data, high reliability
Particle Composition	Ba	Impact mass flash spectrometer	40	15	Spin	Wide field-of-view, low sample rate
B1	Bb	2 Impact mass/flash spectrometer (1 at standby); interplanetary instrumentation	105	22.5	Continuous all-axis	Continuous observation in direction of main stream, good reliability
Major Asteroid Flyby C1	Ca	Low resolution visual TV	[illegible]	15	All-axis for maneuvers, encounters and playback. Otherwise no stabilization required	Size and shape determination, some surface details, low data rate
	Cb	Low and high resolution visual TV	16	30	As above	Good detail, high data rate
C2	Cc	Low and high resolution visual TV, photometer, polarimeter, IR radiometer, interplanetary instrumentation	75	50.5	Continuous all-axis	Maximum useful data

*About axis perpendicular to plane of ecliptic

The primary objective of a comet probe mission is to conduct flythrough scientific observations of a comet and to transmit the results of these observations back to Earth. The specific scientific objectives, in the order of their increasing requirements on spacecraft systems performance designed to support the appropriate scientific instruments, the specific scientific objectives are to: (1) measure the distribution of matter and magnetic field through the coma (comet's atmosphere) of selected comets, (2) observe the nucleus of a comet, and (3) determine the chemical composition of cometary material. Table 3 presents a full complement of scientific instruments for accomplishing these objectives. A science payload consisting of Items 1, 2, 3, 5, and 6 and one each of Items 8 and 9 would be identical to the Mariner C science complement.

The primary objective of a close-approach asteroidal probe mission is to conduct flyby scientific observations of a close-approach asteroid and to transmit the results back to Earth. The specific scientific objective is to measure the physical and chemical properties of an appropriate close-approach asteroid.

A secondary objective of both probe missions is to perform particle and field measurements in the interplanetary medium enroute to the target with some of the instruments to be used during encounter.

Table 3. Comet probe science payload

Item	Instrument	Weight, lb	Power, w	Function[a]
1	Magnetometer	6.1	7.0	P
2	Dust detectors (2)	2.3	0.2	P
3	Plasma probe	7.0	3.5	P
4	Ion-electron trap	8.0	2.0	P
5	Ionization chamber	2.6	0.5	P
6	Geiger-Mueller tube	2.1	0.4	P
7	Ion mass spectrometer	8.0	8.0	P, C
8	Lyman-alpha photometers (2)	3.0	3.0	P, C, O
9	UV photometers (2)	3.0	3.0	C, O
10	UV spectrometer	22.0	12.0	C, O
11	TV subsystem	35.0	16.0	O
	Total	99.1	55.6	

[a] P signifies determination of the distribution of matter and magnetic field through the coma of selected comets; O, observation of the nucleus; and C, determination of the chemical composition of cometary material.

The detection of life throughout the solar system is of great interest. The possibility of exploring comets to determine the presence of organic compounds fundamental to life has been suggested. Spectroscopic observations of comets indicate unequivocally the presence of CN, C_2, C_3, and CH in the coma. The icy core (nucleus) is presumably composed of the frozen gas molecules of CH_4, CO, CO_2 and other gases.

Scientific measurements performed by a spacecraft during its intercept with a comet fulfill two roles in determining the composition of comets: (1) to complement measurements performed at Earth astronomical observatories by direct sampling of the particle, field, and molecular composition of a comet, by close-range observation of its physical features, and by detecting predicted but unobserved spectral emissions; and (2) to supplement measurements performed on Earth by confirming spectral lines previously recorded, especially those that are ambiguously identified. Onboard measurements can best serve their complementary and supplementary functions if they are correlated with simultaneous photometric and spectroscopic observations from Earth.

Possible Comet Probe Missions

The mission to Pons-Winnecke in 1969-1970 is the only one found which is suitable for using an Atlas/Agena launch vehicle and for accomplishing the scientific objectives. The mission to Tuttle-Giacobini-Kresak in 1973 may be accomplished using an Atlas/Agena combination; however, the comet is faint and not recoverable for at least 3 months after launch. No earlier launches to periodic comets using an Atlas/Agena were thought feasible. A mission to Tempel (2) in 1967 looks favorable for an Atlas/Centaur launch. Similarly, missions to Kopff in 1970 and Brooks (2) in 1973 fall into the Atlas/Centaur class. Weight breakdowns for these spacecraft are shown below.

Table 4. Weight breakdown for Atlas/Centaur comet probes

Subsystem	Weight, lb	
	Photovoltaic configuration	Isotopic configuration
Structure	90	90
Interface	20	20
Science		
Tracking platform	26	26
TV tracker	16	16
Encounter science	50	50
Cruise science	40	40

Table 4. Weight breakdown for Atlas/Centaur comet probes (cont)

Subsystem	Weight, lb	
	Photovoltaic configuration	Isotopic configuration
Boom	10	10
Data automation system	10	10
Attitude control	80	80
Midcourse propulsion (150 m/sec)	100	100
Telecommunications	100	100
Antenna	10	10
Thermal control	30	30
Power (200 w)	119-162	110
Panels or isotopic unit	69-112	70
Isotope support structure	--	10
Power conditioning	10	--
Batteries	40	30
System total (200 w)	701-744	692
System total (300 w)	737-800	742

Table 5. Weight breakdown for Atlas/Agena comet probes

Subsystem	Mariner C (1964)	With Type II trajectory modifications (late 1969)	With Type I trajectory modifications (early 1970)
Science			
Comet tracker and experiments	15	25	71

Table 5. Weight breakdown for Atlas/Agena comet probes (cont)

Subsystem	Mariner C (1964)	With Type II trajectory modifications (late 1969)	With Type I trajectory modifications (early 1970)
Independently mounted experiments	8	16	16
Electronics and data automation system	48	36	36
Guidance and control			
Attitude control and central computer and sequencer	39	39	39
Gas system	29	29	29
Sensors	7	7	7
Propulsion			
Midcourse motor	50	66	52
Telecommunications			
Data encoder and command	42	42	42
RF and tape recorder	64	64	64
Antennas	10	10	10
Power			
Panels	70	63	63
Regulator	16	16	16
Conditioning	32	32	32
Battery	33	33	33

Table 5. Weight breakdown for Atlas/Agena comet probes (cont)

Subsystem	Mariner C (1964)	With Type II trajectory modifications (late 1969)	With Type I trajectory modifications (early 1970)
Thermal control			
Thermal-control assemblies	13	13	13
Structure			
Pyrotechnics and actuators	6	6	7
Structure	59	59	76
Cabling	17	17	17
Total	565	573	623

Additional detailed results are supplied in SPS 37-32, pages 56 through 67.

Additional comet studies will be initiated in-house during the second half of FY 1966. The first half of FY 1966 will be used on the development of more specific comet scientific objectives and the generation of comet trajectories.

ADVANCED VENUS 1970 MISSION STUDY
NASA Work Unit 684-30-06-00
JPL 388-60101-2-1610

The effort planned was to have consisted of a conceptual design study of an advanced *Mariner* mission to Venus in 1970. However, subsequent to the generation of the task, the launch date was postponed to 1972. As a result of this rescheduling, the study effort has been postponed to the second half of FY 1966.

The FY 1966 effort will be initiated with a determination of the potential scientific objectives of such a mission and the preparation of the RFP for a contracted study to be issued during the second half of FY 1966.

BLANK PAGE

HIGH ENERGY MISSIONS – ADVANCED PLANETARY PROBE
NASA Work Unit 684-30-08-01
JPL 388-90101-2-2920

During the latter part of the second quarter of FY 1965, an unsolicited proposal was submitted to NASA Headquarters by the TRW System, Inc. (formerly Space Technology Laboratories), for a deep space planetary probe system study. TRW proposed to extend their previous in-house funded studies and conceptual design techniques for missions to the outer planets by a contract study that would embody the following:

1. Designs to maximize the communications capability of the spacecraft by use of large unfurlable parabolic reflector for which TRW has established extensive practical experience through prior programs.

2. A modular design concept which would permit the basic spacecraft configuration to be adaptable to flyby, orbiter, and planetary capsule entry missions.

3. A multi-target capability for the outer planets.

4. Low-cost mission concepts for the development of highly reliable design concepts for long range program utilization.

5. Use of radio isotope thermoelectric generators to supply power for missions away from the Sun.

Subsequent to the proposal evaluation by JPL, NASA Form 1044 was prepared and submitted for approval to initiate a contract with TRW for the study. A statement of work was prepared which delineated the scope of effort desired by the study on the basis of the unsolicited proposal. The study is intended to provide data on conceptual designs and feasibility to develop first-generation spacecraft concepts adaptable for long-range, long-duration planetary missions in the region extending from Mars to increasingly greater distances from the Sun. The study shall encompass the conceptual design of spacecraft systems to accomplish a variety of program objectives including: (1) basic flyby missions of the planets Jupiter, Saturn and Pluto, and (2) examination of the growth potential of the basic concepts through the use of modular design concepts developed by TRW to perform orbiter and planetary capsule entry missions.

Early in May a study approval was received and a request for proposal was prepared. Budget reviews during May delayed processing the procurement for several weeks. A contractor conference was held on June 4, at which time the unsolicited proposal and statement of work was reviewed. A request for proposal was issued to TRW on June 29, 1965; response date is July 27, 1965.

During the first half of FY 1966, effort under this task will concentrate on the monitoring and direction of the above contract.

The results of this study as they are developed will be used in an in-house ATS effort that will be initiated early in FY 1966 to develop conceptual designs for the exploration of the outer planets. A related in-house study is discussed under Work Unit 684-30-03-01.

STATEMENT OF WORK, TRW STUDY, ADVANCED PLANETARY PROBE

The following objectives appeared in the revised statement of work submitted to TRW.

I. Introduction

The objective of this program is to conduct a conceptual design and feasibility study to develop first-generation spacecraft concepts adaptable for long-range, long-duration planetary missions in the region extending from Mars to increasingly greater distances from the Sun. The study shall encompass the conceptual design of spacecraft systems to accomplish a variety of program objectives including (1) basic flyby missions of the planets Jupiter, Saturn and Pluto, and (2) examination of the growth potential of the basic concepts through the use of a modular design concept to perform orbiter and planetary capsule entry missions. Particular emphasis is placed upon the spacecraft design tradeoff analysis leading to configuration optimization for a range of injection weights which would have the highest probability of mission accomplishment with the following scientific objectives:

1. Measurement of the spatial distribution of interplanetary and planetary particles and fields.

2. Measurement of the salient features of planetary atmospheres, with particular emphasis upon remote measurements from a flyby spacecraft.

3. Observations of the planets, i.e., visual, IR, etc.

II. Scope of Work

In the performance of this study, the Contractor shall:

1. Develop spacecraft system conceptual designs for each of the objectives stated under I above by accomplishing the following

   a. Establish the functional requirements for spacecraft systems to perform the missions.

   b. Forecast the applicable state-of-the-art for the time period considered.

   c. Perform design tradeoffs as a basis of the rationale employed for design selections.

   d. Synthesize the appropriate system concepts.

e. Identify the problem areas and indicate approaches to their solution.

f. Review the system concepts in terms of the Mariner Mars 1964 and International Quiet Sun Year (IQSY) Pioneer spacecraft system designs.

2. Provide a description for each of the systems developed under paragraph (1) above which shall include, but not necessarily be limited to, the following:

a. System block diagrams.

b. Operational sequences.

c. Weight and power estimates.

d. System pointing accuracies and orientation maneuvers.

e. Spacecraft and science experiment internal-external interface compatibilities, including radioisotope thermoelectric generator radiation and thermal effects.

f. Redundancy considerations for increased reliability.

g. Evaluation of the design variations required for each of the scientific objectives showing the design complexities involved.

h. Spacecraft conceptual configurations and launch vehicle(s) general mechanical and dynamic compatibility.

i. Optimization of the alternative spacecraft systems developed in (1) with the launch vehicle choices showing tradeoffs involved.

3. Prepare descriptions of the subsystem designs studies and the mechanization approaches to be employed. This shall include, but not necessarily be limited to:

a. Means by which subsystem designs meet the system, or functional requirements of (1).

b. The design tradeoffs considered and the rationale used for design selection.

c. The long-lifetime reliability design considerations.

d. Identification of the problem areas determined and approaches to their solution.

4. Investigate spacecraft modular concepts which would provide orbiter and capsule entry capabilities to the basic flyby design for potential growth of the system. This shall include, but is not limited to:

   a. The mechanization feasibility and spacecraft interface compatibility.

   b. The operational feasibility and basic spacecraft optimality considerations.

   c. Modifications required to the basic spacecraft to utilize the modular concepts.

5. Conduct a reliability analysis for the system(s) selected which shall include, but is not limited to:

   a. Long lifetime missions to the outer planets.

   b. System/subsystem reliability assessments.

   c. Reliability improvement techniques.

   d. Probabilities of mission and partial mission successes with projected launch vehicle reliabilities for the time period of interest and system failure modes analysis.

6. Perform a cost/effectiveness analysis for each mission considered in (1). This analysis should result in a set of normalized numbers for comparing the various missions, and shall state the premise upon which the analysis is based.

7. Prepare preliminary estimates of schedule and cost for those system(s) developed under paragraph (1) above. Major variations in cost and schedule shall be noted. The cost estimates shall be in the same format as the costing categories for the Mariner Mars 1964.

HIGH ENERGY MISSIONS – JUPITER FLYBY
NASA Work Unit 684-30-09-01
JPL 388-90101-2-2920

A Jupiter flyby mission study, originally funded by Office of Advanced Research and Technology (OART) in FY 1965, under an OART Task entitled High Energy Missions: Jupiter Flyby, NASA Code 124-06-01-06, is one of two studies being sponsored jointly by OART and Office of Space Sciences and Applications (OSSA). OART funding reductions through the year for this task precluded following the original plans to contract with industry to perform this study. Early in May, study approval through the joint sponsorship was received and a request for porposal was issued to industry. Upon final evaluation of proposals received from industry on July 6, a contractor will be selected competitively and funded to an approximate level of $100,000.00.

The intent of the study is to provide data on: (1) the expected return from the mission, and (2) the capabilities and resources required for mission accomplishment in the time period 1973 to 1980. Three launch vehicle combinations, Atlas/Centaur, Saturn IB/Centaur and Titan IIIC/Centaur will be considered in accomplishing the mission. Within the time period, launch energy and DSIF compatibility design constraints the contractor is required to determine the alternate means of accomplishing the mission objectives by: (1) establishing the functional requirements of the spacecraft, (2) forecasting and applying the applicable state of the art, (3) synthesizing the appropriate system concepts, and (4) reviewing the system concepts in terms of the *Mariner* Mars 1964 spacecraft system design. In addition the contractor is required to provide schedule, cost, and probability-of-success estimates for the system concepts developed. The study contract will be monitored and directed during FY 1966.

The data provided from the study will be used as the basis of in-house studies that are planned for the later part of FY 1966. Current and future in-house activities are being devoted to establishing the scientific objectives and mission requirements for future study.

STATEMENT OF WORK, JUPITER FLYBY MISSION STUDY

The studies necessary to the generation of an RFP for contract to perform a mission study of a Jupiter flyby were completed during this report period.

The RFP was submitted to 17 companies in early June. Responses are due on July 6.[1]

The objectives of the study as defined in the statement of work are as follows:

1. The Contractor shall perform a feasibility study to develop spacecraft design concepts for a flyby mission of the planet Jupiter. The study shall consider a range of alternate design concepts for

[1]As of this writing, proposals have been received from the following companies: General Dynamics, General Electric, Lockheed, Martin, North American Aviation, and Philco. Evaluation is under way.

accomplishing the successive mission objectives listed below within the applicable design constraints:

a. Interplanetary and planetary measurements of the spatial distribution of particles and fields. Measurements shall include but not necessarily be limited to:

   1) Magnetic fields.

   2) Solar plasma.

   3) Dust and micrometeorites.

   4) Ionized radiation.

b. Measurements of the planetary atmosphere of Jupiter which shall include but not necessarily be limited to:

   1) Composition.

   2) Temperature and pressure.

c. Measurements of the physical properties of Jupiter which shall include but not necessarily be limited to the observation of the cloud cover and possibly gross features of the Jovian terrain.

2. In the performance of this study the Contractor shall:

a. Develop the conceptual designs for spacecraft systems for each of the objectives listed in paragraph (1) above by accomplishing the following:

   1) Establish the functional requirements for spacecraft systems to perform the mission.

   2) Forecast the applicable state of the art for the time period considered.

   3) Perform design tradeoffs as a basis of the rationale employed for design selection.

   4) Synthesize the appropriate system concepts.

   5) Identify the problem areas and indicate approaches to their solution.

   6) Review the system concepts in terms of the Mariner Mars 1964 spacecraft system design.

b. Provide a description for each of the systems developed under (2.) (a.) above, which shall include, but not necessarily be limited to, the following:

   1) System block diagrams.

   2) Operational sequences.

   3) Expected performance characteristics and design reliabilities.

   4) Weight and power estimates.

c. Provide estimates of schedule, cost, and probability of success, including success of partial missions, for each of the systems developed under paragraph (2.) (a.) above, and indicate the tradeoffs involved. The cost estimates shall be in the same format as the costing categories for the Mariner Mars 1964.

BLANK PAGE

Part B
Physics and Astronomy

BLANK PAGE

PHYSICS AND ASTRONOMY (1[illegible])

BLANK PAGE

MAGNETODYNAMICS IN SPACE (188-36)

MAGNETIC PHENOMENA
NASA Work Unit 188-36-01-01
JPL 385-60101-2-3280

The objective of this task is to investigate extremely low-frequency (ELF) signals (3-3000 cps) generated in or above the ionosphere. A field station has been established where such signals can be detected and recorded. Surface measurements will be coordinated with rocket and satellite measurements (OGO Search Coil Magnetometer Experiments). These simultaneous data will be analysed to study the origin and propagation of the ELF signals and their relation to other geophysical phenomena.

The ELF field station now consists of a complete three-axis system capable of monitoring magnetic fluctuations between 3 and 30 cps. An evaluation of the signals being detected in this frequency range is underway in order to classify them and to investigate possible contamination by man-made signals. A narrow band spectrum analyzer that will sweep between 3 and 3000 cps designed for possible use both at the field station and on a rocket has been purchased for this task.

During this report period, evaluation of the sweep frequency analyser was completed. An automatic programmer was installed at the observatory to permit recording of data while personnel are absent. A temperature-controlled circuit breaker was also installed to prevent damage to the unattended equipment due to overheating.

A vertical antenna was added to the sensor array in order to permit the vertical electrical field (3-3000 cps) to be detected and recorded. Two magnetotelluric current systems for the detection of both components of the horizontal electric field (3-3000 cps) were made operational.

The preliminary evaluation, classification, and analysis of recorded data is continuing as is the preliminary design of a search coil experiment and an electric field experiment suitable for use on a rocket.

Several hours of observatory data were taken simultaneously with operation of the search coil experiment on OGO-A. This was intended as a pilot study in preparation for more useful measurements expected on OGO-C. Intercomparison is being delayed until the satellite data are received.

BLANK PAGE

SOLAR-WIND PLASMA PHYSICS
NASA Work Unit 188-36-01-02
JPL 385-60201-2-3280

ADVANCED COMPUTER PROGRAM

The advanced computer program for analyzing the *Mariner II* plasma data was completed and run successfully for nearly all of the 40,000 plasma spectra obtained by *Mariner II*. For each spectrum, it gave plasma mean velocity, temperature, and density, the alpha/proton density ratio, and a parameter representing a non-Maxwellian high-energy spectrum tail.

To date, the following conclusions have been resolved from the data analysis:

1. There was always a measurably large solar wind flowing from a direction within ten deg of the Sun.

2. Streams of high-velocity, hot plasma were observed; these streams were apparently associated with M-region magnetic storms.

3. The geomagnetic-activity index Kp was highly correlated with the plasma velocity.

4. The plasma density was generally highest at the leading edge of a high-velocity stream. (However, *unlike* the velocity and temperature, the density calculation depends on the assumption of radial flow.)

5. Velocity and temperature were not strong functions of distance from the Sun; density and flux varied approximately as the inverse square of the distance.

6. A model in which the alphas and protons had equal thermal velocities fit the measured spectra better than did a model in which the two ions had equal temperatures. This situation might indicate that the plasma temperature was determined by local hydromagnetic heating rather than by thermal conduction from the lower corona.

7. At Venus encounter, we detected neither a magnetosphere, nor a magnetopause, nor a bow shock. The measurement of the solar-wind pressure at that time was necessary for the calculation of an upper limit of the dipole moment of Venus from the negative findings of the plasma probe, magnetometer, and energetic-particle detectors.

8. There is often a high-energy non-Maxwellian tail to the spectrum, which appears to be more pronounced for higher plasma velocities. It appears to be independent of the rate of change of velocity but may be associated with field reversals such as have been found in the wake of a collision-free interplanetary shock front (e.g., October 7, 1962).

PUBLICATION

Neugebauer, M., and Snyder, C. W., Solar-Wind Measurements near Venus, Journal of Geographical Research, Vol. 70, pp. 1587-1591, 1965.

JPL Technical Memorandum No. 33-243, Vol. I

ADVANCED MAGNETOMETER INSTRUMENTATION
NASA Work Unit 188-36-01-03
JPL 385-40201-x-3230

The objective of the magnetometer development program is to complete a second-generation low field vector helium magnetometer of inherent reliability and to extend development of the second generation system to provide high incremental resolution with wide dynamic range. To perform operational evaluations over temperature ranges compatible with Lunar, Cislunar, Planetary and Interplanetary missions.

PROGRESS

An article published in JPL SPS 37-32, Vol. VI, reports some of the characteristics of helium lamps and cells pertaining to designing for long lifetime operation. A comprehensive report on lamp and cell characteristics will be prepared after final testing of new units in the second generation magnetometer breadboard.

Life testing of Mariner C type lamps and cells continues. Because the life tests have not indicated appreciable degradation rates in an eight-month period, the study of degradation mechanisms has been deemphasized, and the effort on lamps and cells has been redirected toward the study of fabrication techniques. Figure 1 shows the evolution of the helium cell for the second generation system and the new fabrication technique which allows rapid production of lamps and cells of spectral purity.

Preliminary design work has been performed to establish hardware and shielding requirements for complete evaluation of a magnetometer sensor, including offset measurements, over temperature in vacuum. Because of cable stiffening at low temperatures, initial effort will be based on allowing only for a two-axis offset measurement. The initial work on vacuum-temperature offset measurements will be performed on the Mariner C life test unit to extend the prelaunch evaluation of that instrument.

Tests of system signal for various helium lamp pressures were performed to determine the validity of previous assumptions used in the choice of operating pressure (Fig. 2). The Mariner C lamps were filled at a pressure determined by the intensity of the 1.083μ light intensity. As the attached curves of system signal and 1.083μ light intensity vs pressure indicate, the assumption was incorrect. The test results also established that lamps of larger diameter tubing than that used for the Mariner C lamps are more efficient. Observations made on the visible light characteristics vs pressure suggest a relatively simple method of measuring pressure in fabricated lamps, and spectral studies will be performed in the future with the goal of establishing a parts screening procedure.

The feasibility of operating the vector helium magnetometer at field levels in excess of 0.2 gauss has been established (Fig. 3). In operation at high sweep field levels, it was found that the sensor signal was what theory predicts, whereas all work done previously at sweep levels of approximately 100-500γ did not agree with theory. A test is presently being prepared to accurately determine the sensor transfer function over a range from 0 to 1000γ. Preliminary testing strongly indicates that previously used sweep vector amplitudes are not at all optimum. The implication of results to date is that system noise and stability might be improved by an order of magnitude by actually using fewer parts because of an increase in sensor signal for smaller sweep vector amplitudes.

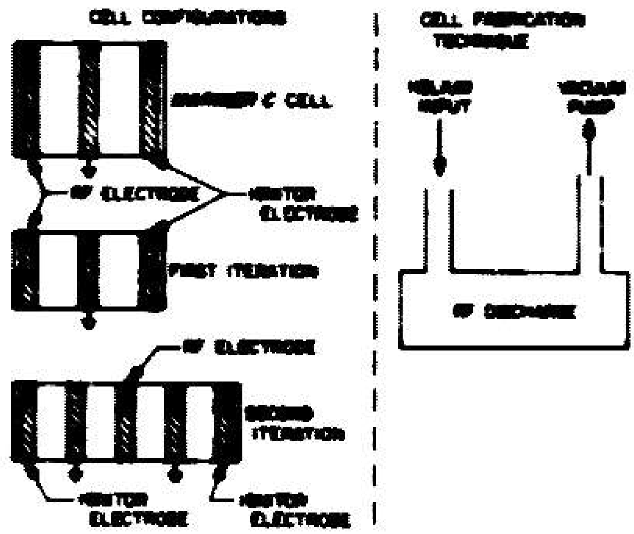


Fig. 1. Advanced magnetometer - helium absorption cell development

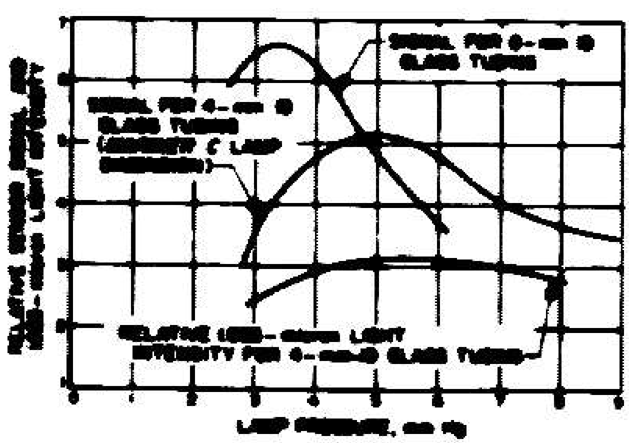


Fig. 2. System signal as a function of pressure

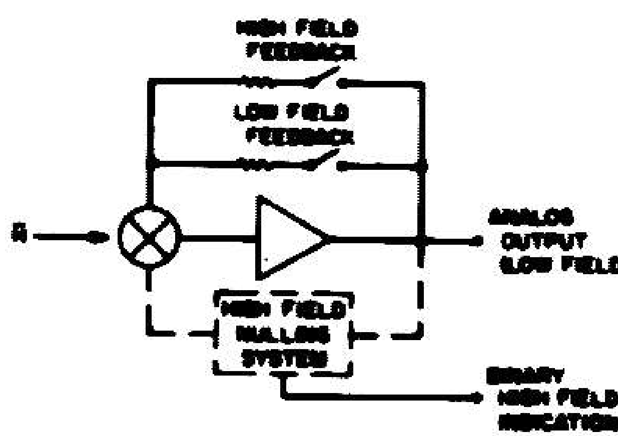


Fig. 3. Proposed mechanization of high field magnetometer

ENERGETIC PARTICLES (188-46)

RADIATION EXPERIMENTS
NASA Work Unit 188-46-01-01
JPL 385-60301-2-3280

The long-term objective of this program is the development of new experiments in the particles and fields area. Two experiments are under development. One utilizes a spark chamber system to measure the energy and angular distribution of energetic protons, alpha particles, and neutrons. The second experiment is a low-energy-particle telescope utilizing solid-state detectors. It will measure the energy spectrum of protons and heavier nuclei on the range ~ 0.1 to ~ 10 Mev/nucleon.

SPARK CHAMBER

The primary effort (under W. McDonald and L. Lewyn) is directed toward studies of protons associated with solar flares; however, we also intend to adapt the apparatus to neutron measurements, to be correlated with the charged-particle results. The presently planned program envisions a series of experiments employing instruments of increasing sophistication and proceeding from laboratory investigations to balloon flights, satellite measurements, and ultimately Voyager-class interplanetary experiments.

The instrument employs spark gaps in which solid plates are replaced by parallel wire grids, orthogonally oriented. Each wire passes through a magnetic core which can sense a current pulse. A spark produces a current pulse through each of two perpendicular wires, thereby identifying the coordinates of a particle that produced the spark. High voltage is applied after receipt of a counter pulse (subsequently height-analyzed) which indicates passage of a particle through the chamber.

During FY 1965 a planar laboratory model chamber with a nearly complete set of flight-design electronics was fabricated and tested. The major electronic components are: counter electronics, core readout electronics, high voltage modulator, analog-to-digital circuitry, and spark chamber digital readout and storage circuitry. A flight unit will require, in addition, a telemetry encoder and/or onboard recording system. For the test a laboratory pulse height analyzer was used.

During the report period, the model chamber was tested with respect to optimum wire spacing, filling-gas variations to minimize critical voltage, and effects of contamination on chamber performance. A new data processing system was completed, having improved data storage and display for easier analysis of test results. Also analytical studies were conducted which showed the feasibility of the neutron measurement.

Design and fabrication of balloon instrumentation is now proceeding. The formerly planned solid-state detectors will be replaced by scintillation counters in the balloon experiment, where the lighter weight of the solid-state detectors is not such a crucial consideration as it is on a spacecraft experiment. The scintillation counters have the additional advantages for the balloon experiment of economy and the fact that the triggering detectors can be made larger in size to give better count-

counting statistics. Because of the greater ease of fabrication when scintillation counters are used, a cubical, rather than the former spherical, spark-chamber geometry will be used.

A preliminary balloon experiment is being prepared for a flight from NCAR facilities in Texas or Arizona during FY 1966. This is primarily a feasibility and operational experience experiment. It will employ a planar instrument which approximates as closely as possible a modular unit of the eventual cubical chamber. A potential scientific result will be the angular distribution of cosmic ray albedo.

Fabrication of the cubical chamber will be carried out in preparation for a high-latitude balloon experiment proposed for summer, 1966. It is contemplated to make this chamber capable of giving neutron distributions as well as those of charged particles by placing a He^3 target inside it and analyzing the (charged) products of the (n, p) reaction.

LOW ENERGY PROTON TELESCOPE

Most of the work accomplished in the second half of FY 1965 has been done since April because of the time committed to the Mariner project. The principal effort has been directed to answer two questions: What is the effect of light upon the thin solid-state detectors of the type to be used in the front of the telescope when no window is employed? How good a charge-sensitive preamplifier can be built using all solid-state components? D. Johnson and H. R. Anderson have worked on the first problem, while R. Lockhart has done essentially all the work on the preamplifier. We have also attempted to measure the thickness of the dead layer on the front of the solid-state detectors and to measure the light pulse produced by plastic scintillation material when relativistic particles (mu mesons) pass through it.

The response of four detectors to light was measured by placing them in a vacuum chamber having a window. The chamber and detector were placed in a calibrated, parallel beam of light from the JPL star tracker calibration facility. (This was made available by G. Meisenholder, Section 344.) The color temperature of the light approximates that of the sun. The intensity was varied from 0.04 to 5.6 foot candles, while the detector amplifier chain was stimulated with a pulser which inserted charge in parallel with the detector. The full width at half maximum (FWHM) and the amplitude of the output pulse (position of the peak) were measured as a function of light intensity. The FWHM increased with light intensity typically by a factor of 2 to 3 from the dark condition to about 1 foot candle. The position of the peak shifted also and in some cases did not return to its original position when the light was shut off. We concluded tentatively that the detectors could be used in an intensity up to 1 foot candle but decided to make more measurements.

A simple facility was set up and calibrated with a CdS cell which had previously been calibrated absolutely in the star tracker facility. The light intensity can be varied both with a diaphragm and by varying the distance from source to detector. Three detectors have been exposed to 0.0, 0.11, and 0.7 foot candles with a constant input pulse. In this case, the peak position did not shift with changing light intensity. From this and other indications, we conclude that the shift observed earlier was caused by drifting amplifier gain. The noise increased by a factor of about 2 in going from dark to 0.7 foot candles. From the preliminary data so obtained, we conclude that the detectors can be used bare up to about 1 foot candle. Further measurements are required, however, and we need also to measure the dependence of noise increase upon the wave length of incident light.

The solid-state preamplifier developed in breadboard form during late 1964 has been assembled in a prototype configuration, and its noise level has been measured using a pulser input as a function of capacitance across the input terminals. The result is that the preamplifier noise is ~16.5 Kev FWHM with 100 pf at the input. Using a better PHA than previously available, we will measure the noise and gain stability as a function of input capacitance and temperature, using a solid state detector and radioactive sources.

Secondary results are that the dead layer of a detector has been measured by observing the energy deposited by Am^{241} alpha particles when the detector is oriented perpendicular to an inclined 45 deg to the particle beam. The particles were found to lose about 10 Kev in the dead layer. The layer therefore corresponds roughly to the range of 40 Kev protons.

No quantitative results have been obtained from the plastic scintillator measurements because of equipment failure, but preamplifiers, delay lines and coincidence circuits have been built and tested with which to make the measurements. We expect to have data very soon.

As reported in the May OSSA Review we plan in FY 1966 to (1) complete the measurements discussed above, (2) build a prototype sensor including detectors and preamplifiers but not the digital logic, and (3) to calibrate the sensor with protons in the energy range 50 to 500 Kev. The principal investigator will be on leave at Rice University after September 1965 and this calibration will be performed there. One or more proposals to fly the instrument will be submitted in FY 1966.

BLANK PAGE

SOUNDING ROCKETS (879)

BLANK PAGE

EXPERIMENTS (879-10)

AEROBEE
NASA Work Unit 879-10-01-01
JPL 745-10101-1-3280

The objective was to study the ultraviolet airglow and aurora of the Earth w h spectrometers and photometers.

LAUNCHES

1. Aerobee 4.115 was launched on September 18, 1964 at Wallops Island, Virginia. The UV spectrometer, 1100 - 3200 A, made the first complete measurement of the Earth's ultraviolet albedo and a measurement of limb emission spectra with the use of a telescope.

2. Aerobee 4.111 was launched on January 13, 1965 at Wallops Island, Virginia. The UV spectrometer, 2100 - 4200 A, made the first measurement of photo-electron-excited nitrogen second positive bands and obtained extensive spectra of nitric oxide and ionized molecular nitrogen.

3. Aerobee 4.112 was launched on June 29, 1965 at White Sands, New Mexico. The UV spectrometer 1100 - 2800 A, measured the spectra of oxygen and nitric oxide band systems.

PUBLICATIONS

1. Green, A. E. S., and Barth, C. A., Calculations of Ultraviolet Molecular Nitrogen Emissions from the Aurora. Journal of Geographical Research, Vol. 70, pp 1083-1092, 1965.

2. Barth, C. A., and Pearce, J. B., Rocket Measurement of the Photoelectro-Excited Ultraviolet Dayglow. Space Research VI, COSPAR, Buenos Aires, 1965.

3. Pearce, J. B., and Barth, C. A., Rocket Measurement of the Ultraviolet Aurora. Transactions American Geophysical Union, Vol. 46, p. 60, 1965.

BLANK PAGE

Part C
Bioscience

BLANK PAGE

BIOSCIENCE (189)

BLANK PAGE

EXOBIOLOGY (189-55)

GROWTH AND PHOTOSYNTHESIS
NASA WORK UNIT 189-55-02-01
JPL 386-51101-2-3260

ACTIVITIES DURING REPORTING PERIOD

Preliminary experiments have been completed, using pure suspensions of Chlorella pyrenoidosa to establish suitable durations of illumination, purge time, dark collection periods, and cell concentrations. These experiments consisted of: (1) innoculating filter paper discs, supported on metal planchets, with approximately 10^7 - 10^8 chlorella cells; (2) inserting the samples into a glass incubation chamber; (3) closing the chamber and generating $^{14}CO_2$ by acidification of a solution of $NaH^{14}CO_3$ containing 25μ C of radioactivity; (4) incubation of the sample under illumination; (5) purging residual $^{14}CO_2$ from the chamber; (6) removing the samples and collecting $^{14}CO_2$ generated during dark respiration by inverting glass planchets containing films of $Ba(OH)_2$ over the cell suspensions; (7) counting the radioactivity absorbed.

Controls consisted of distilled water blanks, media, and suspensions of killed cells. A dark control of live cells during illumination has not yet been performed.

The results were consistent with previous experiments reported by Levin (Quarterly Progress Report No. 13 to NASA, Radioisotope Biochemical Probe for Extraterrestrial Life, Contract # NASr-10). However, the conditions of our experiments were less favorable for obtaining high sensitivity. When the $^{14}CO_2$ concentrations in the chambers was 0.07μ C/ml, a 1-hr exposure to light with 30-min purge and 30-min dark collection periods gave greater than 16,000 cpm for cell concentrations of the order of 10^8. Counts obtained from control samples ranged from 7% to 20% of the experimental ones.

Experiments were performed to test CO_2 retention factors at different pH levels, in terms of counts recovered on $Ba(OH)_2$ films after media was subjected to atmospheres of $^{14}CO_2$ and purging. Recoverable counts increased exponentially as pH was increased from 4 to 9. The results indicated an increased rate of $^{14}CO_2$ evolution from the medium and rates of absorption by the $Ba(OH)_2$ film during two 30 min collection periods at pH 4, 6, and 7.

Calibration experiments were also performed to determine the approximate counting efficiency obtainable by the solid absorbent $^{14}CO_2$ collection technique used in these experiments. Efficiencies better than 15% of theoretical were obtained throughout the counting range obtained in these experiments.

Although experiments having controls of live cells incubated in the dark in the presence of $^{14}CO_2$, have not yet been performed, these experiments ubdoubtedly demonstrate the basic feasibility of this kind of photosynthetic life-detection experiment.

FUTURE ACTIVITIES PLANNED

The planned work for the next quarter entails:

1. Determining whether significant amounts of dark CO_2 evolution can be obtained from photosynthetic bacteria after illumination.

2. Further studies of the effect of retention on collection of CO_2 from media at different pH's.

3. Determining effects of $^{14}CO_2$ concentration, biological activity of experimental material, and light intensity on the sensitivity of the technique.

4. Initiation studies on the effects of the presence of soil on photosynthetic CO_2 absorption and dark evolution.

It is intended to develop an experiment which makes minimum assumptions about biological CO_2 fixation by Martian organisms. Therefore, several other possibilities will be kept in mind for planning work during FY 1966. These include:

1. The possibility that metabolic products formed in the dark after photosynthesis may not be CO_2.

2. That CO_2 fixation by chemosynthetic Martian organisms may also be important.

3. That the return of CO_2 to the atmosphere may involve an indirect process not associated with the dark metabolism of photosynthetic organisms.

Further work planned late in FY 1966 involves verification of $^{14}CO_2$ fixation by chemical analysis of pre-illuminates samples.

FLUOROMETRY
NASA Work Unit 189-55-02-02
JPL 386-50201-2-3260

In accordance with the agreement between Dr. Orr Reynolds and Dr. R. V. Meghreblian on October 6, 1964, the total effort of the fluorometry group has been directed toward determining the feasibility of the analysis of primate urine for the biosatellite program. Therefore, during the past two quarters, progress in life detection by fluorometry has been linked mainly with results in biosatellite instrumentation for which breadboards are now becoming available.

DETECTION OF ORGANICS

The conversion of a variety of organic compounds to fluorescent derivatives by temperature-programmed pyrolysis has been demonstrated.

Since the examination of the pyrolysis products resulting from exposure to various temperatures will permit elucidation of the course of the reactions taking place, characterization of the pyrolysis products from simple hydrocarbons, amino acids, sugars, and natural soils will be carried out. The course of chemical transformations taking place during pyrolysis should also be investigated.

The concept of a fluorometric assay of general organic compounds which involves trapping volatile organic products of pyrolysis on a cool surface and directly observing the characteristic fluorescence, will be implemented into a working breadboard design of a small automated instrument.

DETECTION OF BIOLOGICAL MOLECULES

Qualitative and quantitative determinations of a variety of highly conjugated biomolecules have previously been developed. The assays include determination of aromatic amino acids, proteins containing aromatic amino acids, nucleic acid bases such as adenine and guanine, and chlorophylls.

Further investigation of various metal porphyrins as well as bacterial chlorophylls will be carried out with both pure and naturally occuring substances in various soil media.

The method of determining the fluorescence properties of all nucleic acid bases will be further refined with respect to hydrolysis conditions and removal of interferences by soil constituents.

Fluorometric methods will be developed for carotenoids, quinoues, and their derivatives, since those compounds are believed to play important roles in the light absorbing mechanism in photosynthesis.

A partial development breadboard instruments for the assays of protein, chlorophyll, and nucleic acid bases has already been achieved as a result of the biosatellite instrumentation. The key components developed in this category include the fluorometric optical system, heating elements and mechanical displacement pumping system.

An additional development of breadboard instruments will be attempted within the limit of engineering and material resources.

DETECTION OF BIOLOGICAL FUNCTIONS

Previously the growth of microorganisms has been measured by the increase in fluorescence intensity of either protein or chlorophyll. Provisions of suitable growth environments and suitable nutritional conditions are the keys to success. Nutritional media will be developed for support of growth of soil microorganism; indeed, hot water extracts of native soil might provide the basic medium for culturing these endogenous organisms.

Since photosynthesis necessarily involves light-powered electron transport along an electron carrier chain and since organic electron carriers are in general fluorescent, the fluorometry of organic electron carriers is a highly general method for detecting photosynthesis. The techniques for measurement of photosynthesis will be developed so that one can provide an excitation radiation appropriate to both chlorophylls and the electron carrier systems.

Again, the breadboard for measuring growth and photosynthesis already has been partially developed in the work completed for the biosatellite instrumentation.

PROTOTYPE DEVELOPMENTS (JPL 386-50202-2-3220)

This task was initiated during the second quarter of FY 1965. Discussions were held with Nello Pace of the University of California, Berkeley campus, to establish the tradeoffs between engineering capability and scientific desirability of analyzing for a large number of primate urine chemical compounds. This technical interchange resulted in the selection of four chemical compounds for analysis. These compounds represent a combination of compromises which permit a realizable experiment package within the engineering design constraints and yet yield significant scientific information on the effects of long term exposure to weightlessness.

The compounds creatinine, creatine, calcium, and urea were selected for the biosatellite primate urine analysis experiment (elaborated in a subsequent section of this work unit report). The preliminary weight estimate for this experiment is 10 lb, with a volume of 300 in.^{3} and a maximum power drain of 10 w. The basic effort under this task is the development of instrumentation concepts which could be translated into flight hardware. Two items have already been reduced to the prototype stage. The first item is a completely automated micrometric syringe to dispense microliter quantities of calibration fluid into each of the analytical experiments. The prototype has been evaluated for accuracy and has demonstrated a volumetric accuracy of better than 0.05 microliters in a 25-microliter delivery volume. This is approximately a 0.2% error and is well within the anticipated accuracy of the various experiments performed by this system. The unit will hold sufficient fluid to provide at least one test per day for one month with twenty additional tests during the preflight calibrations.

The second item is the fluorometric readout amplifiers plus a breadboard of the output data coding system. A thermal controller has also been developed for use in maintaining a close temperature control on each of the analytical test cells.

The temperature control is required to stabilize the fluorometric conversion efficiency of each of the chemical reactions to simplify the data processing.

In order to integrate into the biosatellite program, technical personnel have attended various technical direction meetings held by Ames Research Center and General Electric Corporation. The purpose of these meetings has been to acquaint JPL personnel with the current status of the biosatellite, the potential locations for the experimental hardware and the various problems to be encountered in installing this experiment in the spacecraft. These meetings have successfully provided JPL the knowledge required to integrate the experiment into the biosatellite spacecraft.

Preliminary design has been started on the Associated Ground Equipment (AGE) to support this experiment at JPL and in the field. Procurement of long-lead-time items has been initiated. The chemical analysis support position of the AGE will be firmed up as soon as volumetric ratios, specific chemicals, temperatures, and other operating parameters have been defined through actual operation of the breadboard instruments.

SCIENTIFIC FEASIBILITY STUDIES (JPL 386-50203-2-3260)

Breadboard units for four chemical analytical systems to be used for a primate urine analysis (for biosatellite) have been designed, fabricated, assembled, and are being tested and evaluated. The four units are in different stages of progress but have a common basic methodology that consists of flow-through liquid systems operating by peristaltic pumps for metering and transporting the fluids. Reagents are added to each sample which then forms either a chromophore or a fluorophore, determined quantitatively by colorimetry or fluorimetry using appropriate light sources, filters, and detectors. In some cases the reactants are heated in order to develop the end products. The experiment is calibrated using standard solutions.

Creatinine

This urinary constituent is reacted with alkaline picrate solution to form a pink color (absorpt. max. 490μ). A tungsten light source is used with absorption filters and cadmium sulfide detectors. The instrument is now totally automated and has been gathering reliability data for 2 mo. The lifetime of pumps and tubing is being established. The data is consistent throughout the ranges of concentration of fluids used in the calibration test. The instrument operates through a sequence of six test cycles and six rinse cycles every 6 hr, continuously.

Calcium

This constituent is detected by coupling to calcein solution forming a fluorescent product which is excited at 490μ and emits light at 520μ. Initially a mercury source was used for illumination but the resulting photolysis of the calcein solution required this be changed to a tungsten source operating at voltage maximum. This instrument is fully automated, and data has been accumulated to examine reliability of the components and repeatability of the data. Because of the mixing ratio of reagent to sample (50:1) one phase of the mixing process is incomplete. This problem is currently being overcome by using a larger volume than planned. Since some calcium derivatives adhere to glass surfaces, special precaution has been used in coating the walls of the flow-through fluorometer cell with Teflon.

Urea

This constituent can be determined either colorimetrically or fluorometrically by reacting with diacetylmonoxime and sulfuric acid at 100°C for 20 min (excitation at 380μ, emission at 520μ). The fluorescent output is low causing a less than desirable signal-to-noise ratio. The colorimetric curve deviates from linearity. The breadboard is being operated manually during the experimental phase; however, the fully automated breadboard has been fabricated and needs only final assembly. The heater unit consists of a coil of tubing surrounded by a helix of resistance wire and has been tested and found to be temperature stable, chemically inert, capable of higher pressures than used, and does not introduce extraneous bubbles.

Creatine

This constituent is converted to creatinine by dehydration using HCl at 100°C for 15 min, and performing the same assay as described for creatinine. The instrument has been fabricated and assembled. The heater for the creatine conversion is similar to that used for the urea experiment.

Planned Activities

The completion of four fully automated breadboard units will be carried out during the next several weeks. Reliability data for components and subunits will be established and reproducibility of data determined. At present, simulated urine is used as a sample. In the future, urine samples derived from primates on the special diets to be used during the spaceflight will be introduced into the test system. Numerous changes are planned for improving the instrument. Selected narrow band pass interference filters, improved light sources, field effect transistor detectors, more resiliant and more resistant materials for the tubing, focused optics, reduction in pump size and volume, and improvement in mixing chambers. Tests of materials to withstand corrosive chemicals and examination of materials such as adhesives for natural fluorescence will be extended.

An accumulator has also been designed and a breadboard fabricated for use in conjunction with this experiment. Removal from the main urine line of 10% of each emptying will provide sufficient accumulation of sample for one test cycle. The system collects and mixes up to four emptyings during each 6-hr period and delivers it to the analytic unit. This unit is manually operated and will be automated during the next quarter.

PRIMATE URINALYSIS (JPL 363-50201-2-3260)

In order to study the physiological effects of prolonged weightlessness and accompanying stress by the *in situ* chemical analysis of the urine of a mammal flown in the biosatellite program, simple and reliable methods for estimating urinary constituents are required. Direct single-step methods have been developed for assays of urinary calcium, urea, creatinine, and creatine.

The determination of urine calcium was made by adding urine to an alkaline solution of calcein and measuring the fluorescence of the product. The fluorescence intensity is proportional to the concentration of calcium added and the method compares favorably with the conventional methods. Urea in urine has been determined by a method using diacetylmonoxime. Comparative studies with colorimetric determination of ammonia following urease treatment of urine and internal standard sample recovery studies proved that the reaction is specific to urea and the assay has good reproducibility. The concentration of creatinine has been determined in an aliquot of urine with alkaline picrate. It has been learned that good reproducibility is dependent upon accuracy of reagent concentration, pH, time, and temperature during color development. Creatine was determined by first converting it to creatinine by heating in acid at 100°C for 15 min. The difference between the value obtained after this procedure and the value originally obtained for creatinine represents urinary creatine.

The concepts of various analytical techniques have been implemented into a working breadboard design of a small automated instrument. Two fully automated breadboards for assays of calcium and creatinine have been constructed, and the assays by these breadboard systems are reproducible. In urea assay system, various material problems as well as many mechanical and optical problems have been solved and the functions of various instrumental components have been tested. These tested components are currently assembled into an automated system for urinary urea assay.

Besides the development of the breadboard model of the instrument, some back-up experiments in the quantitative analysis of urine samples have been conducted. Characterization of the reaction of urea with diacetylmonoxime in acid medium has been carried out with respect to the reaction mechanism, kinetics, and products. In addition an alternative method for determination of urea using Ehrlich's aldehyde reagent has been investigated. This method does not involve heating and the color of the reaction product responds quite linearly with urine concentrations.

The assays for magnesium, phosphate, glucose, catecholamines, and 17-hydroxycorticosteriods will be developed as they are needed.

Thirty-day tests of the analytical equipment developed for calcium, urea, creatine, and creatinine will be performed during the next two quarters.

The various analytical systems which have been developed in the breadboard phase are currently being integrated into the flight hardware. The engineering prototype is scheduled for completion by September and the flight type approval model will be assembled by December 1965.

BLANK PAGE

BIOSCIENCE EXPERIMENT DEVELOPMENT
NASA Work Unit 189-55-02-03
JPL 386-51301-2-3260

Because of the common goals of this task and the biosatellite program (NASA 883) and as the latter has a critical schedule, the two work units have cooperated in a single effort to develop an automated and miniaturized breakboard capable of making fluorometric as well as colorimetric analyses. The components consisting of pumps, valves, illumination sources, detectors, heating units, chemical mixers and materials of construction have been investigated.

A field test was conducted in collaboration with the Wolf Trap growth experimenters. Drs. Weston and Soffen (University of Rochester and JPL) and engineers from Ball Brothers Inc. performed the first field test of this instrument near Death Valley, California. The test was successful, with growth becoming evident in 18 hr. A motion picture film recorded this test, and desert soil samples were retrieved for laboratory analysis.

Continuous surveilance has been maintained over out-of-house life detection experiments to update the survey report.

Future effort will consist of extending current activity by developing the wet chemical analytical systems. Construction of the breadboard for a fluorescence life detection experiment will be initiated, and some study of the methodology for photosynthesis will be carried out. Additional effort will consist of continuing the development of the Mars biological microscope.

BLANK PAGE

EXOBIOLOGY INSTRUMENTATION
NASA Work Unit 189-55-02-04
JPL 386-51401-2-3220

The purpose of this task is the development of instrumentation to perform wet chemical analysis of planetary soil. The approach consists of developing various analytical instruments that can be incorporated into a modular system. Such a system would perform a variety of analyses upon a sample of planetary soil delivered into the analyzing instrument. Under this task, an automatic zeroset or resetting tracking photometer has been developed to follow changes in light scattering and tubidemetic analyses such as were carried out in the Wolf Trap experiment. The tracking photometer will follow the settling curve of particulates carried in solution, providing a maximum signal-to-noise ratio and a nearly optimum condition for the detection of growth by nephelometric techniques.

Another technical development has been the design of test chambers to perform both single- and dual-stage chemical analyses. One design, the two-stage test cell shown in Fig. 1, has been subjected to the 145°C dry heat sterilization cycle to evaluate performance for storage, valving, and transport of sterilized fluids. This test included two optical paths at right angles to monitor fluorometric reactions. This particular stainless steel configuration is not considered for flight use, but

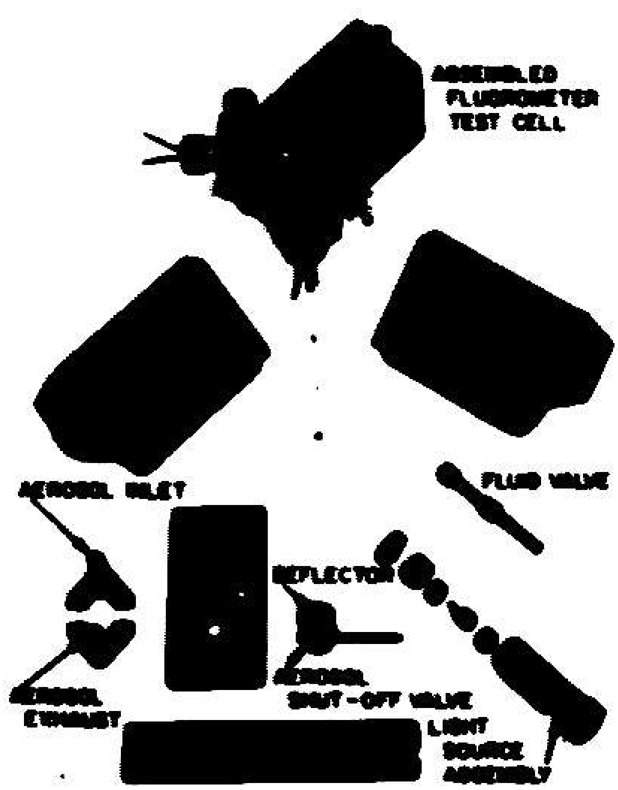


Fig. 1 Fluorometer test cell

serves to demonstrate a capability and a technique. The design of multiple-step test chambers is continuing with emphasis upon the problems of reliable porting, valving, pumping, and sequencing.

The problems of instrument calibration through the direct addition of calibration chemicals into the test chambers has been investigated. One resulting design was a small self-contained motor-driven micrometric syringe that dispenses mircoliter quantities of test fluid upon command from an electrical actuator. This technique is proposed for the in situ calibration and base line compensation of an automated chemical analyses laboratory.

A solid carrier amplifier for a pH meter has been completed. This amplifier used advanced state-of-the-art solid-state devises such as metal-oxide field effect transistors. Compared to standard commercial units, the new unit is smaller, has fewer parts, uses lower power, and is more reliable. Temperature coefficient ard pH sensitivity data are shown in Fig. 2.

Thermal testing of the Minivator breadboard electronics was carried out. This testing evaluated the stability of the logic scanner and sequencer system, the drift characteristics of the stabilized light source, and the gain sensitivity of the pH amplifier.

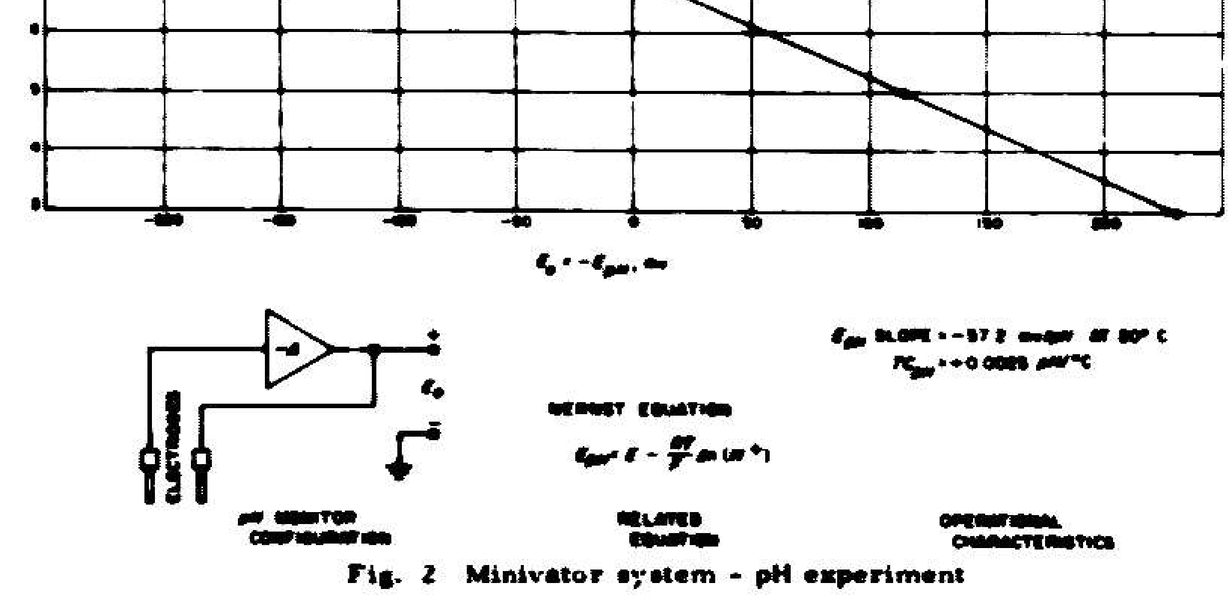


Fig. 2 Minivator system - pH experiment

IMPROVEMENT OF ELECTRON MICROSCOPE RESOLUTION
NASA Work Unit 189-55-02-05
JPL 386-51501-2-3240

In this process, a series of bright and dark field electron micrograph images of a crystalline specimen are taken. These images are then analyzed by a computer into their Fourier components which then reveal the phase relationships of those diffraction maxima which contributed to each partial image. With the knowledge of all of these diffraction maxima intensities and phase information, a single high-resolution image can be synthesized by the computer.

A reasonably stable test specimen has been chosen. This material, indanthrene olive, is resistant to a hot, concentratrated electron beam and should suffice until negotiations for an image intensifier are complete. At that time, it should be possible to record clearly the presently delicate and low contrast images from more interesting organic materials, such as DNA in viruses.

Progress has been made in recording the low-order diffraction interaction mircrograph. This step verifies the theoretical model proposed when simulating this technique using optical wavelengths.

The goniometer stage which gives control over specimen tilt has been received, and the image intensifier is the only necessary remaining component.

In FY 1966 this work unit will be funded by DART under Work Unit No. 125-24-03-06.

BLANK PAGE

MARS BIOLOGICAL MICROSCOPE
NASA Work Unit 189-55-02-06
JPL 386-50501-2-3260

Two life detection instruments and two experimental study programs have been under development during the report period. The instruments are an abbreviated microscope and a flying spot histochemical microspectrophotometer. The abbreviated microscope has been developed and is being evaluated by introducing known aerosal samples of biological and non-biological nature. Direct photomicrography is compared with videophotography to ascertain reduction in resolution caused by the communication link and noise. The flying spot instrument is in an advanced stage of development. The optics have been improved to give a two-micron beam spot within a 50 μ excursion path. The optical filters and photomultiplier circuitry have been corrected and specified to detect and switch modes of operation from scan to view with less than 10% difference of output signal. A heat-resistant plastic tape (H-film) capable of withstanding heat sterilization has been examined for incorporation. The histochemical injection system has been improved to eliminate problems of overflow, smearing, scoring of tape and optical immersion oil. The instrument has had successful preliminary tests using suspensions of known bacteria.

A study has been made of the feasibility of using infrared microspectrophotometry to detect organic material _in situ_ at the 5-10 μ wave length region. The microscope attachment for an infrared spectrometer has been calibrated and the spectrum of biological and biochemical samples obtained. The results appear to be promising.

Biological motion at the microscopic level can be detected by a technique in which only changes in a field are recorded. The separation of biological and non-biological motion (Brownian movement) can be accomplished by frequency analysis. In order to study this a unidirectional system (capillary blood flow) was selected to simplify the problem. Magnetic tape recordings of a capillary bed were obtained using a videomicroscope coupled to a high-speed tape recorder. Analysis of this has been initiated.

Most of this work will be interrupted since this task has been canceled. Some of this will be carried out under Biological Experiment Development.

BLANK PAGE

JPL Technical Memorandum No. 33-243, Vol. I

BIOSCIENCE INSTRUMENTATION STUDY
NASA Work Unit 189-55-02-07
JPL 386-51802-2-3220

An engineering evaluation was performed on the following potential life-detecting instrument systems: Atmospheric gas chromatograph, Gulliver, Wolf Trap, Ultraviolet Spectrophotometer, Mass Spectrometer, Organic Gas Chromatograph, J-Bands, Multivator, Minivator, and Optical Rotatory Dispersion. The evaluation of these instruments included direct contact with the potential experimenters and their organizations. A review of pertinent drawings, schematics, test data, etc., and the evaluation of related published literature was carried out. The results of this evaluation will be published as a part of the Voyager - Minimum Biological Payload Studies by G. Hobby, D. Hitchcock, and G. Thomas.

Further effort consisted of updating the engineering development status for each instrument to reflect the engineering progress achieved. Participation in the Bioscience Working Group meeting held on March 22, 1965 at Newport Beach, California was included in this task.

BLANK PAGE

DETECTION OF LIFE-RELATED COMPOUNDS

NASA Work Unit 189-55-03-01;
189-55-03-03*
JPL 386-51201-2-3260;
386-51901-2-3260

The scientific objective of this task is to provide information for defining a chemical life detection experiment. The analytical procedure being developed is based on the combined techniques of gas chromatography and mass spectrometry. The procedure to be followed is: (1) thermal treatment of the sample to yield volatile fragments, (2) separation of these volatiles by gas chromatography and (3) mass spectrometer determination of the component(s) present in each gas chromatograph peak.

GAS CHROMATOGRAPH-MASS SPECTROMETER STUDIES

The immediate activities of this task are concerned with the two main interface problems in uniting a gas chromatograph and a mass spectrometer; i.e., enrichment of sample components in the chromatograph effluent and removal of carrier gas from the effluent stream. The work on these problems involves: (1) investigation of enrichment devices used intermediate to the two instruments, and (2) study of pumping methods for removal of carrier gas. Molecular separator devices, to be used in this work, were ordered from Sweden and have been received. The test system to be used in studying pumping methods is nearing completion.

GAS CHROMATOGRAPHY-MASS SPECTROMETER TECHNIQUES; PREPARATION OF ORGANIC SAMPLES FOR GAS PHASE ANALYSIS; AND GAS CHROMATOGRAPH-MASS SPECTROMETER ANALYTICAL SYSTEM

The activities under this task are primarily concerned with the study of methods of sample preparation and treatment for use in the detection of biologically important substances. Thermal treatment procedures were investigated to convert non-volatile samples to substances of sufficient volatility to be separated and detected by gas chromatography and analyzed by mass spectrometry.

An extensive study of the pyrolysis of mesoporphyrin has been completed. The pyrolysis conditions were determined which yielded the greatest amount of representative fragments. Based on this study, similar work was carried out with deuteroporphyrin, etioporphyrin, protoporphyrin, hematoporphyrin, phylloporphyrin, pyrroporphyrin, and etiochlorin (of the chlorophyll series), in which the ideal pyrolysis conditions were determined, and the representative fragments identified. The analytical techniques used included gas chromatography, mass spectrometry, and nuclear magnetic resonance. A series of papers reporting this work are planned to be submitted for publication. The first is now in draft.

The study of methods of sample treatment for detection of biological substances in soils has also been continued. Samples of a desert soil were pyrolyzed in a reducing atmosphere of hydrogen: 45-60 min, 400-450°C. The reaction products

*Jointly funded under NASA Code 185-37-26-09 and 189-37-26-10.

were collected and analyzed by gas chromatographic and mass spectrometric methods. Of the products that have been identified, the predominant ones are: carbon dioxide, ethylene, methane, ethane, and butanes.

MAJOR PURCHASES

Bids have been requested from manufacturers to supply a high resolution mass spectrometer for use in this program. The instrument will allow faster analyses of the products of pyrolysis studies; in addition, the instrument will be connected to a gas chromatograph, using separator devices, so that a laboratory instrumental system may be studied.

FUTURE PROGRAM

Gas Chromatograph-Mass Spectrometer Studies

Pumping methods for the removal of carrier gas will be investigated. Chemical pumping as well as ionic pumping are to be considered. The development of molecular separator enrichment devices will continue toward optimization of the units for use in the instrumental system to be assembled. The pumping system and enrichment devices will be assembled into a breadboard simulating their use in a gas chromatograph mass spectrometer instrumental system.

The time sequencing of mass spectral scanning of the gas chromatograph effluent will be studied with a specially modified mass spectrometer so that a scan initiation will occur at the most opportune time.

Work will continue on the handling of data from a combined GC-MS system.

Chemical Studies

Pyrolysis studies will be performed on representative desert soils containing 0.5 to .0% organic matter. These studies will involve a determination of the optimum pyrolysis conditions to yield the most useful information concerning the structure of the organic material present. In addition, varying amounts of pure compounds such as the porphyrins, whose pyrolysis patterns are known, will be added to samples of the soils, and the pyrolysis of the mixture studied.

Work on other pure compounds such as the peptides and metallo-porphyrins will continue.

Instrumental Techniques

The high resolution mass spectrometer will be acquired and put into operation. A laboratory instrumental system will be assembled having a thermal treatment unit, a gas chromatograph, molecular separators, and the mass spectrometer as contiguous units.

The study of thermal treatment techniques will continue. The possibility of performing differential thermal analysis (DTA) and fluorometric analysis on the sample simultaneously with the pyrolysis will be investigated. DTA studies will include rapid heating rate analyses.

Gas chromatographic studies planned will include the development of suitable column packing to separate the polar organic compounds which are obtained during the pyrolysis of high molecular weight organic materials; in addition, feasibility studies on the use of very low flow rates will be performed.

BLANK PAGE

DESERT MICROFLORA
NASA Work Unit 189-55-04-01
JPL 386-50301-1-3260

SOIL GAS EXCHANGE

Five preliminary studies have been completed for measuring soil CO_2 evolution with a gas chromatograph using an unactivated silica gel column. At 20° C, the retention time was 90 sec. Sieved and powdered 1.0 to 0.5 gm samples of a sandy Mohave Desert soil were incubated at 0.5, 1.0 and 1.5 F.C. moisture values. One % $CaCO_3$ was added to some soils. The addition of 1% $CaCO_3$ had no detectable influence on CO_2 production following the addition of H_2O. A higher level of CO_2 was produced at 1.0 F.C. than at 0.5 F.C. or 1.5 F.C. CO_2 curves obtained for both wet and dry sterile soils were similar and these curves differed significantly from those of the wet or dry soils containing viable indigenous soil microflora.

A measureable increase in CO_2 evolution could be obtained on powdered 0.50 gm samples of soil 30 min after the addition of H_2O. At the termination of one experiment on 0.50 gm of powdered soil the number of aerobic bacteria had increased from 60×10^4 to 1.505×10^4 after the addition of H_2O at 1.0 F.C.

Sensitivity of the system has been increased to a detectable CO_2 concentration of 0.0025%. Further instrumental changes have been made to include concurrent measurements of CO_2 and O_2 changes in soil gas exchange experiments.

SOIL STORAGE AND PRESERVATION STUDIES

The purpose of this study has now become two-fold: (1) to determine the effects of various environmental factors or possible changes in stored samples, and (2) to determine variability in properties of samples of desert soil of similar genesis and development.

Soil samples from four sites in relatively arid areas of California have been collected and stored for approximately one year under the following conditions: (1) temperatures of -195 to +55° C, (2) atmospheres of N_2, CO_2, and O_2, (3) vacuum of 10^{-6} to 10^{-7} mm Hg, and (4) freeze-dried state.

In the field, soils have been isolated and protected in a plot at 12,400 ft in the White Mountain Range of California. A comparison of chemical elemental abundance and microflora abundance in 18 samples from the field plot showed little variability between samples.

Twelve old, stored soils collected 70 to 85 years ago from arid areas in California and maintained in the air-dry state were obtained from Prof. Hans Jenny, Hilgard Museum, University of California, Berkeley. Four out of six of these soils from the surface one-ft level have shown algal growth of typical desert soil algae, primarily non-spore formers. Aerobic bacterial counts varied from 10.5×10^3/gm of soil to $5,000 \times 10^3$; anerobic counts varied from $<0.0 \times 10^3$ to 33×10^3; microaerophilic bacteria varied from 1×10^4 to 1×10^7. There were no survivable fungi.

CONTRACTOR PROGRESS

Cultural and identification studies of desert bacterial isolants have been continued under Contract No. 950783 by Prof. Walter Bollen as principal investigator at Oregon State University, Corvallis. Thirty-four additional White Mountain isolants were sent for study in February and another twenty-six isolants from California desert soils were sent in April. Identifications have been completed on more than forty isolants. These were primarily Bacillus, Corynebacterium, and Brevibacterium spp. A complete, detailed progress report of 58 pages has been received on physiological and morphological characteristics of Bacillus spp.

REPORTS, MEMOS, AND OTHER PUBLICATIONS

1. Soil Algae Occurring in the Valley of 10,000 Smokes Desert, Alaska, Trans. Amer. Microsc. Soc. Vol. 84 (1), p. 151, 1965.

2. Microorganisms in Valley of 10,000 Smokes Desert, SPS No. 37-32, Vol. IV, pp. 196-202, Feb. 1 - March 31, 1965.

3. Soil Extract as a Culture Medium, SPS No. 37-32, Vol. IV, pp. 202-208, Feb. 1 - March 31, 1965.

4. Soil CO_2 Production Measured by Gas Chromatography, SPS No. 37-32, Vol. IV, pp. 208-212, Feb. 1 - March 31, 1965.

5. Abundance of Microflora in an Area of Soil at White Mountain Range, California, SPS No. 37-32, Vol. IV, pp. 212-214, Feb. 1 - March 31, 1965.

6. Abundance of Chemical Elements in an Area of Soil at White Mountain Range, California, is being published in SPS No. 37-33, Vol. IV.

7. Soil Chemistry and Sampling. A paper written for National Academy of Science, National Research Council, Space Science Board, to be published in "Biology and the Exploration of Mars."

8. Measurement of Soil Moisture by Thermal Conductivity Probes, to be published in SPS No. 37-34, Vol. IV.

9. Influence of $CaCO_3$ on CO_2 Evolution in Soil; Technical Memo submitted to G. Hobby, Feb. 23, 1965

MEETINGS ATTENDED AND PERTINENT DISCUSSIONS

1. Ames Laboratory, Feb. 17, 1965. Discussions on desert soil microflora and respiration.

2. Oregon State University, Corvallis, Feb. 18 and 19. Discussion of contract concerning desert bacteria physiological and morphological characteristics.

3. NASA Youth Science Congress - participation as judge. Los Angeles, California, March 12 and 13, 1965

4. AAAS, Arid Lands Symposia, Flagstaff, Arizona, May 4 to 6, 1965. Presented paper on "Characteristics of two soil ecosystems in the Arizona Upland Desert."

5. JPL - CIT Bioscience Review, May 20, 1965, presented pertinent aspects of Desert Microflora program

6. AAAS - Western Soil Science Society of America, Riverside, California, June 23, 1965. Presented paper on "Role of Soil Science in Space Exploration."

BLANK PAGE

BIOSAMPLING
NASA Work Unit 189-55-04-02
JPL 386-50401-2-3260

A study contract for examining the feasibility of a pneumatic vacuum system for collecting samples on the surface of Mars has been completed and a final report submitted to NASA as well as to the biosciences subcommittee. This system appears to be feasible for collecting dust particles up to 100 μ in diameter, and it is believed that this will be the biologically enriched fraction. A prototype instrument is being fabricated by Litton Industries

Future efforts will be to perform laboratory and field tests, to upgrade the pneumatic system, and to examine other methods of a less passive nature. A mechanical system has an inherent weakness of reliability but is the most positive in dealing with an unknown biology and surface.

BLANK PAGE

BIOLOGICAL SAMPLE ACQUISITION SYSTEM
NASA Work Unit 189-55-04-04
JPL 386-50101-2-3220

Emphasis has been placed on the development of a small, lightweight sample acquisition system capable of collecting, transporting, recovering, and delivering a dry, friable sample of soil particulates to an analytical instrument. In order to provide such a sample, it was necessary to determine the operating parameters and their relationships to changes in ambient conditions and power sources. As a result, a small vacuum test chamber was instrumented to allow the evaluation of these performance parameters. Using the major parameters, a sampler system has been fabricated and tested. A preliminary report of this technique was made in JPL Space Program Summary 37-29, Vol. 4. The system, shown in Fig. 1, does not function at atmospheric pressures lower than 50 millibars absolute due to the back pressure created in the aerosol transport tubing. To overcome this problem, the jet aerosolizer was relocated to the inlet of the cyclone centrifuge as shown in Fig. 2. By relocating to this position, the atmospheric pressure drop in the transport tubing is now eliminated. It appears, instead, as a portion of the atmospheric pressure. Particulates now may be collected satisfactorily at pressure ranges as low as 10 millibars.

A second technique was developed under contract No. 950771 with Litton Industries of Minneapolis, Minnesota. Litton's technique shown in Fig. 3 consists of changing the aerosolizer location to the exhaust of the cyclone centrifuge. This particular unit will operate at pressures as low as 5 millibars absolute. A performance curve is shown in Fig. 4.

Both of these techniques have advantages over the first technique, which was developed at JPL. The difference between these techniques is that in the Litton process the experiment test chambers will be maintained under a positive pressure in relation to ambient pressure, whereas the JPL technique will allow the experiment test chambers to exhaust directly into the ambient atmospheric pressure. This means a difference in the flow characteristics through the cyclone centrifuge and the chamber. Both techniques have been evaluated. A single cartridge of liquid carbon dioxide will give a sampling period of about 2 min for a single aspirator for either approach.

A design review was held at Litton Industries during the last quarter. This was held prior to the actual fabrication of their proposed sample collection system. During the first quarter of FY 1966, Litton will fabricate and test this unit and provide JPL with a working unit as well as experimental test data. Delivery of the sampler is anticipated in November 1966. This will complete this particular contractual effort.

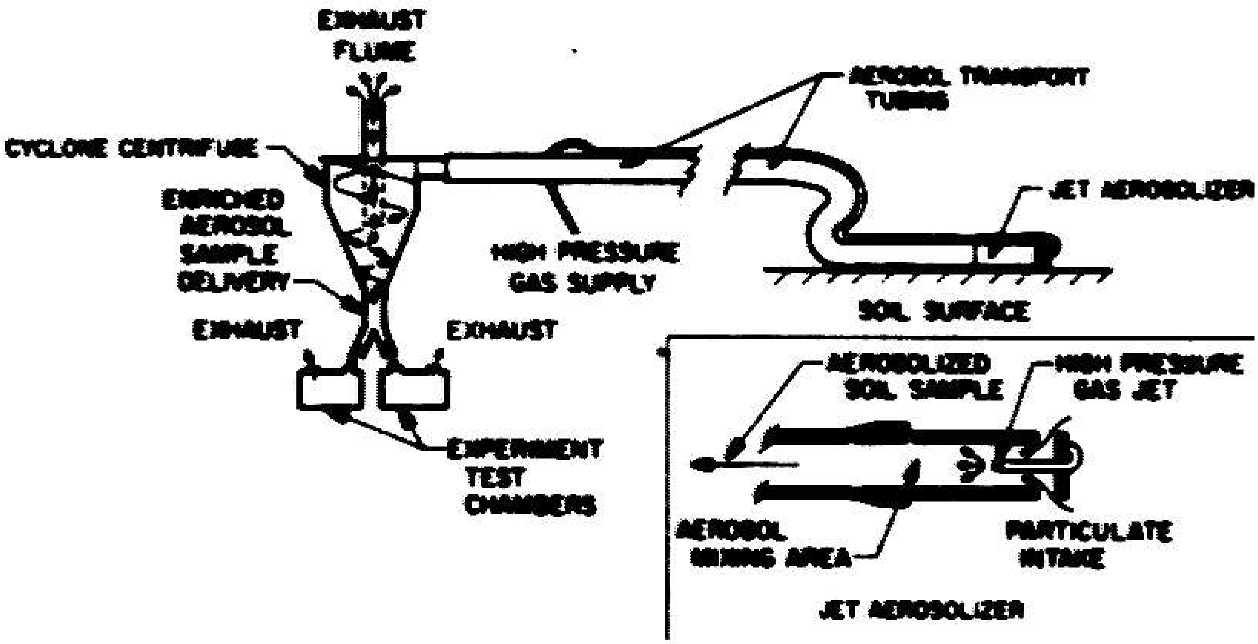


Fig. 1. Surface sampling

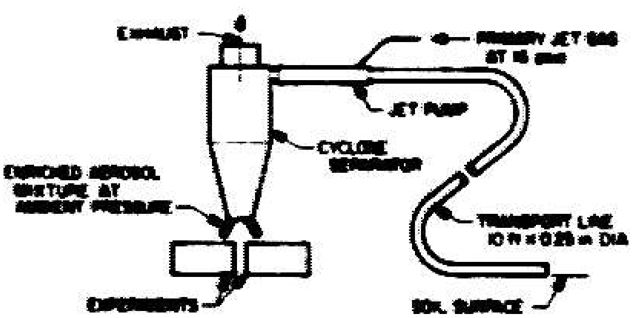


Fig. 2. Surface sampling - JPL aerosol sample collection

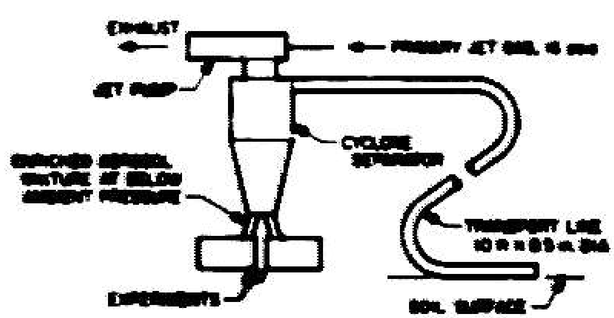


Fig. 3. Surface sampling - Litton's aerosol sample collection

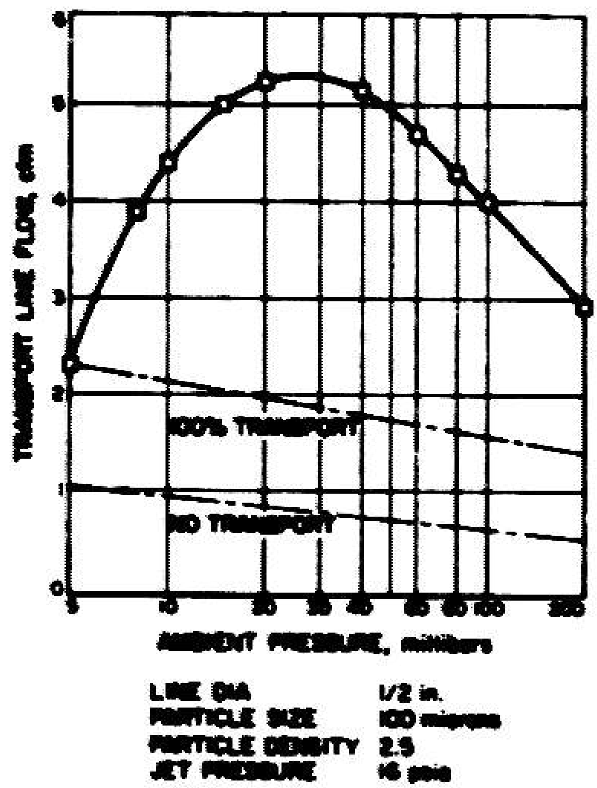


Fig. 4. Surface sampling - Litton collector output

BLANK PAGE

BIOCHEMICAL SEPARATION
NASA Work Unit 189-55-04-06
JPL 386-52001-2-3260

Studies of the coupling to insoluble carriers, such as cellulose, to substances capable of detecting, isolating, and concentrating components characteristic of living organisms, other organic molecules, and metal ions were continued. External publications describing the effectiveness of methods we developed for isolating antibody and antigens are listed below. We have verified that DNA will react with anti-purine antibody and the conditions required, and thus laid the ground work for isolation of DNA on an insoluble adsorbent. We have published an effective method for coupling antibody to cellulose with retention of activity. We have developed a spot test for hydrogen peroxide using peroxidase coupled to cellulose.

With respect to the detection of intrabacterial enzymes, the detection of catalase by the method published in Nature, Vol. 206, p. 1019, 1965, has been examined with respect to increasing the sensitivity of the method by the use of pressure transducers. The method has been considered in terms of the detection of other bacterial enzymes capable of producing gases by specific reactions.

The program has been terminated by NASA.

EXTERNAL PUBLICATIONS

1. Weetall, H. H., and N. Weliky, New Cellulose Derivatives for the Isolation of Biologically Active Molecules, Nature, Vol. 204, p. 896, 1964.

2. Weliky, N., Weetall, H. H., Gilden, R. V., and Campbell, D. H., The Synthesis and Use of Some New Immunoadsorbents, Immunochemistry, Vol. 1, p. 219, 1964.

3. Weetall, H. H., and Weliky, N., An Immunoadsorbent for the Isolation of Purine Specific Antibodies, Science, Vol. 148, p. 1235, 1965.

4. Wetall, H. H., Weliky, N., and Vango, S. P., The Detection of Microorganisms in Soil by their Catalatic Activity, Nature, Vol. 206, p. 1019, 1965.

5. Weliky, N., and Weetall, H. H., The Chemistry and Use of Cellulose Derivatives for the Study of Biological Systems, Immunochemistry (In press).

6. Weetall, H. H., and Weliky, N., The Coupling of Biologically Active Substances to Insoluble Polymers: Antibody on Cellulose, Biochem. Biophys. Acta (In press).

7. Weetall, H. H., and Weliky, N., The Precipitation of Salmon Sperm DNA with Purine-Specific Antibody, Nature (Submitted).

8. Weetall, H. H., The Development of the Capacity for Systemic Anaphylactic Shock in the Chicken, The Journal of Immunology (Submitted).

BLANK PAGE

PLANETARY QUARANTINE STERILIZATION (189-58)

MICROBIOLOGICAL FILTERS - LIQUID AND GAS
NASA Work Unit 189-58-00-03 (FY 1964)
JPL 386-55803-2-3156

A contract for this study was awarded to Wilmot Castle Company, Rochester, New York, with an effective date of September 18, 1964, and a duration of 8 months. The contract price was $45,592.00, cost-plus-fixed-fee contract.

The following HEPA (high efficiency praticulate) filters have been tested:

1. American Air Filter
2. Cambridge Filter Corporation
3. Flanders Filter Incorporated
4. Mine Safety Appliances Company

Seventy filters were tested by challenging them with an aerosol of viable particles of Bacillus subtilis var. niger spores. Efficiency was determined by counting the number of particles collected by air samplers located in the test duct on the downstream side of the filter. Calculations indicated a viable particle challenge of 250,000 per min. The sampler orifices were designed to be isokinetic for 112.5 linear ft/min (equivalent to 50 ft^3/min in the 8- x 8-in. duct used). Linear velocity profiles across the face of the various filters ranged from zero to over 900 ft/min due to variations in filter media and lack of homogeneity. All equipment including ducts, filters, samplers, isolators and related material was decontaminated with ethylene oxide daily. Filter efficiencies based on the number of challenge particles upstream of the filter versus the number downstream of the filter ranged from 99.9736 to 99.9999%. The size range of the viable particles used made it necessary for the filters to be at least 99.99 - % efficient, using this system, before they could be considered acceptable as HEPA filters. Only two groups of filters had zero rejections. Rejections on the basis of failure to meet the efficiency requirements ranged from 0 to 75%.

MEMBRANE FILTERS

This phase has been approximately 40% completed. Although membrane filters are generally more reliable than depth filters there seems to be little correlation between designated pore size and filter efficiency or reliability. One would expect that the smaller pore sizes would be more efficient that the larger ones and that pore sizes of 0.25 microns or less would effectively remove organisms of the size of Serratia marcescens (the challenge organism) but this was not found to be the case. Ratings are not complete at this time.

CURRENT STATUS

Work was discontinued on this study. As of May 5, 1965, the contractor formally notified JPL that completion of the contract could not be attained within the time and funds originally estimated. Additional funding was allocated for an extension of this contract.

A new work statement will be prepared delineating the additions and modifications which are considered necessary because of the findings under the original contract. An interim final report is being prepared by Wilmot Castle, and this will be studied prior to preparation of the new statement of work to determine necessary additions and deletions in reference to the original work statement. A contract extension will be negotiated between JPL Procurement Division and Wilmot Castle based on work remaining to be done and additional work desired. There will be increased emphasis on filters for liquids and gases and decreased emphasis on HEPA filters. At the current state of the art, sufficient data exists on HEPA filters. Absolute filtration should be our prime consideration. At the present time all absolute filters for liquids and gases are under suspicion because of unexplained filter failures during the initial testing period. The cause of the failures will be investigated as a part of the contract extension.

JPL Technical Memorandum No. 33-243, Vol. I

DEVELOPMENT OF A BIOLOGICAL INDICATOR FOR DRY HEAT STERILIZATION
NASA Work Unit 189-58-00-06 (FY 1964)
JPL 386-55806-2-3156

Contract was awarded to Wilmot Castle Company, Rochester, New York. The effective date of contract is August 10, 1964, and the contract price is $27 349.20, fixed-price contract. A survey of plastics, insulating materials, silicones and ceramics was completed, resulting in the selection, procurement and laboratory evaluation of types having properties necessary for proper fabrication, handling and stability of the indicator at 135°C. It has been demonstrated that a biological indicator can be produced which will remain viable after exposure in an atmosphere of dry nitrogen to a temperature of 135°C. Production of clean, freeze-dried Bacillus subtilis WC 18 spores has been standardized to prevent incipient germination. The continuous flow centrifuge used was cooled with dry ice to maintain the low temperature required to prevent germination. A Bacillus subtilis var. niger strain was found which seems to have twice the heat resistance of a strain used in many laboratories for thermal resistance studies. Agitation which provides aeration appears to increase the proportion of positive cultures from heated Bacillus subtilis WC 18 spores. Diphasic cultures, a spore dispersing agent, a cellulose sponge culture technique and hyperbaric oxygen tension were among the recovery techniques explored. An erratic survival pattern exists and was under investigation. It was determined that the Aclar film used to encase the indicator is permeable to ethylene oxide and cannot be externally decontaminated with this agent but can be treated with germicidal solutions.

During this period work was discontinued on this study because of lack of funds to complete the original contract. After investigation of work accomplished and effort expended it was decided to fund an extension of the original contract and to increase the scope. Additional funds have been approved and allocated.

The following activities are planned for the future: after receipt and study of the interim final report, a statement of work will be prepared and a contract extension will be negotiated. Protocols will be prepared for all procedures necessary to fabricate and use the indicators. Procedures will be developed to promote outgrowth of viable but thermally injured spores. Sterilization temperatures other than 135°C will be investigated to determine the behavior of the indicator at 105, 125, and 145°C. The possibility of developing an indicator in the form of a thermally protected spore strip may be investigated. Sterile insertion and transfer techniques to eliminate contamination will be studied.

BLANK PAGE

MICROBIOLOGICAL PROFILE OF CLEAN ROOMS
NASA Work Unit 189-58-00-10 (FY 1964)
JPL 386-55810-2-3156

The study phase (phase II) of this contract has proceeded successfully through the report period. No major problems or technical difficulties were encountered. At the end of June 1965, the Douglas Aircraft Company (DACo) had completed 11/18ths of the sampling program as follows:

1. Four weeks of microbiological sampling in the Class II clean room (3 sampling sites within the clean room and 1 sampling site outside the clean room) and the Class IV clean room (1 sampling site inside and 1 sampling site outside the clean room), and

2. Three weeks of microbiological sampling in the Class III clean room (1 sampling site inside and 1 sampling site outside the clean room).

Seven weeks of microbiological sampling remain to complete the task (2 weeks in the Class II clean room, 2 weeks in the Class IV clean room and three weeks in the Class III clean room).

MICROBIOLOGICAL RESULTS

It must be emphasized that the present study is only 60.11 % completed and all of the results being presented should be considered preliminary and provisional.

Air Sampling Studies

Class II Clean Room. The number of viable airborne particles ranged from 0.0 - 1.0 per cubic ft (ft^3) of air (during lunch period when the room is empty) to 10.0 - 20.0 per ft^3 of air (when the room is fully staffed and operated under normal in-use conditions).

Class III and IV Clean Rooms. The number of viable airborne particles ranged from 0.0 - 0.5 per ft^3 of air (during lunch) to 0.5 - 2.0 per ft^3 of air (when the room is fully staffed and operated under normal in-use conditions).

Surface Sampling Studies

Settling Strips.

1. Class II Clean Room. 10^3 microorganisms (1000 to 9999) were recovered per square ft (ft^2) of surface over a 1- to 10-wk exposure period.

2. Class III Clean Room. 10^2 microorganisms (100 to 999) were recovered per ft^2 of surface over a 1- to 10-wk exposure period.

3. Class IV Clean Room. Recovery was essentially the same as for a Class III clean room.

The results obtained with other samplers and procedures (Elliott, AGI, Andersen, settling plates, and human handling experiments) are not available in sufficient numbers for comment. Results obtained with these items will be discussed after completion of the study.

JPL Technical Memorandum No. 33-243, Vol. I

SUPPORTING ACTIVITIES FOR STERILIZATION
NASA Work Unit 189-58-20-01
JPL 386-81101-2-2945

A microbiological laboratory, developed exclusively for sterilization activities, was completed during this period. The sterilization laboratory, approximately 1000 square ft in area, has the capability to perform media preparation, incubation, and detection and counting of microorganisms. This laboratory, operated by the sterilization group, monitors outside microbiological research and development tasks and supports JPL in-house research.

A portion of this task funding was used to determine the levels of microbial contamination present in the Hughes Aircraft Company facilities concerned with the assembly and testing of the Surveyor spacecraft. Microbiological air samples of five different areas were taken. Stainless steel settling plates were also used to determine the rate of microbial fallout in the respective areas. Samples were taken for a ten-week period. The results obtained in the study are preliminary and should be considered tenative. They indicate:

1. The total number of viable aerobic mesophiles recoverable from test surfaces (stainless steel strips) appears to stabilize and within the range of 10^2 to 10^3 organisms per square ft.

2. The number of airborne particles appeared to be dependent, at least in part, on the number of persons and type of activity occurring within the area.

BLANK PAGE

JPL Technical Memorandum No. 33-243, Vol. 1

MICROBIOLOGICAL RECOVERY TECHNIQUES FROM SURFACES
NASA Work Unit 189-58-20-02
JPL 386-81401-2-2945

This study is designed to evaluate the effects of various physical, chemical, and physiological factors on the recovery and growth response of microorganisms before and after certain dry heat cycles. Such factors as atmosphere, temperature and nutrients will be evaluated. Initial tests will use known organisms carried on typical spacecraft type surfaces.

The study consists of three phases:

1. Recovery of organisms from surfaces (spacecraft and others).
2. Recovery and regeneration of heat damaged organisms (spores).
3. Development of improved methods of assaying spacecraft parts.

A survey of vendors was made and 12 were considered to have the capabilities to conduct studies of one or more of the various phases. The twelve (12) companies were solicited for proposals and ten (10) responded with proposals. (JPL RFP #3597).

A technical evaluation team has been selected to evaluate the proposals. The team consists of J. Iandolo, A. Irons, and J. McDade.

Proposal Evaluation Criteria have been developed for the technical assessment of the proposals. Assessment points have been assigned to the various criteria and a chart issued to the members of the evaluation team to assure consistent evaluation.

After the technical review of the proposals is completed the Procurement Division will be contacted. The cognizant buyer negotiator and the cognizant scientist in charge of this task will then determine the most eligible vendor and negotiations will be started which will lead to the issuance of a contract of approximately 12 mo duration.

BLANK PAGE

DEFINITION OF A STERILIZATION TRAINING PROGRAM
NASA Work Unit 189-58-20-03
JPL 386-81501-2-2945

A work statement, prepared during the report period, defines and specifies the study for a program to instruct, train, orient, and motivate all levels of personnel in procedures techniques, manipulations, and attitudes required for the production of sterile spacecraft. The requested study will determine the groups to receive instructions and will outline the instructional material for each group. It will further provide guidelines for the selection of teaching material, faculty, and training facility.

The technical work statement passed through the JPL approval cycle and reached the Procurement Division on about June 25, 1965. A Request for Proposal will be issued shortly

FY 1965 funds in the amount of $20,000.00 have been committed to the task.

A contract will be issued in the first quarter of FY 1966, and completion is expected in the third quarter of FY 1966. The list of bidders includes companies, an academic institution, and a government agency selected on the basis of the following experience:

1. Microbiological contamination control.

2. Development of industrial training programs especially in the clean room or bio-clean room operations.

3. Handling of spacecraft hardware.

4. Operation of clean and bio-clean areas.

BLANK PAGE

JPL Technical Memorandum No. 33-243, Vol. I

CLEAN ROOM PROTOTYPE (PROJECT EASL)
NASA Work Unit 189-58-20-06
JPL 386-81801-2-2945

Preliminary reports (Ref. 1-3) have been made on the microbiology of clean rooms. However, at present, data concerning the levels of microbial contamination that may exist within industrial clean rooms are scanty or totally lacking. Information on the levels of microbial contamination within spacecraft assembly areas is not available. In order to obtain more definitive information on the microbiology of clean rooms, the JPL Sterilization Group initiated two tasks: (1) determination of microbiological profile of clean rooms (Ref. 4) and (2) development of a clean room prototype as an experimental laboratory in which microbiological research and training could be conducted.

The data obtained in the task concerned with the microbiological profile of clean rooms will result in a firm estimate of the levels of microbial contamination that exist in industrial clean rooms (Classes II, III and IV according to the Air Force Technical Order 00-25-203 (Ref. 5)). However, the operational recommendations and requirements established in the NASA Interim Requirements (Ref. 6) have necessitated an updating in design for spacecraft assembly and test facilities. Therefore, in order to determine the efficacy of the procedures specified, and the ability to reach the levels of microbial contamination allowable as established in the NASA Interim Requirements, it was necessary to construct and operate a facility according to the interim requirements (Ref. 6). To provide such a facility, the JPL Sterilization Group task Clean Room Prototype was merged with funds and objectives from the Voyager Project Office to establish an experimental assembly and sterilization laboratory (Project EASL) at the Jet Propulsion Laboratory.

Construction of the EASL facility began March 15, 1965 in a portion of the southwest corner of the low bay area in JPL Building 233. The project was completed on July 1, 1965. The purpose of this facility is to conduct an investigation into some of the procedures and techniques for assembly and/or test of spacecraft hardware under full implementation of the NASA Interim Requirements. Assembly and test shall be at the component and modular levels. Simultaneously, a duplication of the work being done in the EASL facility shall be conducted under non-bioclean conditions, or the routine laboratory conditions and procedures. Scheduled microbiological assays of the hardware and assembly environment shall be conducted throughout all operational states of both the bioclean and non-bioclean assemblies. Finally, both the bioclean and non-bioclean assemblies shall be exposed to dry heat (135°C) for 24 hr in a nitrogen atmosphere and then assayed for sterility. The cost in time and money for both types of assembly, as well as the ability to satisfy the sterilization requirements, will be compared, contrasted, and reported. Operational reliability of the assembled units will also be checked.

The rationale of microbiological monitoring, assay, and certification of sterility has been discussed in the JPL Specification No. GMO-50470-GEN, entitled Assaying and Certification of Hardware to Comply with Planetary Quarantine (Ref. 7). The procedures to implement this specification are described in the JPL Sterilization Group Procedure No. 1 (Ref. 8) having the same title as the referenced specification (Ref. 7).

The activities planned for the EASL facility by the JPL Sterilization Group include (items marked with asterisks indicate monitoring activities: all others are microbiological research studies):

*1. Microbiological Assays and Monitoring. Microbiological monitoring routines shall be established and applied to demonstrate the reliability of the facility to conform to the requirements set forth in the NASA Interim Standard (Ref. 6). The following activities shall comprise the microbiological studies to be conducted in EASL:

   a. Microbiological sampling of air.

   b. Sampling of air for a total particulate count.

   c. Microbiological sampling of environmental surfaces.

   d. Microbiological sampling of spacecraft hardware.

   e. Microbiological sampling of clothing and packaging material.

   f. Microbiological sampling of personnel.

*2. Visual assay.

   a. See Ref. 7 and 8.

*3. Parametric measurements.

   a. See Ref. 7 and 8.

*4. Terminal heat sterilization.

   a. Dry heat (135° C) for 24 hr in:

      1) Nitrogen atmosphere.

      2) Dry air atmosphere.

   b. Supporting data required:

      1) Instrumentation of sterilization oven and hardware with thermocouples connected to a recorder.

5. Microbiological Research.

   a. Modification of old, or development of new, microbiological sampling equipment and/or procedures.

      1) Air sampling.

      2) Surface sampling.

b. Determine the survival curves for surface-exposed microorganisms in laminar flow (horizontal and vertical) air streams.

1) Naturally contaminated surfaces.

2) Artificially contaminated surfaces.

a) Fungal spores.

b) Bacterial spores.

(1) Members of the genus Bacillus.

(2) Members of the genus Clostridium.

c) Bacterial vegetative cells.

(1) Staphylococcus aureus.

(2) Escherichia coli.

(3) Proteus vulgaris.

(4) Pseudomonas sp.

d) Viruses (Bacteriophage). Coli T series.

6. Evaluation of personnel attire on dissemination of microorganisms.

a. Range from fully clothed (Bunny suit, facial mask, surgical gloves, booties) to no protective clothing (street clothes).

7. Evaluation of germicides for in-use application situations.

a. Facility decontamination.

b. Decontamination of handled or dropped tools.

c. Decontamination of handled or dropped hardware.

d. Any other situation requiring sterilization or decontamination.

*8. Microbial recovery from surfaces.

a. Routine procedures.

1) Contact methods.

2) Direct plating.

3) Rinse methods

b. Sonic removal (effect of sonic cleaning on microbial contamination of hardware, tools, other assembly items and also artificially contaminated surfaces.

*9. Recovery of microorganisms from hardware interiors.

10. Other application situations as operational problems are uncovered.

Scheduling of these activities is presented in Table 1 and Fig. 1.

Table 1. Activity Schedule

Activity	Frequency
Microbiological Sampling	Daily
Visual Assay	Daily
Parametric Measurements	Daily
Microbiological Research	Daily, or as operating schedule permits

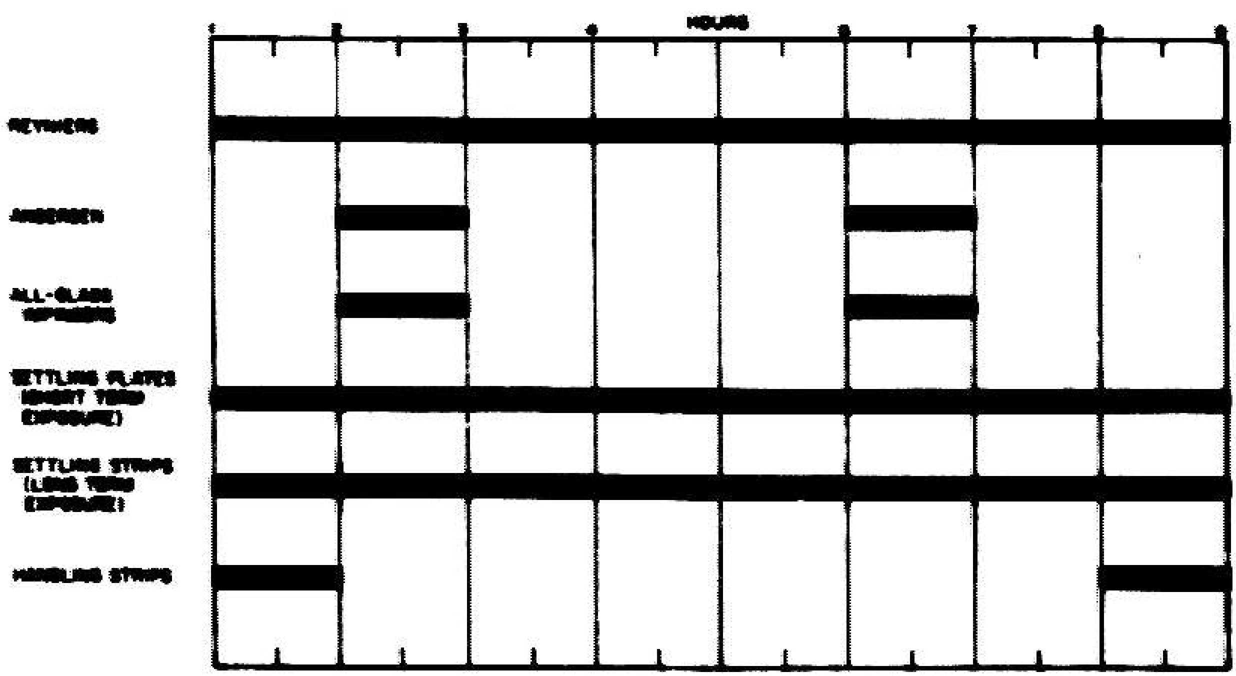


Fig. 1. Typical microbiological sampling schedule

Currently, the EASL facility is scheduled to have a hardware assembly series for one month, followed by a 2 - 3 wk evaluation of results and preparation period for the next hardware assembly series. Monitoring activities shall be conducted throughout all phases of EASL operation (including terminal stages of construction and balance and checkout, as well as during actual operation by Division 35 after phaseout of the facility group). Microbiological research activities shall be conducted during the assembly phases of EASL operation as scheduling permits. Following completion of a hardware assembly series, and during evaluation and preparation of a new hardware assembly series, specific, detailed microbiological research activities will be conducted.

The materials and methods for implementing the monitoring activities have been described (Ref. 7 and 8). The technical implementation of the research activities is beyond the scope of this report.

The microbiological data accumulated in the EASL facility should provide NASA with a sound technical basis for determining the design of facilities necessary for hardware that must meet the requirements of planetary quarantine. It would seem that this situation represents a first and places JPL in a unique position.

REFERENCES

1. Michaelson, G. and Vesley, D., Industrial White Rooms vs. Hospital Operating Rooms, Air Engineering, Vol. 5 pp. 24-29, 1963.

2. Microbial Contamination in a Clean Room When Occupied by Operating Personnel, Protection Branch Report of Test No. 1-65, Fort Detrick, Frederick, Maryland.

3. McDade, J. J., Irons, A. S., and Magistrale, V. J., A Microbiological Survey of the Hughes Aircraft Company Facilities Involved in the Assembly and/or Testing of Surveyor Spacecraft, SPS 37-35, April 30, 1965.

4. Microbiological Profile of Clean Rooms, JPL/Douglas Contract No. 950920.

5. Standards and Guidelines for the Design and Operation of Clean Rooms and Clean Work Stations, Air Force Technical Order T. O. 00-25-203, dated 1 July 1963.

6. Sterilization Group, Progress Report Number 1, Appendix B, JPL Engineering Document No. 284.

7. Assay and Certification of Hardware to Comply with Planetary Quarantine, JPL Specification No. GMO-50470-GEN.

8. Assay and Certification of Hardware to Comply with Planetary Quarantine, JPL Sterilization Group Procedure No. 1.

BLANK PAGE

MICROBIOLOGICAL EXAMINATIONS OF SPACECRAFT PARTS/INTERIORS
NASA Work Unit 189-58-20-07*
JPL 386-81901-2-2945

The original contract and two modifications were concluded in April 1965. The results contained in the Dynamic Science Corporation final summary report pointed out the limitations of past study and indicated the need for more investigative work to extend the capabilities of the present techniques.

The original contract was funded for $50,032.00. Two modifications (modification 1 for $29,885.00 and modification 2 for $9,500.00) brought the total funded for the entire proposal to $89,417.00.

During the period of April through June 1965, no additional work was performed. However, negotiations were in progress to continue investigations under modification 3 for $43,721.00. This extension would bring the total cost to $133,138.00.

Future activities involve improvement of the recovery techniques now available and the development of new procedures consistent with the aims of the study including:

1. Detailed study of methods of pulverization of several classes of solids to improve the efficiency and applicability of the method while simultaneously reducing any physiological damage to the entrapped organisms.

2. Determination of the optimum conditions for leaching toxic substances from the pulverized solids and to devise methods by which the soluble inhibitors (leachates) and the inhibitors present within the solid (nonsoluble) may be neutralized or inhibited.

3. A broader, more detailed investigation leading to the development of culture media which optimize the recovery of injured organisms. A study of this type would necessitate the consideration of several classes of substances to counteract the injurious effects of pulverization and leaching. Growth factors and metabolic constituents not normally required by the organisms under other conditions will be studied. The trace metal content, the ionic strength, the pH and redox potential will also be considered.

4. A protocol for the Recovery of Microorganisms in Solids will be prepared. This statement will define the best procedure for the recovery of entrapped microorganisms, regardless of their physiological condition, from the interior of compatible solid materials used in spacecraft construction.

*In FY 1966 this work unit will be identified by NASA Code 189-58-22-02.

BLANK PAGE

STERILE ASSEMBLY TECHNIQUES
NASA Work Unit 189-58-20-10*
JPL 386-82201-2-2945

During March 1965, Lockheed Missiles and Space Company (LMSC) completed contract work on Feasibility of Sterile Assembly Techniques, NASA Work Unit 189-58-00-12.

Results of the study indicate that glove box techniques may be used to assemble an electronic circuit. In general, assembly takes about three times as long in the glove box when compared with assembly on the bench. Hand soldering, dip soldering, staking, nut/bolt connections, epoxy bonding and potting operations may be effectively accomplished in an ethylene oxide (12.0 %) - Freon 12 (88.0 %) gaseous mixture (ETO), in sterile nitrogen, or in sterile air. Occassional ETO "skips" in decontamination were observed with capacitors being the item most frequently involved in the "skips." The final study report was received during March 1965. The study was satisfactorily and successfully completed by the LMSC.

Based on the results obtained, it was decided to do a continuation study at the Lockheed Missiles and Space Company under this work unit.

Final input from the feasibility study was necessary for development of a request for proposal (RFP) to continue studies of sterile assembly techniques. These studies will emphasize equipment development, actual use situations, and reliability of the barrier system to produce and maintain a sterile environment and product.

A procurement package has been assembled and cleared through financial planning to commit the FY 1965 funds to continue the sterile assembly work at LMSC.

Assembly is to be conducted in a sterile environment established through use of a microbiological barrier system. Both sterile assembly and sterile repair situations will be investigated. All operations will be conducted in a sterile environment (not the ethylene oxide - Freon 12 mixture or sterile nitrogen). Emphasis will be placed on the microbiological aspects of getting tools and equipment into the sterile work area and on the removal of the sterile product in some type of protective envelope. The integrity of the barrier will be challenged both chemically (with Freon and/or Helium gas) and microbiologically (with bacterial spores). All phases of the operation will be monitored microbiologically. It is hoped that negotiations with Lockheed can be completed by the end of July and work can be resumed in early August 1965.

*In FY 1966 this work unit will be identified by NASA Code 189-58-21-01

BLANK PAGE

Part D

Manned Space Sciences

BLANK PAGE

MANNED SPACE SCIENCES (190)

BLANK PAGE

JPL Technical Memorandum No. 33-243, Vol. I

PLANETOLOGY (190-42)

LUNAR SPECTRAL PHOTOGRAPHY
NASA Work Unit 190-42-03-01-5*
JPL 390-10101-2-3250

PROGRESS

For the past six months, the main areas of work have been: (1) telescopic spectral photography of the Moon, (2) photographic process control studies, (3) fundamental problems in interpretation of lunar spectral photography, (4) design studies for AES lunar orbital experiment.

Photography of the Moon through ten bandpasses using the Stony Ridge 30-in. reflector continued through January, 1965. In January, two excellent sets of images of the Copernicus-Kepler-Aristarchus region were obtained. Since then efforts to renew the telescope contract with the Lockheed-California Company have been unsuccessful owing to a prolonged discussion of contractual details. Dr. Shoemaker kindly offered time on the USGS telescope in Flagstaff, but a shortage of manpower and lack of a suitable camera has precluded use of these facilities. Plans are presently being drawn up of a camera for the new JPL 24-in. telescope, which can also be adapted to other telescopes.

Photographic process control studies have proceeded in-house and on contract with Vidya Division of Itek Corporation. In-house studies included the investigation of techniques for matching film gammas by copying, and a study of methods of making composite spectral images. Ektacolor prints, dye transfer prints, and black and white masks have been made successfully from the lunar telescopic images. The masking technique appears to hold the most promise for it can null out albedo differences and show only the spectral reflectivity differences.

Vidya Division of Itek Corporation has completed a sensitometric study of the JPL interference filters and films and has investigated repeatability and control problems. The results are given in Lunar Sensitometry Optimization, Vidya Report No. 186, May 7 1965.

Work on the interpretation of lunar spectral data has been in two areas: (1) A critical review of published data on lunar colors has been completed. Many of the compiled data have been recalculated and replotted to facilitate comparisons. Agreement with the spectral photography results is good, and geologic interpretation is in progress. (2) A study has been started of the fundamental parameters affecting spectral reflectivities of rocks. New spectrophotometric measurements in the laboratory on mineral and rock powders indicate that grain size and packing each affect the shape of the spectral curve (see Fig. 1 and 2). These effects apparently have not been studied in detail before. They are sufficiently large for most silicate rocks to influence not only the faint lunar spectral differences, but to also affect interpretation of terrestrial data.

*Jointly Funded Under NASA Code 185-41-02-01

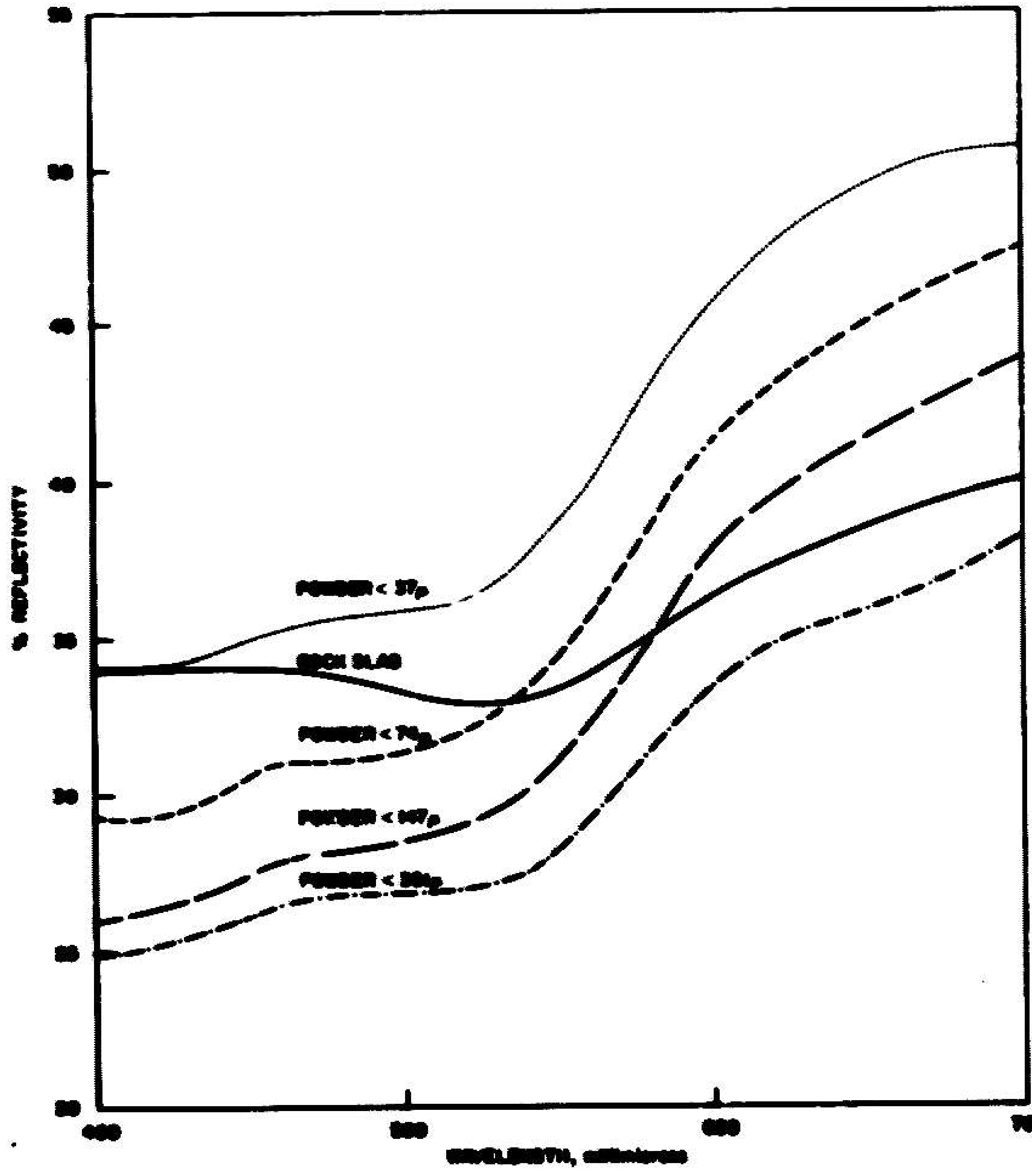


Fig. 1. Spectral curves for rhyolite

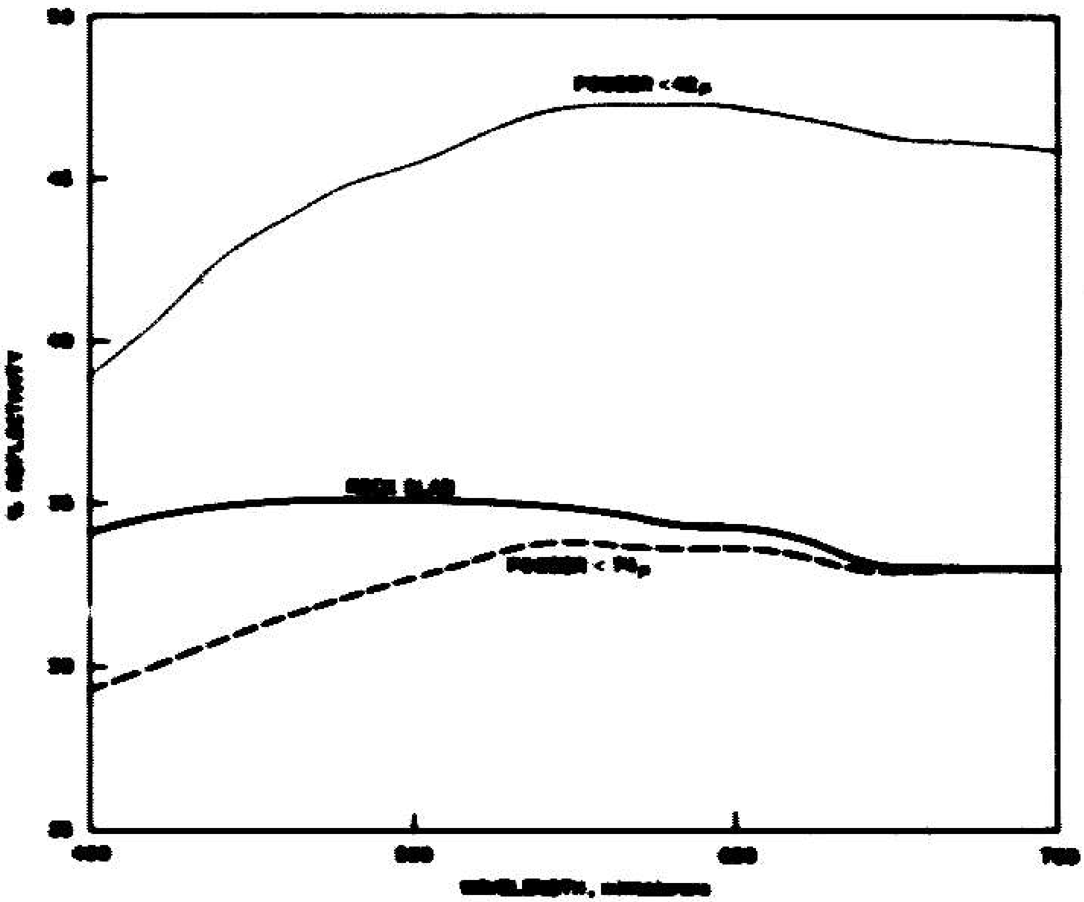


Fig. 2. Spectral curves for quartz diorite

REPORTS

A paper entitled A Proposed Multispectral Photography Experiment for AES Lunar Orbital Mission was presented at the Eleventh Annual Meeting of the AAS in Chicago on May 6, 1965 by J. Cronin of AFCRL, J. Adams of JPL, R. Colwell of UC (Berkeley), and W. Tifft of U. of Arizona.

A comprehensive report of the results of spectral photography studies at JPL over the last two years is in progress and should be completed by August 1965.

FACILITIES AND MANPOWER

Most major procurement items (spectrosensitometer, film processor, etc.) ordered last fall have arrived, and temporary facilities for a close-control photography laboratory were completed in late June 1965. A full-time technician was lost to the project July 1. Manpower presently consists of two full-time scientists and no technicians.

FUTURE ACTIVITIES

Immediate attention will be given to completion of the comprehensive report. Further cooperative work with W. Tifft and R. Noble of U. of Arizona is necessary in the first quarter of FY 1966 to establish preliminary design constraints for the AES telescope package.

Work in FY 1966 will be directed toward (1) establishing a detailed, quantitative procedure for exposing, handling, and processing lunar spectral photography, which can give results in terms of specific design tradeoffs for an AES orbital mission, (2) finding a suitable method of data reduction -- presently the largest problem for the AES experiment, (3) establish guidelines for the interpretation of spectral reflectivity data from the Moon, Earth, and Mars.

AIRBORNE MICROWAVE RADIOMETRY
NASA Work Unit 190-42-20-16
JPL 390-20301-2-3250

The object of this task is to provide airborne passive microwave instrumentation and to perform quantitative airborne measurements over selected test sites with the purpose of correlating the measurements with terrain characteristics. Two types of instruments and, therefore, measurements will be available: multi-frequency, nonimaging type, and single-frequency, imaging type.

A two-frequency, nonimaging-type airborne radiometer was successfully flown aboard a DC-8 aircraft in May 1965. The two frequencies of operation were 15.8 and 22.2 GHz. A 35-mm aircraft camera was collimated with the radiometer and provided excellent optical pictures of the observed terrain. The correlation between the optical and radiometric data appears good. The flight covered water, vegetated, desert, mountainous, and densely inhabited areas. Details such as small lakes, freeways, and orange groves were clearly discernable on both optical and radiometric data. Figure 1 shows the 35-mm camera and radiometer housing on the rear of the DC-8 baggage compartment door. Figure 2 shows the radome and camera viewing port as seen from the outside of the aircraft. The reduction of data to quantitative values is currently underway.

Another airborne radiometer similar to the one outlined above but operating at 9.3 and 34 GHz is nearing completion. The two dual-channel radiometers are scheduled for installation aboard a NASA aircraft during the month of July 1965. Flights over selected test site areas are to commence the first part of August.

A contract with the Raytheon Company of Massachusetts has been issued for a microwave ground measurement program. This program, which utilizes a mobile van truck with three microwave radiometer, will be used in conjunction with the aircraft flights at selected test sites. The ground measurements will provide ground-truth information necessary for proper data analysis of the airborne measurements. The contract is for a six-mo period commencing July 1965 and the estimated cost is $60,000.

An agreement with the Autonetics Division of North American Aviation for the use of a single-frequency imaging type radiometer is nearing completion. This radiometer, to be installed on the same NASA aircraft, will provide stereoscopic images of the observed terrain. Installation of this device is scheduled for November 1966.

During the next six mo, numerous flights over various areas will provide large amounts of data. Upon reduction, this data in conjunction with the comprehensive ground measurement data, will allow the assignment of quantitative values to materials and topography heretofore unassigned.

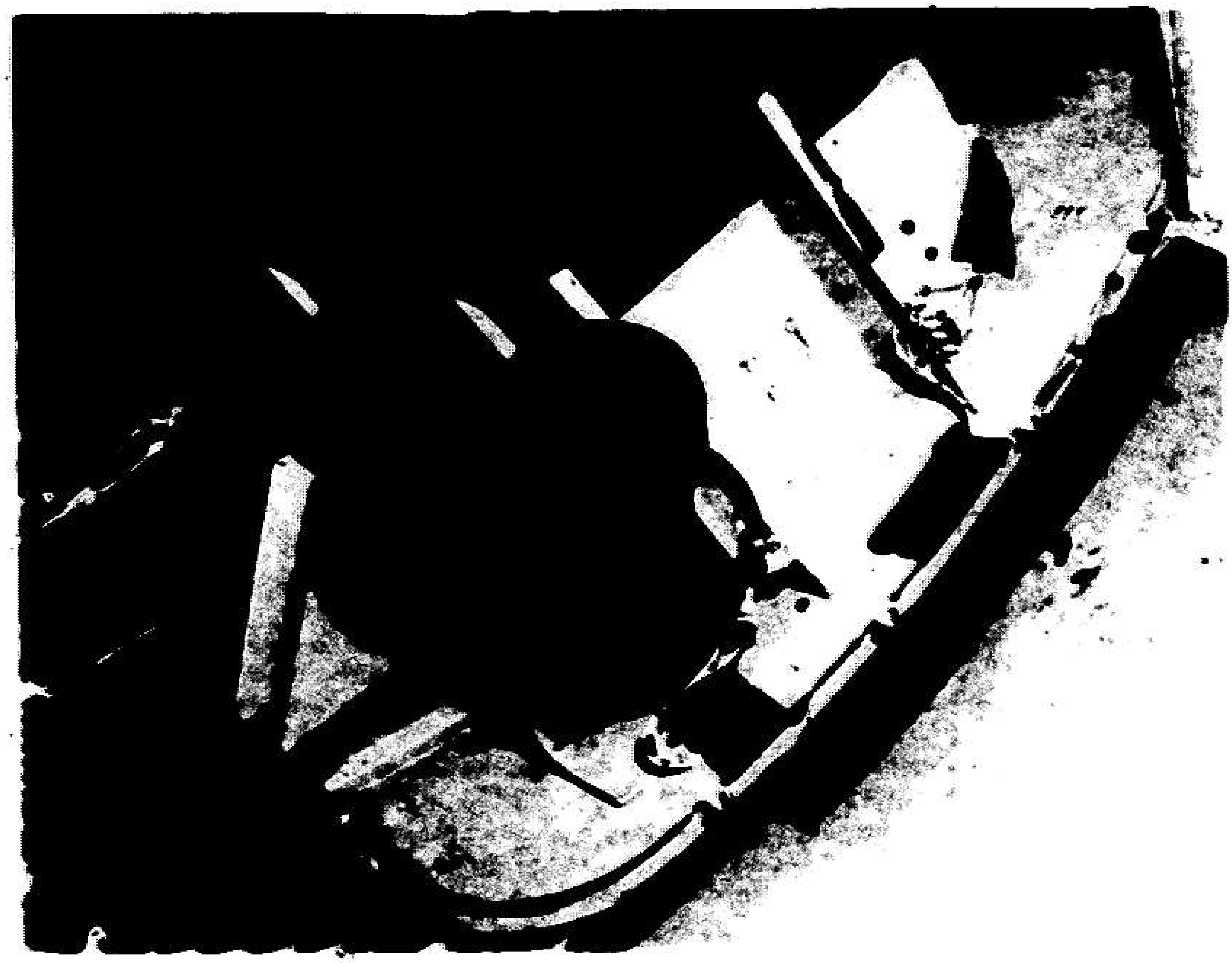


Fig. 1. Camera and radiometer housing

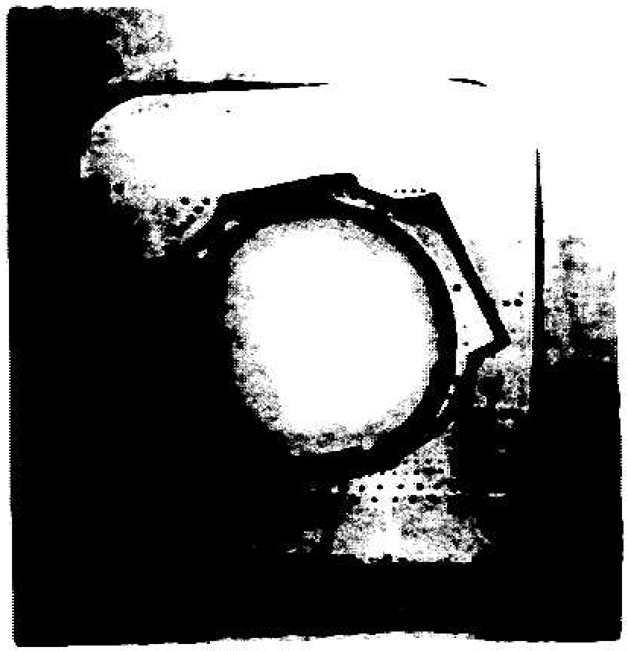


Fig. 2. Radome and camera viewing port

BLANK PAGE

INFRARED THERMAL EMISSION FROM SILICATES
NASA Work Unit 190-42-20-20*
JPL 390-20101-2-3250

Both laboratory and field spectroscopic investigations are included in this work unit. Progress in each is described.

LABORATORY STUDIES

A lengthy series of experiments have been carried out on direct observation of emission spectra of common rocks, minerals, and their corresponding granulated equivalents between 7.4 and 15.4 microns to indicate circumstances under which remote spectral analysis of planetary thermal radiation may provide useful petrologic information on material covering the outermost surfaces of these bodies.

The instrumentation used was a standard Beckman IR-7 double beam optical null spectrophotometer equipped with special blackbody reference source and external sample furnace. Specimens 2.5 cm square and 1/2 cm in thickness were heated to a maximum temperature of 500°C to overcome background radiation of the spectrometer. The entire instrument system was flushed continuously with dry nitrogen to remove atmospheric water vapor and CO_2. The results presented here were obtained in double beam operation. The curves then show relative normal spectral emissivity directly.

The experiments indicate that three factors govern spectral position and intensity of features in the emission spectrum of complex silicate assemblages: (1) bulk mineralogy of the sample, (2) geometric complexity of the emitting surface, and (3) sample temperature. Temperature effects account for shifts of a few wave numbers per 100°C change in temperature. They are best illustrated by the displacements, generally to longer wavelengths, of spectral features between the room temperature reflection and 500°C emission spectrum of dunite, Fig. 3. Such displacements will be unimportant in isothermal experiments. The effects of bulk mineralogy are illustrated in Fig. 1. The data were obtained at 500°C and all specimens had polished emitting surfaces. The granites and Brüderheim chrondritic meteorite represent rough limits to overall peak shifts that can be associated with changes in bulk mineralogy occurring in igneous rocks or meteorites. The extremes of major emission minima are 200 cm^{-1} apart. A second feature illustrated is that nearly mono-minerallic rocks produce sharper emission curves than do those of complex mineralogy. Thus syenite, phonolite (aphanitic equivalent of a feldspathoid syenite), anorthosite, and quartz exhibit sharp emission minima, whereas corresponding minima for granite and gabbro are much broader and less well defined. All of these results can be thought of as expressions of a law of additivity which states that emission of radiation by one species will be unaffected by the presence of other materials whether they emit or not. In this case the emission curve of any assemblage is comprised of a weighted average of emission curves of its individual constituents. Spectral positions of emission features in complicated assemblages thus reflect averages of positions for individual constituents. As one mineral dominates the assemblage the resultant spectrum reflects the relative simplicity of that single species.

---

*Jointly funded under NASA Code 185-42-20-01

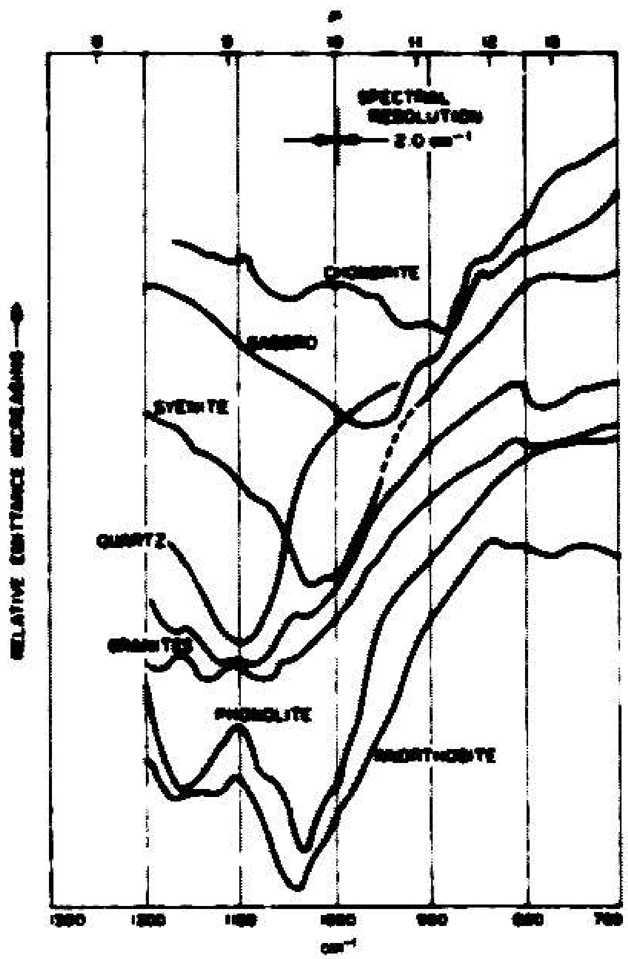


Fig. 1. Relative emissivity: curves displaced vertically with X3.4 verticle scale expansion

Effects produced in emission spectra of rocks by granulation are shown in Figs. 2 and 3. Absorption or reflection spectra are given for comparison with the emission results. The emission curve of a reference blackbody (soot blackened cup) is shown at the bottom of Fig. 3. Curves labeled "rough" and "polished" refer to the surface character of solid specimens. All other curves refer to granulated material of various size fractions as indicated.

Except for dunite, dramatic changes toward black or graybody emission occur with the transition from solid to granulated material. For granite and quartz monzonite, the transition is accompanied by a shift in emission minimum of about 60 cm^{-1} as well, more than one quarter of the entire shift noted with the extreme variations of bulk composition expected in nature.

In contrast, the prominent <u>reststrahlen</u> in dunite at 929 cm^{-1} and the 790 cm^{-1} band due to quartz in the quartz monzonite and granite spectra persist essentially undisplaced, though diminished in contrast throughout all spectra.

The important displacements in band position shown in Figs. 2 and 3 must in some way be related to geometrical surface effects, since there are no known differences except particle size and state of aggregation between various samples. It is significant that of the examples shown, band shifts occur only with rocks containing quartz. This suggests that because of the unusually high reflectivity of this material compared with that of, for example, the feldspars (60% vs. 30%) spectral detail from the quartz persists with granulation over that of other constituents. The spectral contribution of quartz may thus dominate the emission spectra of finely pulverized assemblages containing this material. Whatever the origin of these anomalies, which is at present uncertain, their existence poses a problem in interpretation of emission spectra from powdered rocks containing quartz. These results also demonstrate that a simple law of additivity generally does not hold for emission from powdered silicates.

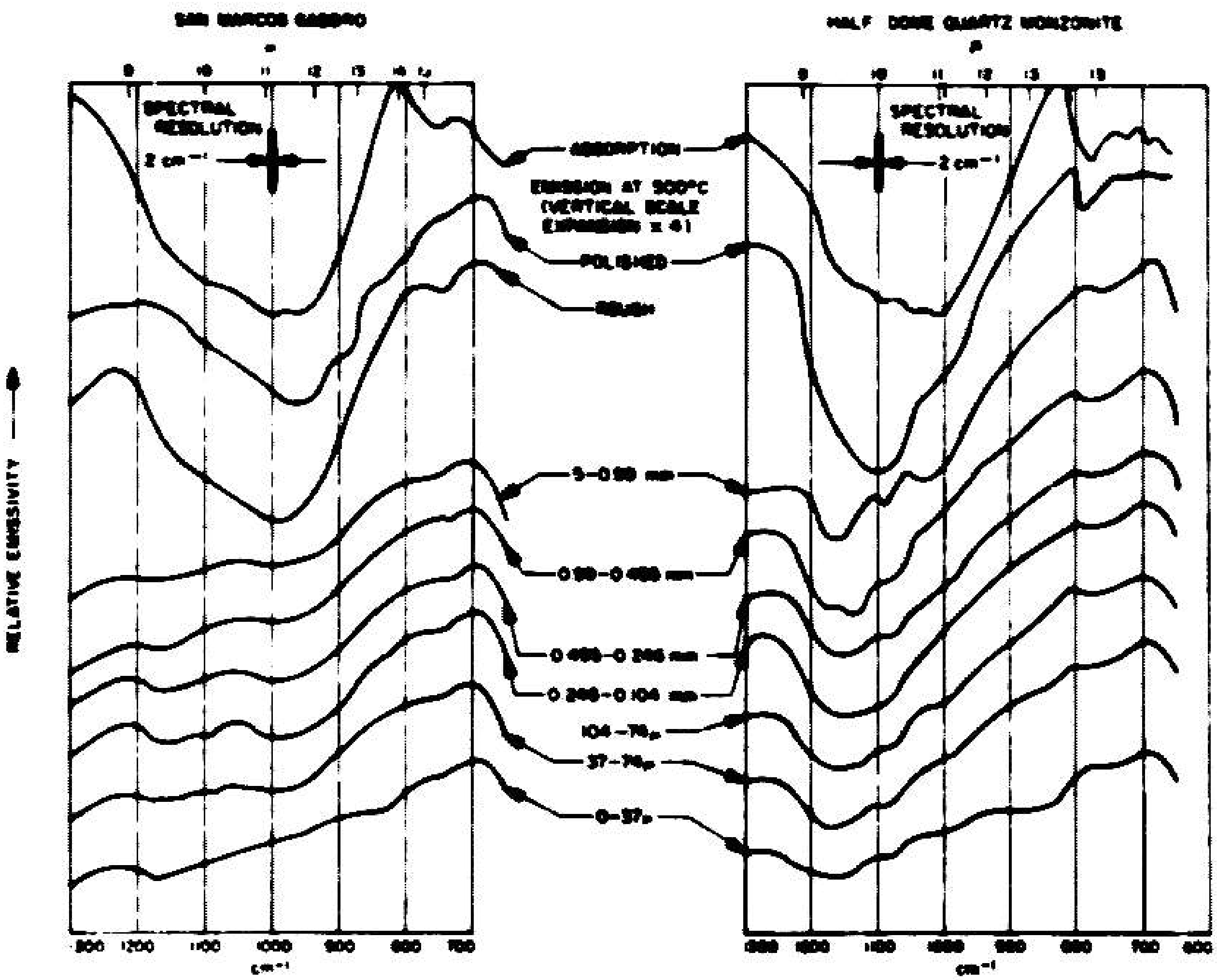


Fig. 2. Comparative emissivity of San Marcos gabbro and half dome quartz monzonite

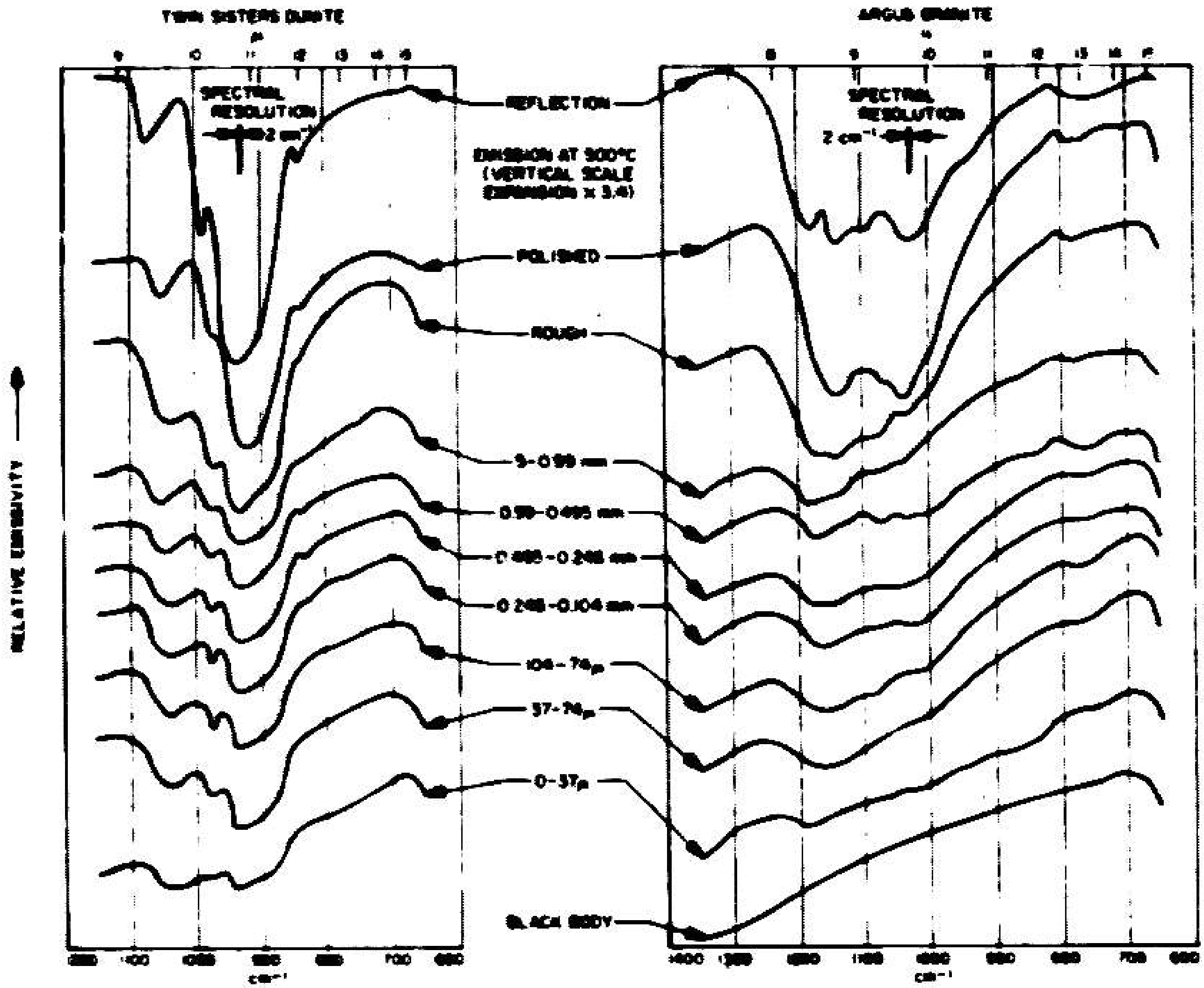


Fig. 3. Comparative emissivity of Twin Sisters dunite and Argus granite

Results of a preliminary study of effects on silicate infrared spectra produced by proton bombardment are given in Fig. 4. The two curves shown are specular reflection curves of polished Twin Sisters dunite before and after a simulated lunar 5-kv hydrogen ion bombardment of 10^4 yr. The peak shifts noted in this example can be explained in terms of a change in surface reflectivity (i.e. surface roughening) rather than crystallographic changes. If the results of proton bombardment were to introduce say 8 μ irregularities into the surface, then 10 μ waves would undergo less diffuse scattering than those of shorter wavelength and the reverse would follow for longer waves. Thus the shift of a specular reflection peak to longer wavelengths would arise with appropriate changes in surface geometry. Such displacements in fact are observed with simple roughening of polished specimens.

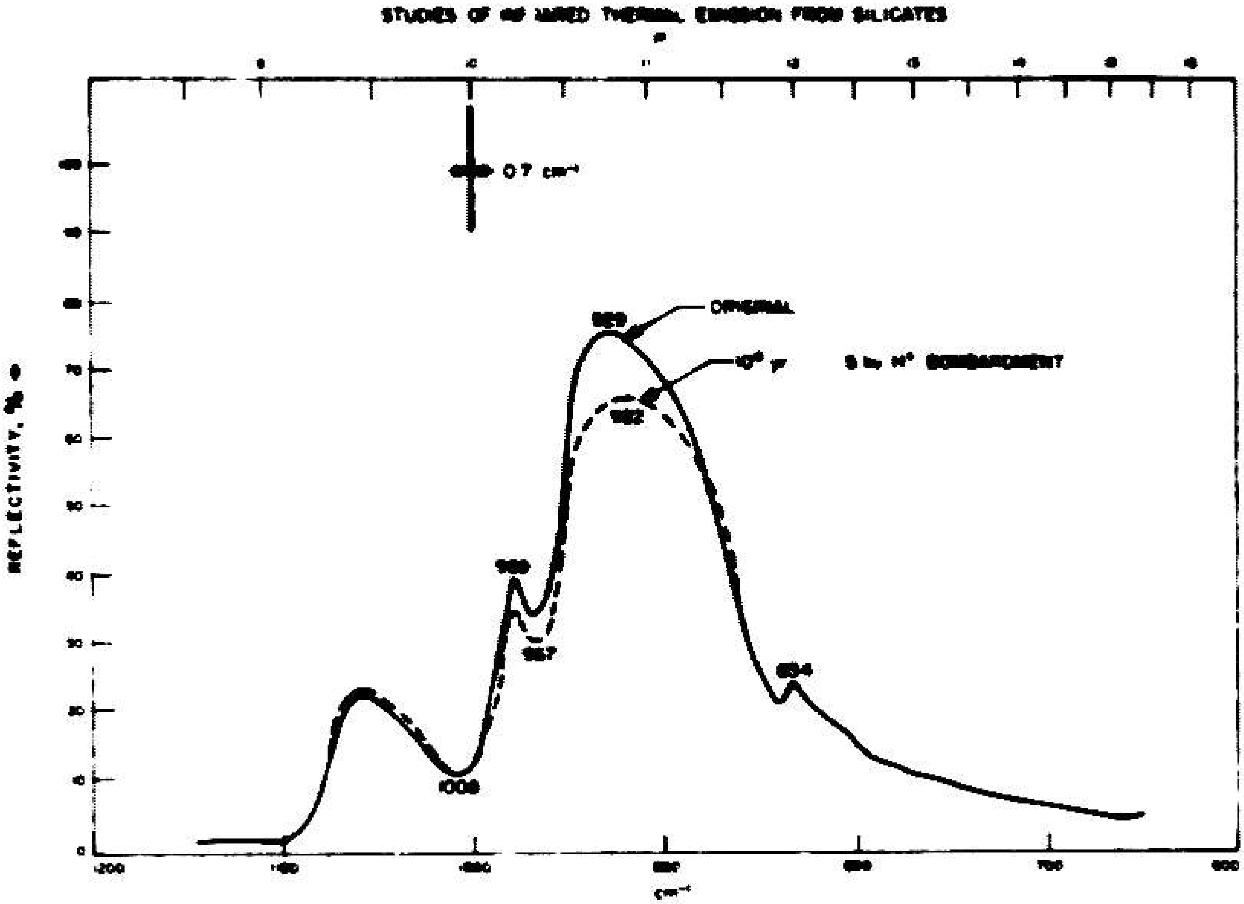


Fig. 4. Twin Sisters dunite change in reflectivity with proton bombardment.

Finally we note that the essentially negative opinion of Hovis (Ref. 1) on use of emission methods for identification of organic solids do not apply to the case of silicates. His conclusion is that for a significant emission feature to appear, the specimen under examination must be the order of the wavelength of examination in thickness, with a strong absorption feature. All of the emission results presented here disprove the first requirement, since the samples used were optically thick (i.e. 0.5 cm, compared to thicknesses for 99% absorption in silicates the order of 0.01 cm or less). His interpretation is apparently based on arguments from the theory of radiative transfer concerning radiation emergent from a finite layer of absorbing material, arguments which do not apply if there is scattering or reflection at the boundaries (Ref. 2). The condition of zero surface reflection in homogeneous, isotropic solids cannot, however, be satisfied where there is strong absorption since just the reverse is required by Fresnel's law of reflection. Thus Hovis' conditions are self-contradictory.

FIELD STUDIES

The field program has three purposes: (1) modeling of planetary observations (2) application of the emission techniques to problems of nature terrain emission, and (3) testing of instrumentation and methods in preparation for design of infrared spectroscopic flight hardware. A related and highly significant question concerns the effect of meteorological factors, wind, source and air temperature fluctuations (i.e. atmospheric background and noise) on observation of terrain emission. These questions are particularly relevant to spectroscopic observations of Mars.

Current efforts therefore center on development of instrumentation and techniques for simultaneous monitoring of terrain emission and atmospheric emission, absorption, and scattering and the fluctuations thereof. This section briefly describes the field spectroscopic instrumentation.

Figure 5 is an optical diagram (to scale) of the instrumentation under development. The basic element of the system is the Fastie-Ebert f/5 monochrometer. Radiation collected by the telescope is focused on the entrance slit after chopping by the three-blade chopper C which intersperses source radiation with that from a reference blackbody accurately temperature controlled (± 0.01 °C) to the equivalent blackbody temperature of the sources. The source temperature is determined radiometrically by independent measurement.

After dispersion the radiation is formed on the detector D, which, in the present application, is cadmium-doped germanium having an equivalent spectral D* of 7×10^{9} at 10 μ when operating at or below 20 °K. This temperature is provided by a closed cycle helium refrigerator capable of about 1 watt of 20 °K cooling. The entire detector is enclosed in a vacuum chamber with germanium window as shown in the figure. The amplitude of the signal at the detector, which is proportional to the difference in emission between target and reference, is measured by an amplifier tuned synchronously to the frequency of the chopper. An example of the output thus obtained is shown in Fig. 6. The monochrometer and detector are enclosed in a temperature controlled enclosure which is continuously flushed with dry air applied by a heatless pneumatic air dryer.

Continuous delays in procurement schedules for major components of the system have determined that spectroscopic field observations will not be possible before November of this year (1965).

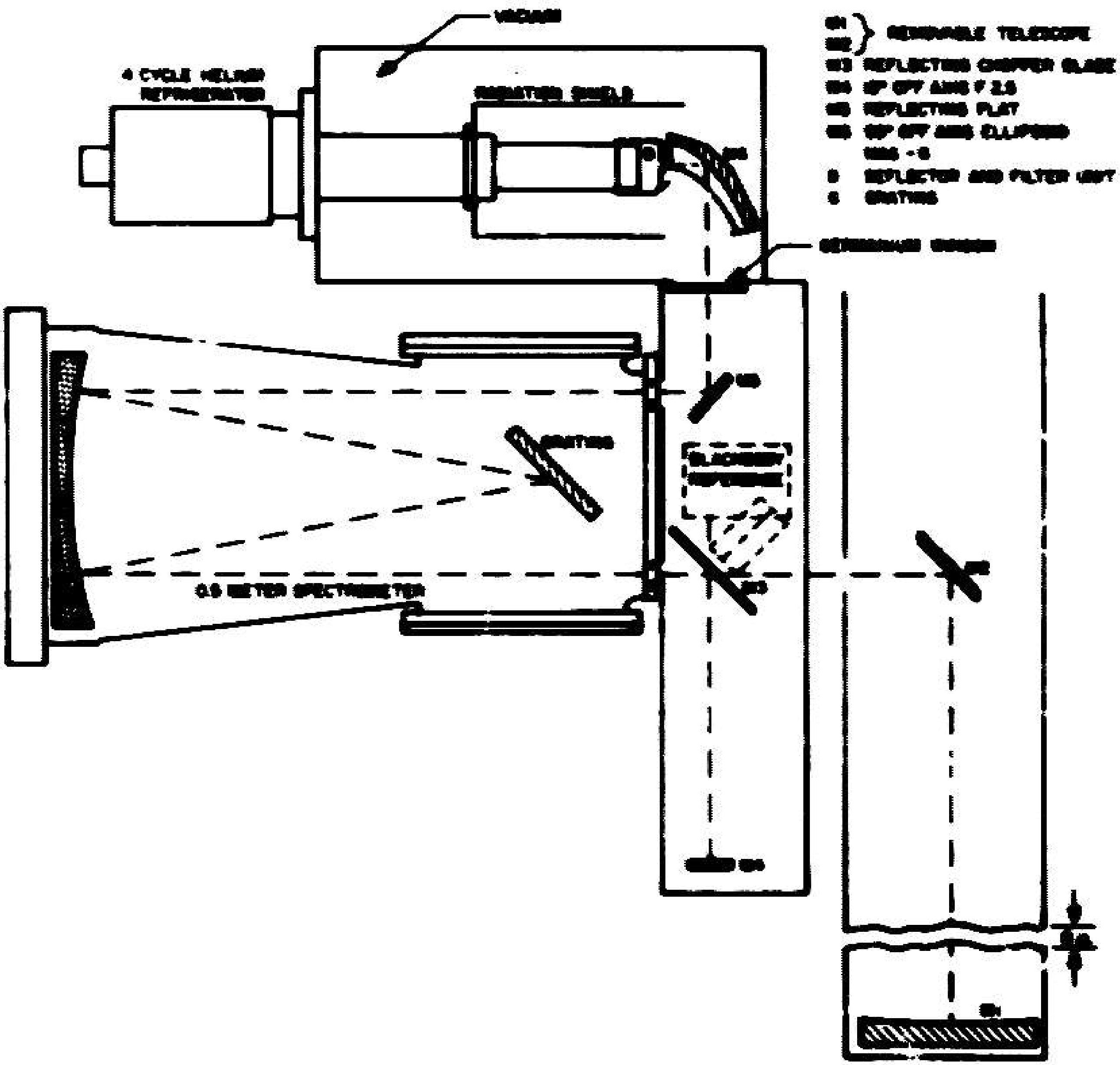


Fig. 5. Optical diagram of the instrumentation under development.

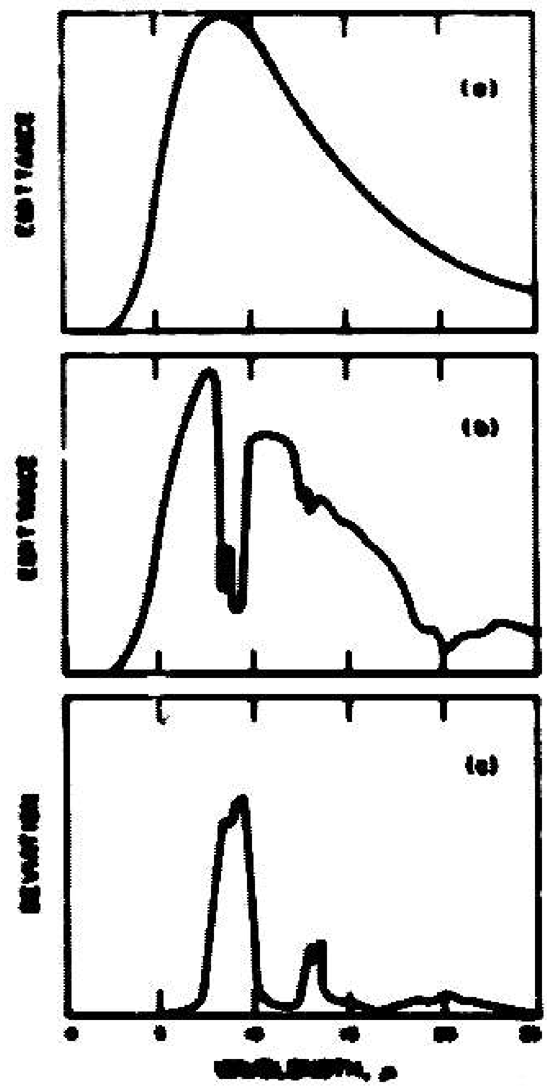


Fig. 6. IR emission from silicates by optical differential method.

REFERENCES

1. Hovis, W. A., "Emission Spectra of Organic Solids from 5 to 6.6 microns", Science, Vol. 143, p. 587, 1964.

2. Milne, E. A., "Thermodynamics of the Stars", Handbuch der Astrophysik, Vol. 3 (i), Springer, Berlin.

BLANK PAGE

POLYCHROMATIC RADAR STUDY
NASA Work Unit 190-42-25-01
JPL 390-20201-X-3240

The objective of this study is to survey available radar components, assess their availability, reliability, and cost, and to prepare a preliminary functional specification for a polychromatic radar experiment. The effort level is 2.5 man-years.

At this time, about one-half of the study has been completed. Currently, no work is being done on the study because two openings for engineers have not been filled, and the Aerobee radar effort requires the full-time attention of all the available manpower. The study will be continued and completed when manpower becomes available. According to the present plan, the Aerobee radar project will release personnel in October of 1965 for work on the study. It is possible, however, that the openings will be filled prior to that time. It is expected that this study will be completed prior to December 1, 1965.

BLANK PAGE

MANNED LUNAR SCIENCE (867)

BLANK PAGE

APOLLO (EARTH ORBITAL) (867-14)

LUNAR AND PLANETARY X-RAY DIFFRACTION
NASA Work Unit 867-14-00-01
JPL 367-30101-1-3220

BACKGROUND INFORMATION

Funding for the X-ray diffraction task became available April 1, 1965 and during the fourth quarter, work was accomplished by three people.

The effort on the design and development program for flight prototype instrumentation for the Apollo program (and/or the Surveyor Block II project) is a continuation of a similar effort which was funded prior to April 1, 1965, by the Surveyor II project at JPL. Neither the Surveyor II budget nor the Apolo budget permitted an major procurement. Funding was essentially at a level sufficient to cover the salaries of the three people.

Some progress has been made.

X-RAY DIFFRACTOMETER

Most of the electronic circuits on the X-ray diffractometer have been redesigned incorporating integrated circuits where possible to reduce size and weight and to increase the reliability of the final design. Breadboards of the following circuits have been fabricated and functionally tested: timing generator, data converter (digital output format), motor-drive logic, 25-kv power supply and anode current regulator, and proportional counter tube preamplifier and pulse-height discriminator.

The 25-kv power supply for the X-ray tube is to be a hermetically sealed supply which encloses all the high-voltage circuitry. The X-ray tube is built into the power supply to eliminate high-voltage cables and connectors. This power supply has been built and successfully functionally checked.

POWERED ROCK SAMPLING SYSTEM

This work is also a continuation of work started under the Surveyor project. The design and fabrication of a breadboard sampling system has been completed. The system consists of an impact-type drill mechanism for making a 1/2-in.-diameter hole in the lunar surface, pulverizing the rock, and for extracting the pulverized rock (by a vibrating vertical conveyor) from the bottom of the hole and delivering this material to the specimen preparation station. After the specimen cup has been filled, another feed mechanism positions the specimen cup on the X-ray diffractometer specimen stage ready for X-ray analysis. Functional testing of this breadboard has started.

Reports of both these efforts have been made in SPS 37-31, Vol. I, and SPS 37-32, Vol. I. This work has also been reported in the semi-annual report JPL Technical Memo 33-218, "Report of Instrument Development and Scientific Research, for July 1964 to March 1965.

FUTURE EFFORT

The remaining electronic circuit breadboards, which consist of the low-voltage power supply, the 2-kv power supply and regulator, and the angle transducer and data converter, will be fabricated and tested. The ground support equipment (GSE) will be designed and fabricated. An engineering prototype of the diffractometer will be designed, fabricated in-house and tested.

Design and development of an X-ray tube by outside contract is planned. Development of a proportional photon counter by an outside contractor is planned. Design and development of a smaller, more reliable 25-kv power supply by both an in-house effort and a parallel contractor effort is planned.

Thermal, vacuum and vibration testing of the high-voltage power supply and the complete engineering prototype diffractometer will be performed in FY 1966.

A continuing effort by FY 1966 in the area of rock sampling is planned and will be handled by a separate group in the Lunar and Planetary Instruments Section.