JET PROPULSION LABORATORY

CALIFORNIA INSTITUTE OF TECHNOLOGY

PASADENA, CALIFORNIA

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Approved:

Frank E. Goddard, Jr.

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

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CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

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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
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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, 1968, under the direction of the JPL Office of Research and Advanced Development, for the NASA 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.

JPL research and advanced development results published during this report period are listed under each work unit.

LAUNCH VEHICLE DEVELOPMENT (180)

INSTRUMENTATION (180-24)

ELECTRO-EXPLOSIVES TEST TECHNIQUE IMPROVEMENTS

NASA Work Unit 180-24-03-01-55

JPL 380-40101-2-3810

J. E. Earnest

OBJECTIVE

The objective of this program is to develop the statistical theory, application technology, and physical instrumentation for the testing of squibs. Nondestructive testing, quantitative and small-sample techniques are stressed.

STATUS

Pressure Transducer Evaluation

Problems in static calibration of piezoelectric transducers have led to past preference at JPL for strain-gauge-type pressure transducers in spite of their bulk, lower sensitivity, and susceptibility to "hash" from squib firing currents.

Good performance by a charge amplifier of a well-known make initially promised to swing the balance in favor of piezoelectric transducers, but it was subsequently found that piezoelectric transducers on hand had unattractive temperature sensitivities by comparison with some strain-gauge-type transducers. As the piezoelectric temperature sensitivities did not meet published specifications, the problem was discussed with the manufacturer; discussions were also held with Lewis staff, who had reported conflicting results. The outcome of these discussions was that the manufacturer had changed early crystal cuts in an effort to improve other characteristics and, in doing so, had elected to trade off against temperature sensitivity. This manufacturer was unable to offer a unit with temperature sensitivity of better than 3% per 100°F.

Temperature sensitivities noted in tests at JPL are sufficient to account for the common anomaly of room temperature firings exhibiting lower apparent pressures than low temperature firings; the practical difficulties of making prefiring transducer calibrations at extreme temperatures makes low temperature-sensitivity desirable, particularly because of the accuracy needed to gain maximum advantage from small-sample tests.

In view of the foregoing, and of the present-day availability of compact solid-state amplifiers which can be located close to the transducer (leading to good signal-to-noise ratios), the pendulum is swinging back in favor of strain-gauge-type transducers. On order, for evaluation, is a 30,000 psi unit, from a proven source, requiring only a 1/2-in. threaded port.

Static Discharge Tests

No satisfactory solution has yet been found to the problem of random steps in discharge voltages arising from transfer switch-bounce, but one manufacturer has undertaken to devise contacts which will remain closed for at least 0.1 ms following initial contact.

Until this problem is solved, discrepancies in quantitative results as obtained at different test centers can be expected.

Thermal Time Constant and Associated Techniques

The laborious calculations associated with changes in thermal time-constant test frequencies have been overcome with a simple nomograph-type template, thus making rapid measurement over a range of frequencies practical. This in turn has revealed that the thermal time-constant of squibs as measured by the third-harmonic technique is typically frequency-sensitive.

Further work envisaged in this area includes an attempt to get direct readout of thermal time-constant from cooling curves, and an investigation of the practical significance of the frequency-dependence of third-harmonic results.

The first known "cross-country calibration" for third-harmonic measurements was made in May and June — samples tested in Pasadena were shipped to Prof. Rosenthal in New Jersey, and the results were duplicated by him.

Bridge pulse tests and power sensitivity have now been recognized as being complementary, with the pulse test giving information relating mainly to the "all-fire" region and the power sensitivity tests giving information relating mainly to the "no-fire" region. Circumstances may justify use of either test, or of both.

Squib Ignition Time

Efforts to devise a generally-applicable technique for sensing the instant at which a match head ignites have been unsuccessful, and work in this area has been suspended.

Small-Sample Techniques

It is believed that the small-sample techniques now on hand have been optimized to the practical limit, allowing a reduction by a factor of at least 5 by comparison with the sample sizes required by more conventional techniques. Of the various NASA centers, only Langley is known to be attempting to take advantage of the significant economies offered by these techniques.

PUBLICATIONS

None.

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LIQUID PROPULSION (180-31)

THROTTLING TECHNIQUES FOR HYDRAZINE REACTORS

NASA Work Unit 180-31-07-01-55

JPL 380-10301-2-3840

T. W. Price

OBJECTIVE

The objective of this work unit is to study technology areas associated with throttled, high-thrust monopropellant reactors and to generate the required engineering data so that such devices can be successfully operated over a 10:1 throttle range.

APPROACH

Thrust levels above 500 lb_f are virtually unexplored for monopropellant devices. Therefore this technology area will be investigated somewhat independently before adding the complexity of throttling. Several promising throttling schemes will be explored, including one which will be obtained from a qualified contractor.

PROGRESS

Late in this reporting period permission was received to proceed with the full program originally proposed. The major activity this period has been the preparation of a Work Statement which will lead to a competitive procurement action. The end item of this contract will be a prototype 1000-lb_f-thrust, throttleable monopropellant reactor, which will be delivered to JPL for further testing. It is expected that a request for proposals will be released very early in FY 69.

Prior to the preparation of the Work Statement noted above, a mission analysis study resulted in two significant changes to this work unit. These were the thrust level and the propellant. For the mission considered, a 1973 Mars lander, the 500 lb_f thrust level previously considered would land practically no scientific payload, while 1000 lb_f would permit a meaningful mission to be conducted. The analysis also indicated that higher specific impulse would be very beneficial; hence, the higher performance propellant mixture of 75% hydrazine – 24% hydrazinium nitrate will be evaluated.

During the next reporting period proposals will be evaluated and a contractor selected. Also during the next period the in-house program will be pursued with the design and fabrication of experimental hardware.

LUNAR PLANETARY EXPLORATION SRT SCIENCE (185)

SPACE CHEMISTRY (185-37)

FLIGHT MODEL INFRARED INTERFEROMETER

NASA Work Unit 185-37-32-01-00

JPL 383-32101-2-3250

R. Beer
R. Schindler

OBJECTIVE

The objective of this task is to develop a flightworthy, high-resolution infrared interference spectrometer for atmospheric analysis on advanced planetary missions (flyby or orbiter). The instrument will provide spectra at a resolution of 0.5 cm^{-1} for the purpose of elucidating the detailed composition and physical state of atmospheres, including spatial, height, and secular variations.

PROGRESS

Interferometer Servo-Drive Contract

Work on this contract was stopped in September 1967, resuming under a renegotiated contract on January 12, 1968. The terms of the renegotiated contract call for the vendor to supply the mechanical assembly (including the magnet and drive-coil) only. Completion of the electronic design and construction is now an in-house effort. Progress on the contract is satisfactory and it is hoped that it will be completed before the end of June.

Design of the servo-drive electronics is complete and most of the individual circuit boards have been tested. Testing of the complete electronics system will commence before the end of July and will be completed by the end of September. Integration with the interferometer and systems testing will take place during October and November.

Optical System

Quartz cat's-eyes have been designed that will require no mechanical adjustment since they will be fabricated to the correct tolerances. These units, weighing only one-third of the present units, will permit a large reduction in the weight of the total structure. An order for the all-quartz units will be placed within the next 3 mo.

Although a quartz beamsplitter is already on hand for preliminary instrument testing, a calcium fluoride beamsplitter, useful over the entire spectral region of interest, is now being fabricated by Frank Cook, Inc. Unnecessary portions of the present cubically shaped beamsplitter have been removed to increase transmittance and reduce fringe distortion.

The tuning fork optical choppers for the instrument have been received. Tests have shown that they comply with the requirement of 1 min. of arc angular reflected image stability.

The fore-optics housing, which also houses the basic interferometer and the servo-drive, as well as the IR detectors, has been completed and the components are now being assembled. Optical alignment of the fore-optics will be completed during July, and the fore-optics will be integrated with the interferometer during August and September.

Infrared Detection System

One channel of the two-channel infrared detection system (including the signal digitizer) has been completed. The slow-speed, simplified laboratory data recording system using an incremental tape-recorder, is being integrated with the detection system. Testing of both channels will be completed in October.

System Integration and Testing

Integration and testing of the complete interferometer system with the laboratory data recording system will commence in December.

Data System

Design of the high-speed, PCM data system is now under way. Fabrication of the data-encoder is being done in-house and is to be completed by December.

Specification of the requirements for data decoding and data formatting is now being done and procurement of the necessary hardware, including a small computer, will begin in September. Delivery of this equipment is scheduled for January 1969.

System Specification

A document defining the system performance requirements has been written. If all the criteria are met, the instrument will be capable of 0.5 cm^{-1} resolution over the entire 2000-8000 cm^{-1} region with a signal-to-noise ratio of more than 100 in an observation time of less than 2 min.

ANTICIPATED PUBLICATIONS

1. Schindler, R., "Progress Report on the Flight Model Interferometer," SPS 37-52, Vol. III, August 31, 1968.

PUBLICATIONS

1. Beer, R., "The Flight Model Interferometer—A Rationale for Its Development and Operation," JPL Document 760-21, 1968.

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MASS SPECTROMETRY

NASA Work Unit 185-37-34-01-55

JPL 383-31001-2-3260

383-31002-2-3220

C. E. Giffin

OBJECTIVE

The long-range objective of this task is twofold: (1) the study of new techniques in mass spectrometry, which will enhance the utilization of mass spectrometry in fulfilling the scientific objectives of the NASA lunar and planetary exploration program; and (2) the development and demonstration of flight-type mass spectrometers for lunar and planetary atmosphere analysis. The objectives of the work unit for this fiscal year are:

Martian Atmospheric Sampling

Studies will continue this year into the problems of mass spectrometer sampling of the Martian atmosphere from an entry capsule traveling at high velocities with respect to the ambient atmosphere. This effort will be coordinated with theoretical work being performed on capsule sampling systems.

Three-Dimensional Quadrupole Mass Spectrometer

The 3-D quadrupole has strong potential from the standpoint of lunar atmosphere analysis (since it is in effect an ion storage chamber and integrator) and also it may become the first truly microminiature mass spectrometer with high performance capability. A study of its capability both as a low-pressure mass spectrometer for lunar atmosphere analysis, as well as its limitations for high-pressure and ion analysis, will be conducted.

PROGRESS

Engineering Model Mass Spectrometer

An engineering model, Fig. 1, was completed in the third quarter of FY 68. This instrument incorporates many features not present in the science breadboard, e.g., a low-conductance ion source, ruggedized mechanical design and packaged electronics. Preliminary test results indicate that the instrument has the required capability in the area of mass resolution and rapid scanning. A sterilization cycle was performed on the instrument prior to delivery to the Capsule Systems Advanced Development (CSAD) Project with no degradation in performance noted. Data interface circuits, including a peak detector analog-to-pulse-width converter (PD-A/PW) were incorporated into the ground support equipment (GSE) which was also delivered to the CSAD Project. Included in the CSAD capsule was a complete data automation system for the mass spectrometer. The instrument has functioned properly during all subsystem and system tests performed on the capsule, including capsule sterilization. A modified PD-A/PW converter, one which enables the circuit to function with an extended range scale switch electrometer, has been designed and successfully tested.

Atmospheric Entry Sample System

During this reporting period, development of an atmospheric entry sampling system was initiated. The purpose of this sampling system is to obtain uncontaminated samples of the atmosphere during the terminal descent phase of an entry mission and to introduce the atmospheric samples into the ion source of the JPL entry mass spectrometer under molecular flow conditions.

The atmospheric entry sampling system under development employs a sample tube to obtain samples of the atmosphere behind the entry capsule bow shock wave and a variable conductance molecular leak to provide a uniform sample flow rate into the mass spectrometer.

A breadboard version of a fixed-ball molecular leak has been calibrated and early results were presented at the April 1968 OSSA Review. Later work has demonstrated molecular flow sampling capability up to 760 torr with no evidence of deviation from this required flow regime.

Science Breadboard Mass Spectrometer

Magnet shimming experiments have been performed on the breadboard instrument with significant resolving power increases and peak shape improvement being obtained in the high mass range. These studies are continuing.

PROPOSED EFFORT FOR THE NEXT 6 MO

Mars Atmosphere Sampling

Three different approaches to the mass spectrometer molecular leak problem will be studied. Two of these will be of the constant conductance type, and one of a variable conductance nature. The constant conductance leak offers inherent reliability since it is a passive device; however, it reduces the dynamic range of the mass spectrometer at low inlet pressures. The variable molecular leak on the other hand will alter its conductance inversely with sampling pressure, thereby maintaining a constant dynamic range of sensitivity irrespective of inlet pressure. An engineering breadboard of this leak and control circuitry will be fabricated, tested, and ready for flight model design at the beginning of the third quarter.

Three-Dimensional Quadrupole Mass Spectrometer

The three-dimensional (3-D) quadrupole mass spectrometer will be studied to determine its suitability for quantitative analysis in high- and low-pressure regimes. The emphasis in the low pressure work will be placed on those problems that will be encountered in the analysis of the lunar atmosphere. The high-pressure work will concern itself with the problems of atmospheric and organic analysis, as might be encountered in a high-impact atmosphere or GC/MS experiment. A contract will be let as early as possible in FY 69 for the construction of the science breadboard analyzer. The design and construction of the breadboard electronics for this instrument will be started, including a wide-band low-noise charge-sensitive amplifier. Design and testing of a cold ionizing electron source based on prior JPL work and "tailored" to the 3-D quadrupole will be started.

Finally, a contract will be let to develop a ruggedized flight electron multiplier as a stable ion detector.

PUBLICATIONS

None.

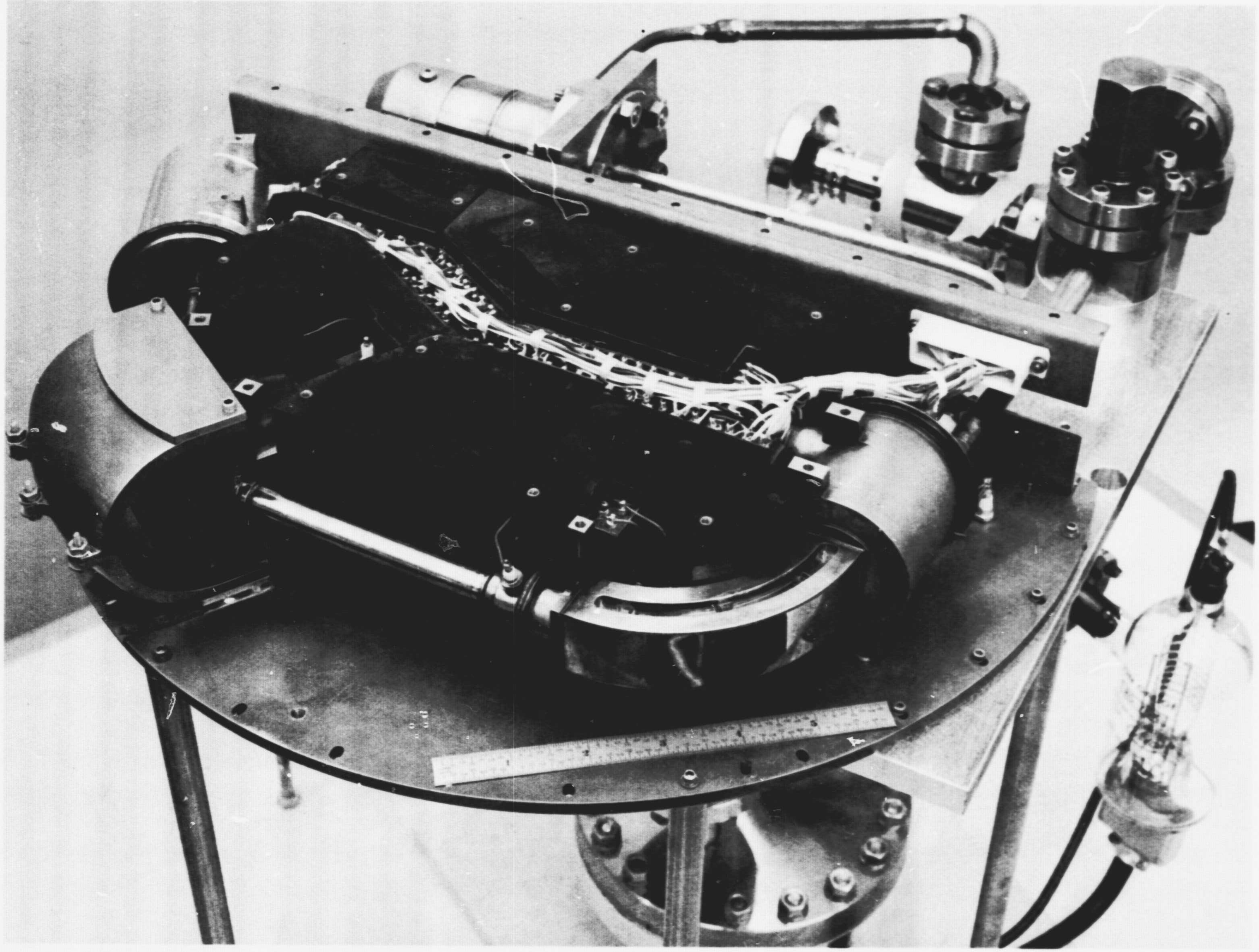

Figure 1. Engineering Breadboard Mass Spectrometer

ASTRONOMY (185-41)

OPTICAL ASTRONOMY

NASA Work Unit 185-41-21-01-55
JPL 383-10201-2-3250
R. H. Norton

OBJECTIVE

The long-range objective of the optical astronomy effort is the comprehensive study of the atmospheres and surfaces of solar system bodies. Present emphasis is on Mars and Venus, but attention will be paid to planets of interest to future NASA missions.

PROGRESS

Observing programs of Mars, Venus, and Saturn, begun in FY 67, were concluded during FY 68. Included in the observations are high-dispersion spectra of Mars and Venus (Schorn), medium-resolution spectra of Jupiter (Newburn), photometry of Mars, Saturn and the satellites of Saturn (Miner), and photography of Mars, Venus, Jupiter, and Saturn (Capen). Reduction of data for these programs is complete or well along. Progress during this reporting period is marked by the publication or submission of eleven journal articles and one SPS contribution. Of particular significance are papers by Schorn and collaborators on Venus carbon dioxide and water vapor measurements, and by Gunn on the effects of solar wind bombardment of planetary atmospheres.

In the program of instrument development, a 1-m Ebert-Fastie scanning monochromator is now operational at the cassegrain focus of the Table Mountain 24-in. reflector. Preliminary tests of the instrument indicate that it will be possible to record a spectrum of Venus covering the 3500-7000-Å range in 1 hr. with a spectral purity of 1 Å and a signal-to-noise ratio of 100.

Construction of the high-dispersion coudé spectrograph for the 24-in. telescope has proceeded on, or ahead of schedule. The main frame and the large camera mirror cell are complete, the finished optics will be delivered in

July, and the remaining mechanical assemblies will be completed by August 1. After assembly and very preliminary testing at JPL, the spectrograph will be shipped to, and installed at, Table Mountain in September, where it will undergo exhaustive testing. Two grating blanks have been ordered and will be delivered by October 10 to Dean George Harrison of MIT, who has agreed to rule the gratings. No firm schedule can be promised for ruling gratings such as these, since they represent state-of-the-art technology. If the finished gratings are not available by February 1, 1969, a smaller grating will be used in the spectrograph until the large gratings are delivered.

PUBLICATIONS

Meetings and Symposia Papers

1. Schorn, R. A., "High Dispersion Spectroscopic Observations of Venus. II. The Water Vapor Variations," Second Arizona Conference on Planetary Atmospheres, Tucson, Arizona, Mar. 10–13, 1968.

2. Norton, R. H., "Surveyor Solar Corona Observations," 49th Annual Meeting of American Geophysical Union, Washington, D. C., Apr. 10, 1968.

3. Schorn, R. A., "Mars and Venus," Institute of Environmental Sciences, St. Louis, Missouri, Apr. 24, 1968.

Open Literature

1. Epstein, E., Soter, S., Oliver, J., Schorn, R., and Wilson, W., "Mercury: Observations of the 3.4 mm Radio Emission," Science, Vol. 157 p. 1550, 1967.

2. Epstein, E., Oliver, J., Soter, S., Schorn, R., and Wilson, W., "Venus: On an Inverse Variation With Phase in the 3.4-mm Emission During 1965/1967," Astron. J., Vol. 73, p. 271, 1968.

3. Smith, H., Gray, L., Barker, E. and Schorn, R., "Use of an Infrared Image Tube for High-Dispersion Spectroscopy," Astron. J., Vol. 72, 1968.

4. Gray, L. and Schorn, R., "High-Dispersion Spectroscopic Studies of Venus. I: The Carbon Dioxide Bands Near 1 Micron," Icarus, Vol. 8, No. 3, May 1968.

5. Schorn, R., Epstein, E., Oliver, J., Soter, S. and Wilson, W., "Quasars: 88 Gc Measurements," Astrophys. J., Vol. 151, p. 127, 1968.

6. Schorn, R., Barker, E., Gray, L. and Moore, R., "High-Dispersion Spectroscopic Studies of Venus. II: The Water Vapor Variations," Icarus, in press.

7. Gunn, J., "Solar Wind Bombardment of Planetary Atmospheres," Astron, J., in press.

8. Capen, C. and Young, J., "Observations of the November 1966 Leonid Meteor Storm," Icarus, in press.

9. Spinrad, H. and Miner, E., "Sodium Velocity Fields in Comet 1965f," Ap. J., in press.

10. Gunn, J., "Photon Noise in Fourier Spectroscopy," Applied Optics, submitted for publication.

11. Gunn, J., "The Grille Spectrograph in Astronomical Spectroscopy," Applied Optics, submitted for publication.

SPS Contributions

1. Schorn, R., "Water Vapor Variations on Venus," JPL SPS 37-49, Vol. IV, 1968.

RADIO ASTRONOMY

NASA Work Unit 185-41-24-01-55

JPL 383-10301-2-3250

B. Gary
D. Jones

OBJECTIVE

The objective of the Radio Astronomy Program is to increase our understanding of the moon and planets by means of (1) ground-based passive radio astronomy at centimeter and millimeter wavelengths and (2) ground-based radar observations. This research not only leads to fundamental contributions to space science but also provides important information in support of flight projects.

PROGRESS

Venus Microwave Program

Microwave observations of Venus have been conducted during the past 4 yr (three conjunctions) with the primary purpose of detecting an absorption feature at $\lambda 1.35$ cm caused by water vapor in the planet's atmosphere. To date, no such feature has been found by any investigator. This puts an important upper-limit constraint on the abundance of water vapor above the level from which radiation at this wavelength typically originates (10-30 km, simple model). Work during recent months has tightened this constraint further. It has been shown, from difficult-to-make superior conjunction measurements, that this dry atmospheric condition applies to the day side half of the planet as well as to the night side.

As a second goal for Venus, it has been tried to determine the day side to night side difference in the planet's brightness temperature (the phase effect) in the 12 to 16 mm wavelength region. Data from the conjunction of 1966 shows the day side temperature to exceed that of the dark side by an average of 200°K. The more thoroughly calibrated data taken during and after the 1967 conjunction appear to be compatible with a variation of this magnitude. In addition, a puzzling absorption feature appears at $\lambda 1.40$ cm: the depth of characteristic origin for radiation of this wavelength is at a regular 450°K temperature on the dark side, but is at the anomalously low 360°K temperature on the day side. Such an inverse phase effect at one wavelength would have intriguing implications for Venus' atmospheric composition and dynamics.

Future studies of Venus in this wavelength interval will be designed to verify the existence of the $\lambda 1.40$ cm absorption feature on the day side. A verification will be sought for the large positive phase effect (~100°K) for a typical wavelength in this region. The 30-ft antenna at Goldstone and the tuneable radiometer will continue to be used for this purpose, and thorough calibrations will become an essential part of the program.

A 27-channel radiometer is being constructed for Venus spectral studies, and it should be installed on the 30-ft, or in an 85-ft compatible cone, during the fall of 1968.

The 18-ft facility at Table Mountain will be used starting in the fall of 1968, to investigate the inadequately measured phase effect of Venus in the wavelength region 8–12 mm. A tuneable paramp with unprecedented sensitivity will be used.

Jupiter Microwave Program

The temperature profile of Jupiter's atmosphere above the clouds could be deduced as being strongly sub-adiabatic (close to isothermal) if a broad absorption feature due to ammonia is present at $\lambda 1.26$ cm. The broadening can be substantially greater than our band coverage at Goldstone, 12–16 mm. Therefore, it is necessary to assemble results from many workers at several wavelengths to test for its presence. JPL's Jupiter measurements support those by others which favor the existence of a 20 or 30°K absorption feature, and we therefore present further evidence for the sub-adiabatic Jupiter atmosphere model.

Venus Radar Program

Radar determinations of the Venus rotation period have continued to improve in accuracy, and with these improvements the values have heretofore steadily approached the earth-synchronous value of 243.16 days. However, reduction of JPL-Goldstone observations during the 1967 conjunction provide what probably is the best determination now in existence — a period of 243.06 ±0.06 days. The difference of about 2 standard errors is frustrating. Statistically, the odds are about 20 to 1 against earth-synchronous rotation. However, the presence of subtle systematic effects cannot be discounted, and synchronism may indeed exist. Reduction of the same data for a position of the Venus rotation axis supports previous determinations that the rotation axis is nearly normal to the orbital motion. Future observations of Venus will resume for the 1969 conjunction.

Mars Radar Observations

Mars is a more difficult target than Venus because of the large doppler spread of reflected signals. Capabilities of transmitter power and antenna size have just recently improved to the point where Mars can usefully be studied by radar. Early observations of reflectivity profiles were tentatively interpreted in terms of altitude variations of visual features. However, during the 1967 opposition a JPL experiment which employed the 210-ft antenna in a bistatic configuration with an 85-ft antenna provided more accurate reflectivities which do not support these feature correlations. The recent reflectivity results do show large variations as the planet rotates under the sub-radar point, from about 2 to 12%, but there is no well-obeyed correlation with visual features. Another aspect of the Mars returns deserving further study is a variation with location on the planet of surface roughness, as deduced from observed variations in the frequency spread in the return pulses. The system will be improved for the next opposition (in 1969) by a factor of 25 by using the 210-ft antenna for both receiving and transmitting, and by using a 450-kW transmitter in place of 100 kW. Further in the future, perhaps in 4 yr, a 700-fold improvement over the present sensitivity could be attained through the use of a megawatt transmitter at X-band on the 210-ft antenna (versus 100 kW at S-band with 210-ft and 85-ft bistatic).

Miscellaneous Observations

The Aerospace Corp. collaboration has continued, and recent observations with their 15-ft antenna at λ3.4 mm have included Venus, Mars, and some quasars. During the next 6 mo, Mercury will be added to the observing list.

A small-scale program to monitor quasars has been started with the Goldstone 30-ft antenna at 12.5, 14.0, and 16.2 mm. In the fall of 1968, supplementary observations of quasars will be started at Table Mountain with the 18-ft antenna at λ11.0, 10.0, and 8.0 mm. In early 1969, the 18-ft antenna might be instrumented for λ2.2-mm observations, in addition. The intent is to coordinate observing at Goldstone, Table Mountain, and Aerospace to provide comprehensive coverage in the domains of time and wavelength (2 to 16 mm), so that the complex morphology of quasar radio bursts can be more completely known.

Facilities

Improvement of facilities is not a goal in itself but is pursued with specific experiments in mind. During the past 3 yr, the Table Mountain 18-ft antenna facility has been continually upgraded and brought closer to a readiness status that will make it the most powerful in the world for its intended use. The system will excell in (1) signal-to-noise sensitivity at 8–12 mm by using a state-of-the-art parametric amplifier, (2) absolute calibration accuracy by using a far-field, high-elevation, boresight transmitter facility, and (3) reliable relative calibration accuracy by being rigidly constructed for its size and thereby having little variation of gain versus elevation angle, and by being situated at a high elevation (7500 ft) and thereby requiring small and reliable extinction corrections. This unique combination of attributes will put the 18-ft facility in a forefront position for studying all the planets and the moon.

Other improvements are discussed under the microwave radiometer development task (185-41-25-01).

Feasibility Studies

Sometimes a facility is built for one purpose without realizing its value for another use. The 210-ft DSN antenna at Goldstone was built for spacecraft tracking purposes. The possibility of accomplishing spacecraft goals by partial use of the antenna for radio and radar astronomy experiments should be considered, so that maximum effectiveness of NASA funding may be realized. Accordingly, a comprehensive review has been started of conceivable ground-based radio astronomy observing programs (~ 25 items) which could be accomplished with this antenna. Results of this study will be summarized during the next 6 mo in the form of a document containing feasibility evaluations for each of the possible programs and recommendations, or a set of proposals, based on feasibility conclusions and scientific needs.

ANTICIPATED PUBLICATIONS

1. Carpenter, R. L., "Venus Radar," Astron.
2. Carpenter, R. L., "Venus Surface Features by Radar," Science.
3. Jones, D. E., Meredith, B. L., "Venus Microwave Spectrum and Phase Effect."

PUBLICATIONS

Open Literature

1. Epstein, E. E., Oliver, J. P., Soter, S. L., Schorn, R. A., and Wilson, W. J., "Venus: On an Inverse Variation With Phase In the 3.4-mm Emission During 1965 Through 1967," Astron. J., Vol. 73, p. 271.
2. Schorn, R. A., Epstein, E. E., Oliver, J. P., Soter, S. L., and Wilson, W. J., "Quasi-Stellar Radio Sources: 88-Ghz Flux Measurements," Astrophys. J., Vol. 151, p. 127.

SPS Contributions

1. Schorn, R. A., Epstein, E. E., Oliver, J. P., Soter, S. L., and Wilson, W. J., "Quasi-Stellar Radio Sources: 88-Ghz Flux Measurements," SPS 37-49, Vol. III, p. 267, Feb. 29, 1968.

MICROWAVE RADIOMETER DEVELOPMENT

NASA Work Unit 185-41-25-01-55

JPL 383-10501-2-3250

F. T. Barath

OBJECTIVE

Under this task, advanced microwave radiometer instrumentation is developed for the radio astronomy task; the instrumentation is used and evaluated in the framework of a ground-based lunar and planetary observation program; and advanced microwave techniques and instrumentation are developed for future spacecraft experiments. Emphasis during FY 68 has been placed upon the completion and use of the instrumentation that was well under way last year.

PROGRESS

The work since January 1, 1968, was in the following areas:

18-ft Precision Antenna Facility

(1) The antenna, installed at the Table Mountain site, was reworked during the reporting period to improve its characteristics and to correct deficiencies that were found in the system after delivery by the contractor. A new quadrupod assembly, designed and built at JPL, was installed on the antenna; the subreflector positioning mechanism was stiffened to reduce deflections while tracking; the individual antenna panels were readjusted to minimize departures from a true parabola. Further panel adjustments and an extensive mechanical measurement program are scheduled for the next quarter. This effort should result in an antenna capable of operation down to 2 mm at full efficiency and approximately 1 mm at reduced efficiency, making this radio telescope, at its excellent location, a leader among microwave observatories. Figure 1 is a view of the 18-ft antenna after the rework.

(2) A small computer that will allow automatic preprogrammed driving of the antenna and correcting for its pointing errors has been delivered, installed, and checked out. The necessary programming is being done now, and operational readiness is expected by about July 15. The system will allow more efficient use of the radio telescope than would manual operation and, by reducing operator fatigue, will permit longer observing shifts.

(3) Negotiations are under way with the Forest Service for permission to locate a new boresight transmitter in the San Bernardino Mountains to replace the one lost in a landslide on Wright Mountain. Approval is expected within 1 mo, and operations with portable gear will begin at that time. A permanent facility will be constructed and outfitted during the first half of the next fiscal year.

Instrumentation Development

(1) The variable-frequency 8-mm radiometer has been completed and installed on the 18-ft antenna at Table Mountain. The performance is as designed. A noisy calibration switch was repaired during the time the antenna was being reworked. The instrument will be used full time for antenna calibrations and for a limited scientific observation program until completion of the low-noise parametric amplifier described below.

(2) The contract for the 8-mm low-noise tunable parametric amplifier was terminated for nonperformance and the material recalled to the Laboratory. The work is being continued at JPL with consultant help, and the system is expected to be operational in October. The device will be incorporated into the 8-mm system and used on the 18-ft antenna for scientific observations. The system will be one of the most sensitive tunable receivers at 8-mm wavelength in existence and will permit continuous observation of the planets as well as a large number of other celestial radio sources of interest.

(3) The multichannel 13-mm radiometer has been considerably modified following laboratory tests in December with the original configuration. The tests revealed an excessive interferring signal from the ferrite Dicke switch, necessitating its relocation. Additional problems have been experienced with the traveling wave tube amplifier power supplies, and the units have now been returned to the manufacturer for the second time for rework. When the system is completed and working satisfactorily, it will replace permanently the variable frequency radiometer system now being used.

(4) During the next fiscal year, a 1- or 2-mm wavelength superbolometer receiver will be procured. It will be used on the 18-ft antenna and also possibly on the existing 10-ft antenna mounted on a Nike pedestal. The 10-ft antenna on the Nike pedestal will be located at Table Mountain and will also be driven by the computer on a time-sharing basis. The bolometer is expected to be sensitive enough to provide a performance capability equivalent to that of the 8-mm parametric amplifier system, making the radioastromony facility at Table Mountain unique for millimeter wavelength observations.

PUBLICATIONS

None.

Figure 1. 18-ft Antenna After Rework

INFRARED INTERFEROMETRIC INVESTIGATIONS

NASA Work Unit 185-41-33-01-55

JPL 383-10601-X-3250

C. B. Farmer
R. Beer

OBJECTIVE

The principal objectives of this work are to develop and make measurements with instruments which exploit the flux gathering and resolution advantages of interferometric techniques in the spectroscopy of planetary atmospheres. Three instruments are involved: the Mk III planetary interferometer, the far infrared interferometer and a new ultra-high-resolution Fabry-Perot interferometer. These instruments will give JPL a capability at the forefront of high-resolution planetary spectroscopy.

PROGRESS

Mk III Planetary Interferometer

This instrument is designed for high resolution (0.1 – 1.0 cm^{-1}) spectroscopy of planets in the near infrared, to be used in the first instance at the Table Mountain Observatory 24-in. telescope and later on, other larger telescopes. It is intended primarily for the measurement of planetary spectra in the 3 – 4-μ range, and as such its development and use are complementary to similar work being carried out in France, where attention is concentrated in the 1 – 3-μ region of the spectrum.

The Mk III planetary interferometer was installed at Table Mountain during the summer of 1967. Full-scale operation was attained in October, i.e., in time for observations during the latter weeks of the Venus conjunction. Spectra of Venus at 5 cm^{-1}, the sun at 0.3 cm^{-1}, and a few cool stars at 2 cm^{-1} have been obtained to date. The Venus spectra have a resolution some ten times higher than ever previously obtained, but the signal/noise, even after 8 hr of integration, is rather low (~20). The available planetary irradiance at these wavelengths, in the case of Venus for example, is some 2 to 3 orders of magnitude lower than the region covered by the Mk III (Connes') instrument. The move to the larger telescope should make a dramatic improvement here. The spectra obtained to date are undergoing analysis and comparison with existing data. The solar spectra obtained earlier in the year were at the same resolution as the only other comparable spectra for this region, those of Migeotte and his coworkers, but were of considerably better signal/noise than the latter. More recently, solar spectra at a resolution $< 0.1 \text{ cm}^{-1}$ were recorded; these data are being processed at this time.

A study contract has been negotiated with the University of Texas to investigate the feasibility of using the system at the McDonald 108-in. telescope. To this end, new instrument baseplates have been procured and mounted on pneumatic vibration isolators within an acoustic enclosure, and various items of associated equipment, including a 9-in. coelostat for solar comparisons, have been constructed.

The system has been operated on a regularly scheduled basis of 12 nights/mo and can be operated "round-the-clock" on planets. Its performance, although inferior to that of the Connes' instrument because of the reduced radiation intensity at longer wavelengths, is most satisfactory and should provide much valuable data over the years. The remaining instrumental problems, solutions to which are in hand, are (1) the variable level of the base plates as the detector Dewars boil dry, (2) acoustic transfer of vibrations from the electronic system and peripheral equipment, and (3) better nulling of the sky emission, which at our wavelengths is much stronger than the signal from a planet.

Far Infrared Interferometer

The far infrared instrument covers the spectral range from 10 to 100μ and will be used for the study of tenuous atmospheres in the region of rotational transitions of the constituent molecules. One of the chief objectives of the present work is to extend the use of far infrared techniques in space flight instrumentation, and this is to be done in part by making balloon-borne observations of absorption and emission in the earth's atmosphere.

A new stepping-motor drive system has been installed; the stepping rate of this system is to be controlled from the chopper. This will ensure that exactly the same number of chopper cycles are observed at each data point. New preamplifiers have been constructed, one using Nuvistors and the other solid-state. Their performances are comparable and a final choice will be made later. Assembly of the flight package has commenced, and balloon flights are planned later. Theoretical spectra for the conditions of the upper stratosphere, and at the spectral resolution of the instrument, have been computed to provide data with which to compare the results obtained from the flights.

Ultra-High Resolution Fabry-Perot Interferometer

This instrument is intended to be used in conjunction with the coudé spectrograph under development for the TMO 24-in. telescope, to provide the increased spectral resolution required for the study of, for example, weak bands in the 8000-Å region, detailed line shapes and line formation in a scattering atmosphere, and the measurement of the width of molecular quadrupole lines.

Two pairs of 110-mm interferometer plates, nominally flat to $\lambda/200$ have been procured. Some conceptual system designs have been made and some of the system definitions completed. The schedule for completion of this instrument has been slipped by about 6 mo, following a reassessment of the commitments of key personnel and a careful evaluation of the early use schedule of the coudé spectrograph.

PUBLICATIONS

1. Beer, R., "Remote Sensing of Planetary Atmospheres by Fourier Scpectroscopy," The Physics Teacher, Vol. 6, p. 151, 1968.

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SPECTROSCOPY OF SYNTHETIC ATMOSPHERES

NASA Work Unit 185-41-34-01-55

JPL 383-10801-2-3250

C. B. Farmer
J. S. Margolis

OBJECTIVE

The objective of this task is to support astronomical and spaceflight studies of planetary atmospheres by obtaining spectra of gases under suitable conditions. There are two main functions: (1) to furnish quantitative band or line data chiefly at infrared wavelengths, and (2) to provide direct aid in verifying identifications of features observed in planetary spectra.

PROGRESS

A number of modifications and improvements to the apparatus in the spectroscopy laboratory were made. A new vacuum transfer optics for the 1.8-m system and a 2-m multitraversal cell, capable of providing paths of length up to 160 m and pressures up to 8 atmospheres, were built and put into operation. The maximum resolution of the over-all 1.8-m system was improved to 0.03 cm^{-1}, a value very close to the theoretical limit for the grating. Modifications were made to the existing 6-m White cell to enable its full optical capability to be realized.

A series of measurements of the very weakly absorbing 7820 and 7880 Å CO_2 bands has been started, using the 6-m multipass cell. These measurements will provide intensity data for the interpretation of the Venus spectra.

The near infrared bands of a number of molecules were studied and in some cases comparison spectra, replotted from the recorded digital output at the dispersion of the planetary observations, were produced. Spectra of all of the CO_2 bands which are observable with a pressure of 2 atmospheres and path lengths up to 160 m were taken in the 1.2- to 2.0-μ region. These were done with a resolution of about 0.1 cm^{-1}. The results were prepared on our digital plotter for routine comparison with the Connes' planetary spectra.

The routine operation of the spectroscopy laboratory as a service to work on interpretation of the planetary spectra was firmly established. The construction of the 16-in. solar tracking system for monitoring the atmospheric spectrum was commenced and is nearing completion.

High resolution spectra of the $3\nu_3$ band of CH_4 at 9050 cm^{-1} were obtained; the spectra were recorded at resolutions down to 0.06 cm^{-1}, and line positions measured to 0.03 cm^{-1}. A paper giving the line positions and transition assignments for the fine structure was written. The work is continuing with the recording and analysis of spectra to obtain the curve of growth and intensity for the band. In association with the laboratory study of this band, further improvement to the operation and performance of the two-stage image tube were made in preparation for observations of Jupiter which will be made at the Mt. Wilson 100-in. telescope at the end of June.

A short series of high resolution measurements of the 0_2 spectrum at 7630 Å was made using the 6-m cell and 5-m spectrometer. These were carried out in order to verify that there is no measurable relative shift of the positions of the P_p and P_q lines due to pressure, a factor important in the determination of the presence and amount of 0_2 in the Martian atmosphere (M. J. S. Belton, D. M. Hunten, Ap. J. 1968).

PUBLICATIONS

1. Fox, K. and Margolis, J., "Infrared Absorption Spectrum of CH_4 at 9050 cm^{-1}," submitted for publication in J. Chem. Phys.

PLANETOLOGY (185-42)

LUNAR AND PLANETARY GEOPHYSICAL MODELS
NASA Work Unit 185-42-11-01-55
JPL 383-20901-2-3250
R. L. Newburn

OBJECTIVE

The objective of the Models Group is to furnish and maintain authoritative environmental models of the bodies of the solar system; of the moon to support Apollo and future lunar missions, of Mars to assist Mariner Mars 1969, Mariner 71, and future Mars missions, and of Venus, Mercury, Jupiter, comets and other bodies which may be the goals of advanced planetary projects.

Immediate objectives of the Models Group are revision of the Lunar Model to include the results of Surveyor, Orbiter, and Luna; addition of material to the Mars Model, including wind and general circulation information, cloud statistics, and information on secular surface changes; and completion of a first Venus Model.

PROGRESS

Lunar Model and Studies, R. Choate and J. de Wys

Formal plans have been made for preparing an updated edition of PD-54, the Surveyor Lunar Model, under partial Manned Spacecraft Center sponsorship.

Mars Model, R. Choate, J. de Wys, and R. Newburn

The entire reporting period has been devoted to editorial work on Document 606-1. It is presently expected that the document will be printed before the end of this reporting period. Additional sections and updating will be carried out during the coming fiscal year.

In addition, Newburn was one of a working group who assembled a "Mars Engineering Model Parameters Document" during March and April for use by

LRC in preliminary design and mission studies. The preliminary draft of Document 606-1 was used extensively in preparing this document.

Venus Model, R. Newburn

A Venus Model has been outlined and the outline circulated to potential laboratory contributors and users for comment upon format and content. All available data from ground-based observations, theory, and Mariner IV and Venus 4 have been accumulated, and preliminary model information has been supplied to laboratory users.

Future Models, R. Newburn

A comprehensive document on the major planets has been prepared for the Grand Tour Study. It gives an outline of contemporary knowledge of these bodies, and it is heavily referenced. This document in preliminary form has been used in three additional laboratory planning studies.

PUBLICATIONS

The following list does not include any of more than 20 separate talks and papers related to the Surveyor Project and prepared during the reporting period by Choate and de Wys.

Meetings and Symposia Papers

1. Wade, F. A. and de Wys, J. Negus, "Possibility of Permafrost Features on the Martian Surface," American Astronautical Society, Apr. 1968, Las Vegas, Nevada.

Open Literature

1. Wade, F. A. and de Wys, J. Negus, "Possibility of Permafrost Features on the Martian Surface," Icarus, in press (should appear in June 1968).

Internal Documents

1. de Wys, J. Negus, editor, "Mars Scientific Model," Document 606-1, (due before end of June 1968).

PLANETOLOGY
NASA Work Unit 185-42-12-01-55
JPL 383-20101-2-3250
A. A. Loomis

OBJECTIVE

The planetology task consists of selected studies in theoretical and experimental planetology. It has the following long-term goals: (1) understanding the basic atmospheric, surface, and subsurface geological properties of the moon and terrestrial planets, (2) applying these findings toward determining the evolutionary history of the planets and the solar system.

Brief discussions of the specific studies composing the planetology task for FY 68 are presented below.

Spectral Reflectance of Planetary Surfaces, J. Adams

The objective of this study is the application of laboratory spectral reflectance data to the interpretation of the geology of planetary surfaces. Laboratory studies are continuing on the electronic and vibrational absorption bands in the common rock-forming minerals. During the past 6 mo particular emphasis was placed on interpretation of new spectral data for Mars obtained by Dr. T. McCord at Caltech. Spectral curves for light and dark areas on Mars have been modeled in the laboratory. These results will be reported in a joint paper with McCord.

During the report period a portable field spectrometer was built by D. LaPorte, using existing equipment at JPL. The spectrometer was tested in the field to determine the feasibility of measuring mineralogical absorption bands through the earth's atmosphere. Preliminary results indicate that (mineralogically) diagnostic bands are detectable over distances of at least 1 mi. Longer path lengths require removal of atmospheric absorption features from the data. This is being attempted now.

Lunar Tectonics, J. Conel and E. Abbott

Mechanical analysis of simple (selected) lunar structures is attempted, in order to provide insight into the megascopic mechanical behavior and history of the moon's surface. An investigation of mare wrinkle ridges has been made using Biot's theory of folding instability of layered media, and applicable Lunar Orbiter photography. The hypothesis is made that wrinkle ridges are fold crests. The theory predicts fold wavelengths for a given thickness of maria fill, density of the substrate, viscosities, and deforming forces. Mare thicknesses are estimated from dimensions of filled craters. Limits are placed on deforming forces by compressive strengths of the materials. Where all parameters are fixed except layer thickness, the ratio (fold wavelength)/(thickness of mare fill) is theoretically constant. Measurements of wrinkle ridges in six maria show this ratio to vary unsystematically from place to place by a factor of about two, and would seem to be too large by a factor of two for likely ratios of maria fill and substrate viscosities. However, there is great spread in the data.

Examination of Lunar Orbiter pictures indicates that wrinkle ridges can be associated with either thrusting or normal faulting, and that small scarps occur with most ridges. The inadvertent grouping of both types of deformation features, together with local variations in mechanical properties or fill thickness, will contribute to the uncertainty in comparison of theory and observation. The evidence suggests that faulting occurs in many instances before large continuous deformation can occur.

Rock Gas Study, F. Fanale and N. Nickle

The objective is to compare the elemental, isotopic, and molecular composition of the gases released from selected samples with the corresponding values for the so-called "Rubey Excess Volatiles" in the earth's atmosphere-ocean sediment system, and with Martian and Venusian atmospheric compositions. Samples of ultramafic rock are being run which represent (1) inclusions from Hawaiian-type basaltic flows; (2) inclusions from basaltic plugs; and (3) large ultramafic bodies. A wide variety of ultramafic petrologies is represented; most are considered by petrologists to represent upper mantle deviations. It is hoped that these measurements will aid in understanding the chemistry of the Earth's atmosphere and ocean prior to the onset of life, and the conditions under which biotic chemistry was initiated. In addition, we expect to obtain information concerning the origin and history of release of planetary volatiles.

Analyses are being performed using RF induction heating, a 1720-glass gas handling and purification line, and a Reynolds-type static gas mass spectrometer with an electron multiplier. We are modifying the existing mass spectrometer system to include a gas chromatograph for total gas analysis.

Geophysical Studies, G. Holstrom

Study is continuing on the coupling of elastic and magnetic strain in a ferromagnetic material. This is important in understanding the response in stress of magnetite in rocks.

A paper on thermal induction of phase boundary motion is written and it is planned to submit it soon for publication.

Subsurface Water Exploration of Moon and Mars, G. Holstrom and A. Loomis

The purpose of this work (partially supported under task 684-20-00-01-55) is to devise an exploration program for the location of water on the moon and Mars. The following progress has been made:

1. An analytical study of possible planetary water environment, and a tentative consideration of exploration methods has been made. A draft report on this work has been written.
2. Participation in a NASA remote-sensing flight in the Imperial Valley, primarily to secure microwave radiometer data from an area felt to be of interest. An additional flight has been requested for fall 1968.
3. Laboratory work useful for data evaluation is planned, and instruments will be used to perform temperature and humidity measurements in shallow holes

Analysis of Permanent Gases Evolved from Solids, H. Lord

The techniques for the separation of H_2, HD, and D_2 by gas chromatography are well known, when the gases are present in approximately 1:1:1 concentrations. However, the separation fails for concentrations typical of natural terrestrial composition ($HD/H_2 = 3 \times 10^{-4}$). Heart-cut techniques were tried, as well as high-temperature palladium diffusion.

In the recently completed test assembly, the valve for sample introduction from the vacuum line to the high pressure carrier gas line could not be made to fulfill the manufacturer's specifications, as there was severe leaking. This is being replaced with a valve assembly using mass-spectrometric leak-tight bellows valves.

The thermal gravimetric analysis apparatus is in working order and has been used to follow weight changes in samples during gas release. When the sample introduction valve is working properly, these released gases will be quantitatively measured with the gas chromatrograph.

Samples of single crystal forsterite, plagioclase, obsidian, dunite, enstatite, oligoclase, and iron were prepared for ion irradiation. These samples were irradiated with various combinations of H^+, He^+, and Ar^+ as a continuation of the study of solar wind bombardment of extraterrestial solid material.

Irradiation Effects Study, D. Nash and E. Abbott

Modifications to the RF ion source have been made so as to allow more general luminescence and darkening experiments to be conducted. An ultraviolet-source system (xenon lamp and monochromator) has been constructed for the purpose of simultaneous UV and proton irradiations of silicate rocks. A beam analyzer and focusing lens have been installed on the proton source to clean up the proton beam and to eliminate plasma-generated source light from reaching the sample.

Preliminary results indicate that for silicate rocks, such as basalt, the energy efficiency of UV-excited luminescence is about 10^{-4}. These data indicate that luminescence produced on lunar surface rocks by direct solar-UV excitation would be too weak to be detectable from earth.

PUBLICATIONS

Meetings and Symposia Papers

1. Adams, J. B., "Evidence for Extensive Basaltic Rock on the Moon and Mars," presented at the American Geophysical Union in Washington, D. C., Apr. 8 – 11, 1968.
2. Nash, D. B., "UV-Excited Luminescence of Silicates and the Moon," presented at the American Geophysical Union in Washington, D. C., Apr. 8 – 11, 1968.
3. Holstrom, G., "A Model for Strain in a Ferromagnetic Material," presented at American Geophysical Union in Washington, D. C., Apr. 8 – 11, 1968.

Open Literature

1. Conel, J. E., "Infrared Emissivities of Silicates and a Cloudy Atmosphere Model of Spectral Emission from Particulate Mediums," submitted to J. Geophys. Res., 1968.
2. Conel, J. E., "Heat Flow from Centennial Flat, Inyo County, California," manuscript in preparation.
3. Conel, J. E., "Composition and Particle Size of the Moon's Surface: Deduction from the Lunar 8 - 14 Infrared Spectrum," in preparation.
4. Holstrom, G., "Elastic Radiation from a Propagating Phase Boundary," Phy. of Earth and Planetary Int., Vol. 1, No. 3, 1968.
5. Holstrom, G., "Non-Linear Energy Transfer in Elastic Waves," accepted for publication in Geophysics; will appear Oct. 1968.

6. Lord, H., "Hydrogen and Helium Ion Implantation into Olivine and Enstatite: Retention Coefficients, Saturation Concentrations, and Temperature-Release Profiles," accepted by J. Geophys. Res., Spring 1968.

7. Nash, D. B., "Target Temperatures and Thermal Accommodation Coefficients of Rock Powders Under Proton Bombardment," submitted to J. Geophys. Res., 1968.

8. Nash, D. B., "UV-Excited Luminescence of Silicates and Lunar Implications," submitted to J. Geophys. Res., 1968.

SPS Contributions

1. Lord, H., "Solar Wind Interaction with Solids," SPS 37-48, Vol. III, p. 155, December 31, 1967.

2. Nash, D. B., "Surface Temperature of Rock Samples Under Proton Bombardment," SPS 37-50, Vol. III, Apr. 30, 1968.

JPL Technical Memorandums

1. Conel, J. E., and Abbott, E., "A Study of Lunar Wrinkle Ridges," 1968, in preparation.

GAMMA RAY AND X-RAY SPECTROSCOPY

NASA Work Unit 185-42-13-01-55

JPL 383-20801-X-3250

A. E. Metzger

OBJECTIVE

First- and second-generation gamma-ray experiments are being designed to determine the degree of differentiation of the moon and planets as an indication of their generic relationship to more primordial matter, and of their own thermal history and general development after formation. This aim can be accomplished by means of orbiting or surface space vehicles. The simultaneous detection of gamma ray and X-ray fluorescence for a lunar orbiting experiment will provide a dual experiment with greater capability.

PROGRESS

Lunar Fluorescence

The simulated emission of secondary lunar fluorescence under bombardment by the solar X-ray flux has been studied in the laboratory. The measured solar flux has been duplicated by a suitable choice of X-ray tube accelerating potential, target materials, and radiation time. The synthesized composite solar X-ray flux in turn irradiates elements of the compound and mixtures whose secondary fluorescent emission is detected. The results show that adequate lunar fluorescence will be induced during periods near solar maximum so that the detection of major elements between sodium and nickel is possible with a relatively simple nondispersive detector. These tests are near completion.

Accelerator Experiments

Facilities at University of California Radiation Laboratory's Bevatron have been made available for the study of gamma radiation induced by the interaction of high energy charged particles with matter. This situation is analogous to the irradiation of the lunar surface by cosmic rays. A dual monitor system has been found necessary to adjust for independent fluctuations in the proton beam flux and the general background level. Induced gamma ray emission has been observed from targets of Fe, SiO_2, Al, and Mg. These data are now being reduced for comparison with the balloon measurements and theoretical calculations. The next set of tests will not be made until a new experimental location with a much lower background level and less sensitivity to the Bevatron magnet is available.

Mars

A Mars gamma ray spectrometer experiment has been given particular consideration in the past several months. The effect of the atmosphere attenuating the surface flux has previously been calculated without considering limb darkening; the correction for the true case has been computed by numerically integrating an appropriate equation.

Atmospheric pressure decreases with elevation. The ability of a gamma ray spectrometer to make a measurement of mean elevation by comparing the ratio of transmission of gamma rays of different energies is under study. As a simulation experiment, a 9-ft^2 surface has been covered with monozite ore. Aluminum sheets are overlayed to simulate different atmospheric depths.

Instrument Development

Gamma Ray Detector

A lightweight scintillation detector prototype is being fabricated based on a University of California, San Diego, breadboard and JPL flight hardened design. The unit is intended for a spacecraft with the weight capability of a Lunar Orbiter or Mariner Mars 1971-type mission. Nearly all parts have been received. The photomultiplier tube and special scintillation crystal to be used are under preassembly tests and have been performing well.

X-Ray Detector

The construction of a breadboard-engineering model X-ray detector for a lightweight lunar orbiter experiment is under way. The sensor will be a krypton-filled proportional counter with a 3/4-in. dia window of 1-mil beryllium. The sensor will be surrounded by a plastic scintillator to be operated in anticoincidence with the proportional counter in order to eliminate the charged-particle background. A second design, which will include a solar monitor detector and electronic pulse-shape discrimination for background reduction, will be built as soon as adequate experience has been obtained on the first model.

Electronics

Construction of a prototype which will be capable of both gamma ray and X-ray pulse height analysis is near completion under contract to UCSD but has recently been held up because of lack of funds. A bench check equipment system has been designed and constructed at JPL and is now in operation. A computer compatible tape punch system has been put together for use with the laboratory pulse height analyzer systems.

Solid State Detector

The laboratory evaluation of the large volume solid state detector has been completed. After exchanging the preamplifier, the manufacturer's specification for resolution has been confirmed. The advantage of solid state detector systems for peak identification is illustrated in Fig. 1, which compares the response of this solid state detector and a scintillation detector to a sample of rhyolite. Each of the peaks marked with an asterisk has been identified with a nuclear transition. Despite the lower response efficiency of the solid state detector, the greater resolution brings out more detail than offered by the scintillation detector. The counting period of 15 min is a reasonable interval for observation of a limited area of the moon from orbit.

PUBLICATIONS

JPL Technical Reports

1. Metzger, A. E., "Performance of a Breadboard Electronics System Developed for a Lunar Orbiting Gamma Ray Spectrometer," in press.

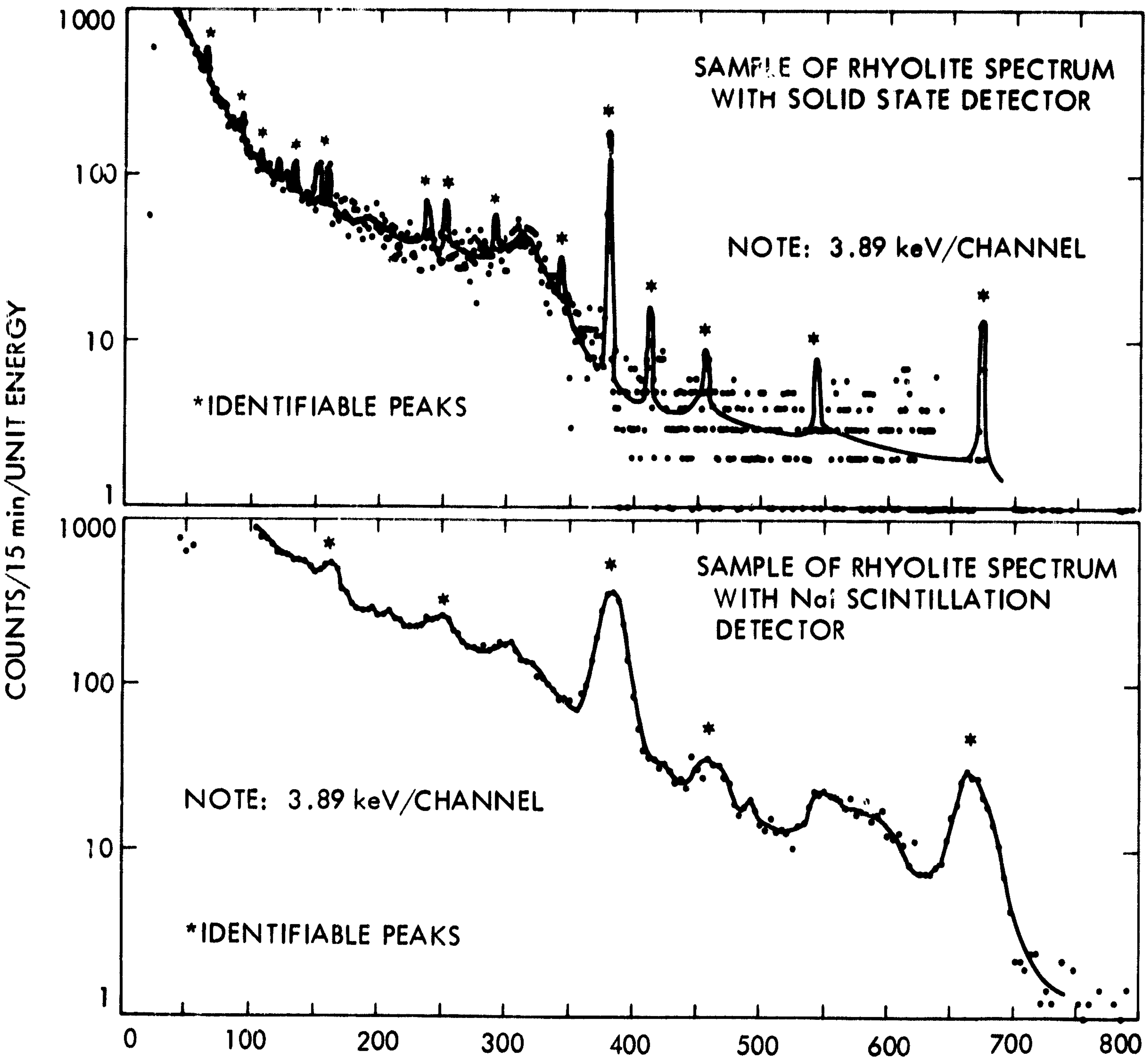

Figure 1. Solid State Detector and Scintillation Detector Response Comparison

MICROWAVE SURFACE PROPERTIES
NASA Work Unit 185-42-35-01-55
J ' ', 383-21001-2-3250
W. E. Brown, Jr.

OBJECTIVE

The long-range objective of this task is to provide microwave instrumentation and analytical techniques for the determination of planetary surface parameters. The short-range goals for FY 68 have been decreased to include only the reduction of data acquired on previous rocket and aircraft missions. No new instrumentation has been initiated. Specifically the X-band systems development and the improved version of the L-band system have been postponed. The L-band coherent system development, started in FY 67, has continued on a low priority basis.

PROGRESS

Data Reduction

The Aerobee radar echo data reduction effort has concentrated on the verification of calibration data and the resolution of some digitizing problems. Each of the reduction steps is in the process of being tested and will be verified prior to a final reduction run on all the data. The programs or software resulting from this effort are listed in Table 1.

In addition to data reduction, some theoretical formulations of the echo behavior have been computerized. Comparisons have been made between theoretical and actual relative echo shapes. One solution to the key problem of relating the echoes to loss tangent and dielectric constant has been derived and partially verified.

The values of dielectric constant and loss tangent, which were derived from the echo, are plotted versus time in Fig. 1. The values measured from samples taken on the surface vary between $\epsilon = 2.5$ and $\epsilon = 4.8$, depending on moisture content. Loss tangent measurements made in one location varied between 0.18 and 0.35, where the moisture content was 5 to 10% by weight. All available samples will be measured during the next reporting period, (A. Laderman).

Mapping Radar

A 1215-MHz side-looking imaging radar, developed at JPL, was flown on NASA Ames Convair 990 December 5 -- 6, 1967, over various regions of the western United States. The radar breadboard was designed with spacecraft applications in mind and utilizes the simplest imaging mode. The raw data, recorded on magnetic tape, were processed on the University of Michigan optical processor (R. Jordan).

The operating parameters of the radar include the following:

Frequency	1215 MHz
Wavelength	25 cm
Peak power	6 kW
Ave power	6 W
System power	140 W
Radar weight (breadboard)	130 lb

The radar image is produced in two stages. The first stage is to establish a range and doppler orthogonal array on the target surface. Range or time thus provides one axis of the "map" and concentric rings on the target surface. The lines of constant doppler shift, hyperbolas on the target surface, provide the other axis for the resolution cells.

The second stage in producing the image is the conversion of range and doppler histories of each target into an intensity versus time plot which resembles a map. The processor essentially performs a continuous Fourier transform for each range element and produces a synthetic aperture equivalent in length to a physical antenna about 60 m long (350 m long for spacecraft geometries). The result is an image such as shown in Fig. 2. The echo nearest the radar represents the target area nearest the radar or directly beneath the aircraft in this case. This echo is thus the surface elevation profile. Regions near this profile are distorted relative to a map. The apparent blurring of the image at increased ranges is a consequence of an interface problem between the radar, data recorder, and processor.

Maps of the Death Valley area are compared with the radar image of the area. The region marked (A) is the same region on all three surfaces. The scales of each representation are approximately the same. The illuminated relief map on the right side of the figure is about the same illumination angle used by the radar, and similarities of the shadow areas can be noted. The lower right section of the radar image is expanded by a factor of 5 in Fig. 3.

An important point is that imagery of the surface of Venus with the resolution shown here (about 100 m) could also be obtained by a similar radar system mounted on a spacecraft orbiting Venus at altitudes of 600 and 1000 km.

A breadboard of a spacecraft-type processor is currently under construction (A. Laderman) and a new antenna system is being designed (R. Jordan). It is proposed that the revised system be test flown in April 1969 on the NASA Ames CV 990 aircraft. There will be an attempt to coordinate the test flight with other disciplines interested in 25-cm radar imagery of the earth's surface.

ANTICIPATED PUBLICATIONS

1. High Altitude Rocket Radar Engineering Report, Oct. 1968.
2. Rocket Radar Data Reduction Report, Aug. 1968.
3. Spacecraft Imaging Radar System Design Report, Aug. 1968.
4. CV 990 Mapping Radar Report, Jul. 1968.
5. Rocket-borne Radar Experimental Results, Oct. 1968.
6. "Radar Studies of the Earth," WESCON, Jun. 1968.

PUBLICATIONS

None.

Table 1. Radar Related Computer Programs

Identification	Function
VERIFY	Plot voltage versus word number
PRELIM	Compute and locate critical data factors
HARP	Average 100 echoes - remove non-data
RAVE	Plot RXS vs angle (RXS - radar cross section)
RALT	Plot RXS vs altitude
FRAT	Plot frame number vs altitude
WORD	Plot RXS vs frame number
TIME	Plot RXS vs time
PIP	Transform and plot Venus RXS
SIGNAL	Plot signal strength vs time
REKD	Plot average calibration amplitude
VOLT	Plot voltage vs frame number
PEAKCHEK	Plot echo peak voltage versus frame
CONTUR	Plot specular reflecting segments of random surface
CONTUR	Plot number vs wavelength
IRD	Imaging radar design
IRDP	Imaging radar design plotting
RGPS	Range gated processor simulation
MORP	Read lunar data, plot comparison versus time or angle
PLET	Comparison plots of earth, moon, venus radar data
PALL	Read theoretical and experimental data for moon, earth, venus and plots theoretical and experimental pair on single frame
FAMILY	Evaluate and plot families of theoretical echo curves by varying separately each of two parameters
CURVE	Label axes and plot curves from cards
IMPULS 3	Generate impulse response for spherical wave on planar target
IMPULS 4	Generate impulse response for plane wave on spherical target
IMPULS 5	Generate impulse response from Hagfors equation
COMA-3 to 5	Convolve rectangular modulation function with respective impulse response functions

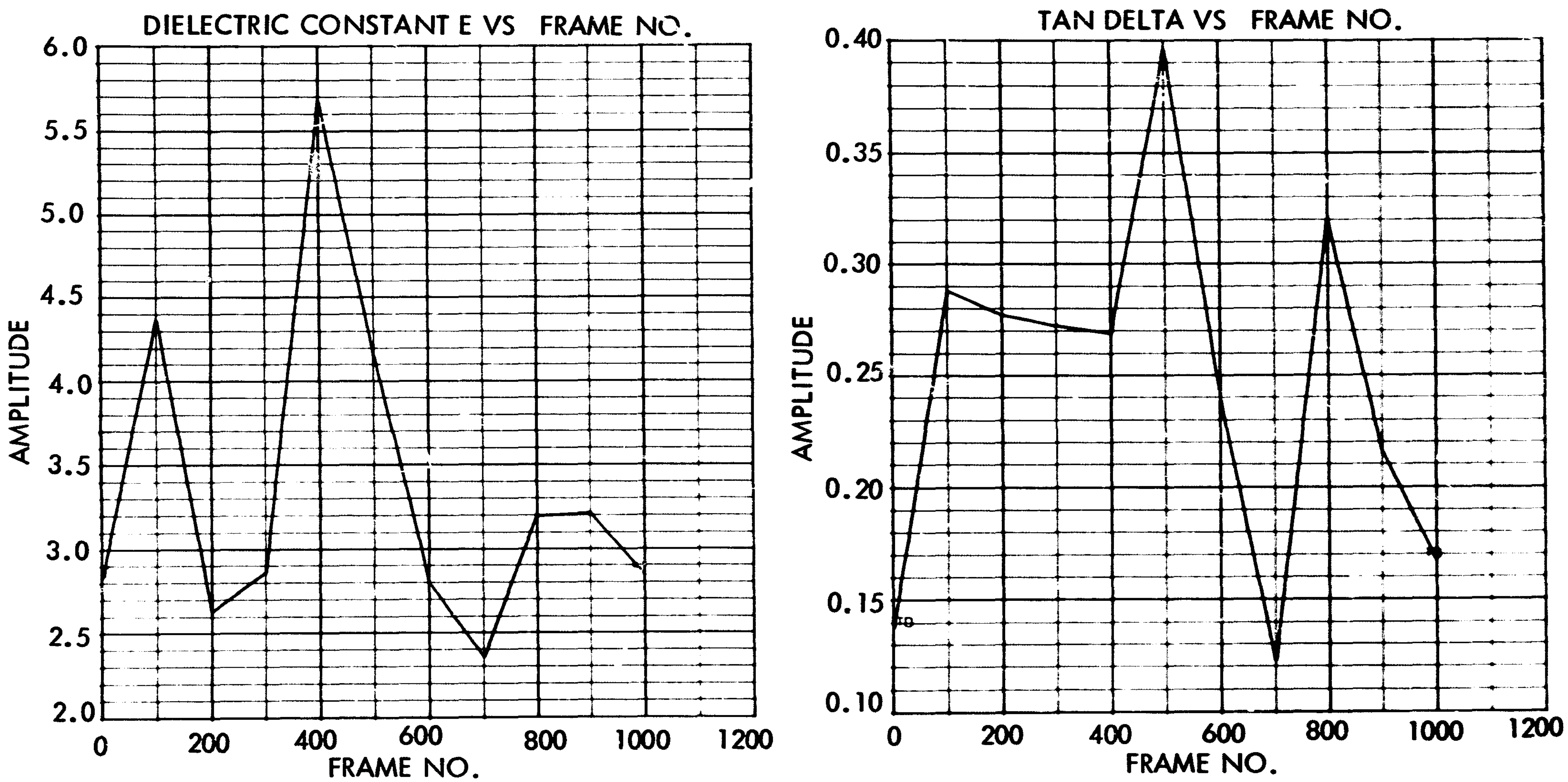

Figure 1. Dielectric Constant and Loss Tangent vs Echo Number (Position)
Derived From Echo Characteristics

Figure 2. Death Valley Area

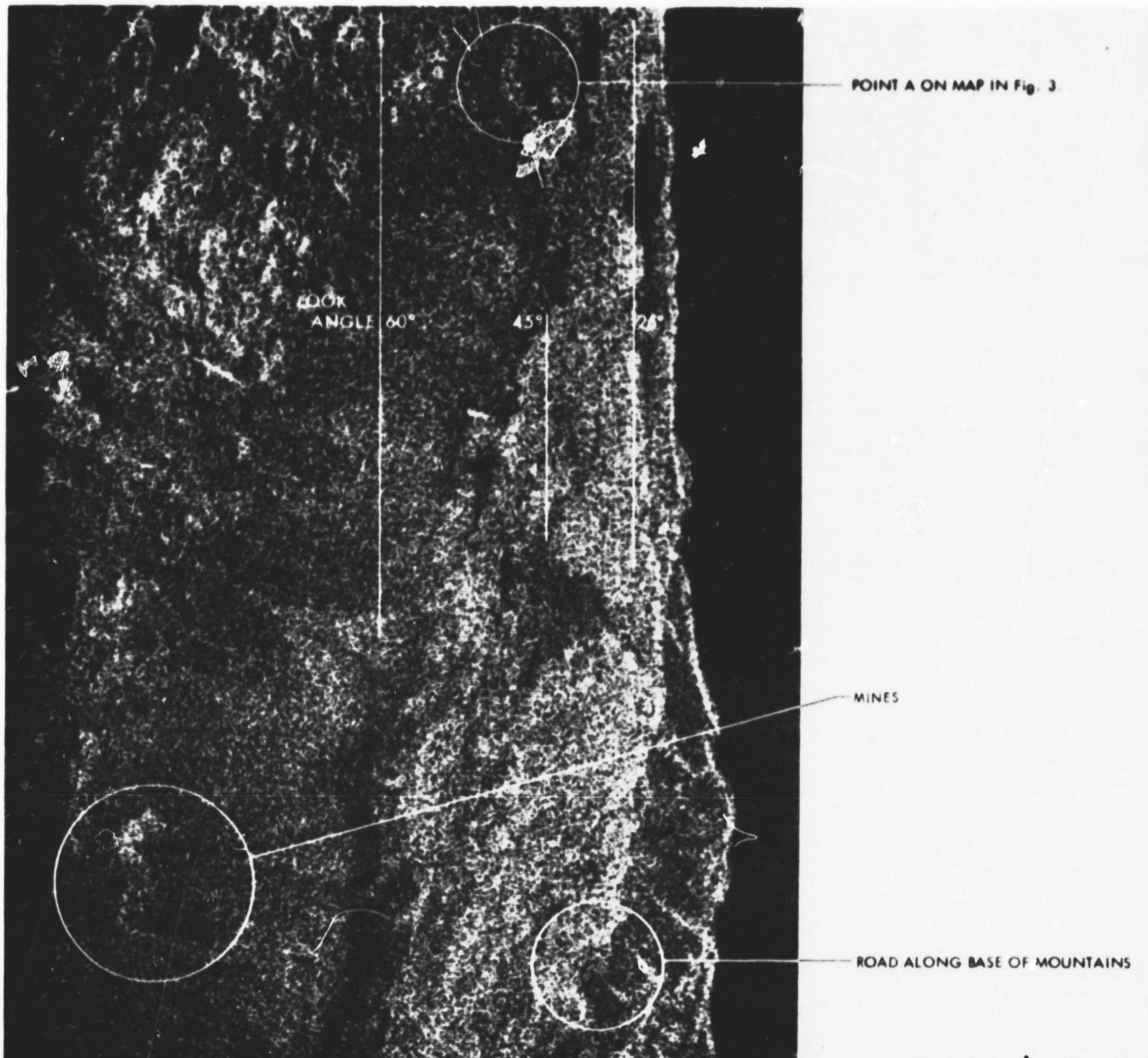

Figure 3. Expanded View of Death Valley Area

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GEOSAMPLING

NASA Work Unit 185-42-49-01-55

JPL 383-20701-X-3220

G. M. Hotz

OBJECTIVE

The objective of the Geosampling task is to develop devices that are capable of delivering representative geological samples to analytical instruments under lunar and planetary conditions.

CONTRACTUAL ACTIVITIES

Hughes Tool Company Contract 951480

Phase II of this contract was completed during the reporting period. This phase of the contract covered the development and testing of a rotary-impact hard-rock drill capable of producing small particulate samples of suitable particle size distribution from solid rock and continuously transporting the rock powder to the top of the drill by means of a helical conveyor. To enhance the sampler's capability in particulate, the drill stem was fitted with an abrading sieve cone located 3 in. above the drill tip so that, in the event the drill did not reach rock, the sieve cone would acquire much more particulate sample than a drill alone. Acquisition test results (see item 1 under Contractor Reports (or summary on p. 88 of JPL Document 701-11) indicate that the quantity of sample delivered by the drill-sieve combination was greater than the quantity delivered by the drill alone by a factor of 2 to 10 in various soil models. In addition, item 1 under Publications indicates that the combination sampler delivers a somewhat more representative particulate sample. The major disadvantage of adding the cone to the drill is the additional time (approximately 8 min) required before sample delivery at the top of the drill due to the approximately 2 cm^3 of sample which must cover the feed holes from the cone to the helical conveyor before the sample can be conveyed vertically beyond the cone.

Philco-Ford Contract 951935 (Basic)

This contract was primarily concerned with biosampler test and development on Program 189 funds but included the desert field testing of geosamplers and bio-geosamplers on Program 185 funds. Item 2 under Publications completely describes all results, including the desert field test results; pages 90–94 of JPL Document 701-11 summarize results of the desert field test only.

Philco-Ford Contract 951935 (Mod. 1)

This contract modification provides for the development of layout drawings of engineering breadboards of eight geosampling devices which have been breadboarded and tested, from which sampler size and weights may be obtained. These layouts are to serve as the bases of detailed designs and construction of certain engineering breadboard samplers and the bases from which designs of samplers for specific missions may evolve. This contractual effort covered the mechanical design only, design of electrical auxiliary was not included; it is nearing completion with final report expected in June 1968.

IN-HOUSE EFFORTS

In-house effort have involved:

(1) The testing of a number of simple sampling techniques suited to planetary and/or lunar small hard landers in consonance with the APMT biosampling effort

(2) The retesting of some of the geosamplers which experienced failures during the joint JPL–Philco-Ford sampler desert field test. The retesting is being accomplished in the laboratory, using soil models brought back from the desert.

(3) Technical monitoring of the Philco-Ford Mod. 1 contract covering the layout design of certain geosamplers

FUTURE WORK

Future work will be to:

(1) Develop sample processors for lunar and planetary use. This will include particle sorters and crushers, sample homogenizers, and metering devices.

(2) Determine tradeoffs between the more complex bulk samplers which require separate processors and the self-processing simple samplers; this will include a parametric study of miniature helical conveyors.

(3) Complete geosampler engineering breadboard designs, including control and sequencer auxiliary, to provide information on the size and weight of these auxiliaries. Design, construct, and test engineering breadboards of certain favored geosamplers.

(4) Investigate samplers suited to the acquisition of samples for sample return missions.

PUBLICATIONS

Contractor Reports, Interim and Final

1. Research Department, Hughes Tool Co., Oil Tool Division, Houston, Texas: Phase II Final Report, "Development Program of a Lunar and Planetary Geosampling Device," JPL Contract 951480, Jan. 1968.

2. Zebal, G. P. and Bachle, W. H.: "Final Report, Development of Advanced Soil Sampler Technology;" Philco-Ford Corp., Space and Reentry Systems Division, Newport Beach, California, Publication No. UG-4289, JPL Contract 951935 (Basic) (Two Volumes), Jun. 28, 1967 to Jan. 31, 1968.

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PLANETARY ATMOSPHERES (185-47)

AEROMETRY–METEOROLOGY

NASA Work Unit 185-47-01-02-55

JPL 383-70401-0-3220

J. M. Conley

OBJECTIVES

The long-range objective of this task is the development of techniques and instruments for the in-situ measurement of thermodynamic and meteorological properties of planetary atmospheres. During FY 68 and FY 69, parametric studies of instruments for the measurement of pressure, temperature and wind velocity are being conducted. These studies include laboratory measurements of the characteristics of the instruments under Mars surface conditions of pressure, wind and thermal radiation. Signal processing is being studied integrally with the basic instruments.

PROGRESS

Instrument Evaluation Studies

Completion of the aerometry–meteorology instrument study contract with G. C. A. Corp. has been delayed because of a cost overrun by the contractor. The original funding of $33, 862. 00 has been supplemented by additional funds of $3, 378. 00; publication of the final report will take place approximately July 1, 1968. Completion of the preliminary tradeoff studies is dependent upon receipt of the G. C. A. report and is now anticipated for August 1968. At that time the presently extensive instrument candidate lists should be narrowed to a few types to be tested and studied more thoroughly.

The meteorology flow system now under construction is a small open-circuit wind tunnel contained within a 4-ft-dia by 16-ft-long vacuum chamber and will be used for testing anemometers and immersion thermometers under Mars surface conditions. Design and construction of the system, which has taken place during the past 6 mo, is now 90% complete. Delivery of the blower has been delayed. If the manufacturer meets his present estimated delivery date of June 28, the system should be completed in late July 1968. A perspective view of the flow system and results of 1/4 scale fan tests are shown on pages 101 and 102 of JPL Document 701-11, OSSA Spring Review (1968).

Upon completion of the flow system assembly, some effort will be expended toward checking out the system for flow profile, turbulence, diffuser efficiency, etc. It is expected that some difficulties will be experienced, particularly with respect to obtaining a reasonably flat profile at low speeds. After satisfactory operation is verified, a series of measurements of the characteristics of anemometers and immersion thermometers is planned. Measurements typical of those being planned for Mars atmospheric densities are:

(1) Threshold, distance constant, and calibration of rotating cup and perhaps propeller-type anemometers.

(2) Zero and sensitivity stability of hot wire/film-type anemometers.

(3) General operating characteristics of an ion tracer-type anemometer.

(4) Magnitude of various heat transfer processes for immersion thermometers in a Mars model atmosphere.

In those cases in which commercial instruments suitable for testing can be obtained, they will be utilized, otherwise it may be necessary to fabricate sensors for testing. Such, for example, will be the case for the ion tracer anemometer.

Studies of data compression methods for use with meteorological data indicate that on-board computation of the wind autocorrelation function is an efficient method of compression which may be readily mechanized for a small lander. The power density spectrum would then be obtained by taking the Fourier cosine transform of the autocorrelation function after reception of the data on earth. A knowledge of the power spectrum would allow simulation of probable Mars winds after reception of a very limited quantity of data such as might be transmitted by a small, hard lander. In addition, the shape of the turbulence spectra might shed some light on the atmospheric stability (Ref. 1). Other data such as maximum, minimum, and mean values would also be transmitted. It is planned, in cooperation with JPL Section 324, to establish feasibility of such a minimal on-board correlator to the extent allowed by the available funds.

Advanced Development Support

The Capsule Systems Advanced Development (CSAD) lander, a 50-lb feasibility model for a minimal Mars hard lander, was dropped from a height of 250 ft onto Goldstone Dry Lake on April 4 and again on May 28, 1968. The folding rotating cup anemometer deployed and functioned properly after each impact in winds from several tenths of a foot per second to 40 ft/sec. Impact shock was approximately 2500 g's and the complete lander had undergone sterilization prior to the drops. The lander with anemometer deployed is shown on page 105 of JPL Document 701-11, OSSA Spring Review (1968).

REFERENCES

1. Cramer, H. E. et al., Final Report under Contract D. S. 49-092-ARO-66, Department of Meteorology, MIT, Cambridge, Mass., 1967.

PUBLICATIONS

None.

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MODEL ATMOSPHERES

NASA Work Unit 185-47-33-01-55

JPL 383-70201-2-3250

C. B. Farmer

OBJECTIVE

The objective of this task is to establish the physical parameters that define the atmospheres of the planets, particularly Venus and Mars. To this end the work devolves into two parts, the provision of a sufficiently broad theoretical basis on which the radiative properties and spectral characteristics of the planets can be explained, and the interpretation of data obtained from astronomical and spacecraft observation of the planets in terms of physical and chemical descriptions of their atmospheres.

PROGRESS

Radiative Transfer, A. L. Fymat

A new method of solving the problem of radiative transfer in inhomogeneous atmospheres (i. e. with albedo for single scattering variable with optical depth) has now been developed. It takes as a starting point the assumption that the albedo differs from a constant value by a small amount throughout the atmosphere; the nonlinear singular integral equations for the X and Y functions of Chandrasekhar and the X^* and Y^* functions of Ueno, which describe the transfer of radiation through an inhomogeneous plane - parallel atmosphere of arbitrary stratification, are then linearized by using a perturbation technique. The solution is presented in the form of a Neumann-type series involving repeated operators which, if convergent, would represent the N-solution of the problem. The convergence of the series solutions has been investigated and the regions of convergence have been delimited for various values of the fractional perturbation parameters.

The method has been applied to a semi-infinite atmosphere and an iteration procedure for computing the fractional perturbation in the H-function of

Chandrasekhar has also been described. An error analysis has been performed and the relative error in the solution, caused by the neglect of the nonlinear terms, has been computed. Curves which are useful for estimating the errors to be expected in any particular problem have been presented.

The perturbation method described above has yielded the first complete analytic solutions of general transfer problems in inhomogeneous atmospheres. It is applicable to polarized or unpolarized radiation fields traversing atmospheres which exhibit isotropic scattering or azimuth-dependent Rayleigh scattering, or any linear combination of these two types of scattering such as resonance fluorescence line scattering.

In the development of the method, a new type of multidimensional singular linear integral equation of the mixed Volterra-Fredholm-type (second kind) was found. This equation which appears to be of general interest was presented both in its ordinary and operator forms and its solution was given in the form of a Neumann-type series. Its domain of convergence was studied in the context of radiative transfer in planetary atmospheres.

For obtaining the reflection function of a given optically semi-infinite atmosphere one has to use the solution of the nonlinear integral equation of Ambarzumian-Chandrasekhar for the H-function. However, as is well known, this equation admits two continuous and bounded solutions which are identical only in the case of an energetically conservative atmosphere. Usually only one of these two solutions is employed while the other solution is ignored and, as far as we are aware, no justification has been provided for rejecting the latter solution. By considering certain integral properties of the rejected solution it has been possible to indicate why it does not represent the required solution.

Several papers relating to this first phase of research have been submitted for publication and are listed in the Publications.

Outgoing Radiation - Temperature Sounding, M. T. Chahine

A highly convergent relaxation method for the inversion of the full radiative transfer equation (RTE) has been developed. The numerical approach is based in principle on factorizing the Planck function in terms of a function of temperature only; the resulting RTE is then reduced to a discrete set of Fredholm equations of the first kind. A relaxation method of solution has been devised and successfully applied to the solution of the set of Fredholm equations.

The method was tested for the outgoing radiation in the earth's atmosphere for the region of the 4.3μ CO_2 band. The results of the first few iterations of all cases tested indicate that convergence is achieved over a wide range of initial guesses leading to an average accuracy of 1°K in the temperature profile for a 3% average residual.

The great advantage of the approach developed here lies in the fact that it has exploited a dominant physical property of radiance occurring over a wide range of frequencies, and related this property to an efficient relaxation method of solution, and that it can be easily adapted for use in different frequency ranges, such as the 15-μ CO_2 band and the microwave regions.

The resulting inversion scheme provides a reliable tool for practical sounding of temperature with the accuracy required for use in numerical weather forecasting in the earth's atmosphere. Perhaps more important, this method is also suitable for unambiguous determination of temperature profiles of the comparatively unknown atmospheres of other planets. The time required for the reduction of a set of measured radiance values to the temperature profile shown here is very small, and the calculations are simple and can even be carried out on a desk calculator. Thus, a readily feasible system for the reduction of the measured radiance values can be arranged to produce temperature profiles in "real time" as data are accumulated.

Interpretation of Planetary Spectra, L. D. Gray

Identification of the features observed in the Connes' Venus spectra was completed, 114 out of a total of 190 assigned bands having been observed for the first time. The spectra and line identifications will be published in France and are currently in press. Many of these new bands belong to isotopes of carbon dioxide for which there were either no previous data or for which the data were of poor quality. Thus it was necessary to calculate partition functions for these isotopes and relative rotational line intensities before their rotational temperature could be determined accurately. In addition to these necessary preliminary calculations, we have examined the question of whether all lines of all bands follow a square-root absorption law. It appears that they do not, and a method has been developed for analyzing those bands which deviate from the square-root part of the curve of growth. The current procedure for analyzing the data should result in less scatter in rotational temperatures and thus should yield a more reliable number. A preliminary analysis of the Connes' data indicated a temperature of 250 ±9°K at 1.2 μ and a temperature of 240 ±10°K at 2.0 μ. In all cases the quoted error is the rms error which is a consequence of the least-squares procedure and does not reflect the influence of presumably nonexistent but nevertheless possible systematic errors. The Connes' spectra cover the range from 1.2 to 2.4 μ, and Schorn's cover the range 0.7 to 1.2 μ. The 7820 Å carbon dioxide band indicates that the average temperature of the Venus atmosphere for 1967 was 242 ±9°K. Work has commenced on the analysis of the spectra for vibrational temperatures. A start was made on the measurement of equivalent widths from the Mars spectra. Several papers were written concerning the composition of the atmospheres of Mars, Venus, and Mercury, and they are listed below.

PUBLICATIONS

Meetings and Symposia Papers

1. Gray, L. D., "High Dispersion Spectroscopic Observations of Venus," Second Arizona Conference on Planetary Atmospheres, Tucson, Arizona, Mar. 10-13, 1968.

Open Literature

1. Abhyankar, K. D., "Scattering of Visible Radiation Around the Spherical Atmosphere of Venus," submitted for publication in Icarus.

2. Fymat, A. L., and Abhyankar, K. D., "Theory of Radiative Transfer in Inhomogeneous Atmospheres: I. Perturbation Method."*

3. Fymat, A. L., and Abhyankar, K. D., "Theory of Radiative Transfer in Inhomogeneous Atmospheres: II. Application of the Perturbation Method to a Semi-Infinite Atmosphere."*

4. Abhyankar, K. D., and Fymat, A. L., "A New Type of Multidimensional Singular Linear Integral Equation."+

5. Abhyankar, K. D., and Fymat, A. L., "On the Solution $H_I(\mu)$ of the H-Equation."*

6. Chahine, M. T., "Determination of the Temperature Profile in an Atmosphere from its Outgoing Radiation," submitted to J. Opt. Soc. Amer.

7. Young, A. T., and Gray, L. D., "An Upper Limit to the Surface Pressure of Venus," Icarus, May 1968.

8. Gray, L. D., "On the Amount of Carbon Dioxide in the Atmosphere of Venus," Icarus, Jul. 1968.

9. Gray, L. D., and Schorn, R. A., "High Dispersion Spectroscopic Studies of Venus: I. The Carbon Dioxide Bands Near 1 Micron," Icarus, May 1968.

10. Schorn, R. A., and Gray, L. D., "High Dispersion Spectroscopic Studies of Venus: II. Observations of Water Vapor," accepted by Icarus.

11. Gray, L. D., "Comparison of Procedures Used to Analyze Spectroscopic Observations: The 7820 Å Carbon Dioxide Band in the Spectrum of Venus," submitted to Icarus.

12. Schorn, R. A., Gray, L. D., and Barker, E. S., "High Dispersion Spectroscopic Studies of Venus: III. The Carbon Dioxide Band at 7820 Å," to be submitted to Icarus.

13. Gray, L. D., and Young, A. T., "Relative Intensity Calculations for Carbon Dioxide: IV. Calculation of the Partition Function for Isotopic Molecules," to be submitted to J. Quant. Spectry. and Radiat. Transfer.

14. Gray, L. D., "Relative Intensity Calculations for Carbon Dioxide: V. Relative Line Intensities of Isotopic Molecules for Transitions From the Ground Vibrational State," to be submitted to J. Quant. Spectry. and Radiat. Transfer.

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*To be submitted to Ap. J.

+To be submitted to J. Math. and Mech.

LUNAR PLANETARY EXPLORATION SRT–
ADVANCED TECHNICAL DEVELOPMENT (186)

PLANETARY QUARANTINE (186-58)

INERTIAL SENSOR STERILIZATION

NASA Work Unit 186-58-02-03-55

JPL 384-82701-2-3440

P. J. Hand

OBJECTIVE

The objective of this work unit is to perform in-house evaluation of the performance and thermal sterilization capabilities of the newest designs of miniature inertial sensors. Additionally, the ability of these instruments to withstand the spaceflight and launch environments of vibration and shock is also being evaluated. This work unit is primarily a housekeeping task covering the necessary JPL manpower, test equipment maintenance, and environmental test facility use required to perform the evaluation of these instrument designs.

STATUS

At this time, the long-term performance and environmental capability are being assessed on the Kearfott Alpha III gyro design, and thermal sterilization capabilities of the Bell Model VII accelerometer are being evaluated. Progress on each of these tasks is reported under work unit numbers 186-68-02-30-55 and 186-58-02-09-55.

PUBLICATIONS

None.

STERILIZABLE GAS BEARING GYRO DEVELOPMENT

NASA Work Unit 186-58-02-07-55

JPL 384-81101-2-3440

P. J. Hand

OBJECTIVE

The objective of this work unit is to develop the Honeywell, Inc., type DGG159 single-axis, gas-bearing gyroscope into an instrument capable of surviving a thermal sterilization environment of 135°C without either failure or significant performance degradation.

STATUS

Work has been progressing at Honeywell, Inc., on the fabrication of the DGG159E model of this gyro design. The E model gyro will draw together all the improvements developed by JPL funding since 1963. These improvements include a low-power spin motor with support bearings capable of 200-g shock levels, thermal sterilization capability, and a high-frequency gimbal suspension pump.

The problems associated with moisture contamination of the spin motor gas bearing, discussed in the last report (R&AD Program Document 701-6, Vol. I), have been corrected. The design of the gas pumping grooves on the journal bearing was changed to permit a gas flow-through condition within the bearing. The flow-through design will be capable of carrying away moisture faster than it can condense. The original bearing was deliberately designed to have a high gas pressure at the center of the journal bearing and no gas was allowed to flow through the bearing. This approach saved some power, but was determined to be sensitive to microscopic amounts of condensed liquid water.

The flow-through design, coupled with 300°F vacuum bake out of all gimbal and motor parts, has effectively solved the motor hang-up problem without sacrificing either of the original design goals of high shock capability or low motor power requirements.

An encapsulation technique using a metallic can was also developed for the motor stator windings to reduce the possibility of particulate contamination entering the bearing from this source.

Methods of identifying both particulate and gaseous contamination within the gimbal have been developed by Honeywell using advanced methods of infra red analysis, ultraviolet fluorescence, mass spectroscopy, gas chromatography, and hot-stage microscopy.

The DGG159E is not in the final stages of assembly. Testing at Honeywell will proceed on a schedule that will allow delivery of the gyro to JPL in September 1968. JPL will then conduct an evaluation to verify the sterilization capability and long term performance.

PUBLICATIONS

SPS Contributions

1. Hand, P. J., "Sterilizable Inertial Sensors (Type DGG159E and DGG334S Gyros)," SPS 37-51, Vol. III, May 1968.

Contractor Reports, Interim and Final

1. Erickson, C. J., "The Design and Build of a Gas Bearing Gyroscope Possessing High G and Sterilization Capability and Utilizing a Low Power Spinmotor and High Frequency Pump," Honeywell, Inc., Fifth Quarterly Progress Report No. 20660 QR5, JPL Contract 951559, Jan. 1, 1968 to Mar. 31, 1968.

STERILIZABLE SUBMINIATURE GYRO MOTOR EVALUATION

NASA Work Unit 186-58-02-08-55

JPL 384-81201-2-3440

P. J. Hand

OBJECTIVE

The objective of this work unit is to evaluate the thermal sterilization capabilitites of one of the newest forms of subminiature ball bearing gyro motors. This task is corollary to task 186-68-02-30-55 in that the motor used is the same as the motor in the Alpha III gyro being evaluated under that work unit number.

STATUS

The 2-yr development contract (952019) placed with Kearfott, Inc., has been proceeding without major difficulty. This contract is divided into two phases.

The first phase deals with the heat sterilization of motor piece-parts and subassemblies at 135°C, for a total of 6 cycles at 70 hr each. This phase will detect any adverse temperature effects at the subassembly level that might be overlooked on the completed motor. During the second phase, two motor assemblies are built up and sterilized at the same conditions as the piece-parts. After each sterilization cycle, the motors are placed on test to see if performance is affected. Life tests are scheduled for both motor assemblies, provided they survive the sterilization environment.

The first phase has been completed without encountering any problems. One significant fact discovered, which was also noted on other sterilization development programs, was that certain of the epoxy adhesives used in assembling the gyro motor actually became stronger after the six sterilization cycles. This indicates that some of the recommended cure cycles may not be long enough.

The second phase has progressed through the point of motor assembly and first sterilization cycle. Prior to motor assembly, the four spin motor bearings used in the assembly were selected from a quantity of eight. This selection was based on a 40X visual inspection. The bearings were processed following standard procedures and impregnated with SR-60 lubricant. The gyro motors were assembled and run-in following standard procedures, with the exception of an increased number of bearing visuals and power input tests. The motors were installed into the sterilization containers and hermetically sealed. To correct a header deficiency, one container was disassembled and recycled. The containers were then filled with one-quarter atmosphere of helium and run-in testing was started. The containers were immersed in an oil bath during run-in testing and the fluid temperature maintained at 115°F. One motor was run an additional 145 hr for a total run-in time (motor and container) of 331 hr before the first sterilization reference. Similarly, the other motor was run an additional 156 hr for a total run-in time of 342 hr. Motor performance and power inputs were checked at intervals during and after completion of the run-in test. These data will serve as a pre-sterilization reference.

After completion of the run-in test, the containers were removed and delivered to the environmental laboratory, where the heat sterilization was performed. After the first sterilization, and prior to power turn-on, the containers were leak-checked to ensure the integrity of the hermetic seal, and motor resistance was checked. The motor performance of each unit was checked, and the power input was monitored on each for the first 30 min of run-in. Each unit was run for 102 hr, during which motor performance and power were checked at regular intervals. The motor characteristics and power input performance were very good throughout the run-in period, with only minor changes in run-down time occurring.

The results indicate that the two gyro motors have successfully passed the first sterilization cycle. From the data, it appears that none of the motor characteristics were affected by the sterilization cycle. It is evident at this point in the program that the ALPHA III gyro motor can safely withstand at least one sterilization cycle. When the motors pass all 6 cycles, they will be subjected to a life test of at least 2000 hr as a check for possible long-term wearout conditions that may have been brought on by the 135°C exposure.

PUBLICATIONS

Contractor Reports, Interim and Final

1. Brophy, T., "C702543 Alpha III Ball Bearing Gyroscope Motor Sterilization Program," Kearfott Inc., Report No. B194000216, May 15, 1968, JPL Contract 952019.

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DEVELOPMENT OF A STERILIZABLE HIGH-PERFORMANCE ACCELEROMETER

NASA Work Unit 186-58-02-09-55

JPL 384-81301-2-3440

P. J. Hand

OBJECTIVE

The objective of this work unit is to develop thermal and gas sterilization capability into a new design of miniature high-performance accelerometer. This would make available a versatile force balance instrument which is capable of either digital- or analog-type of operation. System designers could then make use of this device in planetary orbiters, entry systems, or landed devices as well as for midcourse and terminal velocity control of Mariner-class spacecraft.

The accelerometer chosen for this development is the Bell Aerosystems Model VII. This is the same basic instrument used on the Apollo Lunar Module abort guidance system.

STATUS

A modification to the original contract with Bell Aerosystem has been agreed upon, and work was resumed on the Phase One Program in February 1968 after a 5-mo delay. The basic change was to remove the actual sterilization cycling and testing from the contract with Bell and perform these operations at JPL. In this manner the final amount of the contract overrun was reduced to $8, 830, which was within the limits of available funds.

A follow-on Phase Two Program has been negotiated with Bell, and the contract should be released before the fiscal year closes. This Phase Two effort will involve four more instruments, experiments with advanced fabrication techniques and an advanced pickoff preamplifier design which would eliminate coupling transformers.

The first version of the sterilizable Model VII accelerometer was delivered to JPL in May. This instrument utilizes all materials and methods developed during the first phase of the contract. Principally a stronger and higher temperature adhesive is used in the proof mass assembly and a more stable design of pick-off preamplifier was incorporated.

During the first 20 days of stability testing at JPL the performance of this unit (SN 656) has been very satisfactory. Ten heat cycles have been performed from room temperature to 165°F with bias and scale factor measured before, after, and during the temperature run. At the controlled temperature of 165°F, the instrument has demonstrated a bias stability (1 sigma) of 7.6 μ g. At room temperature the bias stability is 35 μ g, however this includes the effect of the shifts caused by the temperature cycling.

Scale factor has also been satisfactory, demonstrating a 1-sigma stability of 56 μ g at the controlled temperature.

Additional testing will include ±1 g linearity, pick-off scale factor and flexure restraint measurements. After the unit has received 20 heat cycles and more than 30 days have elapsed, sterilization testing will begin. At least 6 cycles of 60 hr each will be performed at 135°C with stability testing taking place before and after each cycle. If the instrument survives the sterilization series, additional environmental testing such as shock and vibration will be scheduled.

PUBLICATIONS

None.

STERILIZABLE SCIENCE DATA BUFFER

NASA Work Unit 186-58-03-02-55

JPL 384-84701-2-3240

P. B. Whitehead

OBJECTIVE

The objective of this work unit is to gain understanding of the design and manufacture of a sterilizable memory for use in future flight projects.

ACCOMPLISHMENTS

During February, General Precision Inc., Librascope Group, delivered to JPL two woven plated wire memory stacks. One of these stacks was mated to breadboard electronics at JPL and became the memory for the entry data system (EDS) of the capsule system advanced development (CSAD). The memory has operated for about 3 mo without failure as part of the EDS. During the last 2 mo the EDS has been included as part of the CSAD system test at SAF.

The other stack is to be used for environmental testing. In preparation for this testing, equipment has been ordered to duplicate the test setup used by Librascope to evaluate the stacks. The equipment includes a programmable pulse generator and two current pulse generators.

FUTURE ACTIVITIES

The sterilization requirements and other environmental specifications developed for CSAD are being compared with similar specifications for Mariner Mars 1969, 1971 and 1973 in order to develop a set of meaningful tests for the second stack. In general, the tests will involve sterilization, shock, and vibration.

Tests will be run on the breadboard memory to determine its temperature margins and its ability to operate under vibration. A high temperature life test will be conducted with the memory operating at its fastest rate.

PUBLICATIONS

None.

SENSOR STERILIZATION AND TEST PROGRAM

NASA Work Unit 186-58-06-02-55

JPL 384-84601-2-3220

R. A. Wengert

OBJECTIVE

The purpose of this program is to develop sterilizable sensors which are unique to scientific instrumentation, and to conduct an evaluation program to prove the sensors worthy for use on planetary entry and landed missions. The units being studied are:

(1) GM counter tubes

(2) Solid-state radiation detectors

(3) Photomultiplier tubes

(4) Inorganic scintillation crystals

(5) An optical detector-scintillation crystal assembly

PROGRESS

G.M. Counter Tubes

The development effort has been completed and units produced according to the resulting specifications are being evaluated in the test portion of the program.

Solid-State Radiation Detectors

All necessary development effort has been completed and, as a result, the state of the art has progressed to the point of meeting the requirements.

Photomultiplier Tubes

The contractor has completed the development effort for this task. Although a change in the value of the quantum efficiency is experienced as a result of heat sterilization, analysis of the test data indicates that the change can be quite accurately predicted. The energy resolutions of the tubes remain very stable. The contract final report is now being prepared and it is anticipated that it will be received by June 30, 1968.

Inorganic Scintillation Crystals

The development effort has been completed and it is expected that the final report will be received by June 30, 1968.

Optical Detector-Scintillation Crystal Assembly

The development effort has been completed and the final report is expected to be received by June 30, 1968.

Test and Evaluation Program

The G. M. counter tubes and solid-state radiation detectors were subjected to a final cycle of heat sterilization on April 25, 1968. The units have been under test since that time with very favorable results. Although this task will be terminated at the end of FY 68, the automated test stations will permit some additional testing to be performed and better statistical information to be made available.

At the close of FY 68, the inorganic scintillation crystals and photomultiplier tubes will not have been tested beyond that effort performed by the development contractors. Such a program should be undertaken in the future.

PUBLICATIONS

None.

STERILIZED SOLID ROCKET TECHNOLOGY DEVELOPMENT

NASA Work Unit 186-58-08-01-55

JPL 384-81901-2-3810

S. N. Prescott

ELECTROEXPLOSIVE DEVICE STERILIZATION

OBJECTIVE

The feasibility of thermally sterilizing electroexplosive squibs and devices for use in planetary exploration spacecraft is being investigated by tests with present state-of-the-art hardware items.

STATUS

Squibs from four manufacturers and two types of electroexplosive devices have been exposed to repeated thermal sterilization cycles and functionally tested. The test results were compared with the results of tests on squibs and devices which were not thermally preconditioned. Samples of the electroexplosive devices used in the CSAD feasibility model were exposed to 2500 g shock pulses and then actuated to demonstrate their ability to withstand the impact of a planetary landing.

TEST ARTICLES

The following squibs and devices were tested during this report period:

Atlas IGN-141 squib	Candidate for Mariner Mars 1969 pin-puller
Space Ordnance System ASI squib	Candidate for Mariner Mars 1969 pin-puller
Hi-shear PC-42-005 squib	Surveyor pressure valve squib
Holex 5700 squib	Igniter squib (additional igniter tests are covered in separate report)

Atlas IMT-90 pin-pusher	Developed for JPL CSAD boom release
JPL 10024212 bolt cutter	Developed by JPL for CSAD parachute release (uses Hi-shear PC42-005 squib)

STERILIZATION METHOD

The squibs and devices were exposed to from one to six sterilization cycles. Each cycle consisted of a 56-hr soak at 275°F (135°C).

TEST METHODS

Each squib was installed in a closed pressure bomb with a crystal-type pressure transducer. A constant direct current pulse was applied to the bridgewire of the squib. Current and output pressure versus time were recorded on an oscilloscope camera.

Each JPL-developed bolt cutter was assembled with an 0.190-dia, 180,000-psi bolt, and its squib was fired with a dc pulse.

Each pin-pusher was installed on a ramp. It was actuated with a dc pulse and the pin propelled a steel ball up the ramp. The current-time and the time interval for the ball to pass two electrical contacts on the ramp were recorded on an oscilloscope camera.

Bolt cutters and pin-pushers were exposed to 2500 g shock pulses of 1.25 ms duration and then actuated as described above.

ANALYSIS OF DATA

The squib firing sensitivity, as determined by the firing delay at constant current, was compared on sterilized and unsterilized squibs and at several levels of firing current.

The squib output pressure was compared on sterilized and unsterilized samples.

The output energy of the pin-pusher, as indicated by the velocity of the steel ball, was compared with the energy from unsterilized pin-pushers.

The bolt cutter function was evident from the separation of the 0.190-dia bolt.

CONCLUSIONS

The Atlas IGN-141 squib is not suitable for thermal sterilization. The other squibs and devices were not affected by exposure to 275°F (135°C). The pin-pusher and bolt cutter will operate satisfactorily after exposure to 2500 g shock.

PUBLICATIONS

None.

STERILIZABLE PYROTECHNIC SUBSYSTEM DESIGN, W. S. Wuest

OBJECTIVE

The objective of this work was to verify the sterilizability of the capacitor discharge squib-firing circuit. The effort was organized as a subsystem of the capsule system advanced development (CSAD) program. One set of flight hardware and one set of operational support equipment were fabricated, and support was lent to the capsule design and systems test.

STATUS

The program is now complete. All objectives were successfully accomplished. The pyrotechnic subsystem was subjected to the prescribed sterilization cycle as a component of the CSAD feasibility model and subsequently passed its operating criteria in conjunction with the capsule system.

The pyrotechnic subsystem was capable of redundantly executing five pyrotechnic events: capsule separation, spin-up, deflection motor ignition, despin, and maneuver package separation. The firing unit weighed 3.16 lb. It was part of the maneuver package, hence was jettisoned and did not contribute to the entry weight of the capsule.

The capacitor discharge type of squib-firing circuit was utilized. This permits the number of squibs which are fired simultaneously to be independent of the current capability of the spacecraft battery. The circuit which was used was substantially the same as the Mariner Mars 1969 squib-firing circuit. The CSAD unit was capable of firing four squibs simultaneously. It also fulfilled the requirement to fire two events simultaneously – capsule separation and spin-up. All squibs were of the 1A/1W type. However, due to the energy storage concept, the maximum current required from the battery was less than 30 ma.

A rack of operational support equipment (OSE) was fabricated to test the subsystem both as a component and as a part of the capsule system. The OSE also incorporated provisions for testing a squib-firing circuit which was provided by others and located in the CSAD lander.

PUBLICATIONS

None.

STERILIZABLE SOLID ROCKET TECHNOLOGY, W. L. Dowler

OBJECTIVE

The objective of this task is to demonstrate feasibility and solve the engineering problems involved in sterilizable solid propellant motors.

STATUS

Because of reduced funding levels, work on sterilizable solid propellant motors was continued at a very low level; thus, significant results have not been obtained.

PLANNED ACTIVITIES

Work toward the 60-lb sterilizable motor feasibility demonstration is planned to continue during the next 6 mo.

PUBLICATIONS

None

STERILIZABLE LIQUID PROPULSION SYSTEM DEVELOPMENT

NASA Work Unit 186-58-08-02-55

JPL 384-82101-2-3840

M. E. Guenther

OBJECTIVE

The objective of this work unit is to develop the technology required for the use of sealed, ethylene oxide-compatible, heat-sterilizable liquid propulsion systems. Such systems will be required for probes or capsules that enter planetary atmospheres. The liquid supply system technology will also have application as a monopropellant supply system for a turboalternator auxiliary power unit driven by gaseous products for hydrazine decomposition.

STATUS

The bipropellant work is being handled primarily by an industry contractor. The contractor has conducted a design and experimental investigation, and has performed a feasibility demonstration of a sterilizable liquid bipropellant propulsion system. To conduct this program, the contractor designed an integrated, modular bipropellant system, procured the required component parts, and assembled the components into a complete system module. The system module was subjected to ethylene oxide exposure. Thermal cycling of the system module was completed and a successful demonstration firing of the sterilized system was conducted January 16, 1968. Post test inspections revealed areas of degradation in individual components but probably not drastic enough to cause a test failure. However, these problem areas detract from a high confidence level and plans were made to correct them and to repeat the demonstration firing. More extensive compatibility testing of materials was also a decided requirement. To accomplish these two tasks, a supplement to the existing (951709) contract was initiated and should be executed approximately July 8, 1968. The supplemental effort valued at approximately $95000 will cover nearly 6 mo effort in time; $45000 is being funded from the existing

FY 68 funds and approximately $50000 incrementally from FY 69 funds. A draft of the final report covering the initial contract effort has been submitted.

A secondary (back-up) effort was initiated in-house for FY 68. This in-house effort is in the form of a prototype monopropellant system capable of withstanding the sterilization environment without appreciable degradation of performance when test fired. The preliminary prototype system was defined. Procurement of all components except for the propellant expulsion tank assembly was initiated. The monopropellant system will utilize components developed from existing in-house efforts and the Martin-Denver contract. Technological information gained from the Martin-Denver contract, as well as in-house information, will be fully utilized in the final design and assembly of a system module. The final design and component procurement is expected to be completed during the first half of FY 69. Assembly of the monopropellant system, sterilization cycling, and a demonstration firing are scheduled for completion by the end of FY 69.

PUBLICATIONS

Contractor Reports, Interim and Final

1. Lukens, S., Project Manager, Martin Corp., Denver Division. AIAA 4th Propulsion Joint Specialist Conference, JPL Contract 951709, June 10–14, 1968.
2. Lukens, S., Quarterly Contract Reports, Martin-Marietta Corp., Denver Division. Nos. MCR-67-15, First, Second, Third, Fourth, Fifth Issue, JPL Contract 951709.
3. Brady, H. F., and Di Stefano, D., Final Report, Martin-Marietta Corp., Denver Division, MCR-68-119.

STERILIZABLE POLYMERS
NASA Work Unit 186-58-13-02-55
JPL 384-83801-2-3510

W. D. Roper

OBJECTIVES

The long-range objective of this work unit is to establish a comprehensive list of polymeric products suitable for spacecraft applications which can withstand ethylene oxide decontamination and thermal sterilization. As an expansion of previous studies, the FY 68 work has included the study of the effects of an additional environment: long-term (500 hr) thermal-vacuum exposure (135°C, 10^{-6} torr) which can be considered as simulating a spacecraft environment.

PROGRESS

During the last half of FY 68 the polymeric materials studies conducted at the Autonetics Division of North American Rockwell Corp., and which were originated from FY 67 funding, were completed with the issuance of a final summary report. These studies evaluated the compatibility of some 180 materials to exposure to ethylene oxide, plus thermal sterilization cycles according to JPL Spec VOL-50503-ETS. The polymeric products were selected from 20 different material categories such as adhesives, sealants, laminates, etc. After each material was given the decontamination and sterilization treatments, physical, mechanical, and electrical property changes were assessed and compatibility ratings based on these changes were assigned to each material.

Of the total number of materials investigated, approximately 50% could be classed as compatible to ETO plus thermal sterilization; 23% were rated marginal and the balance, 27% were found noncompatible. In addition to the establishment of the good space grade materials, it is of equal importance that the noncompatible materials have been determined and can now be eliminated from any further consideration as spacecraft materials.

During this same FY 68 period the polymeric materials studies being conducted within the JPL materials section, and which are an extension of th Autonetics and previous work, have been continuing. In this program approximately 25 materials are being evaluated for compatibility, not only to ETO and thermal sterilization cycles, but also to a thermal vacuum exposure of 500 hr at 135°C and 10^{-6} torr. This latter environment is a simulated spacecraft environment.

During this last period, this materials investigation has progressed to an over-all program completion of approximately 70%. Program planning, sample procurement and preparation, and ETO exposure are essentially complete. Thermal sterilization has also progressed to 60% completion. During this same period, contractual agreement was made with Stanford Research Institute for their thermal-vacuum exposure work of this program This latter exposure work is 25% completed.

In addition to the materials studies within the materials section, it was also planned in FY 68 to develop within the Materials Testing Laboratory, an ETO sterilization apparatus. During the last period a thorough review of the commercially available equipment and an appraisal of various vendor bids were made. An equipment source selection was ultimately completed. The equipment has been ordered and delivery and installation is anticipated during the first half of FY 69.

FUTURE PLANS

It is projected that the present polymeric materials studies will be completed within the first half of FY 69. In addition to these activities, the FY 69 objectives under this work unit will also include (1) the investigation of the interactions of several materials exposed simultaneously to the various sterilization and simulated spacecraft environments, and (2) the completion of the development of the ETO exposure facility. Some continued effort in the expansion of the qualified polymeric materials list is also anticipated.

PUBLICATIONS

Contractor Reports, Interim and Final

1. Lee, S. M., and Licari, J. J., "Effects of Decontamination and Sterilization on Spacecraft Polymeric Materials," Autonetics Division of North American Rockwell Corp., Final Report, JPL Contract 951566, Jan. 12, 1968.

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STERILIZABLE ELECTRONIC EQUIPMENT PROCESSES

NASA Work Unit 186-58-13-03-55

JPL 384-85301-x-3570

R. F. Holtze

OBJECTIVE

The long-range objective of this work unit is to develop and qualify sterilizable material applications and processes for assembling and packaging of electronic equipment. The present effort will attempt to determine the effect sterilization has on physical or chemical interaction between embedment materials and components that would affect the functional use of such subassemblies.

BACKGROUND

Previous results have indicated that embedment compounds did affect the functional parameters of certain components embedded in them, as a result of the sterilization cycles. The test data indicated that embedment compounds exert a definite pressure on embedded components with the pressure increasing as a result of sterilization. When measured at room ambient temperature, the pressure exerted by a typical syntactic foam increases from 1200 to 1900 psi after having been subjected to sterilization conditions. This increased pressure has an effect on certain parameters of components, notably the resistors and capacitors. The present work is designed to evaluate sterilization effects on additional embedment materials and the effect that these sterilized materials have on the parameters of certain selected components.

ACCOMPLISHMENTS

A total of 12 different components was tested. These components were selected from the sterilizable component list issued by JPL and include five resistors of various types, three different capacitors, two types of inductors, one diode, and one thermistor. All components have been procured, burned-in at 275° F, screened for operating characteristics and fabricated into typical cordwood-type modules. A total of 20 parts of each of the 12 different types was embedded in each of the 5 material systems being tested. A control system containing unembedded components was also included. Figures 1 and 2 illustrate typical modules, both before and after embedment.

All modules have been embedded and tested. Four different embedment materials were used. Processing difficulties were encountered with a fifth material, and schedule limitations forced discontinuance of this material. The four materials being tested were (1) Stycast 1090 from Emerson and Cumming Corp., meeting MSFC Specification 222B-Type IV; (2) Scotchcast 5090, Minnesota Mining and Manufacturing Co.; (3) Scotchcast 281, Minnesota Mining and Manufacturing Co.; (4) Stycast 2850 FT from Emerson and Cumming Corp., meeting MSFC Specification 222B-Type III.

Operating parameters of each component in the embedded and control (unembedded) modules have been determined after each of the following manufacturing or environmental test procedures:

(1) Fabrication into cordwood-type modules

(2) Embedment using selected materials

(3) Exposure to both ETO and thermal sterilization conditions

(4) Exposure to low temperature (-35°F)

In addition to the embedded component modules, test work was also done to determine the actual pressure that the different embedment materials did exert. This determination was made using the thermometer embedment method and also by means of pressure-calibrated carbon composition resistors incorporated in the cordwood modules. Pressures exerted by each material were determined after embedment, sterilization, and low temperature exposure. It is hoped that an analysis of the data may reveal a correlation between the pressure exerted on a component and the amount of variation in the electrical parameters of the component.

STATUS

All test work has been completed and the basic data obtained. These data will be analyzed and a final report issued during the first quarter of FY 69.

PUBLICATIONS

None.

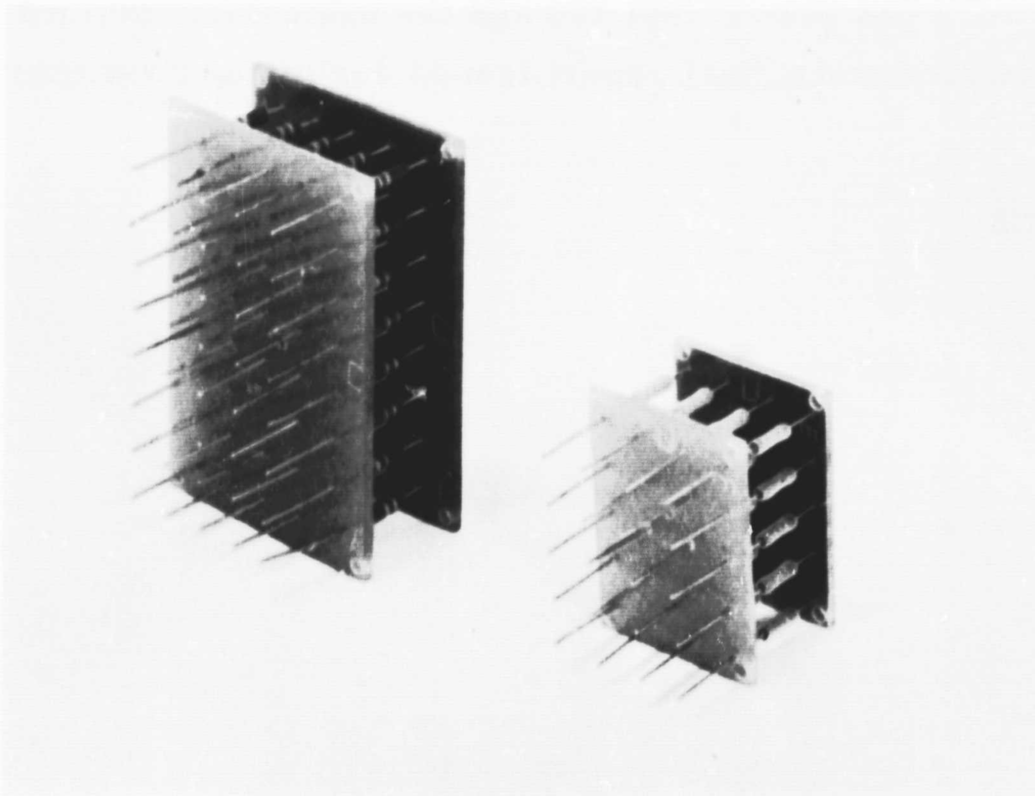

Figure 1. Unembedded Cordwood Modules

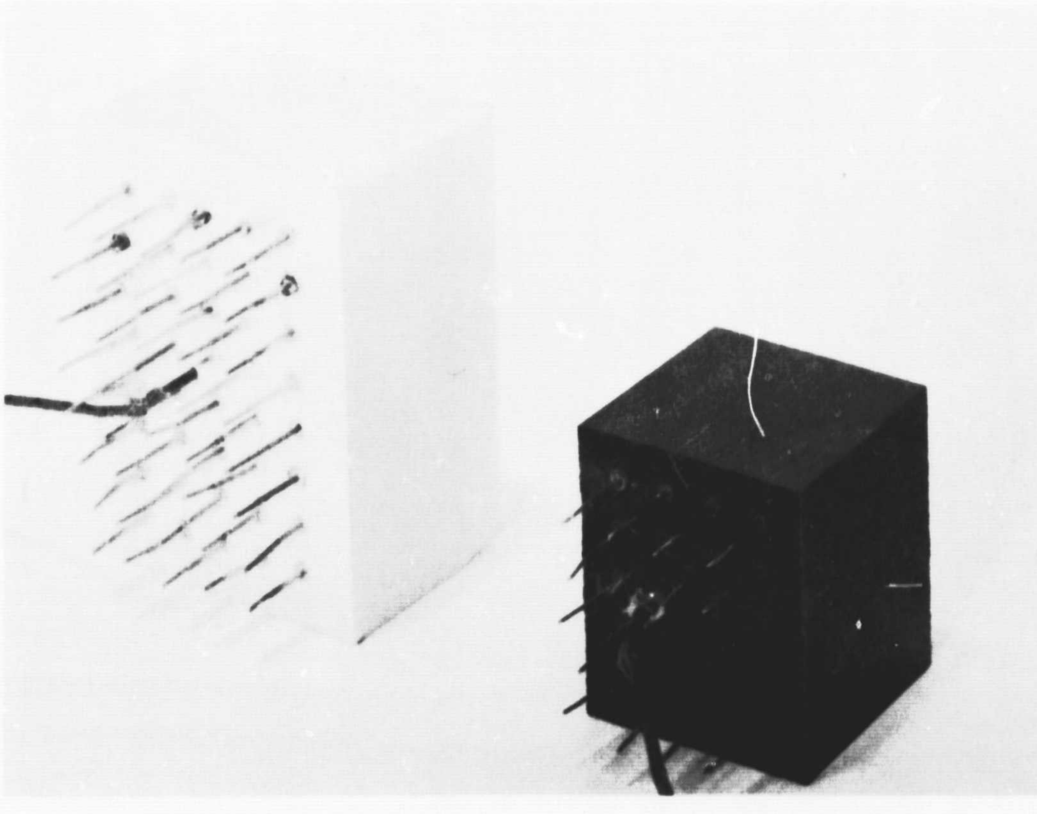

Figure 2. Embedded Cordwood Modules

STERILIZABLE CONNECTORS, WIRES, AND CABLING ACCESSORIES

NASA Work Unit 186-58-13-06-55

JPL 384-85801-2-3570

R. W. Lester

OBJECTIVE

The broad objective of this work unit was to assure the availability of sterilizable flight-type multipin electrical connectors, electrical wires, cabling accessories, and radio frequency connectors and cables. The specific objective for the past 6 mo was to verify the sterilization capabilities of assemblies of selected parts by determining whether exposure to decontamination and sterilization environments resulted in degradation of function or reliability. This work unit was closed out at the end of FY 68.

TEST SPECIMENS

The scope of test work was limited to evaluation of assemblies using parts made of materials found to be sterilizable under other NASA work units, and of designs which were thought to be compatible with sterilization and applications on future spacecraft. It is possible that parts made from sterilizable materials may not withstand sterilization environments due to mutual chemical or physical effects. For example, one concern was the finding that a tensile load of 12 oz would cause soldered hookup wires to be pulled out of solder cups, as reported in a work unit entitled "Sterilizable Soldered Connections." Then, too, critical electrical parameters of RF connectors and cables could change due to physical interactions. Candidate multipin connectors, hookup wires, and cabling accessories were tested in simulated spacecraft subsystem harness assemblies (Fig. 1). Radio frequency connectors and cables were tested as unsupported assemblies.

ACCOMPLISHMENTS

All of the planned exposure cycles, as well as electrical and physical tests of the radio frequency connectors and cables, have been completed and the portion of the planned JPL 700 Series report pertaining to these has been written. Two cable configurations will not be recommended for use on sterilizable spacecraft because of impaired physical properties resulting from ethylene oxide decontamination. In addition, one group of RF connectors was found to be unsatisfactory because an adhesive is used which degrades at thermal sterilization temperatures, resulting in unacceptable mechanical and electrical changes. The exposures and tests of the simulated subsystem harnesses have been accomplished and the temperature sterilization cycles are 75% completed. While some polymeric materials have become discolored, no significant electrical or physical degradation of harness components has been noted. Since all ETO decontamination has been completed, closeout of the contract with Northrop Space Laboratories for this activity has been initiated.

FUTURE PLANS

Since this work unit will not be continued, the conclusion of the harness testing will be accomplished under NASA Work Unit 186-68-10-10-55, "Evaluation and Qualification of Connectors and Wires." Connectors, wires, cables, and cabling accessories which have been shown to be capable of withstanding decontamination and sterilization will be included in JPL Specification ZPP-2010-SPL, "Electronic Part Sterilization Candidates for Spacecraft Applications" with the appropriate indication that testing of these parts is complete and that they have been accepted.

ANTICIPATED PUBLICATIONS

Lane, F. L. and Lester, R. W., "Sterilization Effects on Selected Spacecraft Connectors, Wires and Cabling Accessories," JPL Informal Document, 700 Series.

PUBLICATIONS

None.

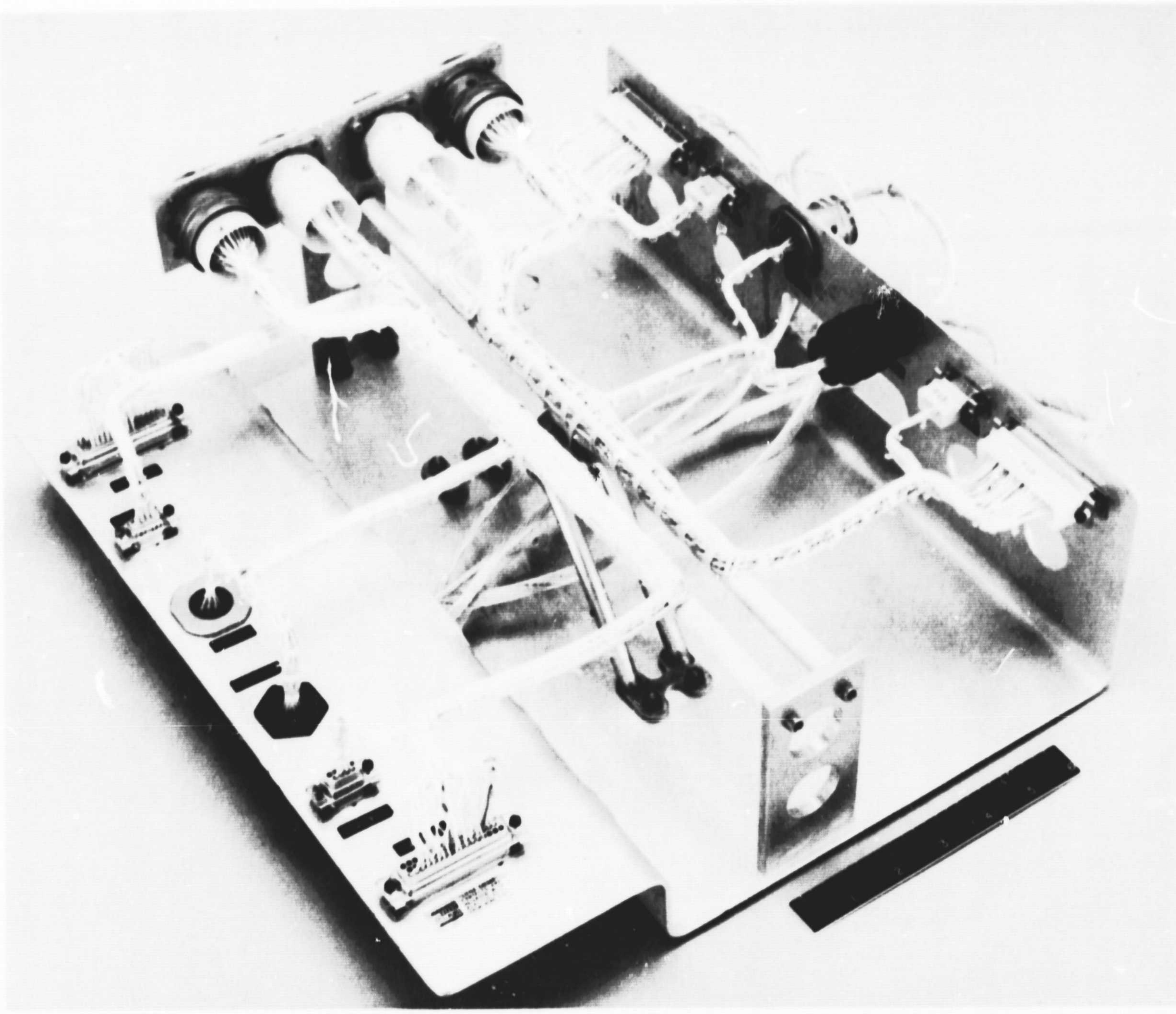

Figure 1. Typical Harness and Fixture Assembly Simulating a Spacecraft Subsystem Interconnect Harness

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MATRIX TEST OF STERILIZABLE PIECE-PARTS

NASA Work Unit 186-58-13-08-55

JPL 384-80401-2-3540

K. Martin

OBJECTIVE

The objective of this task is to support the NASA thermal sterilization policy by studying the temperature-time relationships, the effects of different numbers of temperature cycles, the effects of different rates of temperature change, and the effects of different storage periods at temperature. These relationships of the sterilization environments will be studied for their effects on the reliability of some representative electronic component piece parts during long life.

PROGRESS

ZPP-2127-GEN-A, Capacitor Matrix Test (Litton Systems) Mod. I. Test results as of completion of the matrix phase of the test program (see Table 1).

Linear regression was used to test the significance of the change (trend) of the parameters for each group during the six cycles. Groups P, M, I, E, and C are the temperature-time stresses that JPL considers equally effective for heat sterilization. The other groups have been included in the test program so that higher temperature—shorter time stresses could be evaluated for future reference.

Code 1 - Sprague 350D, 39 ufd, 35 v dc solid tantalum:

There were no catastrophic failures. The capacitance did not change significantly. Eight parts exceeded the 3% dissipation factor (DF) limit. The DF failures by groups were:

Group	Failures	Group	Failures
C	1	H	1
D	3	R	1
G	2		

Groups D and G exhibited an increasing DF trend during the six cycles. One hundred forty-four parts exceeded the 10 μ ampere leakage current limit. The failures by groups were:

Group	Failures	Group	Failures	Group	Failures
B	1	H	12	L	16
D	12	I	1	N	11
F	5	J	12	O	14
G	18	K	20	Q	2
				R	21

All groups except Group P exhibited a significantly increasing trend in leakage current during the six cycles.

Code 2 - Aerovox V423XP, 1 ufd, 200 v dc mylar:

There was one random catastrophic failure. The lead separated from the foil element. There was one capacitance failure in Group Q. All groups except Group Q exhibited a decreasing capacitance trend during the six cycles. However, the parts remained well within the 10% tolerance limit. There were no DF failures. Groups C, D, E, F, G, I, M, N, P, B, C, and H exhibited a significantly decreasing trend in DF during the six cycles. There were no insulation resistance (IR) failures. Groups J, R, and L exhibited a significantly decreasing trend in IR during the six cycles, although they remained well within tolerance.

Test results as of completion of 250 hr. of life testing:

Code 1 - Sprague 350D, 39 ufd, 35 v dc solid tantalum:

There were no catastrophic failures during the 250 hr. of life testing. None of the parts exceeded the capacitance tolerance limits. Seven of the parts exceeded the DF limits during 250 hr. of life testing. The DF failures listed by groups are:

Group	Failures	Group	Failures
B	1	J	1
D	2	K	1
G	1	R	1

All but 2 of the 144 matrix testing DC leakage failures recovered as of 250 hr of life testing. The two parts that remained out of tolerance were in Group Q. Nine parts that remained within tolerance limits during the matrix test exceeded the tolerance limits during the 250 hr of life testing. The DC leakage failures listed by groups are:

Group	Failures	Group	Failures
J	1	Q	8

Code 2 - Aerovox V423XP, 1 ufd, 200 v dc mylar:

There were no catastrophic failures during the 250 hr of life testing. None of the parts exceeded the capacitance tolerance limits. There was one DF failure in Group G, but this is not considered significant. No insulation resistance failures were noted.

Conclusions

Code 1

The capacitance of all groups has remained stable throughout the matrix test and the life test; capacitance does not appear to be a sterilization testing problem. As was expected from past testing experience, the DC leakage failures tended to recover during life testing; but failure during the life test of parts that remained within tolerance during the matrix test was not expected.

In addition, eight out of the nine failures were in Group Q. This problem will be closely followed during the test program. There were 8 DF failures during the matrix test and 7 DF failures during 250 hr of life testing. These failures are predominantly in the higher temperature groups. If this trend continues it could be a serious problem.

Code 2

There have been no significant catastrophic or parametric failures as of 250 hr of life testing. There is no measurement evidence that this type of mylar capacitor is significantly degraded from the effects of sterilization testing.

The following table ranks the recommended sterilization stress levels in an increasing order of degradation:

Group	Temperature, °C	Time, hr
P	105	336
M	115	132
E	135	22
I	125	53
C	145	9

It must be emphasized that the results and conclusions are based on only 250 hr of a 10,000-hr test, and consequently, they are subject to revision during the remainder of the test program.

ZPP-2127-GEN-A, Capacitor Matrix Test (Litton Systems) Mod. II. The pre-test screening (burn-in) has been completed. The matrix test has not started. Consequently, no conclusions can be formulated at this time.

Table 1. Test Matrix

25°C	105°C	115°C	125°C	135°C	145°C	160°C	Hours
[a]Group A 30 parts (Typical)						Group B	3 ±5 min
					Group C	Group D	9 ±15 min
				Group E	Group F	Group G	22 ±30 min
					Group H		36 ±30 min
			Group I	Group J	Group K		53 ± 1 hr
				Group L			92 ± 1 hr
		Group M	Group N	Group O			132 ± 1 hr
	Group P	Group Q	Group R				336 ± 1 hr

[a]Group A is the control group and does not receive heat cycling.

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STERILIZABLE POLYMERIC MATERIALS

NASA Work Unit 186-58-13-09-55

JPL 384-83901-2-3820

S. H. Kalfayan

OBJECTIVE

The primary objective of this task is to provide information on sterilizable polymeric materials for use in the design of planetary spacecraft which are required to meet a biological specification. The immediate objectives are to evaluate the validity of the decontamination and dry heat sterilization practices as applied to polymeric materials for potential use on planetary entry landing capsules, and to evaluate materials at various time–temperature conditions, and in presence of oxygen.

PROGRESS

Evaluation of ETO Decontamination Practices

Quantitative estimation of the decontamination chamber gases by gas chromatography (GC)

It was established that ethylene oxide (ETO) and Freon 12 could be estimated with an accuracy of ±1.4% using this method. Moisture content of the chamber could not be determined quantitatively by GC. Dependence on the chamber pressure to calculate the concentration of ETO was found to be unreliable because the composition of the ETO–Freon 12 mixture introduced into the chamber varied. Fractionation of the gaseous components and the rate at which the sterilant liquid mixture in the original cylinder is vaporized, were considered to be the causes for this variation.

Evaluation of moisture-sensing instruments

An extensive investigation of several types of moisture-sensing instruments, both at atmospheric conditions and at the ETO-Freon 12 decontamination conditions, was carried out. Types of sensors included: electrical resistance (El-Tronics, Inc. Model 102), electrical impedance (Parametrics, Inc., Model 1000), cold mirror optical dew pointer (Technology-Versatronics, Model 707), manual dewpointer (Alnor, Model 7000 U) and wet-and-dry bulb psychrometer (Bendix, Model 566). The last two were not suited for use in the ETO–Freon 12 environment. The Alnor instrument was used as a reference standard and the Bendix psychrometer served as an additional reference.

Results showed that the Panametrics and the Technology-Versatronics sensors were irreversibly affected by the ETO–Freon 12 exposure. The $A\ell_2O_3$ of the Panametrics probe and the bismuth telluride semiconductor of the Technology-Versatronics probe seemed to have reacted with the ETO changing their capacitance or resistance. The El-Tronics sensor fared better than these two. Indications were that its sensitivity to measure relative humidity changed after ETO–Freon 12 exposure. Washing the sensor with distilled water helped but did not remedy the situation completely. The conclusion is that there is no moisture-sensing instrument that will adequately measure the relative humidity of the ETO–Freon 12 decontamination chamber.

Investigation of Dry Heat Sterilization Under Various Time–Temperature Conditions and in Presence of Oxygen

Six selected polymeric products were exposed to the following heat cycles after an initial ETO decontamination according to JPL VOL 50503-ETS specification for TA testing of piece parts and materials:

6×600 h at 105°C in N_2

6×40 h at 155°C in N_2

6×92 h at 135°C in N_2

6×92 h at 135°C in N_2 containing 0.45% O_2

The products were Epon 934 (epoxy adhesive), Viton 377-9 (fluoroelastomer) Stycast 1090 (epoxy encapsulant), Tedlar 30 (polyvinylfluoride film), EG 758 (epoxy-glass laminate), and Mystik 7352 (adhesive tape).

Evaluation of the test data allowed the following conclusions:

(1) At 155°C for 6 × 40 h, the properties of most of the products were more adversely affected.

(2) Heat resistant compounds such as EG 758 were not any more affected by exposure to higher temperatures for shorter periods, than to lower temperature for longer periods.

(3) In general, sterilization at 105°C for 6 × 600 h resulted in lesser loss of the physical and mechanical properties of the polymeric products.

(4) The presence of small quantities of oxygen (0.45%) did not affect the property changes significantly.

(5) Although sterilization at higher temperatures resulted in increased loss of properties, the increase was not too pronounced.

FUTURE WORK

The work planned for FY 68 under this work unit has been completed, and a technical report has been prepared for publication. For FY 69, the task will consist of the evaluation of polymeric materials in planetary environments (high temperatures and pressures, atmosphere of CO_2).

PUBLICATIONS

SPS Contributions

1. Kalfayan, S. H., and Silver, R. H., "The Ethylene Oxide–Freon 12 Decontamination Procedure B. The Quantitative Estimation of Ethylene Oxide Concentration by Gas Chromatography," SPS 37-49, Vol. III, p. 193, Feb. 29, 1968.

SPACECRAFT AND CAPSULE EQUIPMENT DEVELOPMENT (186-68)

PLANETARY ENTRY AND LANDING STRUCTURES

NASA Work Unit 186-68-01-01-55

JPL 384-60101-2-3530

E. Heer
A. C. Knoell
J. A. Garba

OBJECTIVE

The objectives are (1) to study and develop systems and the application of materials with high energy-dissipating capabilities for the protection of spacecraft and/or capsules from impact loads during terminal landing and (2) to establish capability for testing aeroshells and capsule systems including entry heating and pressure profiles, sterilization, vibration, etc.

IMPACT LIMITER LANDING DYNAMICS STUDIES

Landing Dynamics Program

An operational digital computer program has been developed to predict the dynamic response of axisymmetric impact attenuating vehicles consisting of a rigid payload and an impact limiter. Specifically, the program determines the complete displacement, velocity, and acceleration-time histories of the landing vehicle during impact. Initial conditions of horizontal and vertical displacement and velocity, vehicle touchdown angle, and pitch rate may be inputted to the program.

In addition to the usual vehicle material and geometry description which must be supplied to the program, the program also accepts arbitrary values of the surface slope and coefficient of friction. Also, the program contains an automatic error control for defining solution convergence to a predetermined value set by the user.

A present limitation exists in that it is only possible to input vehicle cross-sectional geometry. This limitation will be removed during the first quarter of FY 69 so that the user can input three-dimensional vehicle geometry which is particularly valuable in describing each element of the impact limiter, including the element fiber orientation of the impact limiter material.

The present version of the program has been used to predict the impact response of CSAD (disc-type) lander vehicles. The predicted response has been compared to experimentally obtained test data and reasonably good agreement has been found. It is intended to publish both a usage document and the computational results of this work during the first half of FY 69.

Dovetail Limiter Analysis

An analysis capability has been developed to predict the static and dynamic crushing response of a dovetail spherical impact limiter. The capability includes (1) a set of design relations to determine maximum limiter velocity and deceleration, (2) qualitative expressions to determine the effects of stress waves on limiter dynamic response, and (3) relations to establish the deceleration level at which payload "cannonballing," i.e., penetration of the payload sphere into the dovetail limiter, occurs. The analysis was based on considering vertical impacts of the limiter against a flat, unyielding surface.

The analysis capability is presented in detail in a JPL Technical Report (see Publications). During FY 69 it is intended to extend this capability by comparing predicted limiter response of impacts against spherically curved surfaces.

CAPSULE SYSTEM ADVANCED DEVELOPMENT (CSAD) IMPACT LIMITERS

The first draft of a technical paper describing the results of the CSAD impact limiter development program has been completed (see Publications). The paper presents the limiter system design constraints and covers the design analysis, fabrication, and testing of both balsa wood and phenolic honeycomb limiters.

No further CSAD impact limiter development is contemplated for FY 69.

DEVELOPMENT OF ENERGY-DISSIPATING PLASTIC HONEYCOMB

Work has been completed by the General Electric Co. (under JPL Contract 951172) regarding the materials development of both hexagonal and dovetail cell phenolic honeycomb. This JPL Contract 951172 is a continuing effort from FY 67 for which $100K have been obligated in July 1967. The detailed results of this development program are contained in a General Electric final report (see Publications).

Highlights of the results of this extensive program include:

(1) Improved material performance under high velocity impact.

(2) Demonstrated improvement in energy-dissipating capacity due to dry heat sterilization.

(3) Development of a new honeycomb material (dovetail) capable of good energy dissipation.

(4) Development of fabrication techniques applicable to spherical (dovetail) and disc-type (CSAD) impact limiter systems.

It is intended to continue the development of plastic honeycomb during FY 69.

AEROSHELL TESTING

In order to verify the existing analysis of the CSAD aeroshell and to qualify the design concept for Martian entry, it is planned to expose the structure to a combined time-correlated pressure and temperature pulse.

Work on the test chamber consisted of experimental heat bank investigations and ignition checkout leading to a heat bank design required to deliver a minimum heat flux of 80 Btu/ft^2/sec. The fabrication of the heat bank and reflector has been initiated. Pressure controls for the rapid pumpdown required to obtain a prescribed differential pressure loading on the test specimen are being investigated using a dummy shell.

An investigation of the feasibility for strain measurements in phenolic honeycomb facesheets has been successfully completed. The selected strain gauge type is being installed on the test specimen.

The test fixtures required for the conduction of the test are approximately 80% complete.

Plans for FY 69 include (in addition to the conduction of the 6.5-ft aeroshell test) several modifications to the test chamber. It is planned to extend the capabilities of the chamber to include: vibration in vacuum, hard vacuum soaking, dry heat sterilization, as well as ETO sterilization, low temperature soaking, and rapid pumpdown profile.

PUBLICATIONS

Meetings and Symposia Papers

1. Knoell, A. C., "Structural Development of an Impact Limiter System for a Mars Landing Vehicle," AIAA 2nd Aerodynamic Deceleration Systems Conference, El Centro, California, Sept. 1968.

SPS Contributions

1. Knoell, A. C., "Structural Development of an Impact Limiter for a Mars Landing Vehicle," SPS 37-50, Vol. III, Apr. 30, 1968.
2. Heer, E., Garba, J. A., and Orlik, F. W., "Planetary Entry Test Facility," SPS 37-49, Vol. III, pp. 161-165, Feb. 29, 1968.
3. Garba, J. A., and Heer, E., "Aeroshell Structural Development for Martian Entry," SPS 37-50, Vol. III, Apr. 30, 1968.

JPL Technical Reports

1. Knoell, A. C., "Analysis of the Crushing of a Dovetail Phenolic Honeycomb Spherical Impact Limiter," TR 32-1287, Jet Propulsion Laboratory, Pasadena, California, Jul 1, 1968.

Contractor Reports

1. "Development of Energy-Dissipating Plastic Honeycomb," Report No. 68SD4264 (prepared for JPL under Contract 951172); General Electric Co., Space Technology Center, Valley Forge, Pa., Jun. 14, 1968.

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INPUT DATA FOR HEAT SHIELD ANALYSIS

NASA Work Unit 186-68-01-04-55

JPL 334-70201-2-3510

R. G. Nagler

OBJECTIVE

Analytical studies of the heat shield requirements for a planetary entry mission are only as good as the quality and quantity of data available for use in the computer programs. Lack of this capability within NASA has caused heat shield weight excesses in other NASA programs which are not warranted in the relatively lightweight vehicles anticipated for planetary missions. To accomplish this task JPL will determine what material systems are apropos, gather the available data from NASA, DOD, and industry sources; evaluate the accuracy and adequacy of the available data; and initiate and monitor new data measuring activities to improve present capabilities.

PROGRESS

Additional work has been carried out in gathering and evaluating material properties on ablative systems suitable for Venus missions. Air Force ballistic missile sources have been investigated in some depth. For the most part, the data is confusing and inconsistent and obvious weaknesses are countered by excessive conservativism. Preliminary work on establishing a work statement for mechanical property testing has been accomplished although the already existing proposals for thermal conductance and optical properties have been shelved for lack of suitable funding.

FUTURE PLANS

An SPS contribution will be written summarizing the results obtained in this work unit.

PUBLICATIONS

None.

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COMPUTER ANALYSIS FOR PLANETARY ENTRY HEAT SHIELD

NASA Work Unit 186-68-01-05-55

JPL 384-70301-2-3510

R. G. Nagler

OBJECTIVE

In order to carry out the studies necessary to plan future planetary missions, JPL continually strives to keep up and improve its analytical tools for heat shield analysis. By doing this, JPL provides not only study support on specific missions, but helps in guiding the heat shield resources at JPL and the NASA centers in those areas needing the greatest effort for future programs. To accomplish this, JPL acquires available government-owned computer programs, adapts them to the JPL computer system, and evaluates them as to their relative usefulness and accuracy when applied to anticipated missions.

PROGRESS

During the second half of FY 68 the Avco 1600 program (acquired from the Manned Spacecraft Center) has been adapted to the JPL system. Comparison between this program and the Langley Research Center programs already in use at JPL has been initiated. A small contract has been let with Aerotherm Corp. to provide overlays to allow use of the coupled boundary layer-ablator performance program that Aerotherm wrote for the Manned Spacecraft Center. Aerotherm will also partially debug the system for JPL. This program will allow JPL to make the first attempt at analytically investigating CO_2 combustion in planetary atmospheres.

FUTURE PLANS

None.

PUBLICATIONS

SPS Contributions

1. Nagler, R. G., "Heat Shield Requirements for a 1972 Venus Probe Mission," SPS 37-49, Vol. III, February 1968.

FLIGHT COMPUTERS AND SEQUENCERS ADVANCED DEVELOPMENT

NASA Work Unit 186-68-02-08-55

JPL 384-63701-2-3410

G. R. Hansen, Jr.

OBJECTIVE

The continuing long-range objective of this work unit is the development of advanced circuit techniques and computer technology for the central computer and sequencer subsystems that will be required for future planetary missions. The task requires effort devoted to subsystems required for both capsule and spacecraft applications.

In order to accomplish this task, efforts have been devoted to the CSAD program, computer-aided circuit design, approach guidance, and memory expansion.

PROGRESS

During the last report period, the landed sequencer timer (LST) subsystem was completed and integrated with the capsule system. The LST unit weighs 2.6 lb and requires about 1/4 W of power. The LST subsystem arms the landing sensor, turns the radio ON and OFF, extends the anemometer boom, and provides a timed landing sensor backup signal. The system was successfully checked out, sterilized, and dropped. In addition to taking part in the drop tests, the design and construction of the airborne drop control equipment (drop-box) for these tests was accomplished by personnel in this work unit.

The impact of functional requirements such as inflight modification of the post-separation flight profile and inflight checkout on capsule systems for Jupiter and Grand Tour missions will be determined. This investigation is a continuation of the capsule-oriented work that resulted in CSAD.

Further work is planned in the area of low-power, harsh-environment tolerant circuitry. In particular, those circuits which are the basis for sequencer and timer subsystems, namely oscillators, countdown chains, and electrical actuators will be investigated. The plan is to first try to achieve the minimum power possible using smaller and/or hybrid components in contemporary circuitry. In addition, H-type mechanical resonators, which are purportedly free from the effects of shock and vibration, will be evaluated for usefulness in oscillators. If the degree of power reduction required cannot be obtained by this approach, emphasis will be shifted to an experimental study of MOS devices in two- and four-phase configurations. The organizational changes in the sequencer and timer systems brought about by the change from nonvolatile magnetic to volatile semiconductor circuitry will also be determined.

The Stanford Research Institute has been developing, under a contract supported by NASA Work Unit 125-17-04-01, a computer-aided circuit design program which will accommodate square-loop magnetic core and nonlinear transformer circuit elements. Design verification of four of the circuits used in the Mariner Mars 1969 CC&S maneuver duration shift registers has been accomplished. This program will be installed on the JPL computer during the second quarter of FY 69. Monitoring of this contract will be accomplished under this work unit for that portion done in FY 69.

An effort has been conducted in-house to develop computer subroutines for magnetic cores, diodes, and voltage reference diodes. These routines allow the use of readily available modest speed machines such as the IBM 1620 in the preliminary circuit design phase of magnetic circuitry.

The constant-voltage current-steering switch invented under this work unit in early FY 68 is presently being designed for an expanded memory for a larger CC&S. This larger memory is required to more fully utilize the capabilities of computer oriented CC&S subsystems. It is expected that the use of the computer-aided design routines will result in a verified electrical specification prior to the construction of the engineering breadboard of the constant voltage access switch. It is planned that the electrical design of the switch will be completed in the first quarter of FY 69 with breadboard development starting then and finishing in tne third quarter. Fabrication of a flight model memory will commence in the second quarter.

In addition to this effort, a memory design has been furnished for Mariner Mars 1971. This memory is twice the size of that in the Mariner Mars 1969 CC&S, but otherwise is a minimum change from the 1969 model.

Preliminary discussions have been held with those representing other disciplines within the Division concerning the hardware and interfaces involved in a laboratory model of an approach guidance system. These discussions will continue during the remainder of FY 68 and relocation of the inhibit core logic computer to the proximity of the other elements of the system may occur if conditions warrant.

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OPTICAL SENSOR TECHNIQUES AND COMPONENTS

NASA Work Unit 186-68-02-19-55

JPL 384-64601-2-3440

J. M. McLauchlan

OBJECTIVE

The objective of this work unit is to: (1) develop the electro-optical components and technology common to the design of optical sensors for attitude control and guidance; (2) develop new and improved electro-optical sensors for attitude control and guidance applications.

Included are the following activities: (1) development of improved performance photodetectors; (2) development of an improved performance image dissector; (3) development of improved techniques for the design, fabrication, and evaluation of optical systems; (4) development of a high-accuracy, wide-field digital sun sensor.

PHOTODETECTORS

Both photoconductive (cadium sulfide) and photovoltaic (silicon) photodetectors are currently used in sensors for the Mariner series spacecraft. During the fourth quarter of FY 68 photodetectors of this type, representative of the state of the art, have been procured from vendors. A test station for test and evaluation is being set up and will be put into use in the second quarter of FY 69.

IMAGE DISSECTOR

Flight image dissectors procured for the Mariner Mars 1969 Canopus star tracker have experienced performance problems. To further establish present performance limitations of the image dissector and plan necessary improvements, a diagnostic effort is being conducted. A major problem has been excessive noise when the voltages necessary for high gain are applied. Preliminary tests have indicated that this noise is associated with internal surface leakage at the point where the dynode leads enter the image dissector. Further tests, evaluation, and remedial processing will be conducted in the first half of FY 69.

In addition to the noise problem there are many other performance parameters of the image dissector that can be improved and will thus enable significant improvement in the capabilities of both the Canopus star tracker and the approach guidance subsystem. Preparation of a performance specification and a contractor work statement encompassing both performance and configuration improvements has been initiated. A contract to implement these improvements in the image dissector will be let in the second quarter of FY 69.

Studies are continuing with the electron optical program for the design of electrostatic image systems. These studies are at a low level, for while the program seems to give results of the necessary accuracy it has not been possible to verify experimentally the results in the laboratory. These experiment studies on existing image dissectors will be conducted during the second half of FY 69.

OPTICAL SYSTEM TECHNOLOGY AND TECHNIQUES

The Fortran IV version of the optical design computer program, together with a three-volume users manual and report, has been provided to the cosmic computer center at the University of Georgia.

The optical fabrication facilities have been consolidated and an optical edger has been procured.

DIGITAL SUN SENSOR

Studies being conducted at JPL for advanced missions (Jupiter flybys and Grand Tour outer planet missions) have indicated the need for a high-accuracy wide field-of-view digital sun sensor. This type of sensor, without wide field-of-view capabilities, would also be a significant improvement to the present approach guidance system design. Establishment of detailed performance objectives will be completed during the first quarter of FY 69 and preliminary design will be initiated during the second quarter.

PUBLICATIONS

None.

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GUIDANCE AND CONTROL SUBSYSTEM INTEGRATION FOR FUTURE MISSIONS

NASA Work Unit 186-68-02-21-55

JPL 384-65201-1-3430

J. W. Moore

OBJECTIVE

The objectives of this work unit are to study interactions among guidance, attitude control, computing and sequencing, and power subsystems for planetary spacecraft; to develop coordinated, compatible guidance and control subsystem configurations; and to develop analytical techniques with common application among several subsystems.

APPROACH GUIDANCE

At the end of the second quarter of FY 68, TRW Systems completed work on JPL Contract 951936, "Spacecraft-Based Optical Approach Guidance Evaluation." The primary output from the contract was a computer simulation of the approach guidance measurement system. The simulation output consisted of a spacecraft telemetry data stream containing the tracker and spacecraft attitude data. During the third quarter of FY 68, the simulation was evaluated using data from several check cases. The results were analyzed to operationally verify the simulation and for comparison with expected results.

As a result of in-house manpower limitations and other task priorities, a major portion of the funds in this work unit was reprogrammed into the Ground Support Equipment Advanced Development Work Unit 186-68-02-27. The reprogramming, which occurred in the third quarter of FY 68, reduced the manpower allocated to this work unit to a very low level. Following the reprogramming, the FY 68 objectives were revised. In the fourth quarter, the effort has been directed toward maintaining cognizance of the results of the approach guidance hardware development and evaluation program conducted by the Spacecraft Control Section, Work Unit 186-68-02-23, and to determine and specify planet tracker tests required to define its performance characteristics.

It is anticipated that the effort in the above areas will continue into FY 69 and the results will play a significant role in achieving the milestones set for FY 69.

FUTURE PLANS

Future plans include (1) developing a mathematical description of the prototype approach guidance planet tracker, (2) evaluating the feasibility of spacecraft-based approach guidance systems for planetary missions, and (3) developing navigation and guidance software for a spacecraft computer. The R&AD work unit schedule shown in Fig. 1 outlines in more detail the milestones established for accomplishing the planned efforts. The effort expended in FY 69 will improve the capability to determine the value of approach guidance to future planetary missions.

PUBLICATIONS

SPS Contributions

1. Barone, L. J., and Duxbury, T. C., "Approach Guidance Measurement System Simulation," SPS 37-50, Vol. III, Apr. 30, 1968.

R & AD WORK UNIT SCHEDULE

NASA Code 186-68-02-21-55 JPL Code: 384-65201-1-3430 Resp. Indiv. Suggs, Eric E. Ext: 6249

Title: Guidance and Control Subsystem Integration for Future Missions Date: June 28, 1968

Revision No:

Major Milestones	Prior FY 67 Quarter				Present Fiscal Year 68 Month												Next FY 69 Quarter			
	1	2	3	4	J	A	S	O	N	D	J	F	M	A	M	J	1	2	3	4
1. JPL Contract No. 951936, "Spacecraft-Based Optical Approach Guidance Evaluation"																				
2. Verified computer simulation developed under JPL Contract No. 951936																				
3. Monitor tests on approach guidance prototype planet tracker																				
4. Specify tracker test requirements																				
5. Revise computer simulation																				
6. Investigate methods for simplifying measurement processing and orbit estimation in a spacecraft computer																				
7. Develop prototype software for spacecraft computer																				
8. Study applicability of tracker to future missions																				

Notes: The proposed effort for FY 69 is in-house.

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DEVELOPMENT OF ACTUATOR PROCESSES AND MEASURING TECHNIQUES

NASA Work Unit 186-68-02-22-55

JPL 384-64701-2-3440

J. D. Ferrera

OBJECTIVE

The three major objectives of this task are to:

(1) Finalize the Quantative Leak Test Design Guide (this objective was completed in the first 6-mo period of FY 68).

(2) Develop the capability necessary for testing, and test the two solid propellant electrical thruster motors delivered under JPL Contract 951591 with the General Electric Co.

(3) Continue the establishment of thrust and impulse measuring techniques for thrusters in the milli- and micro-pound range.

A fourth objective (which will extend into FY 69) was initiated in May, 1968:

(4) Attempt to measure thrust as a function of leakage for Mariner-type altitude control gas valves. Valve leakage produces a biased translational force on a spacecraft. The added gas required for a mission to allow for this leakage, plus the gas requ- d to cancel the biased force due to leakages, can mean a severe gas system weight penalty for long duration missions (up to 12 yr as in Grand Tour-type missions) even though the actual thrust level produced is quite small ($<10^{-6}$ lb). Thrust level test data as a function of leakage are required in sizing gas systems for future missions since theoretical predictions on thrusts produced in the low flow regime (10 cm^3/hr) are not sufficiently accurate.

APPROACH AND STATUS

Solid Propellant Electrical Thruster (SPET) Testing

The testing of the two SPET motors supplied by General Electric has been completed. A decision was made early in the second half of FY 68 not to fund General Electric for additional SPET development at this time. For this reason, and because G. E. has made significant improvements in the SPET concept since delivery of hardware to JPL, it was also decided not to carry on a test program as detailed as that depicted in the previous semiannual report. Sufficient testing was performed to conclude the following:

(1) The SPET concept (pulsed plasma) can be reduced to hardware capable of providing thrust in the micro-pound range.

(2) The data supplied by G. E. on thrust levels produced by the SPET motors is in agreement with JPL test data.

(3) As discussed in the G. E. final report, the fuel supplied with the SPET motor is hydroscopie; therefore, extreme care must be taken in making flow rate measurements at operating temperatures. (Since delivery of hardware, G. E. has, with internal funds, developed a fuel which does not exhibit this property).

THRUST AND IMPULSE MEASURING TECHNIQUES

The background on this test apparatus is explained in more detail in the previous semiannual report. As detailed in that report, an inductive non-contacting pickoff is being used with success. The calibration results are explained in detail in the SPS article listed at the end of this report. Tests to determine steady-state thrust levels as a function of nozzle throat area have been run and the results are in agreement with the computer analysis results. Additional tests will be run, simulating as closely as possible flight conditions. A rough measurement of total impulse was made by calculating the effective mass of the test setup and measuring the maximum velocity on the first swing of the cantilever beam resulting from a 20-ms pulse. The mass times velocity product is a measure of total impulse (momentum).

Preliminary results of this test are sufficiently propitious to justify refinement of the procedure. Work on measurement of the thrust-time profile will continue through FY 69. The thrust levels involved in this testing are 2 to 20 millipounds over 20-ms intervals.

THRUST DUE TO GAS VALVE LEAKAGE (See Fig. 1)

The torsion pendulum procured from General Electric in August, 1967, to test the SPET motors has the capability of measuring steady-state thrust levels down to one micropound (±5%). A gas system weighing less than 5 lb and consisting of a gas bottle, fill valve, tubing, valve manifold, and Mariner-type valve was fabricated and mounted on the torsion pendulum platform. With improved readout instrumentation a measurement of 0.15×10^{-6} lb thrust at 3.3 cm^3/hr leak rate (approximate leak rate of the Mariner flight specification) was obtained. Further improvements in the pendulum are required to substantiate this data point; however, the initial results are propitious. One problem area being reviewed currently is the nonrepeatable zero position of the platform. As mentioned, although this is a very low thrust level, the net thrust accumulated over an extended length of time results in a significant weight penalty. Work in the refinement of the test setup and additional testing will continue into FY 69.

This work unit will be terminated at the end of FY 68. The tasks outlined under the last two objectives listed will be continued into FY 69 under NASA Work Unit 731-13-01-03-55 (Extended Mission Gas Actuator Component Development).

PUBLICATIONS

SPS Contributions

1. Ferrera, J. D., "Calibration Results for the Mariner Attitude Control Gas Jet Nozzle Thrust Measurement Test Setup," SPS 37-50, Vol. III, Apr 30, 1968.

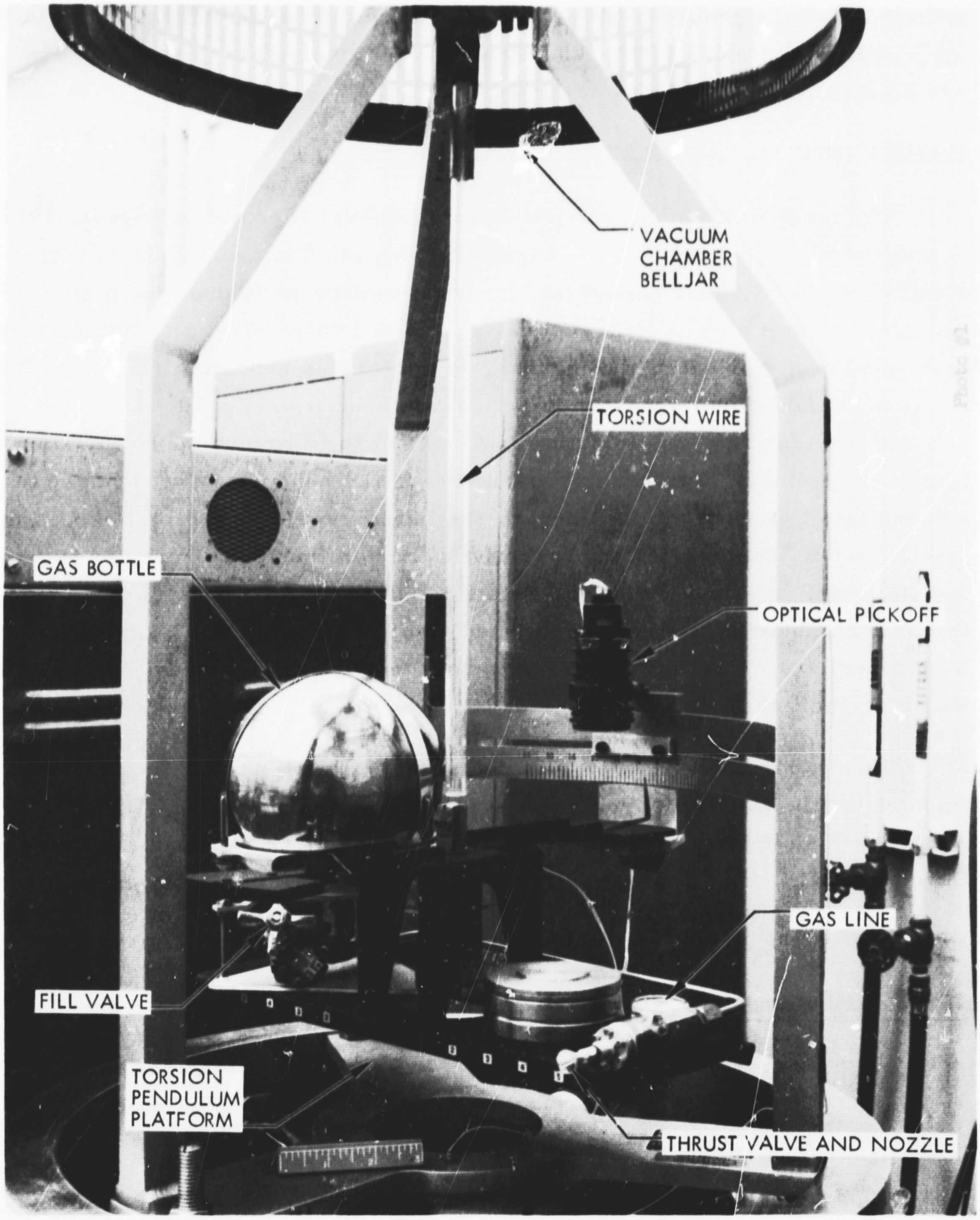

Figure 1. Test Setup For Thrust Versus Gas Leakage Measurement

APPROACH GUIDANCE SUBSYSTEM DEVELOPMENT

NASA Work Unit 186-68-02-23-55

JPL 384-66101-2-3440

F. R. Chamberlain

OBJECTIVE

The long-range objective of the approach guidance subsystem development effort is to develop technology for the use of optical measurements (made during a period of several weeks prior to planetary encounter) for spacecraft guidance. The optical measurements are independent of data used at present for radio orbit determination; they can be used to complement radio orbit determination for an optimum and more accurate solution, or they can be utilized alone in a case of a failure of the radio data acquisition and processing system. Increased accuracy in the prediction of trajectories is advantageous to, and increases probabilities of, success for all interplanetary missions. Missions requiring orbit injection, capsule descent, or multiplanet flyby are particularly benefited. In the case of a Grand Tour mission, the savings of spacecraft weight through more accurate trajectory corrections approaches one-half of the spacecraft weight that would be necessary without approach guidance.

Current objectives include the assessment of nonrepeatable errors in prototype rotating optical wedge planet trackers used for the optical measurements described above; a preliminary study directed toward the use of high-resolution raster methods for approach guidance purposes; and a computer program being developed for use in hardware optimization studies. System integration with computer and software elements will be carried out, leading to limited ground feasibility demonstrations of the approach guidance concept.

Future objectives will include the integration and refinement of all end results stated above as current objectives. Measured hardware nonrepeatable errors will be utilized for an improved estimate of current approach guidance technology limitations by inclusion in existing error models. Extensions of nonrepeatable error testing will include hardware ground feasibility demonstration exercises, and completion of system integration activities will permit ground feasibility demonstration of hybrid or "fully-on-board" approach guidance systems. Evaluation of vidicon technology for approach guidance will be preceded by limited experimentation with existing spacecraft image recording subsystems; later, high sensitivity vidicon systems with improved resolution and distortion rejection will be developed for use as autonomous approach guidance hardware elements; development of error models and feasibility demonstration activities will parallel other efforts based on rotating wedge mechanizations.

Information on the sensitivity of nonrepeatable errors to engineering parameters for both high-resolution vidicon and rotating wedge mechanizations will be used as inputs for the computer optimization program. The program ultimately will assess the relative merits of alternate technologies for a specific mission and select optimum engineering parameters by trading off weight, size, power, and electronics complexity against performance in terms of nonrepeatable errors.

STATUS

A detailed summary of knowledge concerning the optical scanning subassembly is being prepared, as preliminary to the evaluation of nonrepeatable errors and the development of calibration methods. This summary will include the alignment and assembly methods, described in detail, and alternative approaches to these operations will be evaluated by statistical repeatability testing. In illustration of the complexity of the problem being studied, consider that the scan subassembly must possess an open-loop optical gimbal repeatability for 4 arc seconds 1 sigma, in a mechanization which includes 2 encoders, 2 couplings, 6 gear interfaces, 6 anti-backlash devices, and 20 sets of ball bearings. Sensitivity to participate contamination must also be considered, as indicated by the fact that an error of 1 arc second may be developed by a gear tooth displacement of 1μ.

Preliminary design and breadboarding of a stable power supply for the auxiliary sun sensors has been completed and stability tests have been performed. Three adaptive gain control circuits for compensation of variable control system errors (proportional to planet radius) have been designed and partial breadboarding of the circuits has been accomplished. Servo analysis of the three interacting control loops has proceeded to the point at which digital analysis of time-domain state variables may be initiated. Empirical evaluation of servo loop stability will follow final development of adaptive gain control circuits.

Modifications of facilities for optical planet tracker evaluation and feasibility demonstration studies are essentially complete. A system of providing temperature stability has been installed, and final control system stabilization efforts are in progress. Optical test fixtures and direct-access electrical networks for planet tracker prototypes have been fabricated and the auxiliary laboratory cabling has been installed. Preliminary studies of optomechanical devices for stimuli nutation in control system testing are in progress.

An assessment is being made of the feasibility of using Mariner Mars 1969 TV subsystem data for optical orbit determination. Stars near the planet's edge are sensed and their positions are related to the planet's geometric center. Successfully scanned frames exhibit angular changes in the planet–star relationships, and thereby furnish the required guidance data. Feasibility of this approach is dependent on subsystem ability to locate a planet's edge and detect adjacent stars without ambiguities or large errors attributable to uncalibrated system distortion. Photometric analysis of the Mariner Mars 1969 TV subsystem and simulators have been performed and utilized in the design and fabrication of precision calibration targets. These targets are being used to test subsystem ability to detect stars in the anticipated brightness range and to geometrically relate them to the planet's edge.

A computer program is being developed for use in optimizing planet tracker mechanizations for multiplanet missions. Analysis operations involve superimposing the spectral characteristics of solar energy, planetary albedo, optical systems transmission, and electro-optical sensor response. Alternate mechanizations will be evaluated to achieve adequate performance within stringent limitations to power consumptions, size, weight, and electronics complexity. The final program will provide the means for trading off performance and engineering factors, with respect to signal processing sophistication as well as optomechanical and electro-optical mechanizations.

PLANNED ACTIVITIES

Automatic methods will be developed for the control of measurement and simulation operations, monitoring of environmental parameters, and processing of acquired data. Mapping operations in nonrepeatable error testing and calibration will be carried out by two-axis exploration of the field-of-view, with repetitive measures and variations of environmental parameters at each grid intersection. Since the data to be acquired will require sufficient repetition for each set of conditions to be statistically usable, and since in this context sensitivity to environmental factors must be determined both interdependently and as a function of a two-dimensional map, long duration testing with processing of enormous amounts of data will be involved. Automatic methods are considered mandatory, and their development will be emphasized.

Ground feasibility demonstrations of hardware, system integration activities, and system ground feasibility demonstrations will be based on the same automatic methods as thos developed for nonrepeatable error testing and calibration. In ground feasibility demonstrations of hardware, the superimposed angular changes due to attitude motion and trajectory translation will be simulated either by stimuli bundle perturbation, biaxial planet tracker rotation, or both. Data from both the tracker and the simulation equipment will be transmitted by data link to the computer used for orbit determination, and the actual input trajectory will be compared with the estimated trajectory.

System integration will provide for either partial (hybrid system) or complete (fully on-board system) data processing by a prototype on-board computer. System feasibility demonstrations will include, as with hardware alone, the comparison of actual and predicted trajectories. All planning and development of automatic methods for simulation control and data processing will emphasize provisions for extension into system integration and ground feasibility demonstration efforts.

Engineering development activities in the improvement of planet tracker performance will continue, and increased attention will be given to alternative mechanizations, particularly those using already developed vidicon scanning technology. Development of the computer program for hardware optimization will be extended and used in preliminary analyses of both near-term and other missions as appropriate, pending completion of empirical analyses which define the sensitivity of nonrepeatable errors to engineering parameters. An effort will also be directed toward devising and evaluating methods for sensing attitude motion, since errors in maintaining stable geometrical references carry over directly in orbit determination estimates.

Planning will be conducted to provide estimates as to cost and schedule for inclusion of approach guidance technology on near-term missions as engineering experiments or mission critical elements. Due to the very high sensitivity of orbit determination results to operationally immeasurable errors, continued emphasis will be given to recommending flight feasibility demonstration as an engineering experiment prior to requirements for approach guidance technology in mission critical applications.

PUBLICATIONS

1. Fridge, D., and Dozmati, E., "Operation and Instruction Manual for the Approach Guidance Subsystem Mars Simulator," Electro-Optical Systems, Inc., 7149-OM-MS, Pasadena, California, JPL Contract 951699, Dec. 4, 1967.

2. "Final Report of the Approach Guidance Subsystem, Mariner Mars 1969," Electro-Optical Systems, Inc., 7149-FR, Pasadena, California, JPL Contract 951699, Feb. 23, 1968.

3. "Servo Analysis Final Report," Electro-Optical Systems, Inc., 7149-SFR, Pasadena, California, JPL Contract 951699, Jun. 5, 1968.

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REMOTE OPERATION OF A ROVING VEHICLE

NASA Work Unit 186-68-02-25-55

JPL 384-66701-2-3430

V. F. Anthony
J. W. Moore

OBJECTIVE

The objectives of this task are to analyze, design, and develop, and test systems and components for controlling the motion of unmanned planetary surface roving vehicles; to investigate concepts and techniques pertaining to the earth-based and vehicle-based portions of roving vehicle motion control (RVMC) systems; and to produce designs, specifications, and recommendations directly applicable to planetary explorational missions.

BACKGROUND

The feasibility of using unmanned roving vehicles for planetary exploration is directly dependent upon the capability for effectively and safely controlling vehicle motion over long distances and for extended periods of time. The control function must include human participation in the system control loop to provide judgement, reasoning, diagnosis, perception, and reaction to unexpected circumstances while operating the vehicle in unfamiliar and severe environments. Because these human functions are intimately interrelated with other elements of the complete control-mobility system, this work unit is being carried out in mutually beneficial association with an OART developmental task "Man Machine Functions in Control of an Unmanned Roving Vehicle," NASA Work Unit 127-51-01-02-55.

PROGRESS

The final report of the Phase I study and analysis contract with the General Motors AC Defense Research Laboratories was published and distributed January 26, 1968. The report covers a study and analysis of the problem of controlling roving surface vehicles at planetary distances. The first portion of the report presents the foundations of the study - historical background, nature of the roving vehicle motion control (RVMC) problem, and the operational constraints and ground rules for the study. This is followed by a delineation of missions which were postulated, and the terrain models which were assumed. An approach to the analysis of functional requirements is presented, and general system configurations are worked out for each mode of operation.

The various alternatives for subsystem implementation are discussed relative to both the current and projected state of the art, and data are provided for making rough estimates of over-all system weight requirements. A separate section of the report is devoted to the human factors involved in RVMC operations. System parameters are traded off to evaluate their relative significance to the over-all problem and to determine order-of-magnitude values for optimum performance measured in terms of average locomotion velocity. Recommendations are offered for the directions in which future analytical effort could most usefully be applied.

Although image sensors will be needed for path-planning functions, it is concluded that on-board decision-making capability is required at planetary distances, and that the current state-of-the-art points toward nonimage-type sensors compatible with relatively simple, rapid data processing for routine control functions.

Because of funding limitations, the follow-on hardware development and test phases of the program have not been continued with the contractor. However, the work is being included in the in-house effort on a limited basis.

The request, submitted in March, for Surveyor residual telecommunication, telemetry, command, and support equipment has been correlated with the Form DD540 inventory lists of the equipment distributed to NASA in June. Final disposition of the requests is not expected to occur before August 1, 1968.

Figure 1 reflects general deferment of the tasks outlined in the FY 68 schedule due to later than anticipated receipt of the Surveyor equipment, and redirection of manpower to higher priority projects.

Assuming successful acquisition of the equipment requested, the control test model (CTM) vehicle will be updated to provide a test system which has a broader and more flexible capability for command and communication with the vehicle. This offers an opportunity to explore interrelationships and balance between human operator and automatic functions to test concepts and systems while operating remotely over natural terrain, with appropriately induced communication time lags.

Breadboard displays are being assembled for investigating various methods of presenting stereo-video information to the operator in an effort to eliminate the restrictions of the typical stereo viewer now in use.

A vertical view, map-quality, aerial photograph of the Arroyo Seco vehicle test site adjacent to the Laboratory has been taken. The photo, enlarged to 16 times 20 in. resolves 3-in. objects on the surface of the site, and will be used by the operators as one method for determining vehicle location on the test site by correlating the remote TV view with identifiable land marks and other cues. Operators will be judged by their ability to determine vehicle location and then to proceed to some destination marked on a photo overlay. Positioning and navigating by triangulation from prominent land marks, such as those found on Orbiter photos, has been suggested for planetary traverses.

Incidental to the development program, several public information demonstrations of the CTM vehicle have been performed. These demonstrations have consisted of maneuvering the vehicle by remote control over obstacles and rough terrain. Interested groups have included NASA officials, teachers, civic organizations, and high school science clubs.

UNIVERSITY RESEARCH CONTRACTS

Contracts let by NASA Headquarters to Cornell University and to Rensselaer Polytechnic Institute were monitored during the last half of FY 1968.

Cornell University completed the initial design of a model of a lunar surface roving vehicle. This design was begun in the first half of FY 1968.

The basic structure, wheels, drive system, steering system, and radio command transmitter/receiver system were fabricated and assembled. A working vehicle was demonstrated in May 1967. A laser obstacle detector, an inertial heading control system, and a soil-sampling device have been independently demonstrated, but not integrated into the vehicle. The effort will be continued in FY 1969 and future work includes the integration of the above items into the vehicle, improvements in the radio command system, and the design of a vehicle computer for data processing and navigation.

Rensselaer completed a series of related analyses which treated various aspects of the problem of atmospheric entry, soft-landing, surface mobility, and processing of experimental data. A scheme for modeling and estimating atmospheric parameters and for controlling vehicle descent through the atmosphere was developed and evaluated. Liberal use was made of adaptive control techniques in these analyses. An innovative scheme for unpowered aerodynamic braking, descent, and relifting using rotary wing devices was analyzed. Problems of attitude control, terrain sensing, and path-finding for mobile surface vehicles were studied and schemes were proposed for solving these problems. Analysis and evaluation of the proposals was accomplished. Modeling of a system for chromatographic analysis was begun as a first step in determining the requirements for processing data from typical planetary surface experiments. Future work in FY 69 will be concerned with the extension of the above items.

PLANNED ACTIVITY

During FY 69 the program will continue the on-going effort described, with special emphasis on vehicle update, and on operator-vehicle test and evaluation at the test site. In this period, a preliminary set of mission requirements for Mars will be assembled, and a functional design of a guidance and navigation system will be generated, from which a comprehensive test plan for FY 70 can be devised.

Participation in study activities, and in roving vehicle related activities in other areas will be continued.

Technical monitoring of the University Research Contracts will continue during FY 69.

PUBLICATIONS

Contractor Reports, Interim and Final

1. Miller, B. P., Corry, T. M., Johnson, D. W., Johnston, R. J., and Lingerbelt, J. E., "Roving Vehicle Motion Control," Final Report, General Motors AC Electronics Defense Research Laboratories, TR 67-60, JPL Contract 951829, Dec. 1967.

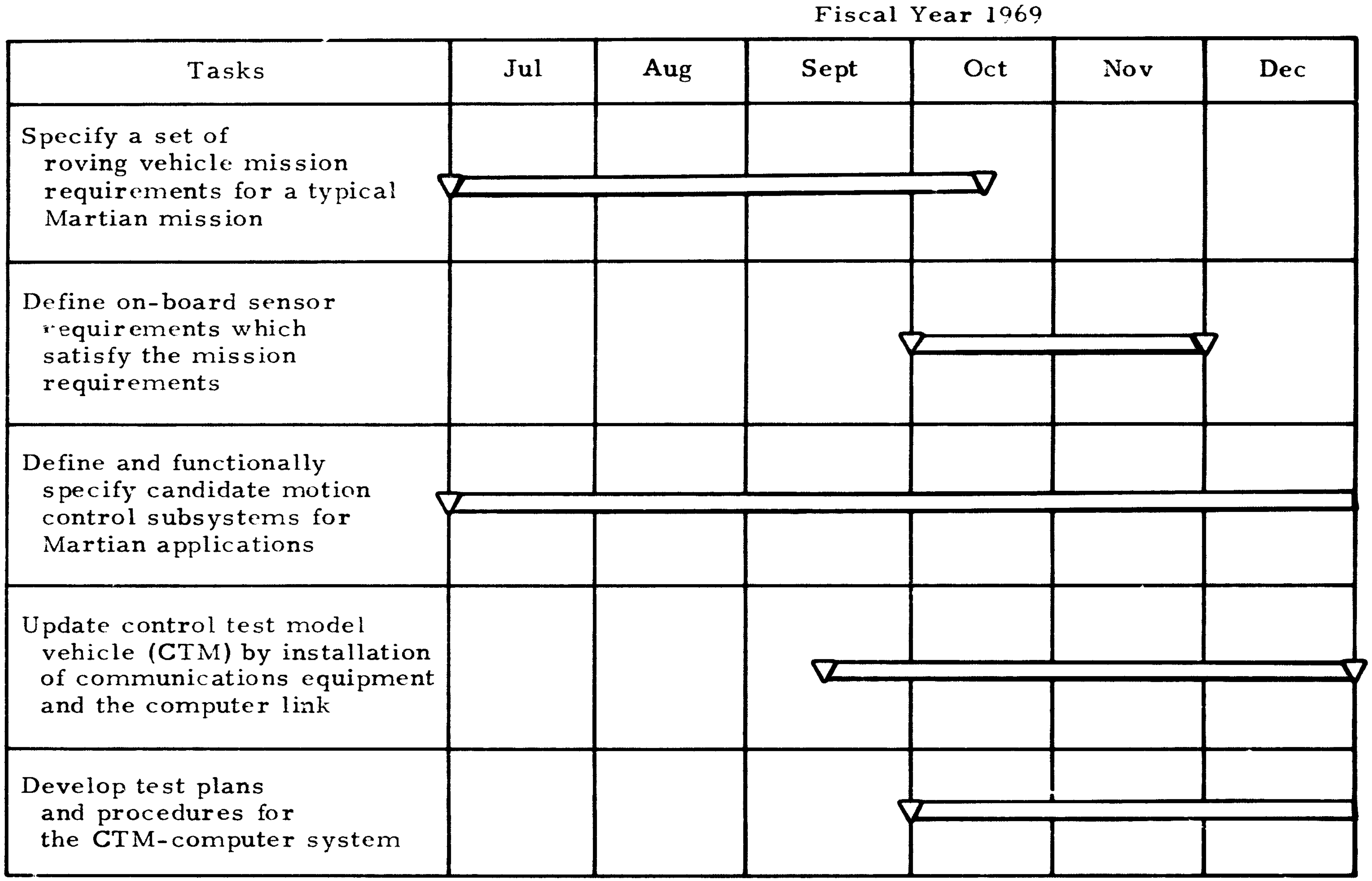

Figure 1. Roving Vehicle R/AD Work Unit Schedule

OSE ADVANCED DEVELOPMENT

NASA Work Unit 186-68-02-27-55

JPL 384-66901-3430

T. P. Cerney
J. P. Perrill

OBJECTIVE

The long-range objective of this task is to develop the guidance and control operational support equipment (OSE) technology to meet the requirements of future planetary missions. Within this objective, the near-term goal is to develop an OSE-unified approach concept. This concept is to be applied to the three guidance and control flight subsystems (electrical power, guidance and control, and central computer and sequencer) to provide an integrated approach to subsystem testing in the laboratory, manufacturing area, system test complex, and launch complex.

OSE UNIFIED APPROACH CONCEPT BEING DEVELOPED

This concept will specify the use of the same basic OSE in all test areas where a flight subsystem exists as an assembled entity. Adaptors, buffers, or additional cabling will be added in areas where more test points are available and where more detailed tests are required.

The basic control element in all test areas will be a small commercially available general-purpose computer. A versatile man-machine interface is to be provided by a cathode ray tube (CRT) graphic system, permitting instant input/output access to the user. A test language will be provided that requires relatively little training and is based on user requirements rather than computer characteristics. The language will have on-line response and will present the user with the capability of direct control access to the unit under test, with automatic checking of responses. Alterations from mission to mission are expected to cost much less than the present method of reworking existing OSE hardware.

The hardware interface unit will provide special purpose logic, signal conditioning, and buffering between the unit under test and the general purpose input/output channels of the computer. The interface unit is to be designed as a "sample-and-hold" device in both directions, with control reserved and maintained by the computer. The software will function as an interpreter between the test engineer and the unit under test. A primary function of the interpreter will be to take a user-defined engineering language test program, and develop the subsystem test program while maintaining an error monitoring and display capability.

The software will be tailored to a hardware configuration of (1) central processing unit, (2) graphic system, (3) subsystem interface, and (4) bulk storage. The software will be modular in concept and real-time in operation, and is classed as an interpreter. Some of the features planned for this interpreter are:

(1) A basic set of frequently-used, thoroughly-checked elementary programs which may be selected and run by the user with minimal effort.

(2) Orderly growth of programs obtained by user experience and the sequencing of elementary subprograms.

(3) A programming language consisting of engineering parameters, rather than the mnemonics used by programmers.

(4) The ability to change, update, clear, and insert into the existing program on-line; i.e., dynamic change of the checkout program without the aid of an off-line software assembly.

PROGRESS

Considerable effort has been devoted to expanding this development and including the participation of related OSE disciplines at JPL. This effort has culminated in the preparation and submission of a proposal for a cooperative development task in computer-oriented OSE to the Office of Space Sciences and Applications. This task would have the objective of establishing the economic and technical feasibility of the computer-oriented test sets (CTS) to support several flight spacecraft subsystems.

The preliminary design of a CTS feasibility-demonstration model to test a Mariner Mars 1969 spacecraft central computer and sequencer (CC&S) subsystem is nearly complete. The detailed hardware and software requirements for a commercial general-purpose computer were completed in March 1968. The procurement of a leased general-purpose computer was initiated and competitive proposals have been evaluated. The contract has been sent to NASA for approval with a contract award target date of July 1, 1968. System delivery is expected in September 1968. Selection criteria for the computer included items related to the use of the same type of computer for the support of several types of subsystems.

The computer system selected includes a central processor with automatic data channels, priority interrupts, a real-time clock, a magnetic tape unit, a card reader, a system control unit, and a line printer. Future activities will include the continuation of software design, generation of detailed flow charts, and coding and initial checkout of the program. Installation of the leased computer will be accomplished, and personnel will attend vendor-supplied training courses in programming and operation. The interface unit to mate the general-purpose computer to a Mariner Mars 1969 CC&S will be designed and fabricated to provide the remainder of the CTS feasibility demonstration hardware.

A small level of effort was expended in support of system level testing of the Capsule System Advanced Development (CSAD) project. In the first half of FY 68, OSE was developed for the lander sequencer and timer portion of the CSAD project. This project is now complete.

PUBLICATIONS

SPS Contributions

1. Perrill, J., "Development of Computer-Oriented OSE" SPS 37-51, Volume III, June 30, 1968.

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DEVELOPMENT OF A WIDE-ANGLE GAS BEARING GYRO

NASA Work Unit 186-68-02-29-55

JPL 384-69101-2-3440

P. J. Hand

OBJECTIVE

The objective of this work unit is to develop a miniature wide-angle gas bearing gyroscope. A gas bearing gyro of this type could find future application for long lifetime missions or for planetary landed applications. The capabilities of this gyro will include thermal sterilization, a low-power spin motor, and the ability to withstand 200 g shock and 25 g vibration. Drift performance will equal existing wide-angle gyros.

The gyro chosen for this development is the Honeywell, Inc., model FGG334S. The spin motor used is identical to the motor of the DGG159E gyro being developed under Work Unit 186-58-02-07-55. The gimbal suspension is different, being a dithered pivot and jewel design rather than the pumped fluid type of the DGG159E.

STATUS

The problems associated with the spin motor design, discussed in the last R&AD Program Document 701-6, Vol. I, have been corrected. The solution is the same as the one described in the report of Work Unit 186-58-02-07-55, inasmuch as the motor designs and, therefore, the problems are identical.

The first FGG334S has been assembled and run-in. Preliminary testing is now in progress. An rms stability of the random drift of 0.042 deg/hr has been demonstrated during these initial tests. Tests remaining are gimbal freedom, torquer linearity, anisoelastic coefficient, step response, and cool-down stability. If performance data during all these tests are according to specification, the gyro will be ready to ship in early July for continued evaluation at JPL. Sterilization tests will be performed after a satisfactory performance base has been established.

If testing continues to go well, gyros 2 and 3 will be shipped about one month apart. Gyros 4 and 5 are to receive additional testing at Honeywell, Inc., and will not be delivered until October 1968.

PUBLICATIONS

SPS Contributions

1. Hand, P. J., "Sterilizable Inertial Sensors (DGG159E and FGG334S Gyros)," SPS 37-51, Vol. III, Jun. 1968.

Contractor Reports, Interim and Final

1. White, D. R., "Sterilizable Wide-Angle Gas Bearing Gyro," Honeywell, Inc., Report No. 20584 QR6, JPL Contract 951529, Apr. 1, 1968.

EVALUATION OF ADVANCED GYRO FOR LANDED OPERATIONS

NASA Work Unit 186-68-02-30-55

JPL 384-69201-2-3440

P. J. Hand

OBJECTIVE

The objective of this task is to evaluate a new class of truly subminiature floated rate integrating gyroscopes for consideration in the design of attitude control systems for future missions. The gyro is the Kearfott Alpha III. This is a subminiature design, 0.4 lb in weight and 4 in.^{3} in volume. Motor power requirements are 2.0 W, maximum. Anticipated drift performance is equal to that experienced in the larger Kearfott gyros used in the Mariner IV, V, and Mariner Mars 1969 attitude control systems.

STATUS

The two high-gain gyros discussed in the last report (R&AD Document 701-6, Vol. I, p. 173) have now completed all normal day-to-day stability and environmental testing at JPL. They are now well into the life-test phase.

Performance of the critical drift parameters, such as spin-axis mass unbalance, input-axis mass unbalance and fixed torques, was satisfactory throughout the day-to-day testing. The day-to-day drift deviation was less than 0.2 deg/hr for the first 400 hr of testing, including the effects of 200 g shock and Mariner Mars 1969 type-approval vibration.

Early in the drift testing phase, data began to disclose a difficulty in the form of a steadily increasing spin-axis mass unbalance drift. This effect is usually associated with a spin motor bearing wear-out condition. At a running time of 2500 hr, one of the gyros (S/N 209) has reached a drift value greater than -2.3 deg/hr/g. The specification limit is 0.50 deg/hr/g.

This excessive drift condition was considered serious enough that the gyro was removed from life test, and returned to the vendor for additional special motor tests. Approximately 1 mo of these additional tests was performed, and the gyro was subsequently returned to JPL. To date, a complete report has not been received from Kearfott, although preliminary verbal information indicates that the trouble is not a wear-out condition, as much as possible dimensional change within the motor.

The second life test gyro (S/N 202) is following a performance pattern similar to the first, in that the spin-axis mass unbalance is showing an increasing trend. At 1360 hr of running time, the drift value was -1.2 deg/hr/g.

The wide-angle version of the Alpha III gyro, also being evaluated, is in the early stages of day-to-day stability testing. Short-term drifts, while not as stable as the high-gain type, are still well within specifications.

During the next 6-mo, this gyro will be subjected to the same shock and vibration environmental testing as the two high-gain units. Assuming this gyro will be more satisfactory on life test than the high-gain gyros, and that the gyro motor being evaluated for sterilization (Work Unit 186-58-02-08-55) will be successful, procurement of a gyro combining these features has been planned for FY 69.

PUBLICATIONS

None.

EXTENDED MISSION CONTROL SYSTEMS DEVELOPMENT

NASA Work Unit 186-68-02-31-55

JPL 384-69301-2-3440

L. F. McGlinchey

OBJECTIVE

The objective of this work unit is to incorporate devices into attitude control systems that are uniquely suited for extended missions. The emphasis for FY 68 was to incorporate a solid propellant electric thruster, being developed under another work unit, into a control system. The electric thruster work unit was cancelled, resulting in a change in emphasis on this work unit to the study of the attitude control of electric propulsion powered vehicles during the nonpowered flight phase. This is within the long-range scope of this work unit, and is directly applicable to an advanced technical studies task for a Jupiter solar electric propulsion mission.

PROGRESS

During the last reporting period, tradeoff studies were completed to arrive at a baseline configuration for the Jupiter solar electric propulsion mission. The baseline configuration that was chosen was a Mariner-type cold gas attitude control, for the nonpowered flight phase. The primary problem to overcome was the effect of interaction with very large solar arrays. However, analysis and computer simulation showed that the Mariner-type system could be made to operate effectively, even with large solar arrays, and the system is well known and fully developed. A complete detailed mechanization block diagram that can be used to derive all necessary component design criteria was developed. The pertinent control system parameters are listed in Table 1. This work fulfills the objective of this work unit.

Besides completing the objective of this work unit, additional work was completed in the area of control system development for extended missions that will directly support future development programs. Specifically, two alternate system configurations have been established for a Grand Tour mission: (1) a momentum exchange system utilizing momentum wheels, and (2), a system utilizing the dual spin concept. The momentum exchange concept was examined in detail during this reporting period. This system would employ momentum management accomplished through the use of reaction jets. This concept is a strong candidate for the baseline configuration for the following reasons:

(1) Continuous control (no inherent deadband required)

(2) A recoverable energy source

(3) Efficient control of cyclic disturbances

(4) Ease in management of propellant expulsion for continuous disturbances

(5) No mass expulsion required to alter vehicle attitude

(6) High reliability (8-yr life test data)

FUTURE

The extended mission control systems development task will not be continued during FY 69. This work, however, will be continued by the Laboratory Advanced Technical Studies Team.

ANTICIPATED PUBLICATIONS

1. Technical Memorandum "An Attitude Control System for an Electric Propulsion Powered Vehicle."

2. Technical Memorandum "Design and Configuration for a Three-Axis Momentum Wheel Attitude Control System."

PUBLICATIONS

None.

Table 1. Control System Parameters

Control System Parameter	Value	Units
Sun sensor scale factor	0.134	V/mrad
Canopus sensor scale factor	0.134	V/mrad
Gyro scale factor	5.4	V/mrad/sec
Sun sensor field of view	±5.0	deg
Canopus sensor field of view	±5.0	deg
Derived rate scale factor	80.0	mrad
Derived rate charge time constant	50.0	sec
Derived rate discharge time constant	100.0	sec
Pitch, yaw, and roll position deadbands	±0.5	deg
Sun and Canopus search rate	2.0	mrad/sec
Rate to position gain	40.0	sec
Gas jet minimum on-time	0.1	sec
Pitch and yaw gas system thrust level	0.09	lb
Roll gas system thrust level	0.15	lb
Pitch and yaw angular control acceleration	4.3×10^{-2}	mrad/sec^2
Roll angular control acceleration	2.9×10^{-2}	mrad/sec^2
Pitch and yaw gas jet lever arms	80.0	in.
Roll gas jet lever arms	67.0	in.

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LONG LIFE AND RELIABILITY CONTROL SYSTEM DEVELOPMENT

NASA Work Unit 186-68-02-32-55

JPL 384-69401-2-3440

W. E. Crawford
H. H. Horiuchi

OBJECTIVE

The long-range objective of this task is to develop and mechanize highly reliable, long-life control system logic and signal shaping circuitry. The immediate objectives are to develop and test an all-digital articulation control system and to develop and test triple redundant majority voting circuits for attitude control logic systems.

STATUS

All-Digital Articulation Control System

The all-digital articulation control system under development is intended to eliminate the disadvantages of the present hybrid system and introduce a variety of design concepts for future applications. A very general design approach was taken so that the basic system would be applicable to various digital control systems. A typical application includes a scan platform for pointing science instruments in a planetary flyby mission and an antenna-pointing system in a surface-landed mission. In addition, the basic system may be applied in a gimballed engine thrust vector control system. Figure 1 is a block diagram representation of the system. The control loop consists of a digital comparator, two-speed oscillators, and an optical shaft encoder to provide feedback. The system uses the parallel binary scheme to process the signal in the control loop. The input signal may be in either an analog, a parallel or serial binary, or an incremental form. In addition, the system may be driven directly by a series of pulses from an on-board computer and sequencer when the control loop is opened. The prime mover of the system is the two-speed oscillator.

The high-speed oscillator is used to slew the platform at 2 deg/sec while the low-speed oscillator is used to track an object (planet, etc.) at approximately 0.1 deg/sec. The system has a maximum angular resolution of 10 bits or 0.35 deg and the platform angular displacement per pulse into the stepper motor is 0.02 deg. The system is provided with a logic circuit which enables a continuous 360-deg tracking of an object.

The digital circuit logic for the entire system was simulated by a computer program to ensure its correct functioning for all modes of system operation. Then the dynamics blocks, such as stepper motor and platform dynamics, were added to the simulation program to investigate the dynamic responses of the entire system. The system breadboard was completed and tested. Satisfactory test results were obtained.

FUTURE WORK

In FY 69, this work will be continued under a new Work Unit 186-68-02-39-55, "Control Systems for Advanced Space Programs." Studies will be conducted to incorporate the developed system into a landed antenna pointing system. Redundant techniques will be investigated to increase system reliability.

TRIPLE REDUNDANT ATTITUDE CONTROL ELECTRONICS

Circuitry has been developed for analog and digital triple redundant attitude control electronics. This includes a complete design for the analog signal shaping circuitry, from sensor inputs to gas actuator driver input. Also complete is the design and breadboard of the triple redundant attitude control logic. A block diagram of the attitude control logic is shown in Fig. 2. The breadboard has recently been completed and is now being tested.

The design goals in the attitude control logic design are briefly summarized below:

(1) The circuit must be able to withstand a single electronic device failure without a logic malfunction.

(2) The circuit must be capable of being monitored by telemetry in order to detect the failure of any single electronic device.

(3) The design should incorporate provisions for ground-controlled testing of each of the three parallel channels of a triply redundant logic circuit (for both prelaunch and in-flight testing).

(4) The circuit should be functionally insensitive to transients on the interface lines (20 V amplitude and 500 μs duration).

(5) The elimination of relays is a design objective. Relays are to be replaced with solid state switching whenever possible.

FUTURE WORK

For FY 69, this work will be continued under new Work Unit 186-68-02-39-55, "Control Systems for Advanced Space Programs." The work being carried further in this area is directly applicable to the design of attitude control systems with long life requirements, such as orbiters, Jupiter missions, etc.

Future work will include the design of adaptive controls for triple redundant circuits. This includes the ability to switch from triple redundant operation to single channel operation during flight to optimize electronic reliability.

ANTICIPATED PUBLICATIONS

1. Technical Memorandum "All Digital Articulation Control System."
2. SPS "Triple Redundant Attitude Control Electronics."

PUBLICATIONS

SPS Contributions

1. Horiuchi, H., "All Digital Articulation Control System Development," SPS 37-50, Vol. III, Apr. 30, 1968.

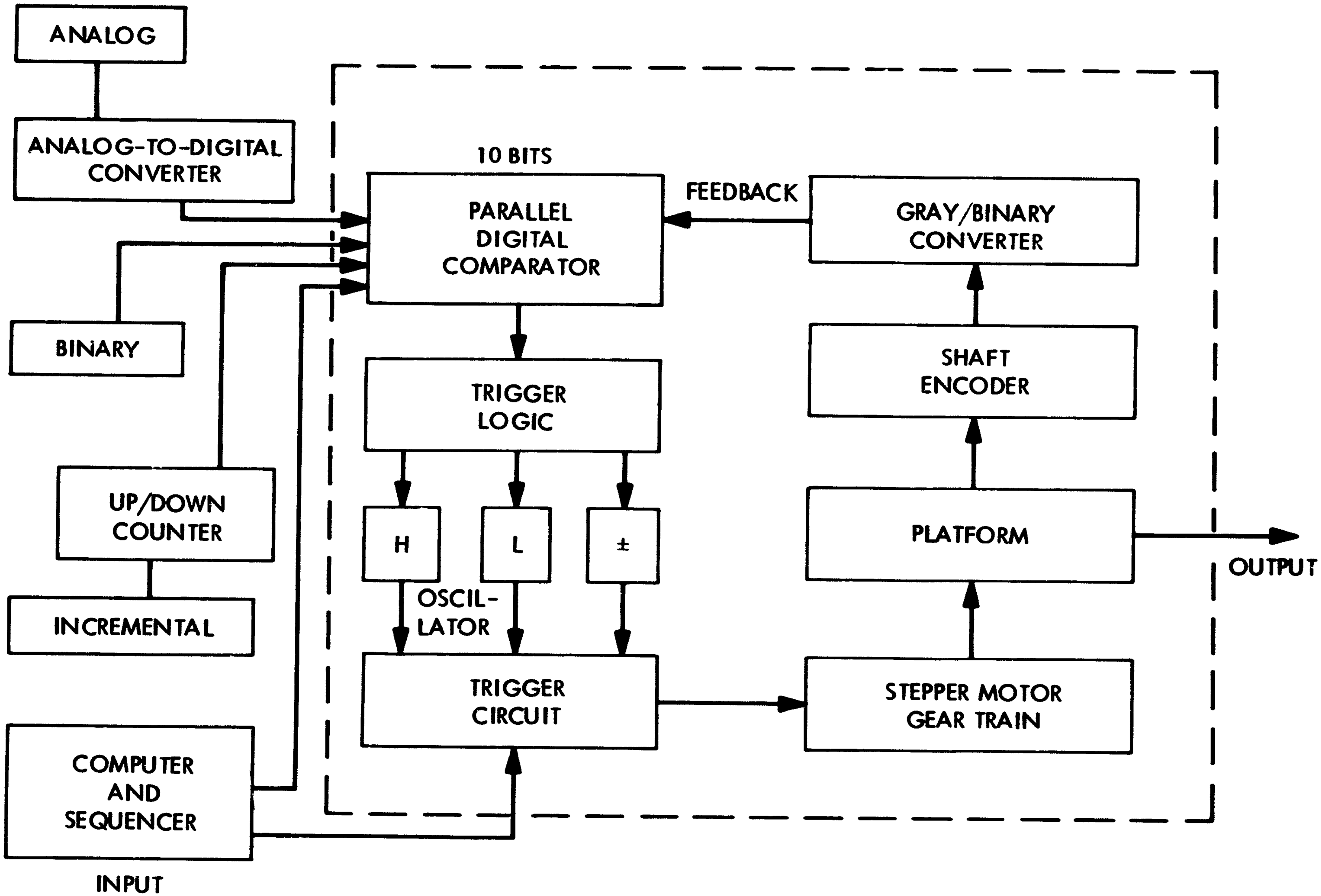

Figure 1. All-Digital Control System Block Diagram

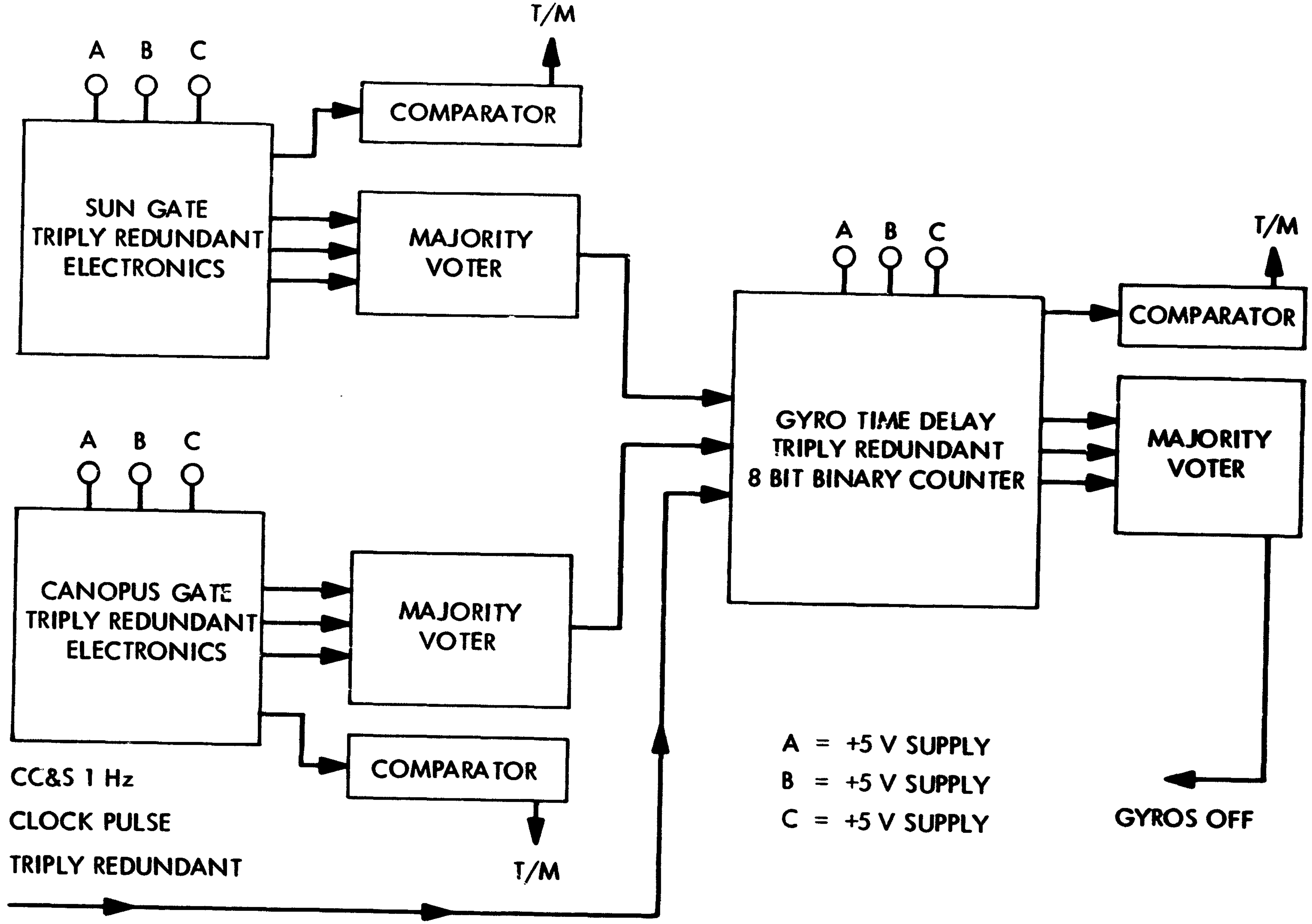

Figure 2. Attitude Control Electronics

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POWERED FLIGHT CONTROL SYSTEMS STUDY

NASA Work Unit 186-68-02-33-55

JPL 384-69501-2-3440

R. J. Mankovitz

OBJECTIVE

The original objective of this task was to develop complete, nonlinear digital computer programs for various powered flight systems, and to utilize these to perform parametric tradeoff studies that could be used to select optimum systems for given requirements. After the completion of a six degrees-of-freedom program for a gimballed engine (chemical propulsion) autopilot system, a budget cut was sustained that caused a revision in the objectives. The objective now is to study the attitude control of an ion engine, electric propulsion powered vehicle, during the powered flight phase. This work is directly applicable to an advanced technical studies task for a Jupiter solar electric powered mission.

STATUS

As reported in the last summary report, tradeoff studies were conducted for the control system of an electric propulsion powered vehicle. A complete six degrees-of-freedom digital computer simulation was developed and used to evaluate system performance. An attitude control system concept consisting of two-axis engine translation with engine gimballing for third axis control was chosen as the baseline design.

During this report period, the basic control loops have been expanded in sufficient detail to permit the determination of component design parameters for both the translator loops and gimbal loops. The block diagram of a single axis translator control system is shown in Fig. 1, and a list of values for the major parameters is included in Table 1.

The gimbal control system is similar to the translator loop, with the stepper motor output proportional to gimbal angular position, which acts through the engine thrust (F_G) and moment arm (L_G) to produce restoring torque. The optimized parameters for the gimbal loop are listed in Table 2.

FUTURE WORK

The objectives have been completed, and this task will not be continued in FY 69.

PUBLICATIONS

Meetings and Symposia papers:

1. Reader, P. D., and Mankovitz, R. J., "Attitude Control of an Electrically Propelled Spacecraft Utilizing the Primary Propulsion System," presented at ASME 1968 Aviation and Space Conference, Los Angeles, California, Jun. 1968.

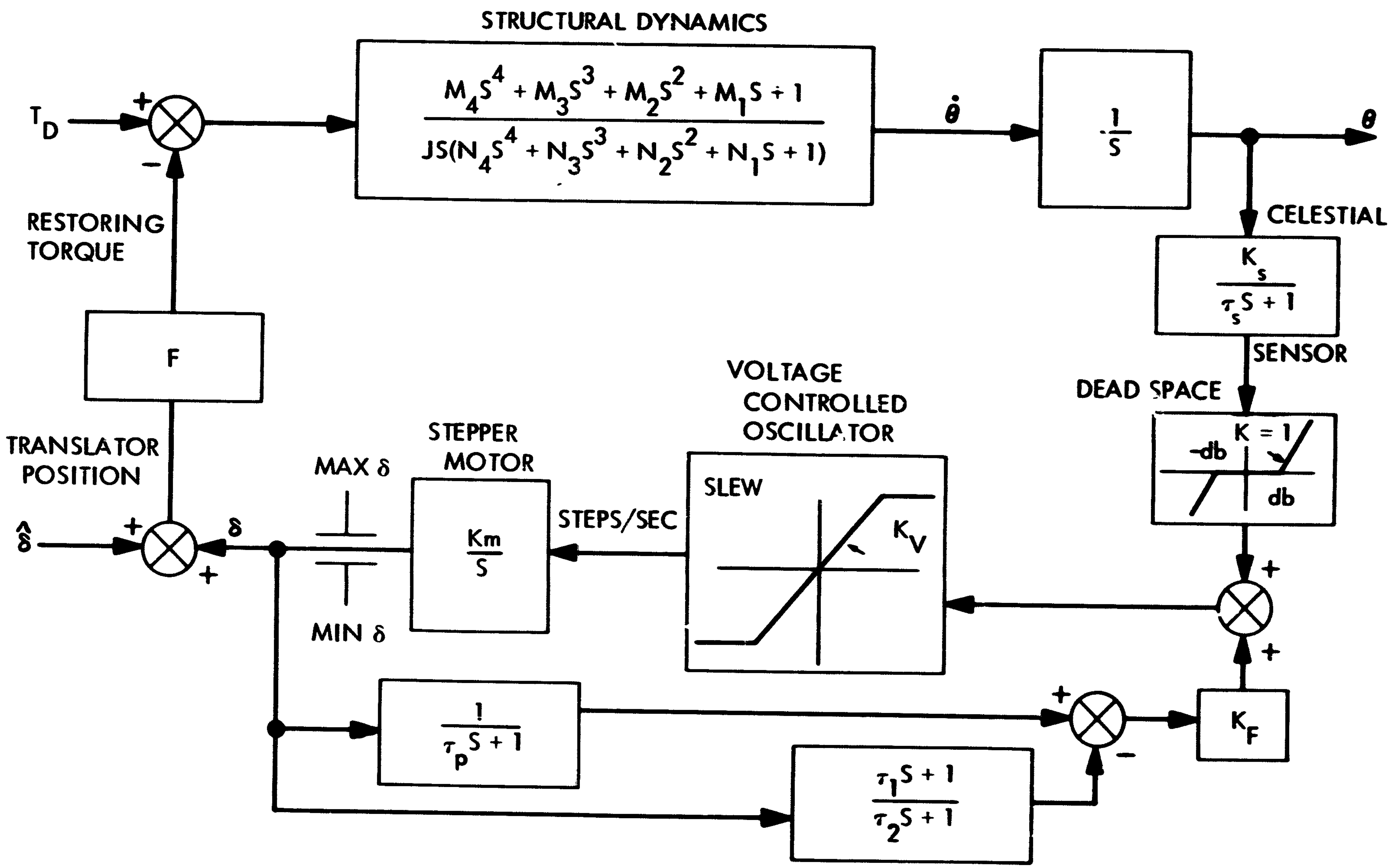

Figure 1. Translator Control System Block Diagram

Table 1. Translator Control System Parameters

Symbol	Value	Units	Description
K_s	134	V/rad	Celestial sensor gain
τ_s	0.5	Sec	Celestial sensor lag
K_V	287	Steps/sec/V	VCO gain
Slew	50	Steps/sec	Maximum stepping rate
K_M	4.167×10^{-4}	Ft/step	Stepper motor-gear train gain
K_F	16.7	V/ft	Feedback gain
τ_p	1000	Sec	Positive feedback lag
τ_1	50	Sec	Negative feedback lead
τ_2	500	Sec	Negative feedback lag
Max δ	1	Ft	Maximum translator excursion
Min δ	-1	Ft	Minimum translator excursion
F	0.01 - 0.06	Lb	Ion engine thrust
J	15×10^3 - 30×10^3	Slug - ft^2	Spacecraft inertia
M_4	6.34	---	Coefficients of structural dynamics model
M_3	0.08	---	Coefficients of structural dynamics model
M_2	5.04	---	Coefficients of structural dynamics model
M_1	0.032	---	Coefficients of structural dynamics model
N_4	0.73	---	Coefficients of structural dynamics model
N_3	0.08	---	Coefficients of structural dynamics model
N_2	2.8	---	Coefficients of structural dynamics model
N_1	0.032	---	Coefficients of structural dynamics model
DB	$K_s \times 10^{-3}$	V	Celestial sensor deadband (equivalent to 1 mrad)

Table 2. Gimbal Control System Parameters

Symbol	Value	Units	Description
K_s	134	V/rad	Celestial sensor gain
τ_s	0.5	Sec	Celestial sensor lag
K_V	1914	Steps/sec/V	VCO gain
Slew	50	Steps/sec	Maximum stepping rate
K_M	1×10^{-4}	Rad/step	Stepper motor-gear train gain
K_F	10.45	V/rad	Feedback gain
τ_p	1000	Sec	Positive feedback lag
τ_1	50	Sec	Negative feedback lead
τ_2	500	Sec	Negative feedback lag
Max δ	10	Deg	Maximum gimbal excursion
Min δ	-10	Deg	Minimum gimbal excursion
F_G	0.02 - 0.03	Lb	Ion engine thrust (2 engines)
J	15×10^3 - 30×10^3	Slug-ft^2	Spacecraft inertia
M_4	6.34	---	Coefficients of structural dynamics model
M_3	0.08	---	Coefficients of structural dynamics model
M_2	5.04	---	Coefficients of structural dynamics model
M_1	0.032	---	Coefficients of structural dynamics model
N_4	0.73	---	Coefficients of structural dynamics model
N_3	0.08	---	Coefficients of structural dynamics model
N_2	2.8	---	Coefficients of structural dynamics model
N_1	0.032	---	Coefficients of structural dynamics model
L_G	1.25	Ft	Distance from engine gimbal to array CG
DB	$K_s \times 10^{-3}$	V	Celestial sensor deadband (equivalent to 1 mrad)

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CAPSULE AND LANDED ACTUATOR DEVELOPMENT

NASA Work Unit 186-68-02-35-55

JPL 384-69701-2-3440

J. D. Ferrera

OBJECTIVE

The long-term objective of this work unit is to develop actuator and actuator components anticipated as being required for future space exploration programs. The short-term objectives for the second half of FY 68 are to:

(1) Continue the study of the antenna actuator (previously developed) along the following lines:

   a. Testing to determine the speed-torque characteristics of the actuator

   b. Hysteresis and incremental resolution tests

   c. Modify the assembly to receive a digital encoder and stepper motor

   d. Determine appropriate digital characteristics

(2) Determine the operating characteristics of jet valves procured from the Walter Kidde Co.

STATUS

Characteristics of the A/D Antenna Actuator

The test program outlined in the first objective above has been completed. Tests were first run on the actuator as an analog unit with an AC servomotor input and infinite resolution potentiometer output. A speed-torque test was run. The stall torque is 38 ft-lb. The maximum speed (at zero load) is 0.060 Rev/min. Other characteristics of this actuator which were determined are:

(1) Infinite resolution potentiometers: linearity - 1/2% over 270 deg

(2) Gear train ratio: 80,000/1

(3) System hysteresis (under load): 5 min of arc (1.5 mrad)

(4) Weight: 5-1/4 lb, volume: 156 in.^{3}

In all these tests, output rotation was measured by using a Leitz dividing head which is capable of measurement to 2 sec of arc. With the completion of the analog testing, the actuator was modified for a digital application (stepper motor input and optical noncontacting encoder output). General advantages of a digital actuator over the analog actuator include the following:

(1) Lower peak power requirements if used in conjunction with capacitor storage

(2) Capability of higher pointing resolution

(3) Simplified electronic interface

(4) Eliminates the need for digital-to-analog converters in all digital systems

(5) Offers greater flexibility in control system redundancy and failure detection and correction techniques

The attitude control servomotor has been replaced by a size 11, permanent magnet, 3-phase, 15-deg/step stepper motor. The infinite resolution potentiometer has been replaced by an optical, noncontacting, 13-bit shaft encoder capable of measurement within 2.5 min of arc. The resolution, based on stepper motor rotation per step (15 deg) and the gear train ratio, is 0.7 sec of arc.

As an indication of the output shaft speed of this actuator for the digital case, at 50 steps/sec into the stepper motor the output shaft rotates at 2 revolutions per day (this relationship is linear).

TEST RESULTS ON THE WALTER KIDDE GAS VALVE

As a result of initial inspection and testing in the second half of FY 68, the following comparisons of the Walter Kidde valve with the Mariner Venus 67 valve can be made:

(1) The Kidde valve has a teflon soft seat rather than a hard seat as in the Mariner valve.

(2) The Kidde valve and manifold weigh approximately one-quarter that of the Mariner valve.

(3) The Kidde valves have an initial leak rate of less than 0.5 cm^3/hr compared to 1-3 cm^3/hr for Mariner valves.

(4) The Kidde valves have an opening response time of 3-4 ms and a closing response time of 1-1.5 ms as compared to the Mariner valve opening time of 10-12 ms and closing time of less than 3.5 ms.

Measurement of input power requirements, thrust level capability, and life tests still have to be performed on the Kidde valves; however, this will be completed before the end of FY 68.

ANTICIPATED EFFORT FOR FY 69

This work unit will continue in FY 69 with a partial listing of objectives to include the following:

(1) Perform the closed loop digital test with the AD actuator mentioned above.

(2) Investigate harmonic drive units as a possible means of decreasing system backlash.

(3) Investigate capacitor storage as a means of decreasing peak power requirements for stepper motors.

(4) Investigate the availability of latching-type stepper motors as a method of holding position during "power off" portions of duty cycle.

(5) Study nutation damper (electromagnetic) assemblies.

(6) Study mechanical de-spin assemblies.

(7) Identify and work toward solutions of problems associated with actuators functional for 10 – 12 yr, and actuators which do not carry their own environment.

(8) Identify and evaluate areas where future actuators can be built as integrated units rather than a combination of independent components as means of improved compactness, weight savings, and improved positions accuracy.

PUBLICATIONS

None.

PARTICULATE CONTAMINATION CONTROL STUDY

NASA Work Unit 186-68-02-37-55

JPL 384-70701-2-3440

J. D. Ferrera

OBJECTIVE

The long-term objective of this work unit is to establish the interrelationship of particulate contamination and present concepts of expected life and/or reliability pertaining to typical electromechanical devices to be used on future flight programs. This information is needed to:

(1) Aid in establishing more realistic reliability figures.

(2) Aid in meeting more exacting future mission requirements such as longer life, lower leakage, higher accuracy, and lower system weight.

(3) Aid in updating cleaning, design, and fabrication alternatives relative to particulate contamination generation both for in-house work and contract specifications.

(4) Aid in performing reliability studies of alternative gas systems proposed for specific missions.

Early in the fiscal year, the funding on this unit was reduced and thus the scope was changed to pursue only the most immediate problems during the second half of FY 68. Under the reduced scope, the effort during the second half of the fiscal year was concentrated on determining the state of the art on long-life cold gas valves. Attitude control studies currently under way in support of advanced technology studies indicate that in order to provide an attitude control gas system for the long-life planetary missions, solenoid valves which will operate reliably with less than 0.2 cm^3/hr leakage (GN_2) with a life of 10 – 12 yr are required.

APPROACH

An effort was initiated in the second half of FY 68 to contact valve manufacturers and users to determine:

(1) If a valve meeting the above requirements is feasible.

(2) If sufficient information is available to draw some conclusions on the relationship between contamination sensitivity and valve reliability.

(3) What design, assembly, and test procedures are practiced to minimize contamination sensitivity in the design and to insure high contamination control in assembly and test.

STATUS

Valve manufacturers that were contacted in the above survey included: Moog, Stratos-Fairchild Hiller, Carleton Controls, Walter Kidde, Sterer Engineering, Circle Seal, and Eckel Valve.

Valve users that were contacted in the above survey included: Goddard-AIMP-E, General Electric-Nimbus, Hughes - Comsat, Ball Brothers Research-OSO, Aerospace, Lockheed Missiles and Space Co., TRW-OGO, Nimbus-D, Marshall SFC-Saturn Valve Clinic, and Rocketdyne.

Initial contact has been made with all companies listed. The consensus of opinion resulting from the contacts is that although there are many valves on the market, some of which are flight-qualified, insufficient test and/or flight information exists to draw any strong conclusions with regard to the first two questions. Recommendations were made by some valve users as to which valves would most likely meet the requirements but in no cases was there sufficient valve history to offer proof of the required capability. For this reason some of the most promising single-seat valves have been and will be procured and will be function and life-tested in FY 69. In FY 69, also, some designs of dual seat valves will be further refined, procured, and tested.

The above work will be combined under a new task for FY 69 and will be terminated. The objective of the new work unit for FY 69 (High Reliability Gas

System Studies, Work Unit 186-68-02-38-55) is the study of gas system components and system redundancy techniques and possible failure detection and correction methods for long-life missions (10 – 12 yr). In approaching valve development in FY 69 the following questions, among others, will be studied:

(1) Particulate contamination and its effect on valve design and assembly.

(2) Reliability of dual versus quad valves as supported by test results.

(3) Alternative redundancy and failure detection and correction techniques.

(4) Accelerated life testing for 10 – 12 yr mission profiles.

(5) Techniques to minimize peak power requirements.

PUBLICATIONS

None.

ADVANCED SPACECRAFT TAPE RECORDER DEVELOPMENT

NASA Work Unit 186-68-03-01-55

JPL 384-60901-2-3340

J. K. Hoffman

OBJECTIVE

The objective of this work unit is to develop a standardized family of digital magnetic tape recorders that have greater capacity relative to size and weight, that consume less power, and that are more reliable than those presently available. Storage capacities of 10^6 to 10^{10} bits are required for use in future NASA spacecraft.

ETM TAPE TRANSPORT DEVELOPMENT SUBTASK

Subtask Description and Objectives

The purpose of this project is to develop a basic reel-to-reel transport design which will embody significant improvements stemming from the various studies which have been conducted by JPL over the past 5 yr, and which will, with minor modifications, fulfill any spacecraft data storage requirement for 10^6 and 10^8 bits. The engineering test model (ETM) is a simple version of the basic isoelastic drive concept. It has a record-to-playback speed ratio not exceeding 8:1 and contains about 500 ft of 1/4-in. tape. With six data tracks, it will provide storage for more than 10^7 bits. The transport is being extensively tested in order to thoroughly demonstrate the adequacy of the design principles.

Status

Performance tests have been conducted at JPL to verify and evaluate transport performance as affected by type-approval level environmental exposure. Motor bearing failure, which occurred during vibration tests conducted during the previous period, was further analyzed. There was definite evidence of lubricant breakdown and overheating. Race damage due to brinneling is suspected but has not yet been verified. Corrective measures such as using larger bearings with carefully established preloads are being considered. During this period the unit was subjected to mechanical shock, acceleration, and vacuum temperature testing. There was no significant damage or degradation of performance apparent as a result of shock or acceleration tests. Operation at low temperature produced a spurious increase in flutter to as high as 6% at midpack tape position. Some tape separation was apparent at various points in the supply reel, and the outermost layers showed some tendency to "walk" or slip off the pack. However, no catastrophic failures of tape pack or transport components were apparent. Greater stability was observed during high temperature operation, although some tape separation did occur near the hub of the supply reel while nearing the end of the unwind cycle. Tape pack instability is considered a significant problem, and plans are being made to investigate it more thoroughly.

Future Activities

Tape transport evaluation will continue to fully establish the cause and effect of environmental test results. Efforts will be made to solve bearing and tape pack stability problems in particular. Specific environmental tests will be repeated as considered necessary. Life testing is planned.

ADVANCED SPACECRAFT TAPE TRANSPORT DEVELOPMENT SUBTASK

Subtask Description and Objectives

The purpose of this task is to develop a more complex version of the isoelastic transport design to provide data rates and capacity adaptable to future spacecraft mission requirements. The intent is to make selected design modifications facilitating an increase in tape capacity (greater than 1000 ft of 1-in. wide tape), while maintaining reasonable optimization of weight, configuration, and power characteristics.

Status

Procurement for development of an advanced spacecraft magnetic tape transport (ATT) was initiated. After detailed technical discussions, negotiations on a proposal submitted by Kinelogic Corp. were basically completed.

Although some questions regarding costs and fee still remain, a contract agreement is expected by the end of FY 68.

The proposed machine will accommodate at least 2000 ft of 1-in. tape in an envelop approximately 4 x 10 x 15 in., providing bit capacities over 10^9. A 1000:1 speed range capability is planned. Further details on this effort can be obtained by reference to the following:

1. IOM 3342-68-054, to J. F. Koukol, from J. K. Hoffman, "Advanced Spacecraft Tape Transport Development," February 20, 1968.
2. JPL Design Requirement DM5043964, "Telecommunications Development, Spacecraft Equipment, Magnetic Tape Transport," February 20, 1968.
3. IOM 3342-68-192, to J. F. Koukol, from J. K. Hoffman, "Advanced Spacecraft Tape Transport Development," June 5, 1968.

Future Activities

Efforts will be directed toward expediting placement of a contract, and commencement of the development program.

PUBLICATIONS

None.

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SCIENCE DATA SYSTEM DESIGN

NASA Work Unit 186-68-03-03-55

JPL 384-60801-2-3240

L. D. Brown
L. J. Goforth

OBJECTIVE

The objective of this task is to develop functional concepts and subsystem techniques for implementing the spacecraft on-board science data subsystem including the following functions and their automation: data conversion, coding, formatting, processing, scientific instrument programming, storage of ground commands. The near-term objectives are to study specifically a stored program data system and to develop an automated facility for studying the control and processing functions of science payloads.

PROGRESS

Stored Program Systems

Synthesis of a Representative Mission

A Mariner Mars 1971 Orbiter mission was adopted as a representative mission of particular interest. JPL personnel cognizant in various spacecraft disciplines were contacted to determine general characteristics of various subsystems appropriate to the mission.

First Candidate SDS Design

SDS requirements were established for the representative mission and a candidate SDS organization was developed. This organization stressed limited flexibility as opposed to total reprogrammability — meaning that the SDS developed was a hardwired equipment which provided operational flexibility by employing selectable wired-in operating modes.

Investigations of Stored-Program Techniques

Techniques for equipping the Mariner Mars 1969 DAS with a stored-program ancillary module were investigated. The techniques studied pertained to the real-time portion of the DAS, but showed promise of more general application.

Evaluation of New Components

Procurements were initiated for two types of read-only memory devices. The utility of such devices had been previously established by the activities cited above and the objective now is to evaluate the performance of commercially available modules.

Candidate SDS Design - First Revision

A first revision of the candidate SDS design has been initiated. The revision will describe SDS hardware and functions in greater detail than was present in the original design. The design will adhere to the constraint that only Mariner Mars 1969 circuitry may be used; this policy has been adopted to insure that the design could be implemented by a Mariner Mars 1971 flight project group.

Computer Facility

The IBM 1130 computer system was officially accepted on January 8, 1968. Studies to determine the requirements for a general interface system to simultaneously attach various scientific instruments were conducted. Procurement of such interface equipment is currently being negotiated.

FUTURE ACTIVITIES

The development of SDS functional models emphasizing the employment of stored-program techniques will continue. It is expected that sufficient progress will be made during the next report period so that a comprehensive SDS model may be defined to serve as a basis for breadboarding activities.

The general interface equipment will be installed with the IBM 1130 system and a light microscope will be connected as an automated instrument.

PUBLICATIONS

None.

SCIENCE DATA HANDLING SYSTEM IMPLEMENTATION

NASA Work Unit 186-68-03-04-55
JPL 384-61601-X-3240
J. W. Spaniol
R. V. Gutierrez

OBJECTIVES

The continuing power, weight, and volume limitations for flight science data subsystems (SDS) require state-of-the-art techniques and devices. The development and demonstration of new logic elements, large scale integrated (LSI) functions, buffer memories, and matrix devices is necessary for expansion of on-board capabilities. A secondary objective is the development of laboratory equipment to evaluate devices, investigate techniques, and analyze systems.

GENERAL HARDWARE DEVELOPMENT

The contract for Phase I of the analog-to-digital converter (ADC) development was let on April 1, 1968. The goal of this development is an LSI successive approximation ADC. Phase I covers the development of the precision resistor ladder digital-to-analog (D/A) module.

A very broad functional organization of the converter elements has been developed to gain the maximum flexibility in the three sections. The final organization will be determined at a design review early in FY 69.

A high-speed successive approximation converter using conventional integrated circuits is being developed to meet the requirements of a Mariner Mars 1971-type television system. Very high-speed conversion techniques are being investigated as alternates to successive approximation.

The counter shift register (CSR) is the first LSI device developed specifically for space flight applications. Test methods and test fixtures have been developed and preparations for exhaustively testing a minimum of 10 CSR devices have been completed. These tests are to describe its operation and to write a standard procurement specification.

The CSR flexibility will be increased by altering the signal input and output connections and other minor changes. The trend of this development is toward a family of devices instead of a single universal device.

A very flexible computational tool will evolve from the ADC successive approximation control logic combined with a table of logarithms. The table can directly generate logarithms and, with the successive approximations, generate antilogarithms. Similarly any type forward/reverse transformation can be implemented with only one table.

CAPSULE SYSTEM ADVANCED DEVELOPMENT (CSAD)

The CSAD-entry data system (EDS) was delivered on March 21, 1968, for integration and functional testing with the other subsystems of the CSAD's capsule system.

Prior to this, the EDS underwent complete subsystem checkout, functional verification and preliminary integration with the mass spectrometer, an instrument within the CSAD capsule system.

The EDS and the other subsystems underwent capsule system functional testing per JPL Proc. CSAD 300.00. Throughout the testing the EDS operated correctly, without any problems. The data were good, with occasional noise which caused errors in the data retrieval system contained within the EDS's checkout system.

The EDS underwent final capsule system functional testing the week of June 3 and is presently being stored with the rest of the capsule system. The memory portion of the EDS has been returned and will undergo further testing.

Presently a general review of the EDS logic is being conducted in order to insure simplification in design, minimization of components and power consumption, and maximization of reliability. Upon completion of the logic review and redesign, the EDS breadboard will be recalled from storage and the recommended changes installed within the unit. At that time, complete retesting of the EDS will be required.

Another area to be reviewed is the memory and its electronics. The memory should have separate receiving circuits in order to improve its margins and noise immunity.

A third area of study will include the multiplexer switches. The CSAD EDS multiplexer uses the PF 157 flatpack which contains four 2N3386 p-channel junction field-effect transistors. These JFET's are employed as switches, but unfortunately are normally closed (when power is off), thus shorting the analog inputs together through high impedance paths. This situation would probably not be acceptable in a flight configuration because some subsystems would have power applied while others do not.

PUBLICATIONS

None.

DIGITAL RECORDING TECHNIQUES

NASA Work Unit 186-68-03-07-55

JPL 384-67401-2-3340

J. C. Ashlock

OBJECTIVE

The objective of this effort is to develop and catalog a background of information concerning recording format, bit packing density, and reproduce-signal detection techniques which can be brought to bear on specific data storage problems.

GENERAL BACKGROUND

A contract totaling $56, 000 was placed with the Ampex Corp. in late 1966, with the aim of developing a mathematical model of the record-reproduce process derived from a detailed understanding of the physics of the process and one that was suitable for computer manipulation. The intent was to then use this model as a tool to investigate how different techniques of digital recording are affected by parameters such as recording format and bit packing density. Work began by developing the model to characterize the record-reproduce process for a single transition of record current as reported in Vol. I of JPL TM 33-353; the model was then expanded to include the case of a sequence of record current transitions as reported in Vol. I of R&AD Document 701-6. Subsequently, the model was to be experimentally validated.

STATUS

The model of the record-reproduce process has been finished, and validation of the model is now complete. The fundamental method of validation was through the use of photographic overlays of experimental and predicted reproduce head voltage waveforms, an example of which was given in R&AD Document No. 701-6. It was determined by this work that the waveshape predictions of the model were excellent in the low thousands of bits per inch of double-frequency coded data, and the details of the predicted waveforms were quite informative at 5000 bits per inch when using saturation recording. As densities were increased, the model degraded gradually and by 10, 000 bits/in. it was indicative only of general trends to be expected as parameters of the recorder were varied. The validation effort is documented as an attached appendix to the contractor's Final Development Report.

It has long been apparent that, if the magnetization pattern as recorded consists of nonoverlapping transitions, the final output waveform is simply the linear sum of the appropriate single pulse waveforms. Work done by Ampex during performance of the original contract indicated that this same linearity feature was not subject to the stringent conditions previously thought to bind it. Even though the nonoverlapping criterion failed at 2000 bits/in., the simple, linear addition of appropriate single pulse transitions held good up to 10, 000 bits/in.

In view of this finding, a $28, 000 extension to the contract with Ampex was undertaken in April 1968. The purpose of this extension is to obtain an understanding of the underlying reasons for the validity of the linear summation concept at high densities and then to take advantage of both this understanding and the linearity feature itself — which allows the entire field of linear filter theory to be brought to bear — to generate hardware designs and breadboards aimed at minimizing error rates due to peak shift and other pulse crowding effects.

The primary result of the work to date is that the linearity feature is inherent in the noninteracting model of tape remanence used in the algorithm of the record-reproduce process. This has shed new light on the meaning of noninteracting models in general. Current efforts are being directed toward understanding the specific types and characteristics of linear filters required to minimize the effects of pulse crowding.

FUTURE ACTIVITIES

Future activities first involve completing an understanding of the types of filters which can be employed to reduce the effects of pulse crowding. This will be followed by experimental verification and application to laboratory recorders.

PUBLICATIONS

Meetings and Symposia Papers

Steele, C. W., and Mallinson, J. C., "A Computer Simulation of Unbiased Digital Recording," 1968 International Conference on Magnetics, Apr. 3–5, 1968.

SPS Contributions

Ashlock, J. C., "A New Model for the Record-Reproduce Process on γ-Ferric Oxide Magnetic Tape," SPS 37-49, Vol III, p. 361–363, Feb. 29, 1968.

Contractor Reports, Interim and Final

Mallinson, J., Steele, C., and Lienhard, L., "A Computer Simulation of Digital Recording," Ampex Corp. Report No. RR 67-36, JPL Contract 951785, Dec. 29, 1967.

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SERVOCONTROLLED TAPE RECORDER

NASA Work Unit 186-68-03-09-55

JPL 384-69001-2-3340

E. Bahm

OBJECTIVE

The objective of this work unit is to develop a digital tape recorder control technique that will:

(1) Allow variable input data rates to be recorded at a constant density even if the data rate changes instantaneously by a certain amount.

(2) Enable data from a tape recorder to be synchronized to an external clock over a wide frequency range.

(3) Operate the motor at sufficiently slow speeds (10 rev/min) in order to substantially reduce the required speed reduction or to completely eliminate speed reduction devices.

(4) Provide the capability of driving the tape at different speeds (goal of 1000:1 speed ratio) with one motor only, and without a mechanical clutch.

STATUS

A contract for the development of a servocontrolled tape recorder was awarded to Borg Warner Corp. in October 1966. The contractor designed and built a servo which controls the ETM tape transport. It was capable of recording data, variable between 300 and 9000 bits/sec. The data rate could increase instantaneously by 400 bits/sec and decrease instantaneously by 100 bits/sec without causing an error.

This data storage system was subsequently modified to demonstrate that it can meet projected Mariner Mars 1971 requirements. Data are now recorded at 130 k bits/sec and reproduced at various rates between 1 and 16 k bits/sec. The speed ratio is therefore 130:1.

As a separate effort, a high-resolution tachometer was used to determine the lowest speed at which a tape recorder motor can be operated, and to study the parameters which cause the low speed limits. The tachometer was of the photoelectric type and had a resolution of 5000 pulses per shaft revolution. It allowed operation of a miniature hysteresis motor at 0.5 rev/min. Further experiments with different tachometer resolutions showed that the lowest speed at which the hysteresis motor can be operated is only determined by the tachometer resolution and quality of the servo, but not by the motor. This is a unique feature of the hysteresis motor and makes it the ideal miniature motor for very low speed applications.

As another in-house effort, a medium resolution tachometer suitable for spacecraft application was developed. It is based on the electromagnetic principle and the resolution is 180 pulses/rev.

Specifications for a hysteresis asynchronous motor to operate over a wide speed range have been drafted. This effort had been delayed to await the results of the servo work with the existing hysteresis motor.

FUTURE ACTIVITIES

This study has now provided for the capability of a motor driving the magnetic tape directly without speed reduction. Such a tape recorder starts and stops very fast because no component is ever accelerated to high speed. It is therefore capable of incremental operation to accommodate low data rates. This technique had been successfully developed several years ago, but could not be utilized for lack of a suitable flight-type tape transport. It is felt now that future interplanetary tape recorders may operate in the incremental mode whenever the data rate is low (resulting in less than 0.2 ips of continuous tape speed). The servo developed by Borg Warner uses a solid state buffer, which could be used in the incremental mode for recording or playback of data blocks in a start–stop operation. This would allow recording at high packing density within the data block. A small gap of approximately 0.01-in. between data blocks would be sufficient for incremental operation. It is planned to add this capability to the existing data storage system (modified BW electronics and ETM transport).

Procurement action will be started for the development of a more powerful hysteresis asynchronous motor for operation at any speed between 1 and 10,000 rev/min.

The feasibility of using the principle of the magnetic drum for a high resolution spacecraft tachometer will be studied.

PUBLICATIONS

SPS Contributions

Bahm, E., "Slow Speed Operation of Hysteresis Motors for Tape Recorders," SPS 37-50, Vol. III, Apr. 30, 1968.

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DIGITAL VIDEO PROCESSING EQUIPMENT

NASA Work Unit 186-68-03-10-55

JPL 384-70901-2-3240

F. C. Billingsley

OBJECTIVE

The long-range objective for this task is to develop equipment for the recording, scanning interpretation, and manipulation of video information. This equipment will be for digital processing, analog electrical processing, optical processing, or suitable combinations thereof. This is a long-range task which is expected to continue as long as digital processing development is required.

The primary objective this fiscal year has been the development of a magnetic tape scan rate converter [Fig. 1(a) and (b)], one of the key links in setting up of a complete image processing system.

This task is an outgrowth of FY 67 Work Unit 125-23-02-01. The parent task will continue to support the development of advanced image processing software. Both tasks are pursued in close cooperation with each other and with the various JPL flight projects.

In addition, JPL is in close contact with similar work at the Manned Spacecraft Center, Houston, Texas.

PROGRESS

The complete hardware system was outlined in a previous semiannual report, JPL Technical Memo 33-353, Vol. 2, p. 271.

This task has primarily supported the development of the magnetic tape scan rate converter, which is an interface between the computer and the RETMA video circuitry. This converter can receive digital data from the computer at computer rates and store these data on magnetic tape. The data are stored one picture per revolution of the rotating recording head. Upon command, the tape is moved to a read station, where another rotating head is used to scan the picture at RETMA video rate. The converter may also be used in the reversed mode, i.e., recording may be done at RETMA rates, with subsequent playback at rates suitable for entry into the computer.

This converter is nearing completion. Mechanical assembly is almost complete. The electronics have been brought to the point of allowing testing of the converter in a stand-alone mode when the mechanical assembly is ready.

Work has begun on developing a CRT system for use with color film. To minimize cost, one of the Ranger kinescope recorders is being used as a nucleus.

In addition, this job has supported development effort on a slow-scan camera system for computer-based video acquisition In particular, a flight camera has been modified for use with an SEC vidicon as a readout device for the electron microscope. This will (hopefully) produce video data without the need for photographic film and its problems.

Initial effort was directed at using a flight model vidicon with a selenium target, built directly into the microscope vacuum system. Difficulties in obtaining an adequate target and with cathode letdown to air have caused the switch of efforts to a sealed SEC vidicon. Currently being rebuilt are the necessary parts of the circuits to suit this tube.

PROBLEMS

Continued delays on the film converter have been caused by low SRT priority in the machine shop in deference to flight projects. No technical problems have been encountered.

The difficulties encountered which have caused the switching of tubes have been outlined above. Current work on the required modifications is progressing smoothly.

Restricted budgets and manpower prevent rapid inclusion of the total image-processing capabilities required for a comprehensive image processing laboratory.

FUTURE PLANS

A skeleton RETMA video bus will be established. Video display from the computer will be obtained via a slow-scan monitor connected directly to the 2701 coupler, and supplemented with Polaroid camera. An attempt will be made to take advantage of the enforced delay by utilizing the system in the skeleton mode to more accurately learn and define the requirements for the interactive display and control console.

It is anticipated that this task can support the establishment of the skeleton RETMA system during the coming fiscal year. Development of the techniques and equipment is a continuing job which will extend into FY 69 and beyond.

The scan converter will be completed and interfaced to the computer after demonstration in a stand-alone mode.

Action on connecting the video translator to the computer via the IBM 2701 coupler, and the design and acquisition of the variable magnification scanner and the interactive display and control have taken much lower priority and will be deferred until budget and manpower availability allow their inclusion.

PUBLICATIONS

NASA Tech Brief 67-10676 was published, covering the scan rate converter.

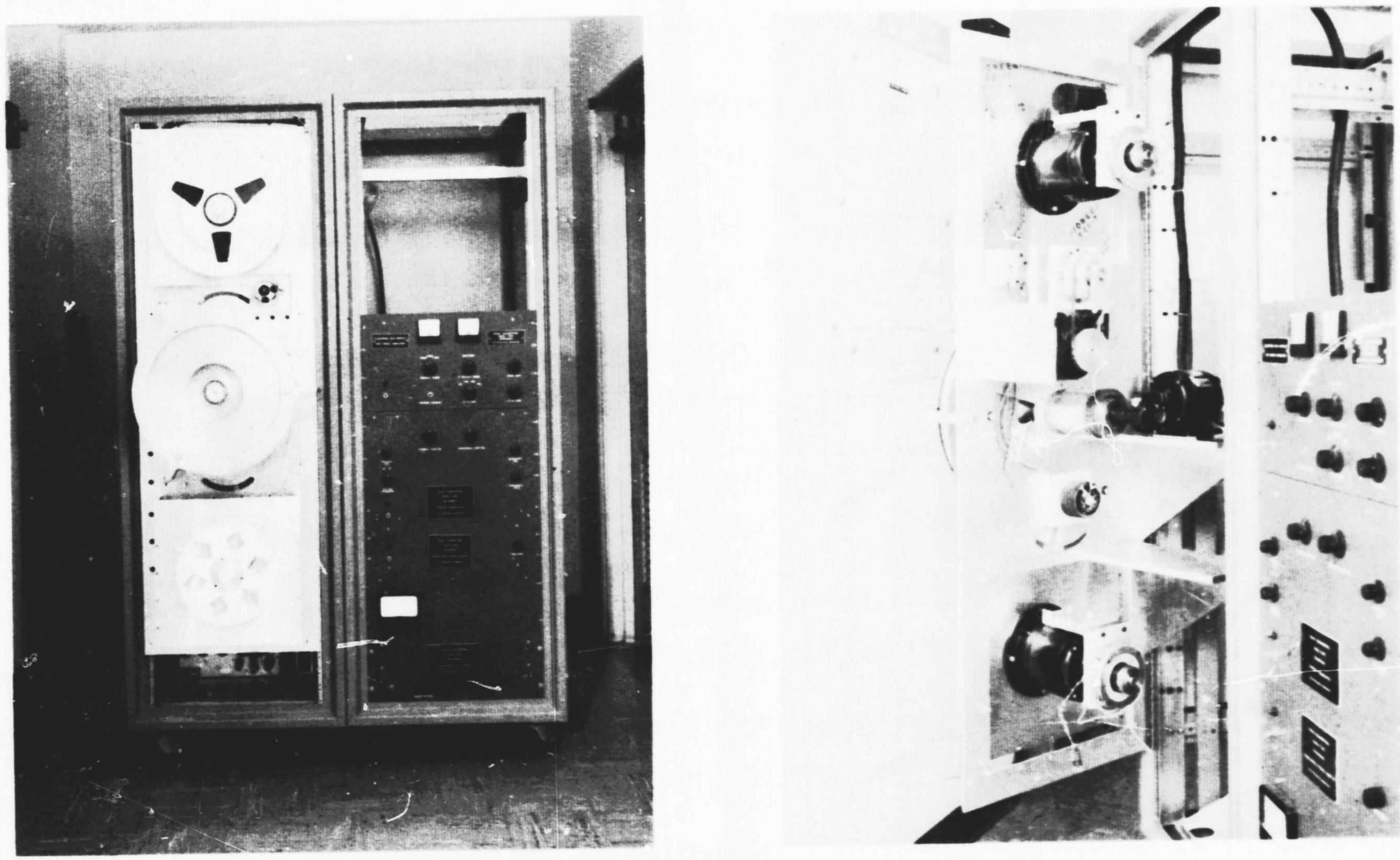

Figure 1. Scan Converting Video Tape Recorder

VIDEO DATA COMPRESSION
NASA Work Unit 186-68-03-11-55
JPL 384-71001-2-3240

R. F. Rice

OBJECTIVE

The development and evaluation of techniques for the compression of spacecraft television data is the objective of this task. In particular, the design goals are the development of algorithms for generating moderate compression ratios of up to 5:1, and simplicity of implementation.

PROGRESS

A coding procedure designated "the code word shuffle" was briefly investigated for the compression of spacecraft TV data. Although anticipated compression ratios were good (3:1 to 4:1) the scheme appeared too complicated and noise-susceptible for spacecraft application (Mariner Mars 1971 specifically) at this time. However, the concept is being considered further by another group for application to earth-based data processing.

The study described above led to the preliminary specification of a new coding algorithm which should be highly applicable to various missions. The algorithm can best be described as a combination of delta-modulation, variable length coding, and standard PCM coding.

The new approach is characterized by simplicity of implementation, good noise immunity, and consistent compression ratios for a wide class of pictures.

The noiseless performance was evaluated for the rather diverse collection of Ranger and Surveyor pictures shown in Fig. 1. For a single code, the compression ratios varied from 1.55 to 1.83 for all pictures shown. A trivial modification to the algorithm on a picture-to-picture basis would generate an average compression ratio of over 2:1 for a mission in which the characteristics of the second Ranger picture are most typical (e.g., a Mars orbiter). A similar modification on a line-to-line basis would provide additional compression.

ANTICIPATED WORK

Immediate concern will concentrate primarily on the decoding problem of the basic system for a noisy channel. This is a step which must necessarily precede system simulation under actual channel conditions. The queueing problem associated with variable rate data will also receive some emphasis.

PUBLICATIONS

1. Rice, R. F., "Introduction to the Code Word Shuffle," JPL Technical Document, 900-138, Apr. 1968.

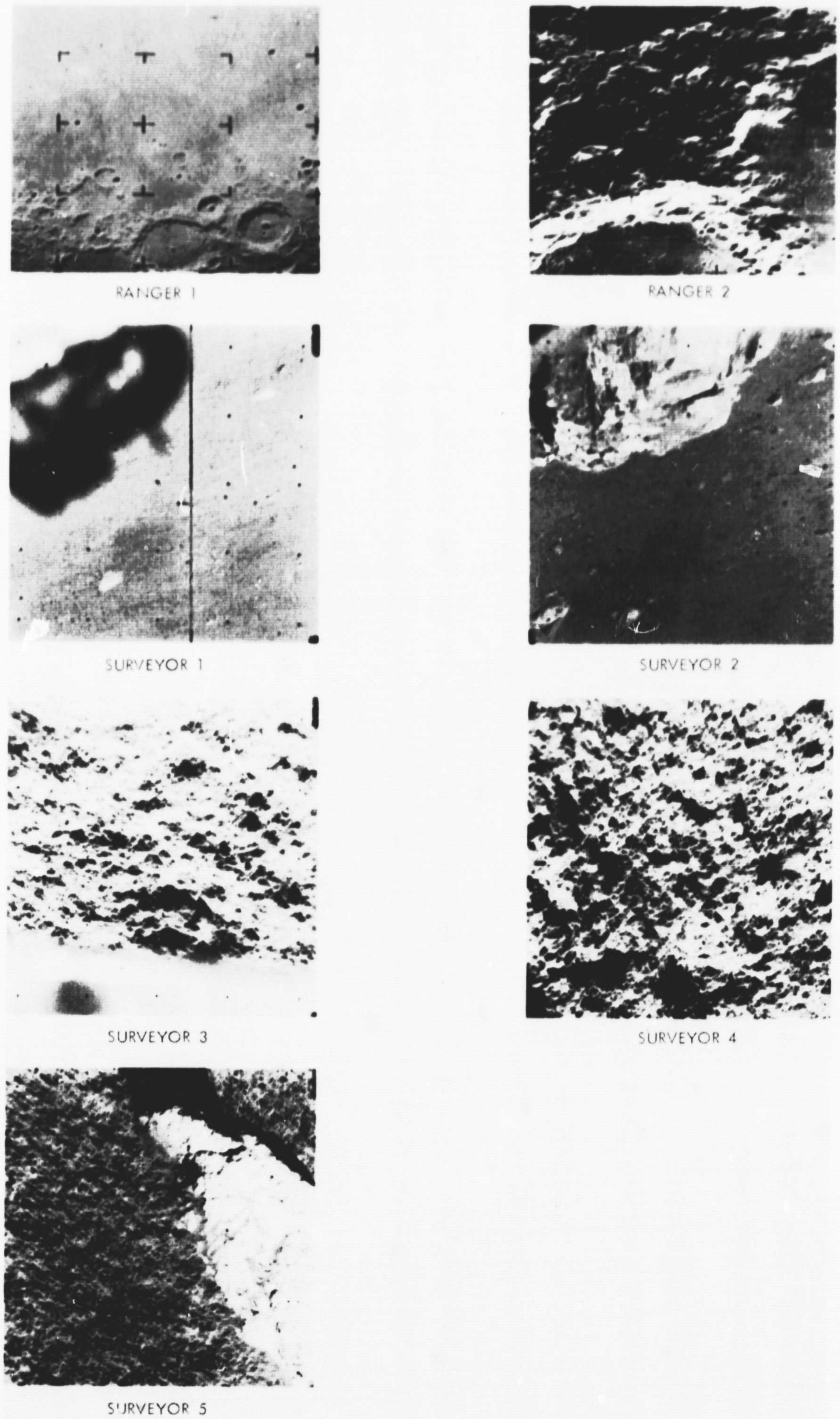

Figure 1. Sample Pictures

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CAPSULE RELAY ANTENNA STUDY
NASA Work Unit 186-68-04-02-55
JPL 384-67301-2-3330

CAPSULE ANTENNA SUBTASK, K. E. Woo

OBJECTIVE

The objectives of this task are to develop a 400-MHz antenna for use on planetary landing capsules and to study the interactions between the capsule relay antennas and the capsule configuration. The program for the current fiscal year includes (1) antenna prototype design and fabrication, and (2) test evaluations.

CAPSULE RELAY ANTENNA

During the third and fourth quarters of FY 68, the CSAD relay antenna (Fig. 1) was fabricated, tested, and delivered. The following are the characteristics of the antenna:

(1) Size: 13.158 in. OD, 10.285 in. ID, 12.296 in. deep

(2) Weight: 11.4 lb (including hybrid and cables)

(3) Electrical performance:

Gain (dB)	Half-power beamwidth, deg	Maximum ellipticity within half-power beam, dB	VSWR
5.0	102	4.0	1.4

The electrical performance of the antenna deviates somewhat from that of the prototype reported previously, as the result of trimming cavity walls.

During the same period, the designing of a general-mission relay antenna was also in progress. The input feeds of the prototype were improved for handling higher power at very low pressures. The antenna with improved feeds now handles 76 W in air and 62 W in 100% CO_2.

In order to further improve the power handling capability, the following modifications to the antenna are being implemented:

(1) Flaring the aperture of the existing antenna.

(2) Fabricating a new cavity having wider slot width.

The completion of these modifications is expected during the first quarter of FY 69.

PUBLICATIONS

SPS Contributions

1. Woo, K., "400-MHz Coaxial Cavity Radiator, Part II," SPS 37-51, Vol. III, Jun. 30, 1968.

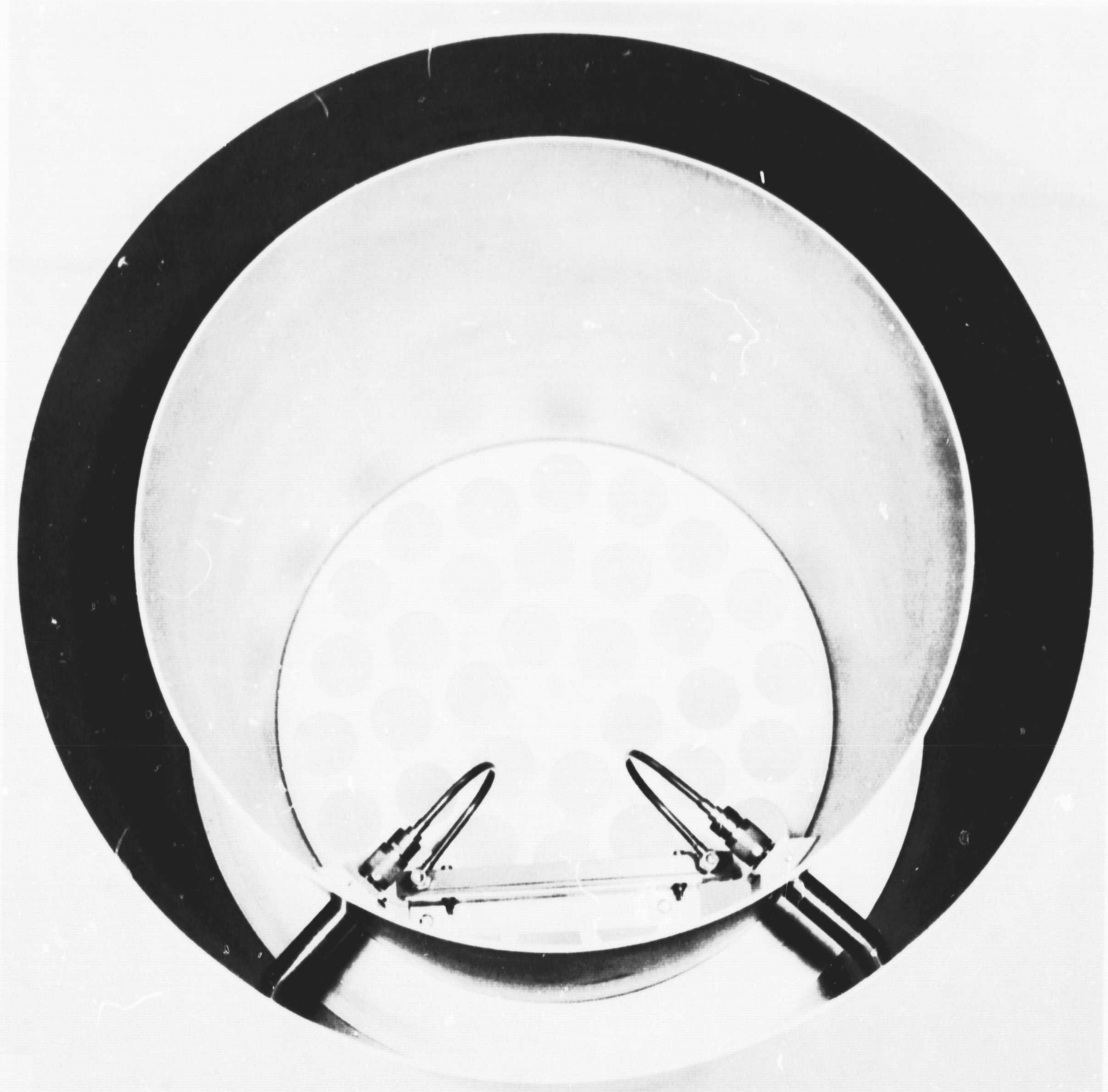

Figure 1. CSAD Relay Link Antenna

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CAPSULE RELAY ANTENNAS

NA Work Unit 186-68-04-02-55

JPL 384-67301-2-3330

ANTENNA PATTERN TOLERANCES SUBTASK, R. M. Dickinson

OBJECTIVE

The objective of this subtask is to increase the accuracy of full-scale spacecraft antenna pattern measurements.

STATUS

Since the last reporting period, this subtask has been carried on at a reduced level dur to application of manpower on the capsule antenna subtask.

Consulting with the Mariner Mars 1969 full-scale spacecraft antenna model measurement personnel on recommendations previously made in this task, and implementation of a new pattern phase and amplitude recording system using the Hewlett-Packard 8410A network analyzer have been the major accomplishments during this reporting period.

NETWORK ANALYZER FOR PATTERN RECORDING

The 8413A phase-gain indicator (a portion of the 8410A) provides simultaneous outputs of phase and relative amplitude in decibels of two RF signals. A pattern recording system using this device has been constructed at the JPL Antenna Range. Once the conversion to this form of recording was accomplished, the ease of operation relative to the normal audio modulated system of recording was apparent. First, no audio components were required as the system works phase locked, CW. (However, up to 10 KHz modulation can be processed through the system.) Second, since the system measures signal ratios, power drifts of the RF generator are removed automatically. Third, analog voltages proportional to phase in degrees and amplitude in decibels over a 60 dB dynamic range are simultaneously available. The ease of operation should be reflected in fewer operator errors.

PLANNED ACTIVITIES

The basic accuracy of the above system will be measured. Next fiscal year a study will begin of methods for determining far-field patterns from near-field measurements in order to better determine free space environment spacecraft antenna patterns.

PUBLICATIONS

None.

NONPARAMETRIC DETECTION FOR CAPSULE RELAY LINKS

NASA Work Unit 186-68-04-04-55

JPL 384-61301-2-3340

H. D. Chadwick
J. C. Springett

OBJECTIVE

Studies of the basic problems relative to the transmission of information between a landing planetary capsule and its parent spacecraft have shown that the detector design and performance is complicated by problems of frequency uncertainty, multipath, and synchronization. In particular, the common approach to noncoherent detection of signals in Gaussian noise does not yield an optimum solution when exact signal and noise characteristics are unknown or are time-varying. As a result, a more general solution, wherein no specific a priori assumptions are made relative to the statistics of the communication channel, should be explored. This approach, commonly known as nonparametric detection, will explore the merits of using nonparametric techniques, and compare them with other detection systems which have been proposed for relay links.

PROGRESS

This new task replaces the task "Relay Link Modulation/Detection Techniques." In the previous progress report it was indicated that future progress in this task would be dependent on the reassignment of personnel. The application of nonparametric detection theory to the relay link problem now appears to be a promising area for research. Some preliminary work has been performed on a possible modulation/detection scheme using the properties of rank vector coding (Ref. 1) combined with frequency modulation.

ANTICIPATED FUTURE PROGRESS

The FM rank vector coding technique will be investigated in more detail with a view toward obtaining performance comparisons with other, more standard, techniques for the relay link application. The first effort will be concerned with optimizing the performance of the system both at the transmitter (selection of modulation signals for minimum bandwidth) and at the receiver (required sampling rate, detection algorithm, synchronization, etc.). With this basic analytical work it will be possible to determine the best design for a system based on this technique. Subsequently, other nonparametric techniques will be proposed and analyzed.

REFERENCE

1. Chadwick, H. D., "Some Extensions of Nonparametric Detection Theory with Applications to Feedback Communications," Doctoral Dissertation, New York University, School of Engineering and Science, Bronx, N. Y., Jun. 1967.

CAPSULE DIRECT LINK ANTENNA STUDY

NASA Work Unit 186-68-04-06-55

JPL 384-61501-2-3330

K. E. Woo

OBJECTIVE

The purpose of this task is to develop a series of S-band, low-gain, circularly polarized, high-impact antennas for planetary capsule use. The present design objectives are:

Impact load: 10,000 g imparted into antenna mounting structure

Gain: 4 to 8 dB

Coverage: Hemispheric, half-power beamwidth ≤ 120 deg

Ellipticity: < 6 dB within ± 60 deg from beam axis

Input VSWR: < 1.2 at 2295 ± 5 MHz

< 1.3 at 2115 ± 5 MHz

Power handling capability: 100 to 500 W

LOW-GAIN HIGH-IMPACT ANTENNAS

During the third and fourth quarters of FY 68, further modifications of the square-cup and spiral antennas have been made:

Square-Cup Radiator

First model (CSAD model)

This antenna is composed of a square cavity ($2.1 \times 2.1 \times 2.2$ in. internal dimensions) filled with Eccofoam PT. It has passed sterilization (275°F) and 10,000-g indirect impact tests. The antenna is being utilized in the CSAD lander as direct link antennas. The CSAD antennas (six are required in the lander, Fig. 1) have successfully passed CSAD sterilization (257°F) and drop tests (2500 g). The radiation patterns of the CSAD antennas, however, have not been obtained since the capsule has not yet been available for pattern measurements.

Second model (non-CSAD model)

This antenna is composed of a small square cavity (1.413 x 1.413 x 1.5 in. internal dimensions) filled with fused-silica. The antenna has passed sterilization (275°F) and 10,000 g indirect impact tests, but needs further improvement in its ellipticity (9 dB). However, since the mechanical and thermal problems of the antenna have been resolved and the refinement of electrical performance can easily be done following the techniques developed for the first model, the design of this antenna is considered completed.

Cavity-Backed Spiral Antenna

With the availability of a suitable potting material (described below), the modification of this antenna to survive sterilization (275°F) as well as 10,000 g indirect impact is in process.

During the same period, searching for a sterilizable high compressive strength foam was also in progress. The foam is intended for use in the cavities of the square-cup (replacing Eccofoam PT) and spiral antennas for the purpose of providing a good margin of safety against balsawood crushing into the antenna cavity during impact. Listed below are the two materials studied:

Imidite "SA"

This foam is sterilizable and has high compressive strength (2300 psi). However, it failed 10,000-g indirect impact tests (potted in both aluminum and titanium cavities) due to slight separation of the material from cavity walls as the result of shrinkage during curing.

Stafoam AA 630

This foam is sterilizable and has high compressive strength (2000 psi). It survived 10,000-g indirect impact with only minor fractures. Since this foam satisfies most electrical, mechanical, and thermal requirements, it is being used as the potting material in the final versions of square-cup and spiral antennas. Further study of this foam is highly recommended for the future.

The direct link antenna study is to be concluded at the end of FY 68. The following schedules are expected to be completed by then:

(1) Electrical testing CSAD capsule antennas

(2) High power testing existing antennas

PUBLICATIONS

SPS Contributions

1. Woo, K., "Sterilizable High-Impact Square-Cup Radiator," SPS 37-49, Vol. III, pp. 345 – 347, Feb. 29, 1968.

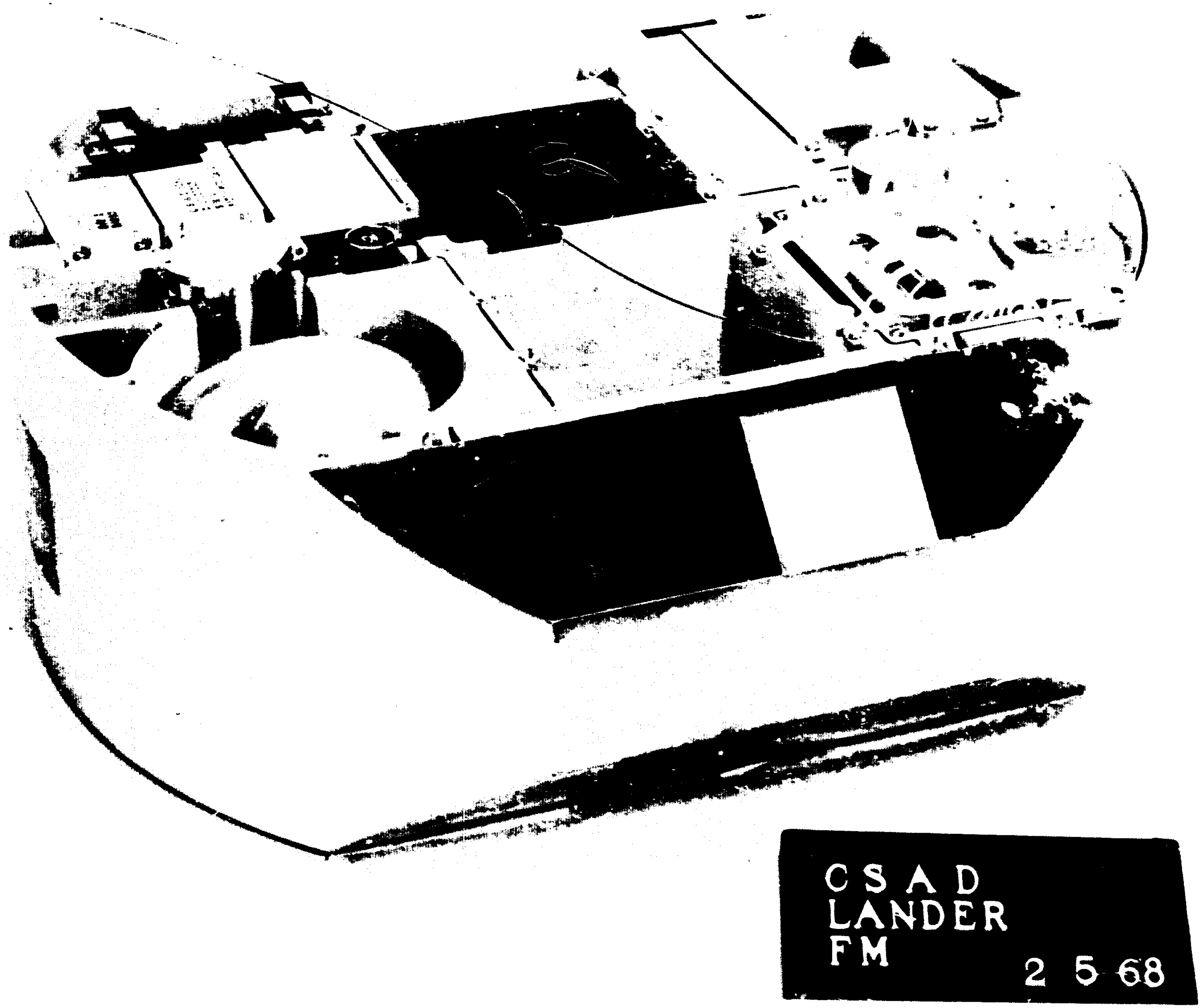

Figure 1. CSAD Direct Link Antennas

CAPSULE RF RELAY

NASA Work Unit 186-68-04-08-55

JPL 384-63101-2-3360

A. G. van der Capellen

OBJECTIVE

The objective is to develop a prototype UHF transmitter and a breadboard receiver for a capsule-to-spacecraft RF relay system. The 13-W, 400-MHz transmitter presently under development is sterilizable. The modulation is bilevel FSK at 500 bits/sec. The long-term goals are higher transmitter power (up to 100 W) and higher bit rate capability (up to 200 K bits/sec).

13-W TRANSMITTER

The complete prototype transmitter assembly is shown, with the covers removed, in Fig. 1. This unit was subjected to a sterilization heat treatment of 125°C for 16 hr in a 98% GN_2 atmosphere. Subsequently, it was installed in the capsule system advanced development (CSAD) entry capsule for system integration tests and another sterilization heat treatment. The only observable change in performance throughout this series of tests was a 10% decrease in modulation index which occurred after the second heat treatment. This anomaly is now being investigated.

Further work on the transmitter will include increased bit rate capability (up to 200 K bits/sec) and increased power output (up to 100 W).

RECEIVER

The construction of the two-channel breadboard receiver, described in an earlier report, has been completed. The receiver has been integrated with the transmitter and the telemetry demodulator to form a complete FSK 400-MHz relay link (without antennas).

Bit error tests have been conducted with hardline, and derived bit sync. Test results are shown in Fig. 2. The receiver was operated in the linear mode (no limiting) and square law envelope detectors were employed.

Demodulator acquisition time measurements were also made and are reported on under "Relay Telemetry Modulation System Development," Work Unit 186-68-04-19-55. Further work will include the study of the effects of limiting and channel unbalance. A final report on the receiver will be produced soon.

PUBLICATIONS

SPS Contributions

van der Capellen, A. G., "Relay Link RF System Development," SPS 37-49 Vol. III, pp. 364 – 365, Feb. 29, 1968.

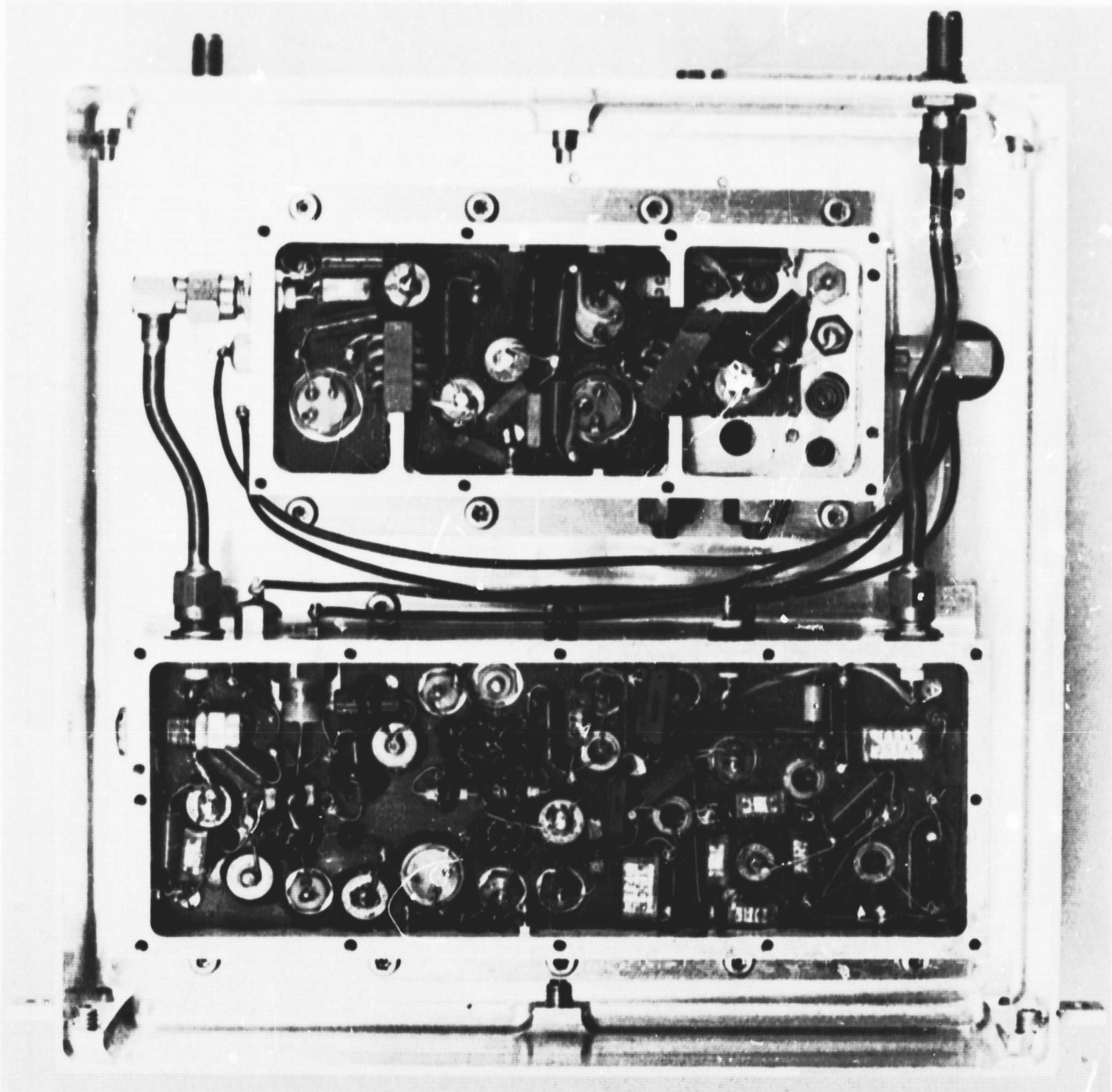

Figure 1. Prototype Relay Transmitter With Covers Removed

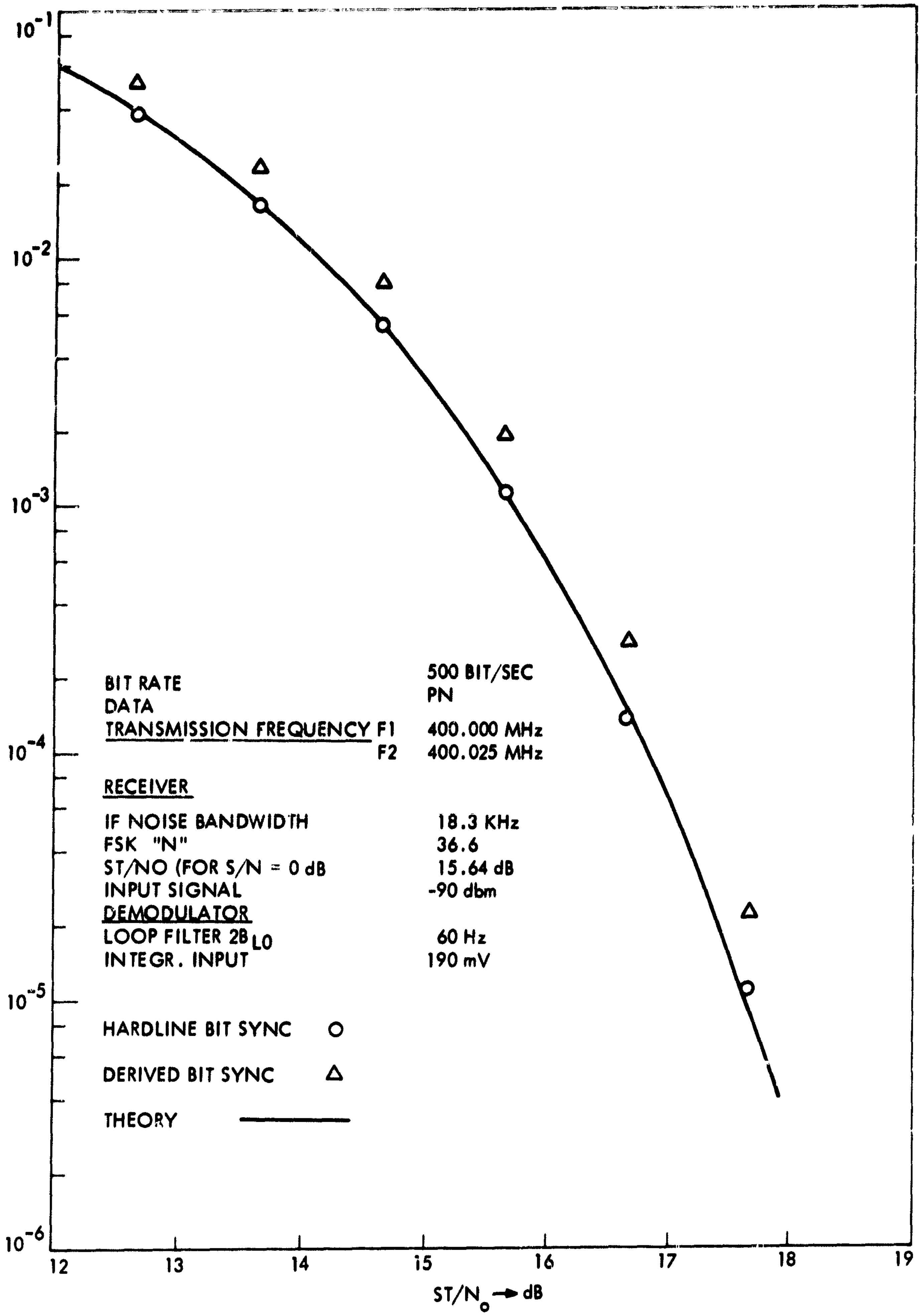

Figure 2. Bit Error Test

RF POWER AMPLIFIERS
NASA Work Unit 186-68-04-09-55
JPL 384-63401-2-3360

L. Derr
R. Hughes

ESFA DEVELOPMENT, JPL CONTRACT 951105

OBJECTIVE

The objective of this task is to develop a 20- to 100-W electrostatically focused amplifier (ESFA) with high efficiency, wide power-output range, radiation cooling and electrostatic focusing for spacecraft applications.

STATUS

The contractor for this development is EIMAC, Division of Varian Associates. Prior to this period, all RF test models of the ESFA were water-cooled and unpackaged. The effort during that stage of the development was to reach the specified electrical goals of efficiency, bandwidth, gain and power output. The collector entrance was also studied to arrive at the most efficient geometry for beam collection. This would provide the highest cooling efficiency when the radiating collector became a working part of the tube. Tube 3, completed last period, performed in accordance with all specified electrical parameters. It then remained for Tube 4 to repeat this performance and to be packaged into the final configuration.

During this period, the final design has been fixed and the preprototype tube has been assembled for test. This design effort has consumed more time and effort than originally estimated. The items which required special design effort before the preprototype could be completed are discussed below:

(1) Electron Gun. The first oxide cathode for the ESFA was designed and tested early in the development program. Subsequent changes in beam diameter and perveance to improve tube efficiency caused the cathode loading to increase beyond the 200 ma/cm^2 level

specified for long life. Since dispenser cathodes were used for the experimental models (because of their natural ruggedness) the design for the final oxide cathode was left until this period, where the final loading requirements would be better known.

The final gun has now been completed. The cathode loading is 147 ma/cm^2.

(2) Electrostatic Lenses. During the experimental phase, the focusing lens leads were individually exposed at the exterior of the tube's body. This allowed independent operation and served to evaluate each lens' ability to control the beam. The end design specifies that all lenses be connected to, and operated at, cathode potential.

It has been observed that some RF power is coupled from the beam to each of the lenses when the ESFA is RF modulated. This feedback could cause the tube to oscillate. The work this period has been to adjust the lens geometry to operate from a common power source and to isolate each lens from the next to minimize RF feedthrough. The RF isolation is being provided by a series of ferrite beads on the interconnecting DC power lead. These beads provide 18 dB of RF isolation between each lens.

(3) Radiation Cooled Collector. This truncated tungsten "egg shell" has been modified to conform to the results of the aperture tests performed last period. A suitable mounting system has been designed for depressed collector operation and physical attachment to the output cavity.

The collector shell operates at a temperature of 1400°C. The radiated heat is directed through the sapphire window by three concentric heat shields. These shields are vacuum cleaned at 2000°C to avoid outgassing problems when they are operated in their high-temperature environment.

A new method of attaching the crossed support rods to the collector shell was evaluated. The rods were brazed directly to the shell using a laser beam. Although the braze was successful, the differential contraction between the rhenium rods and the tungsten shell caused the shell to crack during the cooling cycle. In order to avoid this problem, an alternate method is being used. The collector shell is gripped between pairs of eyelets which are spot-welded to the support rods.

(4) Body Design. The tube's circuits and lens leads are housed in a series of matching "pipe" sections. The sections are brazed together during final assembly, but allow the fabrication to proceed in stages. The outer body becomes the vacuum envelope for the tube, which reduces the number of vacuum seals to one-fifth of that required in the original design.

The mounting base is attached at the collector assembly and at the electron gun, forming a two-point support system. This base will also conduct heat, which is not radiated directly, to the supporting structure.

The RF and environmental testing of the preprototype will be completed in July 1968. Subsequent to completion of the development, five tubes will be procured for evaluation and life test.

LIFE TEST FACILITY

OBJECTIVE

The objective of this task is to provide cognizant engineering direction for the design and construction of a 9000-ft^2 Life Test Facility. This facility will adequately house the long-term tests planned for all flight communication devices developed by JPL.

STATUS

The A and E contractor has completed the final building plans and they have been reviewed and approved by JPL. The planned FY 68 funding support has been removed from this effort and a contractor cannot be selected until the funds have been reinstated.

TUBE EVALUATION PROGRAM

OBJECTIVE

The evaluation of commercially available power amplifiers serves to advance our knowledge, thus improving our capability both for in-house developments and in directing outside development contracts, and, to determine the applicability of each amplifier to future NASA programs.

STATUS

During this report period, hours have continued to accumulate on the Hughes and Watkins Johnson traveling wave tubes on life test. The Hughes TWT, Model 216-H, has now been operating for 28,700 hr and during this time the RF output has decreased only 0.5 dB. The two Watkins Johnson TWTs, Model WJ 274-1, have each accumulated 4600 hr. The RF output on each tube has changed less than 0.1 dB.

Electrical and environmental tests were performed on a 25-W high efficiency Watkins Johnson TWT, Model WJ 274-6. When operated at 2295 MHz, the tube exhibited 25 W of RF output at saturation, 27.9 dB gain, and an over-all efficiency of 41.6%. The tube successfully passed the electrical and environmental tests without any changes in performance. On May 28th, the tube was placed on life test in a vacuum chamber.

PUBLICATIONS

SPS Contributions

1. Derr, L., "Spacecraft Power Amplifier Development Program," SPS 37-48, Vol. III, pp. 278 – 280, Dec. 31, 1967.

ADVANCED SPACECRAFT TELECOMMUNICATION SYSTEMS

NASA Work Unit 186-68-04-11-55

JPL 384-63201-1-3360

M. A. Koerner
F. H. Jean
W. E. Ackerknecht
C. E. Gilchriest
M. K. Tam[1]

OBJECTIVE

The primary long-range objective of this task is to make available the necessary technology, in the form of unified telecommunication system components, to meet the requirements for future missions. The secondary long-range objective is to perform the analysis necessary to carry out the primary long-range objective. The short-range objective is to perform the analysis necessary to support the synthesis and development of first priority telecommunication subsystems.

ACTIVITIES

The five subtasks to meet the objectives are described in the following paragraphs:

1. <u>Low Data Rate/High Impact Direct Link</u>
   The objective of this subtask is to perform the analysis, from a system point of view, of the low bit rate telemetry system (see related Work Units 150-22-17-04, Low Data Rate MFSK Modulation Detection Systems; 150-22-17-06, Low Data Rate MFSK Transmitter; 150-22-14-24, Frequency Generation and Control). Special attention will be given to the definition of the system performance objectives and to the subsystem functional requirements.

   The performance degradation was evaluated for a conventional low rate M-ARY frequency shift keyed (MFSK) system in the presence of uncompensated linear frequency drift. Results were obtained in

[1]Contract Associate, NAS 7-100, Subcontract 951513 and EW-482060

terms of the probability density function of the output voltage which allowed computation of the degradation compared to performance without frequency drift.

Analytical results of W. C. Lindsey and I. Blake were examined to determine the theoretical performance of a PSK/PM system using narrow-band tracking loops. The cases examined were for threshold loop bandwidths ($2B_{Lo}$) of 1 and 3 Hz, and with bandwidths of 10 and 100 Hz, respectively. The jitter of the source oscillator was not included. These results serve as guides for a minimal performance bound for a low data rate link.

2. <u>Relay Link Telemetry</u>

This subtask is devoted to the analysis of problems related to the choice of an efficient telemetry system for communication between a planetary capsule and the parent spacecraft (see related work units 186-68-04-08, Capsule Relay Antenna; 186-68-04-08, Relay Link RF Systems; 186-68-04-19, Relay Telemetry Modulation Systems Development).

The experimental bit synchronizer is being reanalyzed in an effort to obtain a system model which correlates better with the experimental results. Also, a second bit synchronizer block diagram is being analyzed in support of experimental work in progress. Studies will be made concerning signal level variations during capsule transmission, and the effects of the variations on the receiver requirements.

3. <u>Ranging and Radio Subsystem</u>

Effect of Distortion of a Ranging Signal in a Turnaround Ranging Channel on Ranging System Margin and Accuracy

In previous analyses of the ranging system it has been assumed that the ranging signal is not distorted by the turnaround ranging channel. The objective of this task is to determine the effects of distortion.

This work has been temporarily suspended in deference to other tasks.

Spacecraft Tracking Antennas

This task is the analysis of antenna pointing and tracking techniques which are applicable to spacecraft antenna systems. A system design philosophy was formulated, and many available pointing systems have been studied to obtain system design information. Two new techniques are being developed; the first technique provides scanning by varying the amplitude of a pair of feeds for a reflector, and the second technique combines the advantages of phase monopulse and phase comparison conical scan systems. The designs using standard available techniques are being studied to determine whether they are compatible with spacecraft applications. Techniques under consideration include sequential and simultaneous lobing, phased arrays, and array-fed reflectors. A few of the most promising techniques will be selected for more detailed design studies during the next reporting period.

The first phase design of a Mars surface lander pointing system was completed during this period through joint interdisciplinary efforts. The system is a four-gimbal system which used gyros and computer updates to control the acquisition and pointing processes. No plans have been made for the detail-design phase.

Radio Frequency Interference

An interference specification has been prepared for space projects that use the DSN. The document is presently in the approval stage.

4. System Methodology

Reliability

This task is accomplished largely through a contract with Tam Research Associates. The previous contract ended in October 1966. There has been a discontinuity of effort but it is now continuing under a consulting contract of $6000 ending in June 1967 and a manpower support contract for $16, 000 beginning in June 1967. The reliability effort has been suspended in deference to the succeeding task.

Probability Distribution of Hardware Performance Parameter Delivered by a Contractor to a Specification (Task 31-E)

The objective of this task is to determine the a priori probability distribution function of a hardware performance parameter delivered by a contractor to a specification, and to determine strategies for manipulation of the contractor to obtain satisfactory probability distribution functions.

The analysis of this task is complete and literature searches have been performed to confirm the analytical techniques utilized. A final report is in preparation.

FUTURE PLANS

Major effort will be made to accomplish a "technology cutoff date" of July 1, 1969 for the low data rate/high impact direct link, relay link telemetry, and spacecraft tracking antenna systems. Additionally, work will continue in the area of systems methodology, particularly, in the system tolerance work.

PUBLICATIONS

SPS Contributions

1. Jean, F. H., "Performance of a Conventional MFSK Receiver in the Presence of Frequency Drift," SPS 37-50, Vol. III, Apr. 30, 1968.

RELAY TELEMETRY MODULATION SYSTEM DEVELOPMENT

NASA Work Unit 186-68-04-19-55

JPL 384-67801-2-3340

C. Carl

OBJECTIVE

This work unit is concerned with the design, development, and testing of telemetry modulation/demodulation systems for relay link applications.

BACKGROUND

For the past year, the effort on this work unit has primarily been directed toward support of the capsule system advanced development (CSAD) program to develop and demonstrate a 500 bit/sec FSK telemetry relay link. The previous semiannual report described the configuration of a breadboard link that was built for evaluation of key performance parameters, such as bit-error rate and acquisition time. Bit synchronizer loop bandwidths ($2B_L$) of 7.5 and 25 Hz were tried and found to have acquisition times larger than the CSAD design goal (100 bit times).

PROGRESS

The bit synchronizer $2B_L$ was increased to 60 Hz and the test matrix was performed again. The results indicated that acquisition time at threshold (defined as that signal-to-noise ratio at which 10^{-3} error probability occurs; and a signal frequency offset of 2 Hz) was about 50 bit times. The degradation of bit error rate due to bit sync jitter was only 0.3 to 0.4 dB. It was felt that this design would satisfy the CSAD requirements. An identical demodulator unit was built, shipped to the CSAD system test area, and has worked successfully since January.

Meanwhile, design margin tests were begun on the breadboard to fully qualify the limits of performance and understand its characteristics. It was found that the bit synchronizer's phase detector produced a dc bias dependent on the transition probability of the incoming data. This bias, translated to the loop input, would be a frequency offset, and the loop behaved accordingly. It was found that acquisition times for negative frequency offsets were lower than those with the same-valued positive frequency offset. Also, the loop tended to [illegible] lock more often. Evaluated were two alternative phase detector topologies; the most attractive being an "absolute value" type. Its circuitry is simpler and it solved the dc bias problem. All subsequent testing has used this topology.

The breadboard bit synchronizer was mated in April with the actual 400-MHz RF link equipment, developed for CSAD.[1] The first set of acquisition tests and bit-error tests have recently been completed. The bit error tests show good agreement with theory and about the same sync loss of 0.3 – 0.4 dB due to jitter.[1] However, a discrepancy does exist because the breadboard data was 0.8 dB better than the equivalent theory prediction. The main difference between the configuration is linear envelope detectors in the breadboard case and square law in the RF case. This is a second-order problem and will be pursued when time permits. The acquisition time of the synchronizer is comparable to that measured at baseband: about 50 bit times at threshold.

For complete details of the reporting period's progress, reference should be made to the SPS articles listed below.

FUTURE PLANS

For the next 2 mo, it is anticipated that the remainder of the RF compatibility tests will be run. These include evaluating the effect of limiting and channel unbalance; investigation of the envelope detector anomaly; and perhaps, RF swept frequency tests. This will conclude work on the 500 bit/sec link.

Thereafter, we will start to investigate alternative candidates for a 200-K bit relay link, suitable for transmission of capsule entry TV. Study of high speed relay links is the long-term goal of this work unit.

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[1] See report of Work Unit 186-68-04-08-55.

PUBLICATIONS

1. Carl, C., "Relay Telemetry Modulation System Development," SPS 37-50, Vol. III, Apr. 30, 1968.

2. Carl, C., "Relay Telemetry Modulation System Development," SPS 37-51, Vol. III, Jun. 30, 1968.

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RF POWER AMPLIFIERS

NASA Work Unit 186-68-04-21-55

JPL 384-68601-2-3360

L. Derr
R. Plummer

OBJECTIVE

This work unit supports the advancement of DC to RF efficiency in traveling wave tubes (TWTs) for spacecraft application. The goal for efficiency is 55% at 100 W of output power at 2295 MHz. The tube presently under development is conduction cooled, magnetically focused and employs a newly designed single helix.

STATUS

This tube is being developed by the Watkins Johnson Co., under JPL Contract 951299. The project is now 95% completed and the final tube delivery is scheduled for July 1968.

During this period, six tubes were fabricated, five of which have completed their test program. A thorough design review was held at JPL on March 1, 1968 where final instructions to the vendor's efforts were formulated. These instructions have been implemented in Tube 14, which is presently under test. Tube 15 is being constructed and the best design of these two tubes will be packaged and delivered to JPL as the end item of this contract.

In January 1968, the vendor procured high-resolution X-ray equipment which allowed him to determine accurately the helix pitch after the tube is assembled. He first inspected the helix pitches of Tubes 6, 7, and 8. In each he found discrepancies between actual and design pitch. This pointed to the problem of rigidly holding the helix during its insertion into the barrel and the subsequent clamping and mandrel removal activities. A new technique was developed whereby the molybdenum mandrel used to hold the helix during insertion is removed by a chemical etch process. Subsequent X-ray analysis showed that helicies installed in this fashion were positioned precisely as planned.

Tube 9 was constructed with a two-step taper at the helix output. The results were far from optimum. The gain was 12 dB, power output was 100 W and the efficiency 40%. It was decided that the step taper was placed too far from the real saturation region.

Tube 10 used a longer input section to improve the small signal gain, and a redesigned output taper of shorter length. Although the gain was improved to 36 dB, the efficiency was only 41.7% at the rated output power.

Tube 11 employed a linear taper instead of the abrupt step taper and much improvement in efficiency was realized. This tube had a gain of 36 dB and an over-all efficiency of 48.6% at the 100-W level.

Tube 12 was constructed with the same design as tube 11 except for its output taper, which was shortened. This failed to show a real improvement in performance as the gain was 36 dB and the efficiency lowered to 44.7%.

At the design review, March 1, 1968, the vendor presented the design of tube 11 as the best example of the tube's capability and a suitable candidate for the final tube. He asked that JPL grant a waiver on efficiency, lowering it to 47%. It was determined after the design review, that there were areas in the output connector and on the output RF line that were possibly subject to multipactor breakdown. Multipactoring tests at JPL showed no evidence of multipactor and consequently, the present tube and connector design appears adequate. However, it was determined that a slight step in the OSM output connector's dielectric would increase the safety margin. The multipactoring tests were made on tube S/N 6 in a vacuum environment. The output VSWR was varied from matched conditions to 2.4 to 1 and its phase varied through 360 deg. A short section of helix, complete with input and output connectors, will be tested with and without magnets to determine the effect of the magnetic field on multipactor breakdown, and to determine more accurately the safety margin of the design.

Thermal vacuum tests of the potting material to be used, Dow Corning DC-850, indicate that it is within acceptable limits up to approximately 175°C. This temperature is a safe margin above the 150 deg maximum that the collector will encounter. The criteria for elastomers during the tests is that the total weight loss be less than 1.0% and the volatile condensable material (VCM) be less than 0.1%.

The JPL review board granted a waiver in efficiency, lowering it to 47%, and instructed the vendor to make the following changes to the final design:

(1) Change the cathode nickel from 220 nickel to "Nipure" nickel containing 0.1% Zirconium to provide longer operating life

(2) Change the collector clamping materials to minimize differential thermal expansion problems

(3) Modify the output connector to provide a greater safety factor for multipactoring

(4) Vacuum pot the tube in its housing

(5) Spread the input helix turns to provide a better input VSWR.

Tube 13 was constructed using the above changes and a short section of uniform helix following the output phase step to improve the small signal characteristics. Brazing problems occurred at the interface between the helix barrel and the end pole-piece causing the helix clamping to fail. X-rays of the tube showed that the helix had relaxed to an undesirable pitch, which degraded the performance of the tube. Its maximum power output was 73 W and its efficiency was 25%. The gain remained at 36 dB and the new cathode performed well. The spread turns at the input of the helix reduced the input VSWR to the specified 1.2/1.0.

Tube 14 has been constructed using the best realized design, that of tube 11. This tube is now under test and its performance will be reported next period.

The production phase of this program has been negotiated on a fixed price basis. That procurement will be initiated in August 1968, and will provide five 100-W TWTs for the JPL life test program. The best design realized on the development phase will be used for these life test tubes.

PUBLICATIONS

None.

BLOCK CODED TELEMETRY MODULATOR/DETECTOR SYSTEMS

NASA Work Unit 186-68-04-25-55

JPL 384-71201-2-3340

J. C. Springett
F. L. Larson

OBJECTIVE

This task is intended to investigate the performance of relatively high data rate (>10K bit/sec) telemetry techniques. Greatest emphasis is being given to performance of a 16.2K bit/sec system proposed for the Mariner Mars 1969 high rate link. The effects of noisy coherent demodulation, and the evaluation of subcarrier and symbol timing techniques is being pursued. Near optimum performance of the high rate detector is required as the entire system design margin is only 2.0 dB.

Experimental studies are making use of an existing SDS 930 digital computer in conjunction with the RF test console. The primary effort is being directed toward functionally evaluating a particular design for the Mariner Mars 1969 high rate telemetry system. It is also planned to test the system over a wide range of parameters in order to assess the performance relative to future mission designs. The implementation of the block coded detector is based upon techniques developed under Work Unit 125-21-02-03-55.

PROGRESS

The prototype high rate detector was available for testing by mid-October 1967. Somewhat prior to this time, the major portions of the demonstration system software had been delivered and were modified with respect to the SDS 930 computer system. (Note: the system verification effort makes use of a 930 computer rather than the 920 computer planned for operational use.) In addition, subroutines necessary to perform the experimental evaluation were written and incorporated into the demonstration software. By early November, the detector and software were working sufficiently well so that preliminary testing could be started. These tests were conducted with all syncs and RF references hard-wired and noise-free. The results of initial testing showed that some minor problems existed in the software, as well as in the experimental signal and noise setup procedure. The greater portions of November and December were devoted to solving these problems.

The experimental data herein presented were gathered during the first three weeks of January 1968. Although the data should be considered preliminary, they are indicative of the performances of each of the major system elements prior to transfer of the equipment to the spacecraft compatability test area (CTA-21). In particular, the results have shown that the detector itself, with all sync's hard-wired, performed as expected, while the performance of the symbol-tracking loop and subcarrier demodulation assembly (SDA) was below nominal expectations. Results of the testing prompted some changes in these components during CTA-21 installation.

Preliminary testing of components of the HDR telemetry system was performed in four steps: (1) detector only, symbol sync hard-wired, (2) detector, symbol sync hard-wired, + SDA, medium bandwidth, (3) detector + symbol tracking loop, no SDA, and (4) the complete system. The performance loss attributed to each subsystem is summarized in the following table, along with the measured loss for the entire system.

Component ST_b/N_o	Loss, measured as departure from ideal, dB				
	0.5 dB	1.5 dB	3.0 dB	3.5 dB	4.5 dB
1. Lab Set A, hard-wired	0.1	0.15	0.1	0.0	0.1
2. Subcarrier demodulation assembly	0.0	0.1	0.2	0.2	0.2
3. Symbol tracking loop	0.7	0.55	0.5	0.5	0.2
4. Sum of 1, 2, and 3	0.8	0.8	0.8	0.7	0.5
5. Measured degradation, total system	0.8	0.85	0.8	0.6	0.3

The only major discrepancy in the measured data appears in lines 4 and 5 of the table, for high ST_b/N_o, wherein number of data words per run was not high enough (due to available test time) to yield accurate results at ST_b/N_o = 4.5 dB.

Future work will be directed toward refining these measurements and investigating the rather high losses encountered in the symbol loop.

PUBLICATIONS

SPS Contributions

1. Springett, J. C., and Larson, F. L., SPS 37-51, Vol. II in press.

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ENGINEERING MECHANICS STUDIES

NASA Work Unit 186-68-09-04-55

JPL 384-62301-2-3500

H. Bank

OBJECTIVE

The general objective of this work unit is to provide direction to the Engineering Mechanics Division Advanced Development Program, based on insight gained through future project studies at JPL. For this report period, the study activity has extended the aerothermodynamics investigation of the earth reentry testing for Venus entry simulation started in early FY 68. In addition, EMS studies have been concerned with the mobility of unmanned roving vehicles as a result of needs indicated in advanced study activities as well as earlier project studies. These two areas are discussed as follows:

VALUE OF AN EARTH REENTRY TEST TO SIMULATE VENUS ENTRY

As a continuance of the analytical work reported in the last semiannual publication, the work has been extended and refined by computer analysis. The objective can be restated as one of assessing the extent of simulation possible by reentry to Earth with a vehicle designed for Venus entry. Tentative conclusions from the work performed to date follow. Completion of this work activity will be accomplished under Work Unit 124-07-01-01-55, "Planetary Entry Gas Dynamics," with emphasis placed on ablation material response.

For a direct ballistic entry of a high drag body into the Venus atmosphere, a full-scale earth reentry flight test for the same ballistic coefficient and velocity should provide an acceptable simulation of density and velocity time histories, convective heat transfer, and maximum deceleration. The simulation of shock-layer radiative heat transfer and ablation material response would be less satisfactory in the stagnation region, and increasingly unacceptable away from the stagnation point, with the earth conditions being unconservative. A compromise test configuration is possible in which an essentially full-scale configuration is truncated at a location that permits full-scale simulation of the stagnation region. This approach would emphasize the region of best simulation and permit a lower cost launch system to be used.

When some comprom› ء are accepted, it appears that a meaningful earth reentry test of a simulated full-scale aeroshell (or part thereof) for Venus can be made, but with ablator material response being the most uncertain factor. As a minimum, the earth reentry test can place a Venus capsule in a flight environment comparable in severity to actual Venus entry. This environment is difficul to obtain in ground facilities for any significant piece of flight hardware.

Mobility Studies

Mobility efforts during this period were concerned with the investigation of wheel soil interaction mechanics in combination with developing analytical approaches to the "off-road" locomotion problems. These are both a part of the soft soil performance problem discussed below.

Soft Soil Performance

The wheel soil interaction problem is, of course, fundamental to roving technology. Some "off-road" soft soil analysis and experience have been developed on earth vehicles which NASA studies have extended to roving investigations. However, a review of these efforts indicates they are quite limited in scope and have only considered the ideal case of zero surface slope. Recognizing that a primary need of planetary roving missions involves traversing irregular terrain with slopes up to the soil angle of repose, efforts have concentrated on developing the analytical approach considering the effects of slope. A preliminary method is being investigated for the problem using a representative roving vehicle being investigated in the advanced study activity. The method adapts Terzaghi-Meyerhof's strip bearing concepts on horizontal soil, with Meyerhof's ultimate load approach to inclined loads to develop a bearing allowable for inclined surfaces. By calculating the bearing strength at various depths below the surface, a preliminary expression for wheel soil load sinkage on sloped soft surfaces has been developed. In effect this approach applies limit load analysis of the theory of plasticity to soils and assumes the soil is a plastic which obeys Coulomb-Mohr failure conditions. In order to evaluate this expression, a series of initial soil penetration tests have been started which experimentally determine sinkage versus load data for wheel-type loads on sloped surface. These tests consider wheels oriented parallel and perpendicular to the surface, using soils considered representative of planetary conditions. Results of these tests, which should be forthcoming in the next reporting period, should be adequate to establish the validity of this analytical approach.

When developed, this analytical method should permit the evaluation of the following roving performance parameters:

(1) Maximum slope climbing capability

(2) Thrust and torque requirements for drive units

(3) Energy requirements for power systems

(4) Obstacle climbing capability in soft soils

These items will be considered during the next report period.

PUBLICATIONS

None.

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ADVANCED SYSTEMS TECHNOLOGY

NASA Work Unit 186-68-09-09-55

JPL 384-70601-2-2920

E. K. Casani

The CSAD Program has been completed; the objectives, as stated in EPD 491, have been successfully accomplished. The final system test was conducted during the first week of June; subsequently, the system test complex was dismantled.

The capsule system, including both the entry and lander portions, was sterilized and successfully tested after sterilization. The lander was subjected to two impact tests at Goldstone, California. These tests simulated the Mars landing environment: in one test, the lander was impacted on the dry lake bed; in the other, the lander was impacted on the asphalt runway. Both tests were conducted with an impact velocity of 120 ft/sec.

The successful completion of these tests demonstrated the feasibility of the technology required for high g impact and sterilization. These two environments are different from the environments encountered in the design of other unmanned spacecrafts; they are unique to planetary entry and landing. A major step forward toward planetary landing was accomplished by demonstrating the technology required by these two environments.

Figure 1 is the feasibility model which was designed, built, and tested during the course of the CSAD Program.

The CSAD Program Report has been published; it discusses the program, the mission, the system, and the subsystems used in the CSAD Program.

ANTICIPATED PUBLICATIONS

1. Casani, E. K., "Mars Entry and Landing Capsule", to be presented at AAS/AIAA Meeting, Denver, Colorado, 15-16 July 1968.

2. Gerpheide, J. H. and Casani, E. K., "System Advanced Development", to be presented at 19th Congress of the International Astronautical Federation, New York, N. Y. 16-19 October 1968.

3. Casani, E. K., "Planetary Spacecraft/Entry Capsule Interface Design" to be presented at AIAA Entry Vehicle Systems and Technology Meeting, Williamsburg, Virginia, 3-5 December 1968.

PUBLICATIONS

1. Casani, E. K., and Frewing, K., "Performance Improvements to the Mars Entry and Lander System Design," JPL Document 760-19, Jan 19, 1968.

2. Casani, E. K., "Capsule System Advanced Development CSAD Mission Model," JPL Document 760-20, May 6, 1968.

3. Gerpheide, J., and Casani, E. K., "Capsule System Advanced Development Program Report," JPL Document 760-29, Jul. 15, 1968.

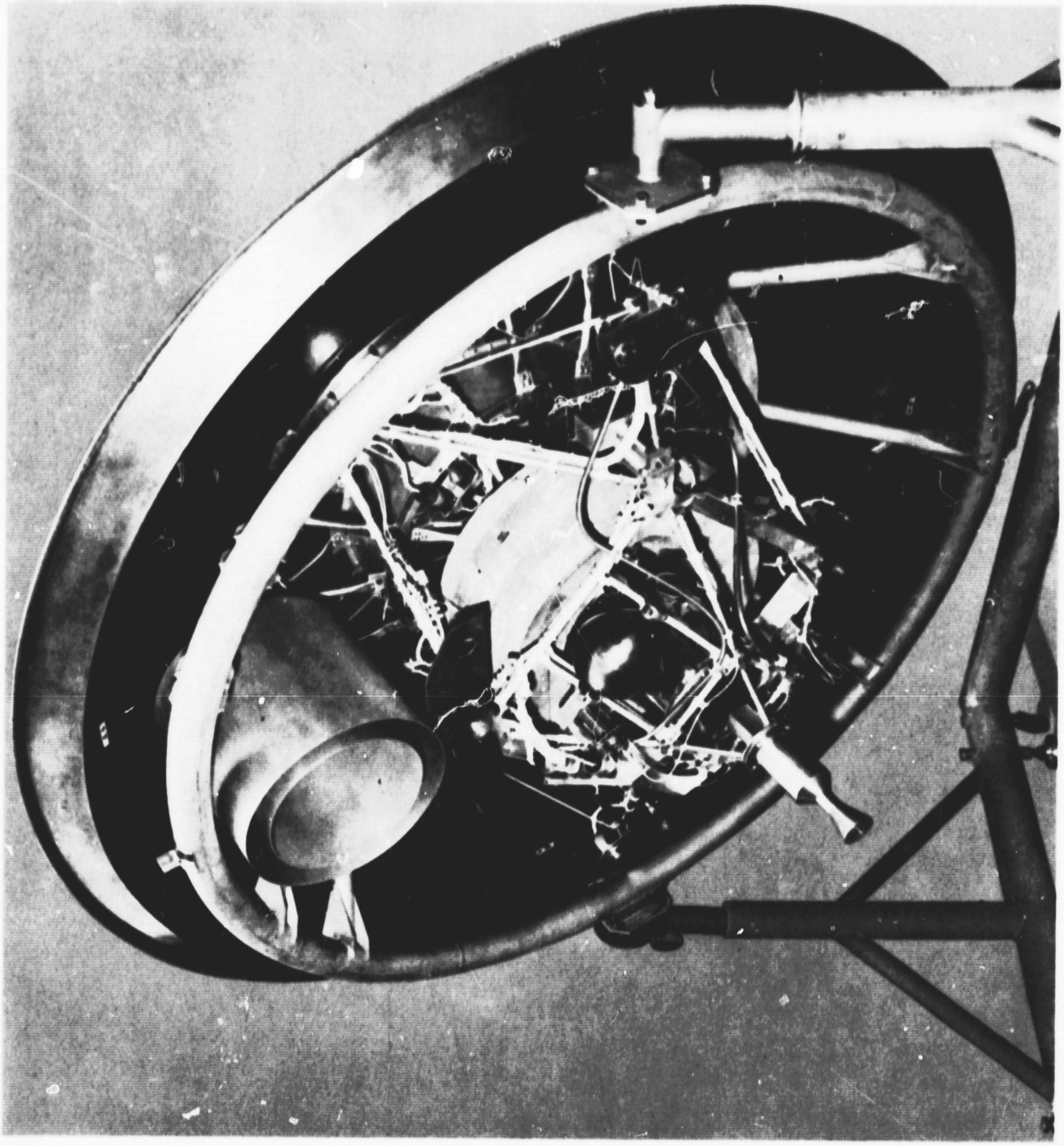

Figure 1. CSAD Feasibility Model

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MODULAR ELECTRONIC PACKAGING ADVANCED DEVELOPMENT

NASA Work Unit 186-68-10-09-55

JPL 384-66601-X-3570

E. R. Bunker, Jr.

OBJECTIVE

The long-range objective of this work unit is to develop, reduce to practice and qualify to anticipated environments, advanced modular electronic packaging concepts, including component interconnections, which are initially generated by industry, by work units such as Advanced Development of Electronic Interconnections, 125-25-03-01, or other sources.

The objectives for FY 68 were:

(1) Development of film insulated wire welding equipment

(2) Development of further electronic equipment welding technology and provision of consulting service to project groups and outside vendors

(3) Study, evaluation, and development of an advanced modular electronic assembly configuration to support future JPL spacecraft designs

(4) The employment of the developed modular packaging technologies to integrate, functionally and mechanically, typical subsystems required for the entry vehicle for the capsule system advanced development (CSAD) program.

COLD ELECTRODE WELDER

In order to minimize confusion, the term "cold electrode" has been substituted for the previous "concentric electrode" in the description of the opposed electrode method of welding. A true concentric electrode welding configuration is described in the next section. Further investigation and analysis of the method of splitting the teflon insulation between the upper electrode and the terminal showed that a higher force was required than that desired for the welding operation. The welding head was modified with a motor-driven mechanism which would allow a two-step operation to be achieved automatically for each weld. With this modification, the weld head would depress with a force sufficient to split the teflon insulation, back off, and then again apply the required welding force before firing the welder electrically. It was found that this two-step semiautomatic welder achieved satisfactory welds for nickel magnet wire with 0.7 mil teflon insulation.

In attempting welds of magnet wire with insulation thicknesses up to 10 mils it was found that a further modification of the welder was necessary. Because of the configuration of the welding head used, independent adjustments of the insulation splitting pressure and the weld pressure were not possible. To overcome this, a weld head was designed which would allow complete independence in the setting of these two pressures. The design of this thick insulation welder has been completed and the necessary parts and fabrication have been ordered. During the next reporting period this welder will be assembled and tested.

Various methods of obtaining an automatic cutoff feature of the cold electrode welder were investigated. The problem was found to be two-fold. In addition to obtaining a clean sharp cutoff of the magnet wire, it is necessary to form it in the proper position under the welding electrode for the next weld. It appeared most feasible to use an X-Y positioning table to hold the work. Cutoff would be achieved by jogging the table to the side one diameter of the electrode. When the electrode is depressed, it would shear the wire and automatically form it under the electrode ready for the next weld. As mentioned before, the additional advantage of the X-Y table would be the capability of automatically positioning it by means of equipment so that the human element involved would be eliminated.

CONCENTRIC ELECTRODE WELDER

The extension of the cold electrode approach of welding magnet wire to blind terminals has been achieved by a true concentric electrode configuration. This consists of two concentric electrodes electrically insulated from each other and individually articulated, with the insulated magnet wire being fed down through the hole in the inner electrode. During the welding operation the electrodes move down until the outer electrode encircles the terminal, making an electrical connection. The inner electrode continues to move down with sufficient pressure to split the insulation, then backs off to the desired welding pressure, where the welder is fired, achieving the weld joint.

During the next period, the concentric method will be refined so as to be capable of being used on the thick insulation wire welder described above.

WIRECON HEADER REDESIGN

Further work on the Wirecon header redesign, designated Wirecon III, as described in JPL TM 33-353, Vol. I, p. 338, will be contingent upon the needs of future spacecraft programs. A survey was made of possible vendors who would be capable of producing the header in this new configuration at a reasonable price and delivery.

STICK MODULE DRAWER

The stick module drawer, designed as a nonfunctional mockup for the data handling subsystem of CSAD, described and shown as Fig. 1 of the "High Impact Electronic Equipment Packaging Technology," p. 297, Semiannual Review, July 1 through December 31, 1967, was exposed to high impacts up to 10,000 g. All of the sticks, some with a few discrete components mounted, were encapsulated, then inserted into the drawer module. A conformal coating was applied to the tops of the sticks and to the output terminals, to provide anchoring in an attempt to eliminate relative motion to each other during impact.

The holding fixture described, which employed the wedge retention method proposed for the CSAD lander, was mounted on the impact table. By suitable orientation of the fixture, high impacts could be applied in the three orthogonal axes. Referring to Fig. 1 above, the axis designations were as follows: +x to the right, parallel to the sticks, +y upward perpendicular to the top of the stick, and +z toward the front, perpendicular to the plane of the stick.

The original test plan was to reorient the fixture after each impact at a given g level. The g levels chosen were nominally 2500, 5000, and 10,000. After successfully completing the 2500-g test in the +x, ±y and ±z directions without damage, it was feared that higher impacts applied in the +y direction might cause the wedges to shear off the thin lower section of the retaining slots of the drawer. So that as much information could be obtained as possible before exposing the drawer to this anticipated failure mode, it was planned to apply the 5000- and 10,000-g levels in the +x, -y, and ±z directions with the intent of returning to +y impact direction later if the drawer successfully survived the higher impacts. No damage was observed at 10,000 g in the +x and ±z directions. During the -y impact at this level the fixture partially collapsed, causing superficial damage to the connector module in the drawer.

The fixture has been repaired, and the remaining impact tests will be run in FY 69 to complete the project. A small brace will be added to strengthen the lower section of the drawer. The effectiveness of the conformal coating in preventing relative motion of the sticks during impact will also be evaluated.

MICROJOINING LABORATORY

The name of this laboratory was changed from "weld" to "microjoining" to remove the limiting connotation that welding was the only method of joining small conductors in advanced development work. In addition to continuing the work described above, development of reflow soldering technology for flat packs will be initiated.

PUBLICATIONS

None.

EVALUATION AND QUALIFICATION OF CONNECTORS AND WIRES

NASA Work Unit 186-68-10-10-55

JPL 384-67201-X-3570

R. W. Lester

OBJECTIVE

The central objective of this work unit is to assure the availability of multipin connectors, wires, radio frequency connectors and cables, and cabling accessories for future spacecraft. The current activities supporting this objective can be divided into three classifications: (1) development of additional sources for flight-type connectors to make procurement easier with significantly lower costs, (2) selecting and developing connectors and wires for the rigorous environments and new applications anticipated for future spacecraft missions and (3), testing connectors and wires to verify that they function reliably when exposed to conditions to be expected for proposed spacecraft missions.

MULTIPIN CONNECTORS

A survey of connector sources has been initiated. Engineering conferences with potential suppliers in the Midwest and East have been held, and visits to West Coast facilities are planned for the first quarter of FY 69. The survey is to be completed by the middle of the fiscal year. Purchase orders for flight-type circular connectors for evaluation were placed with five manufacturers during the last quarter of FY 68. JPL has assisted the selected sources by evaluating the outgassing characteristics of proposed connector insert molding compounds. Appreciable dollar savings and improved delivery schedules are expected to result from development of additional sources of supply. Evaluation of recently developed connectors which may be suitable for some of the temperature extremes predicted for future missions is planned.

WIRES

Evaluation of Kapton (H-film) insulated hookup wire had been scheduled for completion at the end of the third fiscal 1968 quarter. Very little was accomplished due to the unavailability of facilities and personnel. Resumption of testing is planned to start in October and to be completed by November 1969.

CAPSULE SYSTEM ADVANCED DEVELOPMENT

An improved straight-through radio frequency connector for use with semi-rigid cable was recommended for use on both the orbiter and lander assemblies.

STERILIZATION

Work Unit, "Sterilizable Connectors, Wires and Cabling Accessories," 186-58-13-06-55, was closed out with the end of FY 68. The final testing of the simulated subsystem harnesses and completion of the JPL Technical Report will be accomplished as a part of this work unit, " Evaluation and Qualification of Connectors and Wires. "

PUBLICATIONS

None.

ADVANCED MECHANISMS

NASA Work Unit 186-68-12-05-55

JPL 384-68201-2-3550

J. O. Lonborg

OBJECTIVE

The objective of this work unit is to examine certain mechanisms, concepts, and components on an advanced development basis in order to minimize later project problems and to better answer questions concerning optimum mechanization for a given set of requirements.

PROGRESS

Progress on development of deployable instrument masts, a spacecraft chemical heater, and a landing impact/attitude sensor were reported in the last semiannual review. At that time, this task was without funds and work had ceased. Subsequently, additional funds were made available for the purpose of investigating the feasibility of development of a high-impact alpha-scattering instrument. Critical elements of the Surveyor alpha-scattering instrument have been identified and preparations are being made for impact testing them, with the cooperation of University of Chicago personnel. Restocking and refurbishing of the high-impact test facility for support of these tests has been accomplished.

PUBLICATIONS

None.

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SPACECRAFT MATERIALS EVALUATION

NASA Work Unit 186-68-13-03-55

JPL 384-62701-1-3820

J. Moacanin

OBJECTIVE

The objectives of this work unit are to: (1) define materials and design parameters which are relevant for the use of cellular plastics, i.e., foams, as encapsulants for operation in space environment, (2) find materials best suited for proposed applications, and (3) relate changes in mechanical properties of urethane elastomers to chemical changes which occur during heat sterilization.

PROGRESS

Foam Encapsulants

The major part of the review period was devoted to the development of procedures for the determination of the corona inception voltage V_l in foams. To avoid noise pickup, the test specimen jig had to be moved from the commercial tester housing into a vacuum bell-jar; half-inch copper tubing was used to construct corona-free high-voltage conduits. The bell-jar served as an environmental chamber. V_i was taken as the minimum voltage required to observe, on an oscilloscope, breaks in the 60-cycle trace. This corresponded to a current of about 5 μ amps through the specimen. It was found that tests could not be carried out under ambient conditions because of discharges from the electrodes into the air. The technique of blowing the foam around the electrodes was not promising because of the tendency of the foam to pull away from surfaces during cure, creating electrically weak spots (TR 32-1155). The solution to the problem was to use a SF_6 atmosphere, a gas of high dielectric strength (comparable to transformer oil; see Fig. 1). Following this procedure, discharges inside the cellular structure could be measured rather than discharges at the electrodes or at the specimen surface (Table 1). A final report of the ensuing test results is in preparation. This subtask is being phased out.

Mechanical Properties of Sterilizable Urethane Elastomers

Stress relaxation measurements in compression were carried out on glass-filled elastomers. Modifications in both specimen preparation and instrumentation had to be made in order to improve the over-all sensitivity of the measurements. In compression, in contrast to tension, measurements have to be carried out at relatively small strains. Also, a dilatometer was constructed to monitor volume changes on specimens in compression.

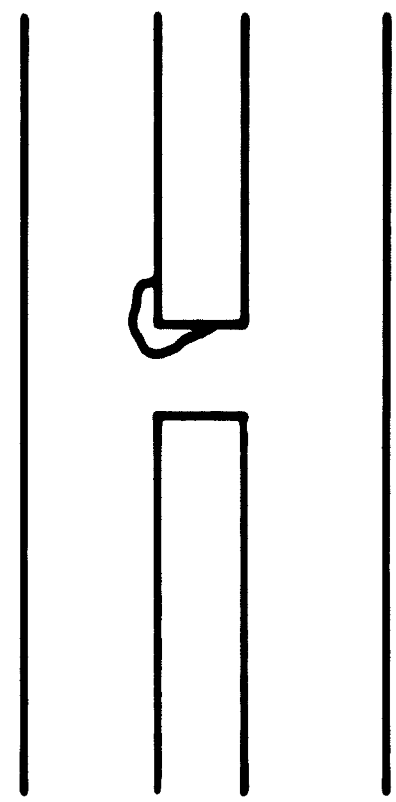
FUTURE WORK

A report on foam encapsulant will be published, completing the work on this subtask. Stress relaxation measurements on filled elastomers will be completed. Attention will turn to the effect of sterilization on long-time storage.

Table 1. Corona Initiation Voltage at Atmospheric Pressure

(1-in. Electrode, 1/2-in. Gap)	
CO_2	18 kV
SF_6	33 kV
CO_2 - Blown Foam in SF_6 atmosphere	26 kV

IMBEDDED ELECTRODES: FOAM IS LIKELY TO CREATE A WEAK SPOT BY PULLING AWAY FROM ELECTRODES DURING CURE



CONTACT ELECTRODES IN HIGH DIELECTRIC STRENGTH ATMOSPHERE (SF_6)

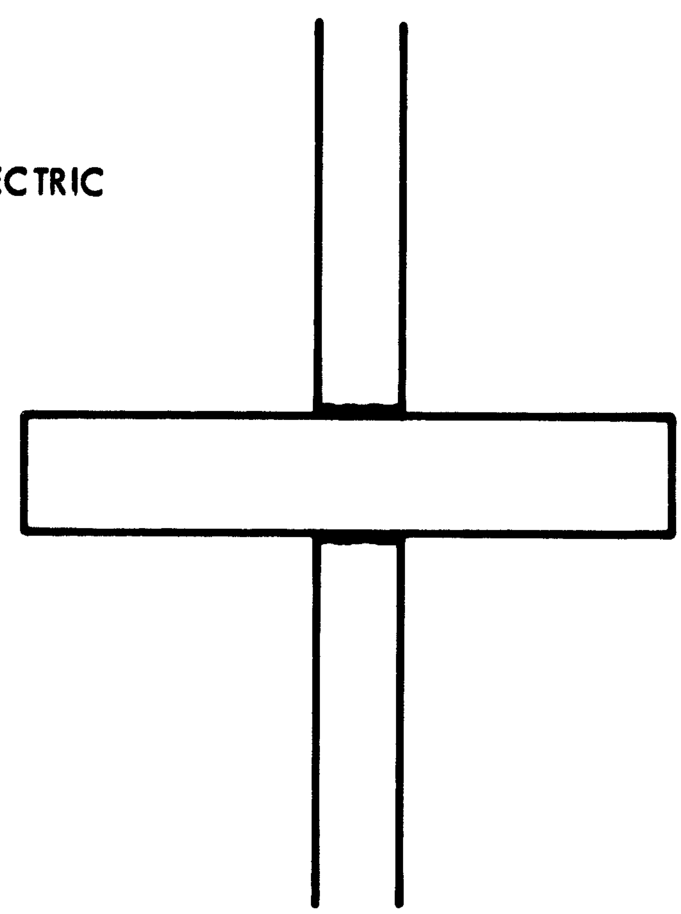


Figure 1. Behavior of Polymeric Foams for Corona Testing

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ELECTRONIC COMPONENT PART HIGH SHOCK

NASA Work Unit 186-68-13-05-55

JPL 384-70401-2-3540

W. B. Bartel

OBJECTIVE

The objective of this work unit is to support the advancement of electronic subassemblies through the investigation of the effects of high shock environment upon electronic piece-parts. The high shock environment is a rectangular shock pulse of up to 10,000 g ± 10%, lasting 0.5 to 1.5 ms.

ACTIVITIES DURING REPORT PERIOD

Contract 951907 was awarded to Litton Systems Inc. on April 10, 1967, for $14,372. The contracted task consists of fabricated test fixtures, mounting the specimens on the fixture, and performing electrical measurements on the parts. The exposure to high shock was performed in-house by the Environmental Test Section. The contract was completed and closed May 2, 1968.

RESULTS TO DATE

Shock testing and parameter measurements were completed on all parts. The resulting catastrophic failures are shown in Table 1. Whereas the relays are inherently inadequate for the high shock environments, they were included to assess their potential. The failure mode in this case was internal damage to the parts. The relays are rated at 100 g by the manufacturer. It was surprising to note that only two failures occurred at 2000 g. Two tantalum foil hermetically sealed capacitors shorted as a result of 2000 g and three capacitors of the same type shorted as a result of 10,000 g. All failed capacitors were axial lead types and failed in the direction of the leads.

With the exception of the relays and the capacitors, all failures were the result of inadequate part mounting. Mount failures resulted in inconclusive test information. Plans to rerun the failed mount portions were cancelled due to funding restrictions.

PLANNED ACTIVITIES

This report completes the effort on this work unit. Because of funding reduction, the work unit was cancelled prior to completion.

Table 1. Catastrophic Failures Component High Shock Evaluation

Class	Types	Total Parts	Failures		
			2000 *g*	5000 *g*	10000 *g*
Capacitors[a]	9	126	0	2	3
Diodes	9	135	6	0	2
Fuses	6	90	0	0	0
Inductors[b]	5	30	0	6	4
Microcircuits	2	30	0	0	5
Relays	4	24	2	0	11
Resistors	17	255	0	0	0
Thermistors	5	75	0	0	0
Transistors	11	165	0	0	0
Total	68	930	8	8	25

[a]One group of 6 specimens; all others, 15 specimens per type.
[b]Six specimens per type; all others, 15 specimens per type.

SPACECRAFT RELIABILITY (186-70)

ELECTRONIC COMPONENT SCREENING METHODOLOGY

NASA Work Unit 186-70-01-04-55

JPL 384-00401-2-3540

W. B. Bartel
W. R. Scott
L. W. Wright

OBJECTIVES

The objectives of screening methodology investigations are to provide improved methods for screening electronic piece-parts utilized in spacecraft assemblies. The resulting improved methods will be used for in-house acceptance testing of nonspecification-controlled parts. Where feasible, such methods will also be incorporated into part procurement specifications for acceptance testing by the parts' manufacturers.

The effort is divided into subtasks for consistency with part types and characteristics being investigated.

ACTIVITIES DURING REPORT PERIOD

Transistor Life Test Method Evaluation

A typical screening test for transistors includes a burn-in at elevated temperatures with derated power applied. Several manufacturers have suggested that the burn-in can be accomplished as effectively at a room ambient temperature but at a higher power level. The ambient burn-in would substantially reduce the complexity and cost of the burn-in by elimination ovens and the associated controls that go with it.

The purpose of this effort was to investigate the effects of room-ambient burn-in versus elevated temperature burn-in in conjunction with electrical test conditions of high voltage versus high current.

A contract was issued October 4, 1967, to the Philco-Ford Corp., Space and Re-entry Systems Division, Palo Alto, California. The testing was completed in June 1968, and JPL review and summarization of the test results should be completed and a JPL final report released by August 1968.

DEVELOPMENT OF METAL OXIDE FIELD EFFECT (MOSFET) RELIABILITY TEST AND SCREENING METHODOLOGY

The MOSFET transistor is a recent development in the transistor field; it has features that are of interest to JPL in numerous applications. These include a high input impedance comparable to vacuum tubes, it is operable at very low power levels, and its use tends to simplify transistor circuitry. The device is also somewhat simpler to manufacture.

Because of the significant difference in operating principles and design between MOSFET and conventional bipolar transistors, the method of screening will be different. It is the objective of this effort to devise effective screening methods for the MOSFET transistors. Purchase orders for development of test methods and proof testing were awarded to two device manufacturers, Fairchild (PO433989, $12,000) and Siliconix (PO433990, $15,000) in April 1967. Test approaches were jointly developed by JPL and the vendors, and testing is in progress.

The preliminary testing has recently been completed and life tests are in progress. Test results to date are being reviewed; however, no firm conclusions have been reached. Indications are that the gate voltage stress at a nondestructive level will be an indicator of the gate punch-through level. Voltage versus temperature stresses are an indication of oxide purity. Impurities in the oxide manifest a drift in the square low drain current characteristic. It was noted that MOSFET transistors do not appear to have the abrupt change in characteristics at low temperatures that is present in bipolar transistors. Some work was done on noise testing but results do not appear very promising for screening purposes.

Testing has experienced a substantial schedule slip at both the vendors. In one case (Siliconix) the vendor destroyed the test sample for the second time, requiring repetition of the tests with a new sample. In the other case (Fairchild), interdepartmental transfers of the work and loss of the test sample in the plant, as well as personnel changes, contributed to the delay. The Fairchild purchase order is now scheduled for completion in September. The Siliconix purchase order is being reviewed for potential cancellation. If continued, it will run to July 1969.

DEVELOPMENT OF POWER PULSE METHOD OF SCREENING RESISTORS

The feasibility of a screening method for resistors was investigated, wherein a short duration power pulse is applied to the part with resistance variation monitored during the pulse period. If successful, this method will replace current methods and effect significant savings in screening cost and time. Reduction in both costs and time, by a factor ranging from five to ten, is anticipated.

The contracted portion of this subtask has been completed. The work included a comparison evaluation on selected resistor types of the power pulse method versus the currently used screening method. The feasibility study has demonstrated that the power pulse method is highly effective; a summary of the results is given in Table 1. The power pulse screen detected 54 parts out of a total of 3900 as being abnormal, whereas the conventional screen detected 9 parts out of a total of 3900. The life test indicated that the power pulse screen detected an additional 15 abnormal parts for a total of 68. In the conventionally screened lot, 30 additional parts were detected for a total of 39. This indicates the power pulse method to be about six times more effective in detecting abnormal parts.

From a cost and time savings viewpoint, a comparison of the two methods is shown in Table 2. This comparison is based on screening a typical lot of 1000 parts by either method.

Beginning next fiscal year, a follow-on subtask will be started to implement the power pulse screening method. Before the power pulse method can be incorporated into a project screening operations, it is necessary to establish optimum pulse levels for all types of resistors to be screened by the method. The follow-on effort will include:

(1) Obtaining all available data from the manufacturer of the power pulse equipment and contractors who have made use of the

Table 1. Power Pulse Screening Versus JPL Screen, Comparison of Test Results

	Power Pulse	JPL
Manufacturer types	13	13
Sample size, total	3900	3900
Screen rejects	54	9
Life rejects	15	30
Total rejects	68	39
Percent rejects detected by screen	79	23

Table 2. Power Pulse Screen Versus JPL Screen, Comparison of Time and Cost

Based on 1,000 part lot

	Power Pulse	JPL
Process time	1 week	5 weeks
Cost	$ 500	$ 2,500
Total project cost[a]	$25, 000	$125,000

[a]Based on 50,000 resistors screened for a typical spacecraft project.

method. These data, together with our test data, will be used to establish pulse levels for a limited number of applicable resistor types.

(2) Supplementary testing will be performed to establish the appropriate pulse level for essentially all resistors on the JPL preferred parts list.

(3) Power pulse equipment will be procured to perform the supplementary testing. This equipment will also be used for project parts screening as pulse levels are established.

(4) Screening specifications and procedures will be prepared for each type of resistor to be screened by the method.

(5) The feasibility of using this method on other parts such as RF inductors, and low frequency transformers and chokes will be investigated, time permitting.

ZENER DIODE COMPARATIVE SCREENING TEST

This program was initiated to evaluate several different screening procedures for the TRW 1N4661 and devices similar in construction. It is also expected that the program will identify failure mechanisms common to the device construction.

The test program has now accumulated 4656 hr of testing and is approximately 6 wk behind schedule because of electrical instability in the component mounting boards.

Group 2 and Group 5, which were previously reported as containing a high number of reverse current drift failures (I_R), continue to have the highest number of failures; however, the failure rate of Group 5 seems to remain fairly constant with time when compared to the other groups.

Butt weld (lead failures) continue to be the predominating failure mode and are likely due to defective welds.

The zener impedance measurement for all groups shows a great deal of instability and does not indicate a positive trend.

Note: This subtask was formerly reported under Work Unit 186-70-01-05.

PUBLICATIONS

Contractor Reports, Interim and Final

1. Salestrom, R., "Evaluation Test Program of a New Method of Screening Resistors," Contractor Final Report: Development of Power Pulse Screening Method, Report No. 327, Mid-Continent Laboratory, Inc., JPL Contract 951504, Aug. 1, 1967.

2. Meyer, H., "Comparative Screen Test, TRW IN4661 Zener Diode," Third and Fourth Quarterly Technical Progress Reports: Zener Diode Comparative Screening Test, General Precision Systems, Inc., JPL Contract 951725, January 15 and Apr. 15, 1968.

ELECTRONIC COMPONENT LONG-LIFE STUDIES

NASA Work Unit 186-70-01-05-55

JPL 384-00501-2-3540

L. W. Wright

OBJECTIVE

The objectives of this work unit are to examine the behavior patterns of electronic parts during life test and investigate methods for the prediction of part parameter values and part failure rates after as much as 7500 hr of operation. These predictions shall be based on early life characteristics. A secondary objective is to investigate part failure modes as a function of time and stress.

ACTIVITIES DURING REPORT PERIOD

Subtask 7 - Accelerated Life Test Program for NPN Planar Transistors

This effort is intended to explore the utility of data from both step-stress and high-constant-stress tests in predicting the behavior of 2N2222 transistors during life when operated under nominal use conditions. The accelerating stress is applied power to produce specific values of junction temperature.

This test program, covered by JPL Contract 950541, is progressing satisfactorily. Work completed to date includes manufacture and inspection of the necessary test samples, screening of the test samples, thermal impedance measurements, fabrication of all life test circuits, completion of 2500 hr of testing on all constant stress groups, completion of step stress tests on all groups, completion of 8500 hr on the rated life test group, and completion of all required failure analysis. The above completes all laboratory work required.

During this report period, the contractor submitted computer tapes of all measurement data. These have been checked to be as required by running a raw data library program printout. The predominant activity of the contractor was the failure analysis of 100 selected failures. The failure modes identified and discussed were: (1) aluminum metal mass transport by high current at elevated temperatures, (2) silicon dissolution into aluminum and transport through aluminum by the mass transport mechanism, (3) silicon and gold transport by solvent transport and by diffusion, and (4) ion migration in the E-B junction as well as in the C-B junction. The failure frequency distribution was examined for the constant stress groups and was fitted to the Arrhenius equation assuming a constant hazard rate. The calculations were made, lumping all failure mechanisms into one and assuming they were all active at 100°C. The predicted hazard rate was 0.00036%/1000 hr at a junction temperature of 100°C. The values of ±4 standard deviations are 0.0047 to 0.0000021.

Currently, the contractor is finishing the final report and the contract is expected to be closed in July 1968.

Subtask 8 - Review of Models and Methods of Accelerated Testing

The purpose of this subtask is to thoroughly review the various models and methods that have been proposed for accelerated testing of electronic parts. Particular attention is being given to determining the underlying and often unstated assumptions associated with these models, and assessing whether these assumptions appear to be valid.

In February 1967, JPL Contract 951727 was established with the Research Triangle Institute of Durham, North Carolina, and work on this subtask commenced. To date, a literature search was performed, identifying 247 items for review. About half of the items were reviewed. A number of papers turned out to be ones that were retitled and submitted to different conferences.

During the contract, a portion of the effort was allowed to be devoted to special research activity. This effort was devoted to the problem of how to analyze data from accelerated tests assuming a constant hazard rate process and an Arrhenius temperature-reaction rate relationship. This effort resulted in computer programming providing for simulation and a study of the properties of the distribution of expected values. The program was then applied to data resulting from an accelerated test program performed by another contractor. This effort will be published in a separate paper. The final report for the over-all contract was published in April 1968. It covered such topics as basic concepts, methods of programming severity levels, thermal acceleration equations, extrapolation, comparison and evaluation of procedures, and numerous appendices illustrating mathematical details. The work was well done and progress throughout the contract was satisfactory. The contract for this effort has been closed.

Subtask 11 - Accelerated Test of Integrated Circuits

This effort is intended to establish a feasible method for performing an accelerated test program on one type of digital integrated circuit. The circuit is of sufficient complexity to preclude direct increases of power and temperature as is frequently done with discrete devices and therefore requires that some less conventional approach be formulated.

This effort was defined in a Statement of Work in February 1967. RFPs were issued, proposals were received and evaluated, and final contract negotiations were completed as of September 1967. However, just prior to obligation of funds, JPL was put on a spending freeze and was unable to execute the contract during the last report period.

Early in this report period, January 1968, it was determined that this effort was critical for on-going programs. JPL then attempted to execute the previously negotiated contract. This effort failed because the contractor withdrew his original proposal (valid for 6 mo) and counter-offered a new price which failed to meet competition. The contract was then negotiated with a different proposer who extended the time limit of his original proposal. At present, the contract has been negotiated and was executed on June 19, 1968. During the next report period, the contractor will prepare detailed program plans and complete the preliminary studies and testing requirements. At the conclusion of that phase, the life test circuits providing for accelerated conditions will be defined.

PUBLICATIONS

SPS Contribution

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Contractor Reports, Interim and Final

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FAILURE MECHANISMS IN ELECTRONIC COMPONENTS

NASA Work Unit 186-70-01-07-55

JPL 384-00701-2-3540

L. W. Wright

OBJECTIVE

The objective of this task is to support the advanced development of electronic subassemblies by effecting an improvement in the reliability of critical electronic parts through the investigation and elimination of failure mechanisms. During FY 68, emphasis has been placed on the identification of materials and processes employed in electronic parts, and on investigation of failure analysis techniques for integrated circuits.

ACTIVITIES DURING REPORT PERIOD

Subtask 3 - Scanning Electron Microscope

A scanning electron microscope (SEM) manufactured by Cambridge Instrument Co. was installed, and debugging was completed early in February 1968. Since that time considerable finesse has been developed with basic SEM techniques, and the instrument has been used repeatedly in the failure analysis of integrated circuits. In several cases the SEM has provided information which would have either been impossible or extremely difficult to obtain in any other way. During the forthcoming period, effort will be expended to gain additional experience in the application of basic SEM techniques, and to do some preliminary work with conductive mode operation of the instrument.

Subtask 6 - Design, Materials, and Process Identification of Electronic Parts

The purpose of this effort is to develop methods and procedures for cataloging materials and process information on parts which are being considered for qualification testing. Information of this type will greatly aid in failure analysis and will provide a sound basis for judgement regarding the continued applicability of test data.

This effort is being pursued in two phases. In phase I, two contractors were required to (1) develop procedures for obtaining and cataloging the desired information, (2) perform an exemplary effort for the 2N2222 transistor, and (3) prepare detailed plans for implementation of a phase II effort encompassing a variety of part types. The phase I effort has been completed and the results of this effort were used as a basis for selection of the phase II contractor. A letter contract with Litton was executed July 25, 1967. The definitive contract was executed October 2, 1967. During the phase II effort, 88 part types will be investigated and documented in individual booklets. The part types include a maximum variation in design and represent about 30% of the standard parts in general use at the Laboratory. Specifically, the following categories are involved: 18 types of capacitors, 4 types of controlled rectifiers, 22 types of diodes, 4 types of inductors, 6 types of microcircuits, 9 types of relays, 15 types of resistors, one type switch, 2 types of transformers, and 7 types of transistors. At the present time, 38 booklets covering 43 items have been received. The parts required for this investigation have all been received by the contractor, photography has been completed on all items, and 12 booklets are in preparation. Delivery of completed booklets is expected to be at the rate of five per week for the remainder of the contract period. Approximately 80% of the work has been completed. Thus far, progress has been satisfactory.

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Contractor Reports, Interim and Final

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2. Privitera, L. J., and Mattlock, J. H., Final Report Identifying the Design, Materials and Assembly Processes, Fairchild 2N1613 Transistor, JPL Contract 952033, Dec. 11, 1967.

3. Privitera, L. J., and Mattlock, J. H., Final Report Identifying the Design, Materials and Assembly Processes, Union Carbide Electronics 2N4044 Transistor, JPL Contract 952033, Dec. 27, 1967.

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8. Privitera, L. J., and Mattlock, J. H., Final Report Identifying the Design, Materials and Assembly Processes, Solitron 2N2880 Transistor, JPL Contract 952033, Feb. 13, 1968.

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18. Privitera, L. J., and Mattlock, J. H., Final Report Identifying the Design, Materials and Assembly Processes, Fairchild μL9040 and μL9042 Microcircuits, JPL Contract 952033, Mar. 25, 1968.

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STATE-OF-THE-ART TRANSISTOR EVALUATION

NASA Work Unit 186-70-01-08-55

JPL 384-00801-2-3540

W. B. Bartel

OBJECTIVE

The objective of this work unit is to perform a preliminary evaluation of those state-of-the-art transistors that become available each year and have potential spacecraft usage. The purpose of this is to be in a better position to advise the design engineers on the reliability and application of the parts before he designs them into an assembly, and to provide basis for selection of parts for later qualification. This work unit will support the JPL preferred parts activity and future spacecraft projects.

The approaches in the evaluation include:

(1) Evaluation of the design and structural features of the transistors

(2) Study of surface effects

(3) Study of thermal resistance

(4) Performance of a short term life test

(5) Analysis of reliability data from manufacturers and users

ACTIVITIES DURING REPORT PERIOD

Since the inception of this work unit, approximately 1000 new transistors numbers of all types have been registered. This represents perhaps 100 types that are suitable for spacecraft application. To date, 50 state-of-the-art transistors have been procured and are undergoing evaluation. Selection of devices for evaluation was made on the basis of:

(1) Need in spacecraft circuit application

(2) The appearance of a new device having unique features and potential applications such as MOSFET, duals, etc.

(3) Significant process or design changes of previously available devices.

(4) Advice from the manufacturer of future production stability.

Activities on this work unit, to date, have included preparation of Transistor Internal Structure Sheets on all types. These detail the internal structural features of the transistors and an analysis of the materials used. Evaluation testing has been completed on 18 types and is in process on the remainder.

It is estimated that of the 50 types undergoing evaluation, 40% will not be recommended for use in spacecraft for reasons of: 1) unstable parameters, 2) inferior design and processing, 3) poor characterization by the manufacturer, and 4) deterioration of availability.

This effort is expected to yield about 30 potential candidates for qualification in support of the preferred parts activity and future spacecraft projects. Because of this advanced work, it is hoped to improve the yield on transistor qualification tests from 50% to 80 or 90%. Data obtained from this work unit will also provide a basis for monitoring the manufacturer's future production for surreptitious design and process changes.

This work unit was originally intended as a continuing effort. However, due to lack of funding in FY 69, the work unit is being discontinued as of the end of FY 68.

ELECTRONIC PARTS RELIABILITY IMPROVEMENT

NASA Work Unit 186-70-02-01-55

JPL 384-00901-2-3540

L. W. Wright

OBJECTIVE

The long-range objective of this effort is to develop means for improving the reliability of electronic parts used in the planetary exploration program. By developing an understanding of the fundamental causes of electronic part degradation and failure, and by determining and applying proper controls to the parts design and fabrication processes, it should be possible to reduce or eliminate certain sources of failure.

PROGRESS

The work under this task was initiated October 1, 1967. A multidisciplinary team was formed with experts selected from applicable discipline areas including materials, applied mechanics, electronic parts engineering, and electronic packaging. This team then proceeded to become acquainted with some of the major practices and problems associated with electronic parts. To accomplish this, a survey of related activities under way at other organizations and at JPL was made. Organizations such as the NASA Electronics Research Center, the Rome Air Development Center, Autonetics, TRW, and Litton Systems were visited and their related activities were evaluated in the light of special JPL requirements. In addition, the 1967 Reliability Physics Symposium held in Los Angeles, November 6–8, 1967, was attended.

Particular emphasis has been placed on the familiarization of the disciplinary experts with areas such as: (1) electronic components reliability evaluation, (2) approach to, and techniques in reliability physics, (3) electronics and materials instrumentation in reliability physics, (4) integrated circuit and electronic components development capabilities, (5) design, analysis, and data processing requirements, and (6) reliability physics parameter relationships. The capabilities in these areas were assessed and evaluations were made with respect to device evaluation and imrpovement through a design appraisal process.

During this reporting period, firsthand experience was obtained by performing design appraisals on three device types: a transistor, a photocell, and a capacitor. The transistor, Motorola's 2N2222, was the first device type toward which effort was directed. This device type had been previously characterized as to its design, materials, and processes as part of another effort covered under NASA Work Unit 186-70-01-07. Except for a few minor improvements suggested in the materials area, it was concluded that to the extent that criteria had been established, the device was well designed and serviceable.

The second design appraisal effort was conducted on a Clairex photocell of a type being used by the Mariner Mars 1969 Project. Some of these cells had failed during system vibration tests, exhibiting a significant deterioration of their conductive properties to the point of complete breakdown. The review revealed poor mechanical design and material usage, and a number of design improvement recommendations were suggested. To verify that these recommended improvements were in fact a valid means for elimination of the observed vibrational failure mode, a number of cells were assembled in-house during the early part of 1968. These cells, assembled in cooperation with both Clairex and Mariner Mars 1969 Project personnel, incorporated the recommended improvements. Subsequently, the behavior of these modified cells was compared with cells of standard construction during vibration tests and was found to be superior. The results of this activity will be provided to Clairex for their consideration.

The final design appraisal effort was devoted to consideration of Component Research Co. s type 05PL capacitor. It was concluded that this device had questionable features from the viewpoint of mechanical design, materials usage, and packaging. Potential means for improvement were recommended but experimentation was not actually performed to validate the recommendations, as was done for the photocells.

Based on the over-all effort, it was concluded that the multidisciplinary team approach does yield good results and that design appraisal methods of device evaluation offer considerable promise. An operating plan for FY 69 was formulated in order that design appraisal methods continue to be investigated as means for device evaluation improvements as well as for device reliability improvements.

PUBLICATIONS

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ADVANCED STUDIES SRT, LUNAR AND PLANETARY (684)

ADVANCED LUNAR STUDIES (684-20)

ADVANCED LUNAR STUDIES

NASA Work Unit 684-20-00-01-55

JPL 388-2xxxx-x-xxxx

J. D. Burke

During the first half of FY 68, the Advanced Lunar Studies (ALS) Team continued its analysis of the Lunar Exploration Program and of selected scientific and systems problems related to lunar orbital and surface operations. A draft functional specification for the experiment system of a particle-and-field subsatellite was circulated to the concerned NASA organizations for review. Functional tests of a lunar rover navigation principle were made in a suitable part of the Mojave Desert. Analysis and design of lunar traverse missions were continued, with emphasis on the long automated traverse mode. The results of these studies and of various related small scale experiments were reported in an Advanced Studies Document, ASD 760-26.

Lunar water research conducted in the JPL vacuum chamber under ALS sponsorship in FY 68 was turned over to JPL SRT groups for review and possible extension to other parts of the problem of finding water in the moon.

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ADVANCED PLANETARY STUDIES (684-30)

FUTURE PROJECT STUDIES – PLANETARY

NASA Work Unit 684-30-01-10-55

JPL 388-301xx-x-xxxx

ADVANCED PLANETARY STUDIES, J. E. Long

OBJECTIVE

The purpose of this work unit is to perform a scheduled series of mission studies to identify attractive candidates for further definition and system and subsystem SR. During the reporting period, a preliminary mission study was performed for a Jupiter flyby mission in 1972, and the first phase of study for the Multi-Planet Mission (MPM) (Jupiter, Saturn, Uranus and Neptune) has been completed. Results of both studies to date have been presented orally to NASA-OSSA. The MPM phase completed defines system requirements and candidate mission designs compatible with the requirements for a ballistic mission (i.e., propulsive velocity imparted at earth launch). Effort during the next 6 mo period will emphasize definition of a solar electric propulsion spacecraft design for the MPM to comparable objectives. A comparative evaluation of both design concepts will be performed to aid in the selection of the preferred approach for project implementation.

1972 Jupiter Flyby Mission

This study was performed to evaluate the applicability and project requirements of three-axis stabilized spacecraft as compared to spin stabilized spacecraft designs being considered for project implementation. Separate spacecraft system designs were generated, one using radioisotope generated power (RTG) and one using a large area solar array (530 ft^2) based on a current development program (20 W/lb solar array technology).

The conclusions of the study effort indicated that for either system design approach, the three-axis stabilized spacecraft system had nearly identical cost, weight, and power requirements to the spin stabilized spacecraft for similar mission objectives and project constraints. Because the three-axis stabilized spacecraft design is a more straightforward application of previous planetary mission experience, there is more confidence in achieving the system performance within estimated weight, power, and resource estimate The three-axis spacecraft design has greater growth capability than the spin stabilized spacecraft concept because of precise science instrumentation pointing and trajectory correction control. It would, therefore, be a more cost-effective development base for Jupiter and outer planet exploration programs. Because of the schedule constraints imposed by a 1972 launch requirement, and due to the current status of both power source development programs, the spacecraft system design utilizing solar array power was considered the most realistic selection. Relatively large solar arrays are more compatible with a three-axis stabilized spacecraft design.

Multi-Planet Flyby Mission

There is a unique mission opportunity in the 1976–1979 time period to fly by the four major planets (Jupiter, Saturn, Uranus and Neptune) with a single spacecraft. The solar system geometry and flight time and energy requirements for the MPM compared to direct flight to each planet is shown in Fig. 1. The most favorable time from a launch energy and allowable closest approach to the planets point-of-view is 1977. Less desirable but realistic opportunities exist for 1976 and 1978. The 1979 opportunity is unattractive because of high launch energy requirements and/or large flyby altitudes from the swingby planets. Trajectory parameters for a representative trajectory design are shown in Table 1.

A number of system designs suited to mission requirements have been defined. Major characteristics determined from these studies are:

(1) Use of optical measurements during planet approach to determine relative spacecraft position is preferred.

(2) Spacecraft weight will be 950 – 1275 lb, depending on science instrumentation, trajectory type, and system design concept.

(3) Spacecraft system power will be 175 – 300 W, depending on science instrumentation and spacecraft system operation.

Table 1. Trajectory B Parameters
(Flyby Outside Saturn's Rings)

C_3 (Max) = 110 km^2/sec^2 Launch: 9/3 – 9/19/77				Allowable Spacecraft Weight Titan IIID/Centaur – 1036 lb	
	Jupiter	Saturn	Uranus	Neptune	
Encounter date	6/17/79	6/28/81	9/11/85	3/5/89	
Altitude at closest Approach	622,264 km (8.7 RJ)	74,732 km (1.2 RS)	86,460 km (3.7 RU)	102,875 km (4.6 RN)	
Time from launch, days	652	1394	2945	4200	
Communications distance, MKM	900	1430	2900	4590	
Earth-probe-sun angle, deg	7.5	6.1	2.9	1.6	
Trajectory correction (M/SEC)					Total (Mean + 3σ)
A. Doppler only	13.5 rms	82.6 rms	237.0 rms	25.1 rms	610.0
B. Doppler + Optical meas.	10.0 rms	34.0 rms	67.3 rms	23.4 rms	238.0

(4) Saturn's rings are a constraint on spacecraft flyby geometry. Engineering estimates indicate they must be avoided as a significant spacecraft hazard.

(5) Successful implementation of present technology advancements appears adequate for the MPM requirements.

(6) A self-reliant spacecraft design with intermittent ground station contact for memory read-out and spacecraft control updates appears attractive for the 9 to 11.5-yr mission.

SMALL SOLAR ELECTRIC PROBE STUDY, T. A. Barber and P. D. Reader*

OBJECTIVE

Work is proceeding toward the releasing of a request for proposal on a small solar electric probe study. The technical scope of the work has been defined, and the study has as its main objectives:

(1) The assessment of state-of-art solar electric hardware to mission application.

(2) The study of the applicability of a minimum cost, small solar electric vehicle to an asteroid probe mission.

(3) The development of program objectives and a program development plan leading to an asteroid probe mission.

The present schedule is directed toward release of the request for proposal early in FY 69.

MISSION STUDY SUPPORT ACTIVITIES, R. D. Bourke

An analysis of the guidance and navigation requirements of a Multi-Planet (Grand Tour) Mission to the outer planets was performed during this period. The capability to perform such an analysis for missions to the large outer planets did not exist at the beginning of the effort and had to be developed.

*Also funded under NASA Work Unit 120-26-07-05
JPL Work Unit 320-60201-x-3110

The result of this development effort was a general navigation accuracy estimation program which produces estimates of navigation accuracy which efficiently and realistically approximate the results produced by SPODP. This program may permit broad parametric guidance analyses which would otherwise be prohibitively expensive to perform. This analysis technique is documented in Refs. 1-3.

In addition, the general trajectory characteristics of the Grand Tour Mission were investigated in detail. Mission constraints, including launch periods, energy requirements, minimum flight times, positive flyby altitudes, and the avoidance of Saturn's rings, have been thoroughly defined. The interim results of this study were reported in Ref. 4.

The final results of the current Grand Tour trajectory design and guidance analysis effort will be reported in an AIAA paper to be presented at the 5th Annual Meeting in Philadelphia, October 21–25, 1968.

Work completed during the previous reporting period was published as Ref. 5.

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2. Long, J., "Preliminary Status Report of a Multi-Planet Mission Study," June 27, 1968.

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1. ASD-760-22; Part I, 1972 Jupiter Spacecraft Technical Description, Part II, 1972 Jupiter Alternate Mission Comparisons, in press.

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VENUS FLYBY STUDY CONTRACT
NASA Work Unit 684-30-01-13-55
JPL 388-30301-2-1610
J. H. Kelley

OBJECTIVE

To perform a study of a 1972 flyby and entry mission to Venus with consideration also of the 1973 opportunity. The mission is intended to include a modified Mariner Mars 1969 spacecraft with an atmospheric entry capsule that is not designed to survive impact.

EFFORTS TO DATE

AVCO was the mission study contractor with Northrop as a subcontractor for the spacecraft aspects of the study. The contract started May 25, 1967, and technical efforts were completed November 25, 1967. An interim review was conducted at JPL in early September and a final presentation was given at JPL December 4. The final report was published in April 1968: AVSSD-080-68-RR.

The contract and this work unit have been completed.

PHYSICS AND ASTRONOMY SRT (188)

MAGNETODYNAMICS IN SPACE (188-36)

MAGNETIC PHENOMENA

NASA Work Unit 188-36-01-01-55

JPL 385-60101-2-3280

E. J. Smith

OBJECTIVE

The primary objective of this task is to detect and analyze naturally occurring, extremely low-frequency (1 to 1000 Hz) magnetic fluctuations above the ionosphere using earth satellites, and below the ionosphere at the earth's surface; and to study their origin, modes of propagation, relation to solar-terrestrial phenomena and dependence on magnetospheric-ionospheric parameters.

STATUS

Simultaneous data are being obtained by coordinating surface measurements at a JPL observatory, with measurements being made by the search coil magnetometer on OGO-4. Numerous whistlers observed on OGO-4 have been correlated with sferics detected at the earth's surface.

PROGRESS

During the past 6 mo, equipment at the field site was modified to improve reliability of operation and to ensure the accuracy of the data by frequent, automatic calibrations.

The major effort was directed toward obtaining more simultaneous data with OGO-4 and with OGO-5 following its launch in March. Data now exists for approximately 300 OGO-4 passes and the first five OGO-5 passes.

FUTURE PLANS

Future plans are:

(1) To continue the reduction and analysis of simultaneous OGO-4 and surface data.

(2) To acquire surface data for additional correlation with OGO-4 and OGO-5.

(3) To attempt to derive useful magnetospheric or ionospheric parameters from the correlated signals.

PUBLICATIONS

None.

ADVANCED MAGNETOMETER

NASA Work Unit 188-36-01-04-55

JPL 385-60501-2-3230

E. J. Smith
F. E. Vescelus

OBJECTIVE

The objectives for this task are: (1) to increase sensitivity, decrease noise of the low field helium magnetometer; (2) to develop methods for qualifying and screening critical magnetometer sensor components; (3) to decrease power consumption, weight, size, while increasing performance, reliability, and maintaining or improving long-term stability; and (4) to develop an operational $\pm 20\gamma$ helium magnetometer breadboard using high reliability monolithic integrated circuits wherever possible.

SYSTEM DESIGN

Progress

The breadboard electronics combined with the Mariner IV life test sensor and power supply were used together during this period to assess the present system capabilities. The unit was first converted to $\pm 20\gamma$ full scale. Its operation and noise were checked with various sweep vector sizes to yield the optimum operating sweep vector of 40γ. With a bandwidth of 0.2 Hz to the 3 dB points, the rms noise was approximately 0.02γ. The system was then successfully operated from $\pm 1\gamma$ full scale to ± 1 gauss ($100,000\gamma$) full scale. The initial results are shown in Table 1. As far as it is known, this is the first time that a helium magnetometer has operated successfully at either such high fields or over such a wide dynamic range. The system bandwidth was also changed from between 40 and 0.1 Hz with the expected changes in system noise being observed.

Planned Activity

Further improvements in system noise will be attempted. It is expected that the detector selection techniques to be developed will significantly aid in

Table 1. Hybrid Magnetometer Performance to Date, Noise Versus Scale Factor

Scale factor (full scale, γ)	Bandwidth (3 dB points, Hz)	Noise (approximate rms noise, γ)
1	0.5	0.027
5	0.5	0.027
10	0.5	0.027
20	0.5	0.027
40	0.5	0.027
.	.	.
.	.	.
.	.	.
1,000	0.5	0.2
5,000	0.5	1.0
10,000	0.5	2.0
50,000	0.5	17
100,000	0.5	40

the selection of detectors that will result in much lower system noise. Also, the relatively constant percentage of noise at the high field end of operation, as seen in Table 1, will be investigated. Methods for effective range changing will also be investigated.

DETECTOR ANALYSIS

Progress

The simulated magnetometer sensor is nearing completion. Upon completion of the simulator, the various types of lead sulfide detectors which have been procured and received will be tested in the simulator.

Planned Activity

The simulated magnetometer sensor will be completed in the near future. Screening procedures are being developed to properly select detectors that are best suited for use in the helium magnetometer. The possible use of other light sources to irradiate the detectors under test with "quiet" (low noise) light will be investigated. It is thought that this might provide another meaningful detector screening tool.

CIRCUITRY DEVELOPMENT

Progress

The hybrid helium magnetometer has been successfully converted to a ±20γ instrument. Additional circuitry (buffer boards) was constructed and integrated into the system to extend the range to ±100, 000γ using the existing Mariner sensor. The existing hybrid system presently has performed from ±1γ full scale to ±100, 000γ full scale, and has been successfully converted to 200 Hz operation. Although the breadboard design is not yet firm, the hybrid system set up for ±20γ full scale consumes approximately 4 1/2 W as compared to 6 1/2 W on the Mariner IV unit. It is felt that the hybrid system power can be reduced even further with subsequent improvements in the power supply, radio frequency supply, and lamp and cell configuration.

Planned Activities

The power and radio frequency supply will be investigated for increased efficiency. Continued effort will be placed in the RF cabling and configuration. The sensor preamplifier will be investigated to determine if any improvements and/or simplifications can be effectively incorporated into the electronics signal chain.

LAMP AND CELL DEVELOPMENT

Progress

Progress in this area has been limited to the effort expended on the sensor simulator, mentioned earlier.

Planned Activities

Lamp and cell configurations will be evaluated with the sensor simulator, both as to different configuration effects on sensor performance and as a screening selection tool on units of a similar configuration.

PUBLICATIONS

None.

ASTRONOMY (188-41)

GAMMA RAY AND X-RAY ASTRONOMY

NASA Work Unit 188-41-01-01-55

JPL 385-10101-X-3230
385-10102-X-3250

A. E. Metzger
J. F. Dolan

OBJECTIVE

The objective of this task is the discovery of the physical conditions existing in extra-terrestrial bodies by analysis of the X- and gamma radiation they emit.

PROGRESS

Balloon Flights

A gondola system was constructed for the purpose of determining the energy spectra of discrete X-ray sources between 20 and 100 keV. The X-radiation is detected in a commercial proportional counter with a 14 cm^2 area window of 25-μ (0.001-in.)-thick beryllium. Particle—caused counts are rejected by a plastic scintillator surrounding the proportional counter which is connected to an anticoincidence system. A trolley provides for in-flight calibration of the proportional counter with the 22-keV Kα X-ray of silver emanating from the radioactive source Cd^{109}.

The xenon-filled proportional counter has a resolution of 18% (FWHM) for the unfiltered manganese Kα line from Fe^{55} at 6 keV, and 11% for silver Kα, an increase in resolution by a factor of three in this energy range over previously used scintillation detectors. A 128-channel pulse height analyzer, telemetry and ground station equipment on loan from Pro. L. E. Peterson, University of California at San Diego, are being used in this series of flights. The system was launched from Page, Arizona, January 15, 1968. During the successful 10 hr flight it obtained a height of 132,000 ft (2.8 cm^{-2} residual atmosphere) and observed the discrete X-ray sources Cygnus XR-1 and XR-3 in the energy range 20–60 keV. Measurements were also made of the general radiation environment from 3 to 110 keV at altitude. The data obtained from the flight, considered in conjunction with previous data taken by other observers, indicates that Cygnus XR-1 may be an eclipsing binary type of X-ray source.

A high background count was observed from the detector during the flight. The poor signal-to-noise ratio was caused by the relatively small ratio of window area to sensitive detector volume in the proportional counter flown in January. Further tests conducted at the neutron generator facility at JPL indicate that radioactive nuclides caused by neutron interaction with the wall material of the detector (aluminum) may have contributed to the over-all background rate.

A new proportional counter has been ordered for installation in the gondola with a 20 cm^2 window area of 375-μ (0.015-in.)-thick beryllium. The sensitive volume of this detector is approximately 60% that of the detector flown in January. Stainless steel construction should minimize the production of radioactive nuclides by neutrons. Tests indicate that the background rate at altitude will be approximately 40% that of the previously flown detector.

A new commercial power supply was obtained for the proporational counter, allowing operation of the photomultiplier tubes observing the anti-coincidence shielding separately from the electrical circuits containing the proportional counter. Also being investigated is an electronic means of discriminating on the basis of pulse rise times between X-ray and (particle caused) background counts in the proportional counter.

Plans were initiated for the design and construction of a new gondola system. It will have the capability of pointing at any given celestial source and tracking it across the sky. It is planned that this system will carry a proportional counter and a solid state detector on separate flights. A new all-digital data telemetry system and ground receiving station is in the initial stages of design.

A flight is planned in August of this year with the improved detector to observe the variable source Cygnus XR-1 once again.

Satellite Experiment

The design of an X-ray detector proposed for an Apollo earth-orbiting or small astronomical satellite mission has been revised and submitted to NASA for consideration as part of a joint X-ray/gamma ray experiment. Prof. Peterson is in charge of the gamma ray part of the experiment, which will use either a 107 cm^2 effective area scintillation detector or a like-size ganged array of lithium-drifted-germanium solid state detectors. The X-ray observations will be conducted with a 445-cm^2 array of proportional counters having a two-chamber internal gas-fill arrangement to allow observation of the spectra of discrete source of X-ray sources between 1 and 40 keV.

PUBLICATIONS

Meetings and Symposia Papers

1. Metzger, A. E. and Dolan, J. F., "X-Ray Emission From Cygnus XR-1," 126th Meeting, American Astronomical Society, Charlottesville, Va., April 2, 1968.

Open Literature

1. Metzger, A. E. and Dolan, J. F., "X-Ray Emission From Cygnus XR-1," Astron. J. in press.

DATA ANALYSIS (385)

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DATA ANALYSIS (385-36)

OGO MAGNETOMETER DATA ANALYSIS: POST PROJECT SUPPORT

NASA Work Unit 385-36-00-01-55

JPL 375-60101-2-3280

E. J. Smith

OBJECTIVE

The primary objectives of this task are: (1) to continue reduction, analysis, and interpretation of OGO search coil magnetometer data, including data acquired after project support is terminated, and (2) to prepare magnetic tapes and other materials for the National Space Science Data Center.

STATUS

The task is being performed jointly by JPL (E. J. Smith) and by UCLA (R. E. Holzer) under a JPL subcontract. UCLA has primary responsibility for reduction and analysis of the digital data. Four graduate students are working on Ph.D. dissertations based on OGO-1, 2, and 3 data.

PROGRESS

(1) Moderately intense magnetic noise bursts between 5 and 300 Hz have been identified in the magnetotail. Their occurrence appears correlated with the position of the neutral sheet.

(2) Spectra and cross-spectra of magnetosheath signals between 0.01 and 140 Hz show a change from f^{-2} to f^{-3} slightly above 1 Hz and indicate the signals are unpolarized and have an isotropic distribution of propagation directions.

(3) Power spectra of signals at the bow shock peak near 1 Hz and then fall off as f^{-3} at frequencies up to 300 Hz. Frequency components above 10 Hz are due primarily to nearly monochromatic, elliptically polarized wave packets having a typical duration of less than 1 sec.

(4) Under magnetically quiet conditions the magnetopause appears to oscillate with a period of nearly 12 min. Compressional waves proceeding outward from the magnetopause appear to modulate the magnetic noise in the magnetosheath, as well as the motion of the shock. At its farthest displacement into interplanetary space, the shock emits plasma waves which propagate several earth radii upstream into the solar wind.

(5) Steady signals between 100 and 1000 Hz are seen inside the magnetosphere mainly during the day within L values of 5 to 6. Parallel and perpendicular signal propagation have been seen, as well as propagation at intermediate angles to the magnetic field direction. Sporadic noise bursts occur beyond L = 5 chiefly over the sunlit hemisphere.

(6) Intense, sporadic bursts have been identified in the magnetosheath, superposed on the persistent broadband background noise. They are quasi-monochromatic signals at frequencies near 100 Hz and appear to be elliptically or circularly polarized.

FUTURE PLANS

Future plans are:

(1) To continue the reduction of recently acquired OGO-1 and OGO-3 data

(2) To continue analyzing the available OGO data

(3) To seek correlations with other OGO experiments

(4) To seek correlations between simultaneous measurements on two or more OGO's.

PUBLICATIONS

Meetings and Symposia Papers

1. McLeod, M. G., Holzer, R. E., and Smith, E. J., "Spectra, Direction of Propagation and Polarization of Waves in the

Magnetosheath in the Frequency Range from 0.01 to 140 Hz," 49th Annual American Geophysical Union Meeting, Washington D.C., April 1968.

2. Russell, C. T., Holzer, R. E., and Smith, E. J., "Magnetic Fluctuations between 30 and 1000 Hz Within the Magnetosphere," 49th Annual AGU Meeting, Washington D.C., April 1968.

3. Olson, J. V., McLeod, M. G., Holzer, R. E., and Smith, E.J., "High Frequency Magnetic Fluctuations Associated with the Earth's Bow Shock," 49th Annual AGU Meeting, Washington D.C., April 1968.

4. Holzer, R. E., and Smith, E. J., "Magnetic Fluctuations Related to Magnetopause Boundary Motions," 49th Annual AGU Meeting, Washington D.C., April 1968.

5. Smith, E. J., Holzer, R. E., and McLeod, M. G., "Magnetic Measurements in the Magnetosheath at Frequencies up to 1000 Hz," 49th Annual AGU Meeting, Washington D.C., April 1968.

6. Smith, E. J., Holzer, R. E., Olson, J. V., and Burton, R. K., "Measurements of Magnetic Fluctuations Between 1 and 1000 Hz in the Lower Magnetosphere," 49th Annual AGU Meeting, Washington D.C., April 1968, and Spring Meeting of URSI, Washington D.C., April 1968.

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INTERDISCIPLINARY SPACE SCIENCES (385-48)

ANALYSIS OF FIELDS AND PARTICLE DATA

NASA Work Unit 385-48-01-01-55

JPL 375 80101-2-3280

M. Neugebauer
T. W. J. Unti

OBJECTIVE

The object of this work unit is to conduct scientific analyses of the fields and particles data obtained from Mariner spacecraft and to prepare for similar analyses of data from OGO and ALSEP experiments.

MARINER II DATA ANALYSIS

Since the presence of Alfvén waves was verified in the Mariner II plasma and magnetometer data, it is of interest to determine whether or not magnetosonic waves also propagate in the solar wind. Waveforms were isolated from the magnetic field data which appeared to be characteristic of magnetosonic waves. The hydromagnetic equations for these waves are more complicated, however, and more information must be extracted from the data than in the case of Alfvén waves. While the Alfvén velocity can be determined from measured data, the acoustic velocity cannot because the specific heat ratio γ and the electron temperature T_e were not measured by Mariner II. For the first analysis, it was assumed that γ had the adiabatic value 5/3 and the electron temperature was equal to the ion temperature. The computer analysis based on these values did not show the correlation between field and plasma required by magnetosonic waves. Several other estimates of γ and T_e were then used, also with negative results.

The lack of correlation between predicted and measured curves probably does not imply the nonexistence of magnetosonic waves in the solar wind. Better data are needed. In order to solve the hydromagnetic equations for magnetosonic waves, several quantities had to be derived, interpolated, or guessed at. For example, the only component of ion velocity measured by Mariner II was the component radially away from the sun. In contrast, Mariner V instruments measured the direction of the incoming ions as well as their energy. For these and other considerations, it may be more practical to await the Mariner V data before continuing the investigation of magnetosonic waves in the solar wind.

An investigation has also been started into the possible relationship between the properties of the solar wind and solar coronal emission. A correlation between coronal emission and cosmic rays has been assumed and has led to interesting results (Simpson and Wang, Astrophysical Journal 149, L73, 1967), but the physics of the intermediate processes have not been thoroughly investigated.

PUBLICATIONS

Meetings and Symposia Papers.

1. Unti, T. W. J., and Atkinson, G., "Interior Field of the Two-Dimensional Chapman-Ferraro Problem with Neutral Sheet," Symposium on the Physics of the Magnetosphere, Washington D.C., September 1968.

Open Literature

1. Unti, T. W. J., and Neugebauer, M., "Alfvén Waves in the Solar Wind," Physics of Fluids 11, 563, March 1968.

BIOSCIENCE SRT (189)

EXOBIOLOGY (189-55)

METABOLISM AND PHOTOSYNTHESIS

NASA Work Unit 189-55-02-01-55

JPL 386-51101-2-3260

J. S. Hubbard

OBJECTIVE

The objective of this task is to develop a life detection experiment to assay Martian surface matter for biological CO_2 fixation. Although the experiment is designed primarily to detect light-dependent activity, it can also detect the dark CO_2 fixation carried out by heterotrophic life forms.

DIRECT MEASUREMENT OF $^{14}CO_2$ FIXATION IN SOILS

The most direct method for detecting biological CO_2 fixation in soils involves exposing the soil to an atmosphere enriched with $^{14}CO_2$, driving off the nonbiologically absorbed CO_2 by acidification, then measuring the radioactivity remaining in the soil. The fixed radioactivity presumably represents $^{14}CO_2$ which has been incorporated into cellular components of soil microorganisms. This procedure has been shown to be satisfactory when applied to soils which contain substantial numbers of microorganisms. In order to define the sensitivity of the method, soils which are known to contain small microbial population were tested. As previously reported, a large amount of $^{14}CO_2$ absorbed by Atacama Desert soil no. 266 made it impossible to determine the level of biological $^{14}CO_2$ assimilation. In some studies with sterilized samples, it was not possible to remove the absorbed radioactivity by repeated treatments with strong acids. This problem now appears to have been resolved. In 40 tests with soil 266, the nonbiological retention of $^{14}CO_2$ was found to occur only when the exposed soils were dried prior to being acidified. When exposed soils were acidified before drying, the radioactivity was reduced to the background level. Drying presumably alters the physical properties of the soil such that the absorbed $^{14}CO_2$ is rendered inaccessible to the acid.

Less extensive experimentation has been carried out with 7 other soils from the Atacama Desert and with 12 soils from the Antarctic dry valleys. The results indicated that the nonbiologically adsorbed $^{14}CO_2$ could be effectively liberated with the revised acidification procedure. Further studies are in progress to confirm these results. Also, the CO_2 fixation capacity of other soils from harsh environments will be examined.

DETERMINATION OF SUBSTRATE SYNTHESIS BY EXTRACTION OF SAMPLES AFTER INCUBATION

A limited effort has been directed toward devising a wet chemical fractionation for demonstrating the incorporation of $^{14}CO_2$ into biochemical compounds. This procedure could easily be integrated with other life-detection experiments which utilize wet chemical methods. Ideally, the types of compounds into which the $^{14}CO_2$ is incorporated could be elucidated in this integrated experiment.

When an exposed soil was extracted with an eight-step procedure, high levels of radioactivity were found in four of the fractions, vis., the methanol-acetone, cold trichloroacetic acid, hot trichloroacetic acid, and hot HCl soluble materials. Radioautographs prepared from thin layer chromatograms indicated that different compounds were contained in each of the four extracts. Further efforts will be made to optimize the extraction procedure and to characterize the biochemical components of the different fractions.

DETERMINATION OF $^{14}CO_2$ ASSIMILATION BY PYROLYSIS AND GAS CHROMATOGRAPHY

When exposed samples are pyrolyzed, the biologically assimilated ^{14}C should be converted to $^{14}CO_2$ and organic products containing ^{14}C. This pyrolysis treatment also liberates the adsorbed $^{14}CO_2$ which is undistinguishable from the CO_2 derived from the organic molecules. Thus a definitive experiment would be the demonstration of the label in the organic pyrolysis products. Tentatively, the experiment involves pyrolysis of the soil samples at 500°C, then passing the pyrolysate through a gas chromatography column. This would first elute CO_2 and subsequently the organics. The organics will be detected either directly or by first oxidizing them to CO_2 in a copper oxide furnace at 700°C. Recently a gas chromatographic apparatus has been devised to determine plausibility of this approach. If the results indicate that the ^{14}C-organics can be distinguished from the $^{14}CO_2$ then the system will be optimized and the sensitivity determined.

FUTURE

This experiment will be ready for breadboarding during FY 69.

PUBLICATIONS

None.

FLUOROMETRY AND BIOSPECTROPHOTOMETRY

NASA Work Unit 189-55-02-02-55

JPL 386-50201-2-3260

J. H. Rho
P. J. Geiger
J. P. Hardy

FLUOROMETRY

OBJECTIVE

The objective of this task is to develop fluorometric assay methods for biological pigments and nucleic acids in soils. The methods are applicable to the detection of life by unmanned planetary landing probes.

STATUS

During this reporting period, work on this project was suspended. Manpower was reassigned to the Biosatellite Experiment project 189-55-02-02-55.

PLANS

Work on the project will be resumed when commitments to the Biosatellite Program are met.

INFRARED METHODS: CHEMISTRY OF SOIL

OBJECTIVE

The previous objective was to develop methods for detecting life and its associated organic compounds in extraterrestrial soils by means of infrared multiple internal reflection spectroscopy (MIR). This has now been modified during the past 6 mo, and the development of MIR spectroscopy as a tool specifically for life detection and biochemical studies of the soil has been postponed. Nevertheless, the procedures developed for extracting biochemical components of soil for examination by MIR are applicable in studies of other detection methods. The new long-range objective is to develop methods for preparing and analyzing samples of biologically related and other organic compounds in the soil by a variety of chemical and instrumental techniques. A short-range objective is to study the structure and components of humic substances. A further short-range objective, now almost complete, has been the development of an improved method for the determination of total soil organic matter.

STATUS

There is at present no entirely satisfactory way for estimating total organic matter in soil. A promising method that utilizes principles involved in gas chromatography has been under development. Organic matter is oxidized by a chlorate mixture or by gaseous oxygen; the CO_2 is then reduced to CH_4 and led through a flame ionization detector for quantitation. By appropriate control of combustion temperatures, total organic carbon is estimated in the presence of inorganic carbon. The method is capable of quantitatively estimating organic matter in a few milligrams of soil containing about 0.1% organic matter as determined by the Allison method. This is equivalent to several micrograms of carbon. Furthermore, the system is capable of being operated at 1000 times greater sensitivity, i.e., at the nanogram level.

Further work on the characterization of the humic substances in soil has not yet been carried out, with the exception of a few experiments on a particular sample of Death Valley soil. This sample apparently contains no humic material but rather organic matter more like kerogen.

Progress in all of the above mentioned work has been delayed by approximately 2 mo, owing to requirements of the Biosatellite Program.

PLANS

The method for estimating total organic matter in soil will be completed. In addition to carbon, some effort will be expended to determine hydrogen also.

Further work will be accomplished on humic materials, particularly with the view toward determining the kinds of phenolic substances combined in the humic complex. This will be carried out by methods mentioned in the last report. Analysis will be by GC/MS, infrared, TLC and other suitable methods.

Future work will be conducted under a new NASA work unit: Soil Chemistry: Preparation of Samples for Organic Analysis, NASA Work Unit 189-55-02-10-55.

TRIMETHYLSILYL DERIVATIVES OF BIOLOGICAL COMPOUNDS

OBJECTIVE

The objective is to develop methods to separate biological compounds from soil and analyze the trimethylsilyl derivatives of these compounds by gas chromatography.

STATUS

Since February 1968, the full effort intended for this subtask has been suspended to work on biosatellite. Because of this, essentially no progress has been made in the development of trimethylsilyl derivative formation as an analytical tool.

Early in the year a cursory survey of the reactivity of N, O-bistrimethylsilyl acetamide with various organic amines was started, but the results were inconclusive.

Preliminary contact was made with Dr. Charles W. Gurke, University of Missouri, Colombia, Missouri, who has performed related studies under NASA contract. An effort will be made to coordinate these studies with those being performed at JPL.

PLANS

An attempt will be made to establish optimum conditions for the preparation of trimethylsilyl derivatives of the reduction products of humic acids, amino acids, amino sugars nucleosides and other compounds from soil, and to positively identify the trimethylsilylated organic compounds from some of these components in soil, using a GC/MS combination. The mechanism of trimethylsilyl derivative formation will be studied.

PUBLICATIONS

None.

IMAGING STUDIES

NASA Work Unit 189-55-02-03-55

JPL 386-51301-2-3260

G. A. Soffen

OBJECTIVE

The principal objective of this task is the assessment and development of imaging techniques for the detection and investigation of extraterrestrial life from a landed spacecraft. This includes micro- and macro-imaging and the ancillary techniques required for recognition.

The objective of the present effort is the development of a microspectropolarimeter capable of selecting optically active particles for microscopic imaging. In principle, it should be capable of finding these fragments among the background of mineralogical particles.

An additional aspect of this task is the collection of biological evidence that will contribute toward the specifications of the landed imaging experiments.

PROGRESS

Progress was made in the development of a microspectropolarimeter under JPL Contract 951925. The accomplishments during the last review period were:

(1) A breadboard was assembled, consisting of an illumination source, a monochrometer, a microscope, polarizing elements, a recording magnetic drum, phase angle discrimination circuitry, and a printer for data.

(2) The instrument has been tested for stability and performance in order to determine that it can perform as theoretically predicted.

(3) Some tests were performed on known specimens to determine resolution and capability. The present performance is about 10 millidegrees.

(4) Some biological material was examined qualitatively.

FUTURE

The major outstanding problems are improvement of the mechanical, optical, and electrical components of the system to optimize the operational characteristics; testing of biological material to assay usefulness of the instrument; and determination of scientific and engineering criteria for flight hardware. Ultimately the experiment should be extended to the quartz ultraviolet region of the spectrum.

PUBLICATIONS

None.

EXOBIOLOGY INSTRUMENTATION

NASA Work Unit 189-55-02-04-55

JPL 386-51401-2-3220

J. L. Stuart

OBJECTIVE

The long-range objective of this work unit is to develop analytical instrumentation techniques suitable for wet chemical analysis of planetary soils. Much of the development work is utilized directly in the Biosatellite Project (NASA Work Unit 883-12-00-01-00).

PROGRESS

Development of a multiword storage/nondestructive readout data storage and processing system has been completed. An analog amplifier and difference bridge photosensor light detector configuration has been completed; it is light sensitive over a four-fold variation in excitation. This is the heart of a fluorometer. An analog amplifier and ratio bridge photosensor which are light-sensitive over the range of two optical density units have been completed. This is the heart of a colorimeter.

A thermal controller has been developed for maintaining close temperature control of the chemical reactions under study in the Biosatellite Pace/Rho Urine analysis experiment. The controller is designed for maintaining a close temperature tolerance at any set point from just above ambient to +110°C with an efficiency greater than 90%.

In addition, circuit designs for five types of process control have been constructed and evaluated. They are used in automating various chemical analyses. The circuits are: (1) to control a pump which meters a fixed volume of fluid for analyses; (2) to control the position of a rotary valve to permit the valve to stop at various positions, each position establishing the transmission of a specific fluid to the analyzer for use in the analysis; (3) a control circuit for metering solutions into a small test cell to establish the proper volumes of the various solutions required to perform the analysis; (4) a modification of this circuit allows the metering drive unit to cycle, causing mixing of the solutions. The circuit is a bi-directional, motor control circuit; and (5) a control circuit for use in accumulation of a sample for analysis. The circuit allows a series of samples to be accumulated, then the total accumulation is discharged through the analyzer units. One unit volume, however, is retained in the accumulator for a subsequent analysis in one of the analyzers. A later command causes this sample to be discharged through the analyzer.

A dynamometer control servo has been developed which permits automatic plots of speed versus torque and current versus torque for low torque dc motors. The servo is accurate and stable over a wide range of operational parameters from no load to stall conditions.

FUTURE ACTIVITIES

Because of manpower and budgetary restrictions, this task is being closed out. No future activity is anticipated until personnel are available from the Biosatellite Program.

ANTICIPATED PUBLICATIONS

None.

PUBLICATIONS

None.

ENERGY TRANSFER MECHANISMS

NASA Work Unit 189-55-02-09-55

JPL 386-50901-2-3260

G. P. Shulman
A. J. Bauman
H. G. Boettger

OBJECTIVE

During the past year, the analytical pyrolysis program has included investigation of the utility of pyrolysis/gas chromatography/low resolution mass spectrometry for extraterrestrial detection of life-related compounds; soil organic analysis by extractive procedures to characterize by established methods the native organic matter in desert soils; and high resolution mass spectrometry for identification of complex organic compounds.

Next year, the latter two areas will not be a part of this work unit but will continue as separate work units. The title of this work unit is being changed in FY 69 to Analytical Pyrolysis.

PYROLYSIS

Progress

The pyrolysis of selected life-related compounds has been continued. A scheme for detection of classes of bio-organic compounds resulted, but preliminary data indicate that additional work will be needed to permit partial identification of the component moieties within each class. Several specimens of geochemical and cosmochemical importance, including desert soil and rock samples, have been subjected to analysis by pyrolysis/gas chromatograph/mass spectrometry. Correlation of the results with those from extractive analyses confirms the validity of this method for identification of the various classes of material.

Pyrolysis of organic matter in the presence of common rock and soil minerals did not affect the qualitative analysis sufficiently to preclude analyses. However, studies of Antarctic desert soils containing significant quantities of nitrate have shown that oxidation of organic matter presents a serious problem in nitrate-rich soils.

Future Plans

Pyrolysis studies will be continued using the high resolution mass spectrometer to assist in identification of complex pyrolysis products, and the quadrupole mass spectrometer for pyrolysis studies on additional component moieties of the various classes. More desert soils, barren rocks, meteorites, and abiogenic "soups" will be subjected to analysis to establish whether the source of soil organic matter can be defined using this technique.

Electrolytic fluorination is an alternative volatilization technique which offers a certain advantage for volatile product identification without the aid of a mass spectrometer. Since the modified Mars landing missions may not have sufficient weight, power, or data transmission capability for inclusion of a mass spectrometer, this approach will be investigated as a possible substitute. In addition, an evaluation of compression techniques for mass spectrometric data will be performed.

SOIL ORGANIC ANALYSIS

Progress

A liquid—solid chromatographic scheme using Sephadex and triethylaminoethyl cellulose columns was tested by conducting the analysis of partially autolyzed blue-green algae of a type common in desert soil. It is capable of separating about 80 types of compounds ranging in solubility from lipids (hydrocarbons) to sugars. A method for extraction of desert soils by organic solvent (chloroform-methanol 2:1) with minimal artifact formation has been developed.

Future Plans

The methodology developed previously will be applied to desert soils. Fractions separated will be characterized by thin-layer chromatography with diagnostic spray reagents, gas chromatographic and mass spectrometric techniques.

HIGH RESOLUTION MASS SPECTROMETRY

Progress

Computer Program Development

The basic data logging and data analysis programs for high resolution mass spectrometry are essentially complete. With the aid of these new routines, most of which had to be developed at JPL, it is possible to record a mass spectrum in computer-compatible format at any scan speed within the capabilities of the mass spectrometer; compress the data from several million points per spectrum to less than 50,000 by extracting and storing the significant peak profiles and rejecting extraneous data; determine the precise mass of each ion species regardless of whether it is a single ion peak or part of a multiplet; and convert this mass to the elemental composition of the ion. Development of a data reduction system for high speed low resolution spectra is in progress. This entails three phases; i.e., recording and logging of data, converting peak positions to nominal masses and normalized intensities, and identification of the spectrum through comparison with known spectra in a library. New programs were developed for the latter phase and the establishment of the library. This effort is now in the final "debugging" stages. A starting library of 2000 spectra has been compiled on cards and/or tape. An additional 5000 spectra will be added before the end of June.

Analytical Investigations

Now that problems associated with instrument operation and data processing have been resolved, the proportion of effort devoted to analytical problems is increasing. To date, identification of pigments (porphyrins and carotenoids) extracted from soil and of purine and pyrimidine bases from pyrolysis of polynucleotides have been performed.

Future Plans

Computer Program Development

The library search procedures will be completed and a study into the problems of automated structure elucidation of complex biological substances, after a high resolution printout has been obtained, will be initiated.

Analytical Problems

Analytical support for the other efforts of the Bioscience Section will be continued and expanded.

PUBLICATIONS

Meetings and Symposia Papers

1. Boettger, H. B., "Automated Data Reduction of High Resolution Mass Spectra of Organic Compounds," American Chemical Society Western Regional Meeting, Anaheim, California, November 1967.
2. Shulman, G. P., "Pyrolysis of Bio-Organic Compounds in an Inorganic Matrix," American Chemical Society Western Regional Meeting, Anaheim, California, November 1967.
3. Simmonds, P. G., "A Comparative Study of Structural Fragmentation by Pyrolytic Techniques," American Chemical Society Western Regional Meeting, Anaheim, California, November 1967.

Open Literature

1. Shulman, G. P., and Simmonds, P. G., "Thermal Decomposition of Aromatic and Heteroaromatic Amino Acids," Chemical Communications, in press, 1968.

SPS Contributions

1. Bauman, A. J., (anon.), SPS 37-48, Vol. I, pp. 24–36, November 30, 1967.

DESERT MICROFLORA

NASA Work Unit 189-55-04-01-55

JPL 386-50301-1-3260

R. E. Cameron

OBJECTIVE

The objective of this task was to study and identify the basic groups of microflora that exist in extreme environments, especially in desert soils, to obtain information about the physical and chemical environment in these soils and the surrounding microclimate relative to desert soil microbial ecology.

ANTARCTIC SOIL INVESTIGATIONS

During Antarctic austral summer 1967–68, 58 surface and subsurface samples were collected from dry valleys of Southern Victoria Land. On-site environmental measurements (microclimate and soil) were made at three field sites during approximately 1-wk periods. Microbiological analyses were made at the NSF Biology Laboratory, McMurdo Station, on 45 samples from 22 sites in the Asgard Range and other areas. An additional 12 samples were collected with Dr. James Turnock, Deputy Director, Apollo Program, for testing at the Lunar Receiving Laboratory. More than 1000 lb of frozen samples were sent to JPL for further testing.

It was found that for any one of the dry valleys, and at a selected site within the valley, the abundance and diversity of microorganisms depended upon variations of ecological factors. Unfavorable environmental factors, e.g., East–West orientation, low solar radiation flux, high southerly winds, low humidities, an infrequent supply of available water, and salty soils low in organic matter, greatly restricted the existence of microorganisms. In unfavorable environments, there were either no microorganisms or only a single population of heterotrophic, aerobic, non-pigmented bacteria of <10 to $1000/g$ of soil. With an increasing gradient of favorable ecological conditions from sites that were least favorable, there was an ecologic succession in diversity of forms and abundance of microorganisms with resultant communities of bacteria, actinomycetes, algae, fungi, protozoa, lichens, and mosses.

For the coming fiscal year, additional soils collected in Antarctic austral summer 1966–67, and 1967–68, will be analyzed and the results correlated with ecological factors operative in Antarctic dry valleys. Other extreme environments will be further investigated to determine details of similarities or differences with Antarctic soil microbial relationships and ecology.

CONTRACTS

Three reports have been received from Prof. W. Bollen, Oregon State University, Corvallis, Oregon, JPL Contract 950783. Results of classification of desert bacteria show that most of them are Bacillus spp. or soil diptheroids, although a number of Antarctic isolants are Micrococcus or Mycococcus spp. The first report on actinomycete isolants resulting from electron microscope studies indicated that most of these microorganisms are Streptomyces spp. Three hundred additional microorganism isolants are currently in various stages of study. Lyophilization of cultures for storage purposes is now under way.

Three reports have been received from Prof. E. Staffeldt, New Mexico State University, Las Cruces, New Mexico, JPL Contract 951602. Identifications have been received for isolants from the Valley of 10,000 Smokes and three Atacama desert soils. Approximately 300 isolants and soils from various desert areas, including some from Antarctica, are in various stages of study. Studies on the majority of isolants and soils have not been completed, although a preliminary classification of isolants places most of the molds into two or three categories: (1) Penicillium or Asperigillus spp., (2) Moniliaceae, and (3) Dematiaceae.

This contract was not funded during November 1967 to date because the contractor (due to accident and illness) asked for an extension without additional funds. Additional funding is required to complete this study and to undertake the identification and moist chamber cultivation of additional

Antarctic soils. To assist in culturing, a fermenter has been sent to the contractor. A lyophilizer is already available at the University.

PUBLICATIONS

Contractor Reports, Interim and Final

1. Bollen, W., "Ammonifying, Nitrifying, and Sulfur Oxidizing Capacity of Antarctic Soils," Oregon State University, Progress Report, JPL Contract 950983, March 27, 1968.

2. Bollen, W., and Nishikawa, S., "Systematic Description and Key to Streptomyces Isolants From Chile-Atacama Desert, Hawaii, and Oregon Soils," Oregon State University, Progress Report, JPL Contract 950983, April 25, 1968.

3. Bollen, W., Au, F., and Byers, K., "Systematic Description and Key to Isolants from Atacama Desert, Chile," Oregon State University, Progress Report, JPL Contract 950983, May 7, 1968.

4. Staffeldt, E., "Microorganisms in Soil Samples From the Valley of 10,000 Smokes, Alaska," New Mexico State University, Progress Report No. 6, JPL Contract 951602, November 27, 1967 (not reported previously.)

5. Staffeldt, E., "Occurrence of Microorganisms in Hilgard Soil Samples," New Mexico State University, Progress Report No. 7, JPL Contract 951602, January 30, 1968.

6. Staffeldt, E., "Comparison of Microorganisms Inhabiting Three Desert Soils in the Western Hemisphere," New Mexico State University, Progress Report No. 8, JPL Contract 951602, February 7, 1968.

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MICROBIOLOGY STUDIES

NASA Work Unit 189-55-04-03-55

JPL 386-50601-2-3260

J. S. Hubbard

OBJECTIVE

This task supports the life detection program through investigations of microorganisms which are adapted to harsh environments. The objectives are to characterize the metabolic apparatus of such species and to devise methods for measuring their activities. Such information is needed in designing experiments for an unequivocal demonstration of Martian-life forms.

GROWTH AND METABOLISM OF HALOPHILIC ORGANISMS

As previously reported, the enzymes of extreme halophiles have been investigated since they are uniquely adapted to function at low water activities. The isocitrate dehydrogenase (IDH) of the extreme halophile, Halobacterium cutirubrum, has been investigated in detail. This enzyme requires salt for both activation and protection from denaturation. However, it was found that the latter requirement can be replaced by low levels of the substrates of the enzyme. For example, a mixture of 4 mm isocitrate and 10 mm $MnCl_2$ confers the same protection as 4 M NaCl. Being able to stabilize the IDH with substrates made it possible to perform classical purification steps which can only be carried out in buffers of relatively low ionic strength. By use of ammonium sulfate precipitation and ion exchange chromatography, IDH preparations have been obtained at about 30% purity. Disc gel electrophorisis showed that two contaminating proteins were present but these were easily distinguished from the IDH protein. When the enzyme was denatured by brief exposure to low ionic conditions, the electrophoretic migration of the IDH was altered. This treatment resulted in the IDH protein appearing in three bands with lower electrophoretic migration dates than the native enzyme. Further studies are in progress to characterize these conformational changes which are associated with the salt requirement. In addition to electrophorisis studies, the sedimentation of the native and denatured enzyme will be examined in the ultracentrifuge.

Investigations will also be initiated with another extreme halophile. This species is even a better model for a Martian organism since it is photosynthetically active under anaerobic conditions in media containing near-saturating levels of salt.

PHYSIOLOGY OF DESERT SOIL MICROORGANISMS

Microorganisms which inhabit the dry valleys of Antarctica represent a useful model in designing experiments for the exploration of Mars. Their metabolic apparatus is adapted to function in a harsh environment, i.e., at low temperatures and with limiting amounts of water.

Many of the Antarctic sites examined by Cameron, et al., were found to contain substantial numbers of culturable organisms.[1] The soils from other sites appear to be sterile or to contain only a few microorganisms (<100 per gram of soil). However, chemical analyses indicated that some of the sterile soils contained as much organic carbon and nitrogen as other soils in which 10^4 to 10^5 organisms per gram were recovered. One possibility is that the Antarctic soils contain populations which are not detected by conventional cultural techniques. Thus, a metabolic assay was devised to test this possibility. Conceivably, this assay could detect substrate utilization by species even though the conditions were not favorable for growth. In this procedure, aliquotes of soils were mixed with ^{14}C-labelled substrate and were incubated in sealed chambers. The substrate was a mixture of low levels of uniformly labelled ^{14}C-glucose and ^{14}C-amino acids. After 1 hr, the reaction was stopped by the addition of acid, and the $^{14}CO_2$ which had been evolved during the catabolism of the substrates was flushed into a hyamine hydroxide trap. The readioactivity in the hyamine hydroxide was then measured with a liquid scintillation counter.

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[1] Roy E. Cameron, Desert Microflora Program, Semiannual Progress Reports, June 1967, December 1967, and June 1968.

Thirty-three soils from the McKelvey Valley, Victoria Valley, Taylor Valley and Asgard Range have been analyzed with the metabolic assay. In general, the results agree with those obtained in cultural experiments. Appreciable amounts of $^{14}CO_2$ were evolved by soils in which more than 1000 organisms per gram were demonstrated. Those soils which were sterile or which contained < 100 bacteria per gram did not give a positive response in the metabolic assay.

An anomaly was noted when the results obtained with Antarctic soils were compared with those obtained with soils from a more favorable environment. For example, comparable amounts of $^{14}CO_2$ were evolved by an aliquot of Taylor Valley soil 537 and an aliquot of JPL-mixed soil from which were cultured 2.4×10^3 and 3.7×10^5 organisms, respectively. This would mean that the amount of $^{14}CO_2$ evolved per culturable organism in soil 537 is more than 100 times greater than that evolved per JPL soil organism. Several possibilities are being examined in order to account for this disparity.

The most obvious explanation is that the Antarctic soils contain large populations which do not proliferate on our laboratory media. Alternatively, the organisms of the harsh environment may be adapted to utilize low substrate levels more efficiently than species found in the more favorable environment (JPL soil). If so, the number of substrate molecules metabolized per Antarctic soil oranism would be higher than that metabolized per JPL soil organism. Still another possibility is that the Antarctic soils may contain nonviable organisms with active metabolic apparatus to catalyze the CO_2 evolution. Conceivably the low temperatures of the Antarctic soils could protect these enzyme systems from the thermal denaturation which occurs in warmer soils. Cultural and metabolic experiments are in progress to examine these possibilities.

PUBLICATIONS

Meetings and Symposia Papers

1. Hubbard, J. S., and Miller, A. B., Properties of the Halophilic Isocitrate Dehydrogenase of Halobacterium cutirubrum, American Society for Microbiology, Detroit, Michigan, May 6, 1968. (Abstract published in Bacteriological Proceedings, p. 117–118, 1968).

PLANETARY QUARANTINE (189-58)

DEVELOPMENT OF ETO SPECIFICATIONS AND PROCEDURES

NASA Work Unit 189-58-21-02-55

JPL 386-82301-2-2940

A. S. Irons

OBJECTIVE

The objective of this task is to develop necessary parametric information to be used for establishment of appropriate ethylene oxide cycles for decontamination of specific spacecraft designs. Materials compatibility and system continuity problems of the design will present limiting constraints on the duration of the humidification cycle and on the time, temperature, relative humidity, and ethylene oxide concentration of the process. Information concerned with the effects of process efficiency of varying process parameters must be established under physical conditions simulating those which will be used for spacecraft treatment. Additional information required may include the flow patterns and diffusion rate of ethylene oxide over and into various spacecraft components and assemblies under the physical conditions of the process variations.

INTRODUCTION

Considerable information is available on the use of ethylene oxide (ETO) as a decontaminant or sterilant for pharmaceutical and medical products. However, the adaptation of this information to the problem of space hardware decontamination requires additional work because of the large physical size of the spacecraft, and compatibility problems of spacecraft hardware with the physical conditions to which the space hardware must be subjected during the decontamination process.

In addition, spacecraft will be exposed to high vacuum for long periods during system tests prior to the possible use of ethylene oxide. This is an important consideration because dehydration of microorganisms makes them more resistant to ethylene oxide.

APPROACH

The approach which will be used to solve the problems involved will be an investigation of the effects on process efficiency of varying the parameters of temperature, humidity, ethylene oxide concentration, pressure, and duration of the humidification cycle under conditions simulating those which will be used for spacecraft treatment.

The proposed variations will be evaluated by inoculating standard surfaces such as glass and actual space hardware with microorganisms and subjecting the surfaces to a complete cycle. Recovering and counting the viable organisms remaining after exposure will give an indication of the relative efficiency of the cycle. Data utilizing recovery and enumeration of viable spores, as well as attribute (go-no-go) data will be used in evaluating the effects of varying the parameters. A contract will be issued to evaluate the effects of the stated variations. This will require the fabrication of equipment capable of producing the conditions required.

Upon completion of the process parameter evaluations, a follow-on contract will be initiated for the development and verification of procedures and verification of process efficiency using simulated flight hardware. It is important that space hardware be used in the evaluations because very little work has been done on actual hardware, and as a result, very little information is available on the effect of cycle variations on these items.

ACCOMPLISHMENTS TO DATE

Cognizance has been maintained of current work in the field of ETO decontamination of various types of materials and of developments associated with the design and manufacture of facilities of decontamination processes using ETO.

Evaluations of the proposals received were completed and contract negotiations were initiated.

FUTURE ACTIVITIES

Currently the Procurement Division of JPL is in the process of negotiating a 14-mo contract with Becton-Dickinson. As a result of this contract an ethylene oxide decontamination preliminary process document and an ethylene oxide decontamination requirements document will be prepared.

A follow-on contract is planned for the development and verification of procedures and efficiency using simulated flight hardware and mated surfaces. This contract will result in a final ethylene oxide decontamination process requirements document.

PUBLICATIONS

None.

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MICROBIOLOGICAL FILTERS – LIQUID AND GAS

NASA Work Unit No. 189-58-21-04-55

JPL 386-80301-2-2940

G. H. Spruce

OBJECTIVE

The objective of these studies was to realistically evaluate the efficiency and reliability of typical gas and liquid filters, as a means of sterilization for liquids and gases.

INTRODUCTION

Fluids, such as battery electrolytes, attitude control gases, fuels and experimental media, to be carried on board spacecraft subject to the NASA planetary quarantine constraints, must be sterilized to comply with the over-all 1×10^{-3} probability requirement.

Due to the heat-labile nature of many, if not most, of these products, filtration has been considered as a means of achieving this objective.

As an initial step in the study of sterilization by filtration, a contract was entered into with the Wilmot Castle Co. for the evaluation of available HEPA filters, following which a second contract was awarded which expended these studies to include various filter media and apparatus for the filtration of (1) gases under pressure, (2) liquids under pressure, and (3) unpressurized liquids in small volumes.

ACCOMPLISHMENTS TO DATE

During this reporting period the Wilmot Castle Co. has completed the test programs under which filtration systems for air, gases under pressure, liquids under pressure, and unpressurized liquids in small volumes were evaluated. The final contract report has been evaluated and revised to more clearly present the findings. Results indicate that existing (at the time of these studies) "off-the-shelf" filtration systems are unsuited to the requirements of any sterilization plan, by virtue of unreliability. It appears, however, that filtering media are available or within the state of the art and that suitable holder mechanisms can be designed to achieve reliable filtration systems within the constraints of current sterilization plan concepts.

FUTURE ACTIVITIES

In-house activity will be concerned with the following:

(1) Preparation of a Filtration Requirements Document based on these contract reports.

(2) Development of procedures to be used for evaluation and acceptance testing of filters and filtration equipment.

(3) Delineation of filtration processes to be used under specified conditions and for specified purposes.

(4) Evaluation of advances in the filtration field which occur subsequently to the studies recently completed.

PUBLICATIONS

Meetings and Symposia Papers

1. JPL Planetary Quarantine Program Status Review, presented at the Sterilization Technology Seminar, Cape Kennedy, Florida, June 12, 1968.

Contractor Reports, Interim and Final

1. Ernst, R., Final Report, Evaluation of Filters to Sterilize Liquids and Gases, Wilmot Castle Co., July 1, 1968.

REVIEW OF HEAT SPECIFICATIONS

NASA Work Unit 189-58-21-06-55

JPL 386-30601-2-2940

W. W. Paik
A. R. Hoffman

OBJECTIVE

The objective of this study is to determine the dry heat resistance of microorganisms under various conditions; to investigate developments stemming from this research; to develop process determination techniques; and to characterize the effects of various thermal process parameters upon capsule terminal sterilization processes.

INTRODUCTION

The attempt to identify and characterize the various parameters which influence the formulation of a dry heat sterilization process is being continued. Several tasks are being performed in this investigation, with emphasis on the derivation of quantitative data and evaluation of various thermal process parameters.

APPROACH

The efforts to investigate various parameters which may affect the thermal resistance of bacterial spores were continued.

Thermal Resistance of Spores at Matings of Surfaces

A method of evaluating the thermal resistance of bacterial spores between surfaces is being developed and tested. The procedure utilizes a thermal joint conductance apparatus (previously described) which possesses the capability of exposing samples to environments of varying temperatures and pressures.

Thermal Resistance of Encapsulated Spores

The thermal death rate of microorganisms within polymeric compounds varies according to the carrier system. Methods are being devised for homogeneously seeding and recovering bacterial spores from conformal coating and epoxy compounds.

Thermal Resistance of Spores on Surfaces

Spacecraft materials were used in an effort to determine if different surfaces would affect the thermal resistivity of *B. globigii* spores.

Thermal Sterilization Process Calculations

The numeric analytic techniques for process calculations are based on the concept of equivalent sterilizing times. After performing preliminary sensitivity studies manually, the process calculations will be programmed for a computer to permit more extensive parameter evaluation.

ACCOMPLISHMENTS TO DATE

Thermal Resistance of Spores at Matings of Surfaces

An acceptable method of evaluating the dry heat resistance of bacterial spores between mated surfaces has been developed. The test data compiled to date are presented in Table 1. Design efforts have also been initiated to evaluate material surfaces other than stainless steel.

Thermal Resistance of Encapsulated Spores

A model system for evaluating the thermal resistance of bacterial spores within solid polymer systems has been developed. The $D_{125°C}$ value for *B. globigii* spores within a methyl methacrylate system is 5.4 hr. The methodology for determining the dry heat resistance of bacterial spores within three other polymer systems has also been completed.

Table 1. $D_{125°C}$ Values for B. globigii Spores on Stainless Steel Surfaces Mated at Various Pressure Levels

Pressure Level, psi	$D_{125°C}$ Value[a], min
Ambient	13.73
100	16.58
5,000	21.54
10,000	22.45
100,000	In progress
200,000	In progress

[a]Mean value of four tests

Thermal Resistance of Spores on Surfaces

The effort to evaluate the dry heat resistance of bacterial spores on spacecraft material surfaces has been completed. The average $D_{125°C}$ value of four tests on the referenced material stainless steel was 17.07 min. The D values for the other seven materials tested ranged from 18.64 min for magnesium surfaces to 20.83 min on conversion coated magnesium.

Terminal Sterilization Process Calculations

During this reporting period, process calculations have been performed for a feasibility model of a possible Mars capsule (CSAD/FM). To support this effort a thermal analytical model of the capsule was constructed, assumptions regarding probability of survival and heat resistant characteristics were made, and microbiological assays during assembly were performed. With these data, a sterilization cycle was determined and applied to the capsule. The CSAD FM sterilization effort has demonstrated the manner in which the process requirements and operations would be implemented for a possible early Mars capsule mission.

The process calculations on the CSAD FM have also resulted in parametric information that is part of the continuing sensitivity analysis. The results of the studies completed during this reporting period are:

(1) Increasing the heating and cooling rates of the terminal sterilization chamber does not result in a significant decrease in over-all process times (when forced convection is not used within the sterilization canister).

(2) A verification of the theory that the process calculations are relatively insensitive to large changes in initial microbial burden numbers at the low D values.

Also, during this reporting period the thermal process integration method was programmed for a computer. The program is being referred to as the sterilization process analysis network (SPAN).

FUTURE ACTIVITIES

Thermal Resistance of Spores at Mating of Surfaces

The studies designed to determine the influence of mated surface pressure levels upon the dry heat resistance of bacterial spores will be extended to include: different material surfaces, the effects of various water activity levels, and different test temperature and O_2 levels.

Thermal Resistance of Encapsulated Spores

The procedures necessary to homogeneously seed polymeric compounds with bacterial spores and then effect recovery are being developed. This methodology will be incorporated into a request for proposals with the objective of obtaining D values for bacterial spores within spacecraft adhesive, conformal, and potting compounds. A secondary objective of this contract will be to determine low temperature D and z values.

Terminal Sterilization Process Calculations

The SPAN program will be exercised for the purpose of continuing the process parameter sensitivity analysis by using the CSAD temperature information and varying input parameters of D, z, N_o, P_s, and verifying some of the results manually derived.

Efforts will be expended to expand the SPAN program to provide the capability of updating P_s values while a calculation is being made.

PUBLICATIONS

Meetings and Symposia Papers

1. JPL Planetary Quarantine Program - Status Review, presented at Cape Kennedy, Florida, June 10–12, 1968.

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MICROBIOLOGICAL EXAMINATION OF SPACECRAFT PART INTERIORS

NASA Work Unit 189-58-22-02-55

JPL 386-81901-02-2940

G. H. Spruce

OBJECTIVE

The objective of this task is to study all factors concerned with the requirements for sterilization of spacecraft part interiors.

INTRODUCTION

Fundamental to the spacecraft sterilization requirements of the NASA Planetary Quarantine program, is the determination of the presterilization microbial burden occurring on and within the structures and component parts of any craft which is to be sterilized. This loading, among other factors, determines the parameters of any sterilization procedure which might be applied.

Work is currently progressing in the determination of spacecraft surface contamination to the point where a reasonable awareness now exists of the microbial levels to be anticipated on typical spacecraft surfaces. In contrast, available information is meager with respect to microbial burden entrapped within the interiors, and between mated surfaces, of vehicle parts.

Two primary aspects of the sterilization program depend upon this information; first, the definition of a flight acceptance test cycle, and second, the calculation of probability of release of entrapped viable particulates upon fracturing impact with a planetary surface.

ACCOMPLISHMENTS TO DATE

During this period the contract with Dynamic Science for microbial cell recovery from solid materials was completed. In addition, a sterility analysis of Mariner Venus 67 electronic parts has been completed which defines those parts which may be sterile as a result of quality assurance thermal screening cycles. For this purpose, parts listed in ZPP-2022-APL-C (Approved Parts List - Mariner Venus 67) were used. This list includes a total of 20, 845 parts (Table 1) of which 20, 875 (81%) undergo thermal conditions equivalent to F_{125} = 14 hr or greater; 3631 (14%) are $F_{125} > 3.5$ hr; and 255, are $F_{125} > 3.5$ hr, where F_{125} is the equivalent process time at 125°C to which the parts have been exposed during thermal screening by quality assurance. There are 1084 parts (4%) which have not been accounted for with respect to definable thermal histories.

FUTURE ACTIVITIES

Current plans call for a similar sterility analysis of Mariner Mars 1969 and CSAD piece-parts.

PUBLICATIONS

Meetings and Symposia Papers

1. JPL Planetary Quarantine Program - Status Review, presented at Cape Kennedy, Florida, June 10–12, 1968.

Contractor Reports, Interim and Final

1. Microbial Cell Recovery from Solid Materials, Final Summary Report, Dynamic Science, May 14, 1968.

Table 1. Cumulative Totals: Electronic Piece-Parts by Part Type - Mariner Venus 67

Part Type	Total No. Parts by Types	$F_{125} > 14$ hr (No. Parts / % Parts)	$F_{125} > 3.5$ hr (No. Parts / % Parts)	$F_{125} < 3.5$ hr (No. Parts / % Parts)	No. Unaccountable / % Unaccountable
Capacitors	4594	1373 / 30%	3141 / 68%	33 / 1%	47 / 1%
Chokes	28	0 / -	28 / 100%	0 / -	0 / -
Connectors	518	0 / -	0 / -	0 / -	518 / 100%
Cores	325	0 / -	0 / -	0 / -	325 / 100%
Crystals	7	0 / -	0 / -	6 / 86%	1 / 14%
Crystal Filters	7	0 / -	0 / -	7 / 100%	0 / -
Delay Line	1	0 / -	0 / -	1 / 100%	0 / -
Diodes	5025	4947 / 98%	60 / 1%	7 / <1%	11 / <1%
Filters	44	0 / -	27 / 61%	0 / -	17 / 39%
Fuses	21	2 / 10%	0 / -	19 / 90%	0 / -
Inductors	194	0 / -	194 / 100%	0 / -	0 / -
Microcircuits	594	594 / 100%	0 / -	0 / -	0 / -
Mag Amp	1	0 / -	0 / -	1 / 100%	0 / -
Photocells	38	0 / -	0 / -	38 / 100%	0 / -
Relays	85	0 / -	0 / -	85 / 100%	0 / -
Resistors	10,855	10,808 / >99%	4 / <1%	9 / <1%	34 / <1%
Silicon Controlled Rectifiers (SCR)	53	53 / 100%	0 / -	0 / -	0 / -
Silicon Controlled Switches (SCR)	10	10 / 100%	0 / -	0 / -	0 / -
Sensitors	6	6 / 100%	0 / -	0 / -	0 / -
Switches	14	0 / -	0 / -	14 / 100%	0 / -
Thermistors	3	3 / 100%	0 / -	0 / -	0 / -
Toroids	11	0 / -	0 / -	0 / -	11 / 100%
Transducers	55	55 / 100%	0 / -	0 / -	0 / -
Transformers	312	0 / -	186 / 60%	6 / 2%	120 / 38%
Transistors	3035	3024 / >99%	11 / <1%	0 / -	0 / -
Tubes	8	0 / -	0 / -	8 / 100%	0 / -
Solid State Detector	1	0 / -	0 / -	1 / 100%	0 / -
Total approved electronic piece-parts / % of total by category	25,845 / 100%	20,875 / 81%	3631 / 14%	255 / 1%	1084 / 4%
		($F_{125} > 14$ hr)	($F_{125} > 3.5$ hr)	($F_{125} < 3.5$ hr)	(Unaccountable)

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PLANETARY QUARANTINE ANALYSIS

NASA Work Unit 189-58-22-04-55

JPL 386-80101-2-2940

R. H. Green
E. J. Sherry

OBJECTIVE

The objectives of this work unit are to perform analysis necessary to define planetary quarantine constraints relative to spacecraft, probes and landers for future flight projects, and to perform research necessary to establish valid numbers for use in analytical studies.

ANALYSIS

Presently, a study is under way to establish a value for the contamination probability due to ejecta caused by meteoroid impact on a Mars orbiter. The upper limit meteoroid flux model used for this analysis generally predicts a flux which is an order of magnitude less than that predicted by the models previously promulgated. This reduction has resulted from discounting the very large meteoroid fluxes measured by microphone detectors. The contamination probability due to such ejecta will be checked against the nominal allocated probability of contamination for this event and tradeoffs with other contamination events will be studied.

During this report period two studies were completed: a preliminary quarantine analysis of a possible Mariner Venus 1972 mission, and an estimation of the number of viable microorganisms left in the liquid propulsion system after fabrication and cleaning. Technical support was provided in the preparation of the "Mariner Mars 1969 Planetary Quarantine Plan," JPL Report 605-87.

The program for the first half of FY 69 will be oriented to the actual planetary quarantine analysis and calculations for possible Mars orbiter and lander missions. As part of this task, and in an effort to use the best available data, a continual updating of the numbers that enter into the quarantine analysis is planned. By establishing firm values for these planetary quarantine parameters, valid tradeoffs can be identified at the planning stage.

RESEARCH

The research in this area continued to be limited to work in the Molsink.

During the reporting period construction of the large Molsink chamber has been completed. The chamber has been tested and shown to perform well. A helium refrigeration system now cools the walls of the Moltrap to 14°K, providing a cryopumping capability and a chamber pressure less than 10^{-12} torr. A quadropole mass spectrometer (run at 4°K) has been incorporated into the chamber, providing a very sensitive means of measuring the molecule species of gases in the chamber or emanating from a test item.

Following the completion of the chamber, Mariner Mars 1969 environmental tests were performed on various subsystems, prohibiting further biological tests. The chamber will again be available for biological testing July 1, 1968.

In the interim, a new test fixture has been designed and fabricated which will permit evaluation of the combined effects of both time and temperature of exposure. This will provide survivor curves which will be representative of the effect of the simulated deep space environment.

Feasibility of experimental methods of determining the rate of mass loss from spores exposed in this environment has been proved using the quartz crystal microbalance. A technique for electrostatic precipitation or coating of spores on the various test items has been developed and tested. This technique has provided a required capability for obtaining an even coating of the spores as proved by electron scan micrographs and direct plating of the coated items.

During the next report period, studies to quantitatively determine the effect of exposure to the deep space environment will be completed. If a significant lethality occurs as a result of this exposure, studies to determine the rate of mass loss and molecular species lost will also be conducted to determine if the lethality is the result of dehydration.

PUBLICATIONS

Meetings and Symposia Papers

1. JPL Planetary Quarantine Program - Status Review, presented at Cape Kennedy, Florida, June 10–12, 1968.

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STERILIZATION SUPPORTING ACTIVITIES

NASA Work Unit 189-58-23-02-55

JPL 386-81101-2-2940

R. H. Green
A. S. Irons
W. W. Paik
G. H. Spruce
M. R. Christensen
E. J. Sherry
A. R. Hoffman
J. A. Stern

OBJECTIVES

Objectives of the sterilization support activities task include:

(1) Maintenance of in-house microbiological capabilities required in support of space hardware sterilization.

(2) Support of microbiological activities conducted by JPL, both in- and out-of-house.

(3) Active support of the NASA sterilization and planetary quarantine programs.

INTRODUCTION

The subtasks grouped under sterilization supporting activities serve as technological support for each of the existing JPL tasks, the objective being the maintenance of an in-house capability to effectively support the NASA sterilization program. Studies of newly encountered problem areas, as well as development of a state-of-the-art awareness of potentially applicable technologies are included under this task. Additionally, this task includes efforts expended in direct support of the SADL and CSAD activities as well as the Martin Marietta Co. math model contract.

APPROACH

The sterilization supporting activities have been divided into the following subtasks, the accomplishments of which are summarized below:

(1) Operation of the JPL Microbiology Laboratory, Building 202.

(2) **Evaluation of NASA Standard Procedures.**

(3) **Evaluation of cleaning techniques.**

(4) **Turbulence studies (effect of turbulence in laminar airflow rooms).**

(5) **Microbial load estimation of selected electronics piece-parts/ surfaces.**

(6) **Sterilization support to the capsule system advanced development program (CSAD).**

(7) **Maintenance of cognizance of outside activities related to automated monitoring.**

UBTASK SUMMARIES

Subtask 1, Microbiology Laboratory Operations

Introduction

In order to define and work toward the solution of the many microbiological problems associated with the sterilization of space hardware, it is, and has been, necessary for JPL to develop and maintain broad capabilities in the field of microbiology. The primary task of defining the problems, as well as developing and maintaining the capabilities required to solve them, has been assigned to the Sterilization Group. A major area of effort of the group is centered in the Microbiology Laboratory which is operated to provide direct support to NASA-funded research and flight projects. This laboratory conducts various types of microbiological assays and associated tasks primarily concerned with space hardware sterilization and planetary quarantine programs.

Objectives

The objectives are:

(1) To design, analyze, develop and operationally support all microbiological experiments and procedures which are performed in support of JPL programs designed to produce sterile space hardware or in support of JPL planetary quarantine studies.

(2) To maintain in-house microbiological capabilities to cope with the many problems that are unique to spacecraft sterilization.

(3) To support all microbiological activities conducted by JPL in- and out-of-house, even though not directly funded by the projects.

(4) To actively support the NASA sterilization programs.

Approach

In order to maintain the required in-house capability and competency, it was necessary to issue a contract for management and operation of the Sterilization Laboratory. The contract, which was awarded to AVCO Space Systems Division calls for a 12 calendar month effort and 65 man-months of technical and associated effort. This contract was initiated October 1967.

All services provided by the contractor are under the technical direction of JPL Environmental Requirements Section and a JPL Microbiology Laboratory contract monitor. Tasks are initiated by Contractor Work Orders submitted to the JPL monitor after approval by the Sterilization Group Supervisor or Environmental Requirements Section Manager. The Contractor's Laboratory Manager submits monthly reports on the following:

(1) Procedures requested and initiated.

(2) Name of person or persons who initiated the request.

(3) Supervisor, technician and aide man-hours spent on each procedure.

(4) Amount of money (labor) expended for each procedure.

(5) Procedures carried over from last period.

(6) Procedures completed during report period.

(7) Total dollars expended for all procedures during report period (labor only).

Accomplishments to Date

A partial list of the studies supported during this report period or still being conducted in the Microbiology Laboratory includes the following:

(1) Development of methodology for the seeding and recovery of B. globigii spores from polymer systems.

(2) A method for determining the dry heat resistance of B. globigii spores in the interiors of epoxy and polymeric materials.

(3) Heat studies on organisms embedded in solid propellants.

(4) Dry heat resistance of spores under varying mating pressures.

(5) Microbiological monitoring of spacecraft during assembly and test operations.

(6) Evaluation of NASA Standard Procedures.

(7) Coupon assay for Capsule Mechanical Training Module.

(8) Effects on spores of exposure time and temperature in the molsink chamber.

Future Activities

Work will continue on those portions of Contractor Work Orders which have not yet been completed, as well as new CWO's as they are issued.

The arrangement whereby AVCO Corp. has provided technician and management support under a CPFF contract has been satisfactory both technically and cost-wise. The performance of AVCO management and personnel has been good. During June, a Procurement Requisition was issued which called for a modified extension of the existing contract. A modification is required because of a steadily increasing work load and the need for an additional technician category, i.e., senior technician. The Requisition calls for a total of 168 man-months of effort during the calendar year October 2, 1968, to August 15, 1969.

Subtask 2, NASA Standard Procedures Evaluation

Introduction

Since the issuance of the preliminary "NASA Standard Procedures for the Microbiological Examination of Space Hardware" in June 1966, the JPL Sterilization Group has performed microbial assays of space hardware and spacecraft assembly facilities in accordance with this document. Based upon this experience and several comparative studies, an evaluation of NASA Standard Procedures has been conducted.

Objective

The objective is to utilize and evaluate "NASA Standard Procedures for the Microbiological Examination of Space Hardware" under actual spacecraft assembly and test conditions.

Approach

To date, a flight vehicle (Mariner Venus 67) and the capsule training mechanical model (CMTM) have been extensively sampled using the microbiological methods described in the NASA Standard Procedures. Other sampling procedures have also been incorporated into these studies in order that a comparative evaluation of the various methods could be conducted.

Accomplishments to Date

The results of these efforts have been incorporated into a report evaluating the NASA Standard Procedures for sampling spacecraft and associated environments. In addition, JPL has provided support in the revision of the first edition NASA Standard Procedures document.

Future Activities

The revised NASA Standard Procedures will be evaluated in the same manner.

Subtask 3, Cleaning Techniques

Introduction

Reduction in the microbial burden on mated or exposed surfaces prior to heat sterilization can reduce the duration of the terminal heat cycle. Thus, cleaning procedures which can be applied to spacecraft hardware are being evaluated in terms of microbial burden reduction.

Objective

The objective is to evaluate cleaning methods currently used during spacecraft assembly as to their effectiveness in reducing the microbial burden accumulating on the surface of structural and hardware materials.

Approach

Evaluations presently being conducted include the use of detergents, degreasing agents, isopropanol, and vacuum techniques for cleaning. Several methods incorporating vacuum are under investigation in an effort to develop a combined cleaning unit and microbiological sampling device. The present approaches include straight vacuum, and vacuum with a built-in sonic energy source.

Accomplishments to Date

Design feasibility studies have been completed and prototype hardware is presently being fabricated.

Future Activities

The prototype vacuum cleaning hardware will be tested under controlled laboratory conditions, then utilized to clean and estimate the microbial burden on the Mariner Mars 1969 PTM spacecraft.

Subtask 4, Turbulence

Introduction

Spacecraft hardware is being assembled within areas of vertical laminar airflow. The introduction of any body into any uniform flow field causes disrupted airflow patterns.

Objective

The objective of this subtask was to determine the effects of disrupted laminar airflow upon microbial burden accumulation during hardware assembly.

Approach

Hardware was assembled in different areas of disrupted vertical laminar airflow. Assembled hardware was assayed for microbial burden. Distorted airflow patterns were characterized with titanium tetrachloride smoke.

Accomplishments to Date

Experimentation was completed during this reporting period, and a final document is being prepared.

Future Activities

Upon finalization of the document being prepared, this subtask will be considered completed.

Subtask 5, Microbial Load Estimation of Selected Electronic Piece-Parts/ Surfaces

Introduction

This subtask was originally proposed to establish procedures for microbiological recovery from surfaces. It was subsequently determined that such procedures could be established with existing knowledge. Therefore, it was decided to obtain quantitative information on surface contamination of electronic piece-parts as purchased and stocked.

Objectives

The over-all objectives of this task were:

(1) To enumerate and categorize the naturally occurring microbial flora resident on the surfaces of selected piece-parts and electronic components.

(2) To provide the data required as input into a mathematical model to be used for establishing the heat sterilization requirements for a spacecraft capsule.

Approach

A contract was awarded to AVCO Space Systems Division to investigate the microbial burdens (aerobic and anaerobic vegetative bacteria, fungi, and spores) on 22 selected spacecraft piece-parts as received directly from the manufacturer. The pieces assayed were primarily electronic parts and polymeric materials used in assembly of electronic components. For each part, 100 samples were generally divided into 5 manufacturing lots. The data obtained provided the statistical distribution of the microbial burden on a particular part and, where separate manufacturing lots were assayed, on the burden among the separate lots. Parts were assayed according to NASA Standard Procedures except where high microbial burden required additional dilutions to reach a countable range.

A computer program in FORTRAN IV was written to compute the averages, standard deviations, and values included in frequency distributions. In analyzing the results, it was found that the data for a particular lot or sample generally indicated a logarithmic normal distribution of microbial burden.

The results of the study indicated low microbial burden on most of the parts; in general, electronic components had a lower burden than the polymeric materials. Potting compounds were found to be highly contaminated.

Accomplishments to Date

The final report of Contract 951577 was received February 5, 1968. Inspection revealed that all desired changes had been incorporated. The report was considered to be satisfactory. Contract closeout forms were completed and forwarded for management approval and action.

Future Activities

Future activities will be concerned with in-house investigation of manufacturing procedures and sterilization time-temperature relationships during manufacture, acceptance testing and screening to determine probable low and high burden levels.

Publications

1. Final Report, Contract 951577 - AVCO Space Systems Division, Microbiological Investigation of Selected Spacecraft Parts and Materials.

Subtask 6, CSAD Support

Introduction

The capsule system advanced development (CSAD) program consisted of designing and developing a Mars planetary ent y and landing system for the purpose of gaining experience in critical new technologies, one of which is capsule sterilization.

Objective

The CSAD sterilization objective was to develop and apply terminal sterilization requirements in a manner in which they may be implemented for a possible early Mars mission.

Approach

The effort expended in determining the thermal process parameters for the CSAD used techniques developed under the heat task (JPL 386-80601-2-2945). The approach was to develop a thermal model of the capsule, determine the microbial burden at various points on the capsule (see JPL Task 386-80401-2-2945) and perform lethality computations.

Accomplishments to Date

During this reporting period, the monitoring program and the a priori process calculations were completed. The capsule was subjected to a terminal sterilization environment that had been determined sufficient to achieve the assumed probability of survival.

Under this subtask, the manner in which terminal sterilization requirements and operations would be implemented for a possible early Mars mission has been demonstrated.

Future Activities

The CSAD activity will include a posteriori process calculations and the publication of papers and final reports.

Subtask 7, Automated Contamination Monitoring

Introduction

Among the major problem areas in the determination of the sterility of spacecraft are the time-consuming procedures available for monitoring and their subjectivity to variation in operation techniques.

It is highly desirable as a corrective measure for these and other such shortcomings to be able to monitor spacecraft surface conditions automatically.

Additionally, it is of value to know the level of microbial contamination in the atmosphere surrounding the spacecraft, since it is from this source that the craft acquires a significant amount of its surface loading.

Automatic monitoring of biological contamination on and around the spacecraft offers not only increased accuracy and reliability, but also sufficient improvement in the time in which the results can be available.

Objectives

Toward this end, a study has been initiated in which the objectives are to research available techniques showing significant potential and further, to develop from these a rapid, reliable, automated, biological monitor for spacecraft applications.

Approach

At the present time one item of equipment, developed for CBR applications, appears to show significant potential for the biological monitoring of spacecraft surfaces. This apparatus employs a technique of "differential migration analysis" utilizing the principal of electrophoresis. It has been demonstrated, apparently for the first time, capable of continuous electrophoretic separation of bacterial cells and mixed inorganic particles. It appears applicable to any mixture whose components carry a charge and have different mobilities in an electric field.

This particular apparatus collects the separated particles which, it is believed, may be subsequently examined under infrared or ultra violet for immediate detection of potentially viable particles (as well as dead organic debris). Additionally, this capability allows for further plating, after the fact, for verification and identification.

A study of the applicability of such applied identification techniques is being performed concurrently. Serious attention is being given to the sonic probe collection technique being developed under subtask 3 as a means of removing bacteria from a spacecraft surface for collection in the buffer solution utilized in the electrophoretic apparatus.

Future Activities

In addition to this technique, other applicable methods will be considered as they become evident.

PUBLICATIONS

None.

MICROBIOLOGICAL MONITORING OF SPACECRAFT ASSEMBLY FACILITY OPERATIONS

NASA Work Unit 189-58-23-03-55

JPL 386-80401-2-2945

M. R. Christensen

OBJECTIVE

The objectives of this study are to develop and document the appropriate techniques and processes necessary to establish or predict the microbial burden occurring on spacecraft surfaces, or at specific locations on the vehicle, during any phase of assembly or testing and within variable or controlled environments.

INTRODUCTION

In the past, environmental microbial fallout estimates were used to draw correlations between facility particulate contamination and the microbial burden accumulating on the spacecraft surfaces. With the initiation of the Mariner Venus 67 Microbiological Sampling Program, and with the availability of various spacecraft associated with flight and feasibility projects, program emphasis has been oriented toward the direct sampling of spacecraft. This approach has been made possible through the cooperation and consent of project personnel.

APPROACH

The program approach is based on extensive sampling of simulated, prototype, and flight hardware under the varying environmental and personnel conditions encountered during assembly and testing of spacecraft. Repetitive enumeration of the microbial burden accumulating on exposed surfaces and at specific locations under these parameters will develop the sampling and assay proficiency necessary to accurately predict contaminant levels.

ACCOMPLISHMENTS TO DATE

The Mariner Venus 67 microbiological sampling program was completed June 17, 1967, and the results, conclusions, and recommendations have been delineated in a JPL Technical Report which is in press. As a result of the 67 program, procedural changes were incorporated into the recently completed capsule system advanced development (CSAD) microbiological monitoring program.

To ensure delineation of the microbial accumulations on the lander system and entry packages, the CSAD capsule was divided into zones. A minimum of 10% of each zone was sampled during designated assembly and test operations by swab-rinse techniques. Assays were made for heat-resistant spores, and enumeration and extrapolation of the spores was zone specific, with summation of the burden from the individual zones resulting in capsule burden. Final presterilization microbial spore estimates for the lander system were 9.3×10^3, as compared to 5.1×10^4 for the entire capsule system. These estimates, along with other parameters, were utilized to derive the thermal process for sterilization of the capsule system.

Inputs from the CSAD program are presently being incorporated into a JPL technical report, "Capsule System Advanced Development, Sterilization Program," and the Mariner Mars 1969 sampling program. In addition, particulate monitoring support has been given to the Mariner Mars 1969 Project and specific assembly and test facilities have been evaluated for particulate contamination.

FUTURE ACTIVITIES

The Mariner Mars 1969 microbiological program is presently under development, with the following objectives considered primary: to develop, refine, and statistically verify the techniques and procedures utilized to estimate microbial burden on previous programs; monitor areas of mated and occluded bio-burden; and provide data relative to the NASA inventory of outbound contamination.

The monitoring program will continue until culminated in February 1969. The knowledge obtained from all programs will be used to document the techniques and procedures for establishing the microbial burden occurring on space vehicle surfaces, or at specific locations on a vehicle during any phase of spacecraft assembly or testing, and will result in a "Space Vehicle Microbiological Sampling Procedures Document" which will be used to monitor all future programs.

Present and future programs in the SADL related to assembly of the capsule mechanical training model (CMTM) will continue to be used to verify sampling techniques and their applications during spacecraft assembly. This has been made possible through the coordination and integration of the SR & AD tasks with the APMT sponsored SADL program.

PUBLICATIONS

Meetings and Symposia Papers

1. JPL Planetary Quarantine Program Status Review, presented at the Sterilization Technology Seminar, Cape Kennedy, Florida, June 12, 1968.
2. "Microbiological Monitoring Program, Mariner Venus 67," presented at the Annual Meeting of the American Society of Microbiology, Detroit, Michigan, May 9, 1968.
3. Report, "CSAD FM Sterilization Program," presented to NASA/AIBS Spacecraft Advisory Committee, Cape Kennedy, Florida, April 2, 1968.
4. Report, "Bioquality Control," presented to NASA/AIBS Planetary Quarantine Advisory Committee, Cape Kennedy, Florida, June 13, 1968.