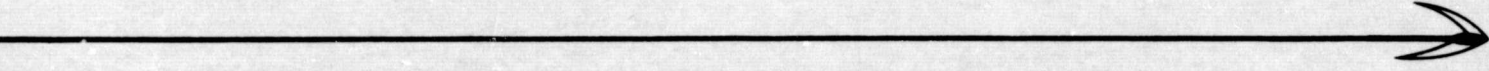


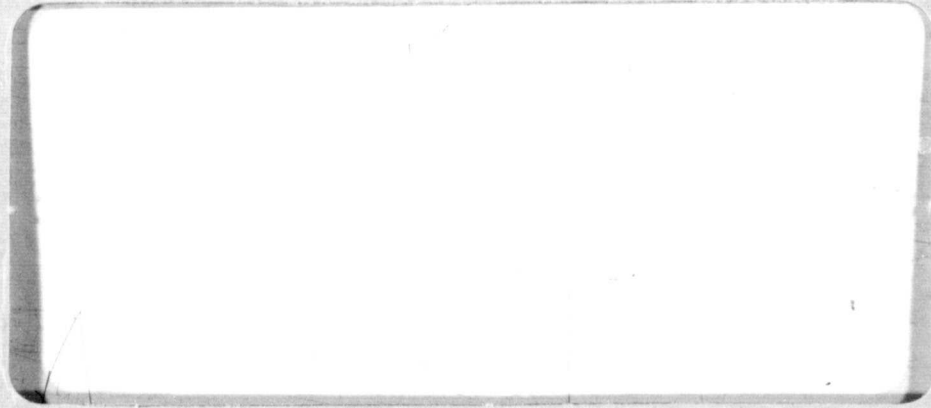
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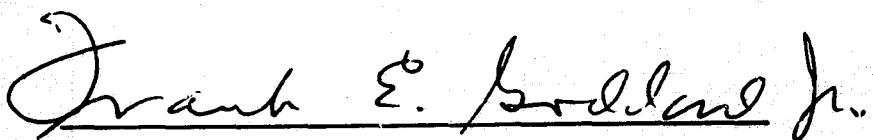
JET PROPULSION LABORATORY  
 CALIFORNIA INSTITUTE OF TECHNOLOGY  
 PASADENA, CALIFORNIA

701-90

SEMIANNUAL REVIEW OF RESEARCH  
AND ADVANCED DEVELOPMENT  
JANUARY 1 - JUNE 30, 1970

August 31, 1970

Approved by:



Frank E. Goddard, Jr.  
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JET PROPULSION LABORATORY  
CALIFORNIA INSTITUTE OF TECHNOLOGY  
PASADENA, CALIFORNIA

70-39411

## INTRODUCTION

This document contains a review of the supporting research and technology in progress at the Jet Propulsion Laboratory during the period January 1 to June 30, 1970, 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.

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HIGH SPEED INTERFEROMETER

NASA Work Unit 160-44-05-01

JPL 361-40101-0-3230

C. B. Farmer

P. W. Schaper

~~NO-3941/2~~

OBJECTIVE

The long-range objective of this task is to demonstrate that spectra between 1.0 and 5.0  $\mu\text{m}$  with a resolution of  $0.5 \text{ cm}^{-1}$  can be obtained with a small interference spectrometer. The instrument weight, volume, and power requirements will be reduced to a point where it is practical to consider its use on remote sensing applications. Such applications might include ground-based atmospheric analysis for trace constituents and their concentrations, balloon or aircraft measurements of meteorological phenomena, or planetary observations from outside the Earth's atmosphere. The immediate objective is to modify a breadboard of such an instrument to permit on-site evaluation of its output and real-time recording of the interferograms, and to verify the feasibility of the proposed instrument concept by tests in various operating environments.

PROGRESS

The high-speed data handling system (DHS), built under contract by Time-Zero Corp. at JPL, was completed and checked out during January. Meanwhile, the computer program modifications required to reduce the data were being completed. The first interferogram made with the new system was taken on January 7 and was successfully processed into a spectral plot. During the remainder of the contract period, JPL and Time-Zero personnel continued development on the IR detector and blackbody reference temperature control system; "cleaned up" the various electronic systems to reduce the noise levels; and finished construction and testing of some subsidiary electronics, such as the telemetry decommutator and simulator, as well as completing documentation of Time-Zero's phase of the design.

In February, the interferometer drive system was taken apart and modified to increase clearances between moving and stationary parts; the temperature controller design was finished and construction completed to incorporate it into the rest of the system. The telemetry receiving station van was "wired up" and a telemetry link between the van and the optical laboratory, one-half mile away, was checked out. Interferograms then were taken with the instrument looking at a bright collimated blackbody source about 30 feet away, to make absorption spectra of the atmosphere, utilizing the radio link.

These interferograms have been reduced to spectra and preliminary studies of their spectral quality, reproducibility and quantitative accuracy are under way. The results of the tests are encouraging in that the spectral quality is excellent; the experience gained thus far has suggested improvements which can be made to the data handling technique and indicates that the advantages of the present instrument design in efficiency and information gathering capability will be fully realized.

After these spectra were taken, a critical optical realignment effort was begun, to further improve the wavelength accuracy and profile of the lines in the spectra produced by the instrument. This effort has now been completed.

Fabrication was completed on a redesigned actuator for the moving cat's-eye that will permit it to cover a longer path difference, thus increasing the maximum possible resolution. Tests revealed a structural resonance problem requiring a partial redesign.

A proposal was written and submitted for the Advanced Applications Flight Experiment program (AAFE).

#### PLANNED ACTIVITIES

During the early part of the fiscal year, effort will be devoted to obtaining spectra of the Earth's atmosphere using the heliostat in the JPL Spectroscopy Laboratory. Spectra will also be obtained using artificial sources and known gas samples. These data will be compared to spectra computed from tabulated line parameters of known species to aid in the identification of the unknown constituents. Concurrently, a study will be made of the intensity and radiometric

accuracy of the overall system so that the reliability of the final data can be realistically assessed.

At the same time, a design study will be undertaken for an extended-range beamsplitter. The existing beamsplitter limits the spectral coverage to  $4000 - 8000 \text{ cm}^{-1}$  and the utility of the system would be considerably enhanced by an extension down to  $1600 \text{ cm}^{-1}$ . We believe such an extension to be well within current capabilities of commercial optical houses.

The moving cat's-eye actuator will be redesigned to eliminate the structural resonance, and after bench testing, will be incorporated in the interferometer assembly in place of the present actuator. This unit will allow the maximum resolution capability of the instrument to be increased to  $0.12 \text{ cm}^{-1}$  from the present  $0.25 \text{ cm}^{-1}$  and reduce the instrument weight by about 20 lb.

Data processing program development will be continued in order that the radiometric data from the instrument can be correlated with the interferograms so that an absolute radiant power density may be assigned to the spectra. The present programs also will be modified to make them more efficient and use less computer time to reduce costs when large numbers of spectra are being produced.

A power inverter system will be procured and incorporated into the instrument in preparation for aircraft and balloon flights and other necessary electronic modifications will be added.

An important objective of this phase of the work will be the determination of the maximum detectable concentration levels of minor constituents.

By the end of the fiscal year, we hope to have gained sufficient data and experience with the system to be able to prepare a detailed specification for the subsequent aircraft and satellite atmospheric studies

PUBLICATIONS

Journal Articles

1. Schindler, R. A., "A Small High-Speed Interferometer for Aircraft, Balloon, and Spacecraft Applications", Applied Optics, vol. 9, no. 2, pp. 301-306, Feb. 1970.

701-90

MULTIPLE ACCESS COMMUNICATIONS RESEARCH

NASA Work Unit 164-21-02-02

JPL 362-10201-X-3310

James W. Layland

*164-21-02-02-3*

OBJECTIVE

The objective of this work unit, which is now terminating, is to develop techniques for developing low-cost, multiple-access satellite telephone communications systems for use in remote areas of the world. A system would be comprised of one satellite, or part thereof, and a large number of ground stations, each with one telephone circuit.

The system objectives are to provide highly reliable speech communications with high intelligibility and fair-to-good quality for the minimum possible cost.

RESULTS

The major investigations of the work unit have been directed toward determining which modulation and multiple-access techniques are most suitable for the envisioned system, and determining the system cost in terms of required satellite and ground station qualities.

Investigation of speech intelligibility and quality as functions of signal-to-noise ratio (SNR) indicated that highly intelligible speech is attained with an SNR of 10 dB in the frequency band of 300 to 3000 Hz. However, acceptable quality is not attained until the SNR is about 13 dB, and good quality requires about 20 dB. These SNRs are significantly less than the approximate 35 dB required by international agreement for trunk line telephone systems. Because of the widely different SNR requirements, different techniques are suitable for trunk line systems and for the direct user-to-user system under investigation here. In particular, wideband FM and PCM systems are most appropriate for trunk line systems, whereas AM (SSB) and fairly narrow bandwidth FM are most suitable for the current application. FM is preferred over AM because

good (20 dB) quality can be achieved with the same power that results in only fair (14 dB) quality with AM, but more bandwidth is required for FM. In either case, frequency division multiple access (FDMA) is most appropriate, on the basis of simplicity. Details of the studies leading to these conclusions are given in the article "On Multiple Demand Access Satellite Systems for Speech Communications in Remote Areas," appearing in SPS 37-59, Vol. III, pp. 40-47.

A major portion of the work was devoted to the study of the performance of a spread spectrum code division multiple access (CDMA) pseudo noise (PN) carrier system. Code division multiple access is generally less efficient power-wise than wideband PCM-TDMA or FM-FDMA, but has the advantages of random access addressing and graceful system degradation.

Two fundamentally different results are possible with CDMA. First, if the system bandwidth is greater than the number of addresses times the speech bandwidth, the channels can be made orthogonal so that there is no interference between channels. The performance is theoretically the same as a SSB-FDMA system. The disadvantage of orthogonal CDMA is that system timing is required, and, therefore, FDMA is preferable for low-cost applications.

The second, and perhaps more interesting, case of CDMA is when the channels are not orthogonal. This typically occurs when the number of addresses must be so large that the bandwidth is insufficient for orthogonality (e.g., for more than 2000 addresses in a 10 MHz bandwidth). Since the channels are not orthogonal, there is interchannel interference. However, the amount of interference depends only on the number of active users, not on the number of addresses.

A digital computer simulation of this type of system has been carried out to study the effects of the interchannel interference on speech intelligibility and quality. Results show that high intelligibility can be achieved with good bandwidth utilization, but the quality is poor. For example, full intelligibility is attained for system bandwidths on the order of 30 KHz per active user, but the cross-channel interference remains extremely annoying for bandwidths even 10 times this large. The requirement of achieving fair to good quality at low cost precludes the use of non-orthogonal CDMA.

PCM techniques might also be feasible for the remote user terminal, provided an appropriate data compression technique could be found. A preliminary evaluation of the "slope-threshold" technique (reported in SPS 37-49, Vol. III, pp. 325-28) shows that it can provide reasonable quality speech with an average sampling rate of 4 KHz, and subsequent investigations indicate that this rate can be reduced somewhat, but not dramatically. Since about 12 bits are required for each sample, this method is not competitive with AM and low-index FM for low-cost single-link speech channels.

A method to simultaneously compute the output of all channels of a CDMA system has been studied and is reported in "Correlation with PN Sequences" in SPS 37-61, Vol. III, pp. 73-77. This method is a form of the Fast-Fourier Transform.

#### SUGGESTED FUTURE WORK

The primary factor determining the feasibility of a multiple-access system for low-density users is the cost of the ground station. Detailed cost studies for various configurations should be conducted by organizations familiar with mass production of microwave antennas and electronics. Further study of data compression techniques for speech should also be conducted.

#### PUBLICATIONS

None.

## DATA RELAY SATELLITE RADIO DEVELOPMENT

NASA Work Unit 164-21-02-04

JPL 362-10401-2-3360

S. Choi  
K. Newcomer  
F. Ott

## OBJECTIVE

The objective of this work unit is to develop certain critical portions of an advanced transponder to satisfy the requirements of the Tracking Data Relay Satellite (TDRS) project. Emphasis will be placed on achieving the following characteristics for the transponder: (1) long life (up to  $10^5$  hours), (2) high efficiency, and (3) high-reliability, low intermodulation distortion under multi-channel operation.

Emphasis of this work unit has been placed on the development of a dynamic phase lock loop. This task complements the "Multi-Mission Spacecraft Radio Research" task (NASA 125-21-09-05-02-55). This OART task is to devise advanced radio techniques with maximum flexibility to satisfy the requirements of a wide range of future missions.

## AUTOMATIC PHASE CONTROL LOOP INVESTIGATION

Most of JPL's recent theoretical investigations are indicating that data-aided loops show promise for future spacecraft receiver applications. The difficulty is to determine a reliable method of implementing the loop. One proven method investigated during this reporting period was a modified Costas Loop. Research through available literature indicated performance equivalent to the squaring loop. The squaring loop was evaluated during the previous reporting period and found to demonstrate two objectionable traits: (1) it degraded the carrier tracking loop threshold by about 12 dB, and (2) the output of the phase detector exhibited 180-deg phase ambiguity, which could result in data inversion. The phase ambiguity could be corrected, but cycle slipping would be a potential problem and the corrective circuitry would result in additional complexity.

For the current task, the decision was made to stay with a second-order loop and correct its known problems. Through the incorporation of proven state-of-the-art devices and techniques into the second order loop, it is believed that the present advanced transponder design goals can be met and maximum reliability obtained.

#### VOLTAGE-CONTROLLED OSCILLATOR INVESTIGATION

During this reporting period, an improved method of measuring phase jitter was established. The heart of the measurement system is the Quan-Tech model 304T wave analyzer. The analyzer's bandwidth may be set to 1, 10, or 100 Hz; its frequency range is from 1 to 5,000 Hz. The 1-Hz bandwidth position was used for our testing, and phase jitter measurements within a few cycles per second of the carrier were recorded.

The measurement system uses a stable reference oscillator, phase detector, and a 3-Hz ( $2 B_{LO}$ ) loop filter to control the test VCO's frequency. The phase detector output is analyzed and recorded. Quantitative measurements are hampered by the noise of the reference oscillator, but comparative values can be obtained.

Preliminary measurements made on fundamental 19.125-MHz and fifth-overtone 76.5-MHz crystals indicated that they were excessively noisy and were not considered suitable for further measurements. A specification for a third-overtone 76.5-MHz crystal was generated, and three crystals were ordered. The crystals are scheduled to be delivered in August.

The primary reason for investigating the fundamental 19.125-MHz crystal was to allow large-frequency offsets. Information obtained from Motorola indicates that they have a method of pulling a third-overtone crystal 0.025%, which represents a frequency shift of  $\pm 500$  KHz at 2 GHz. A contract with Motorola is scheduled to start on July 6, 1970; their method of pulling a third-overtone crystal will be thoroughly evaluated. No further testing of fundamental crystals is presently planned.

The FET oscillator designed and constructed during the last reporting period was evaluated using the new phase jitter measurement technique. In

the frequency range between 8 and 15 Hz, the FET oscillator demonstrated 20% less noise than the bipolar transistor oscillator when both were operated with the same crystal. Above 17 Hz, there was very little difference between the two oscillators. Since the FET oscillator's design has not yet been optimized to the extent that the bipolar oscillator design has, further improvements can be expected. The FET oscillator is presently being repackaged, after which it will be retested over a frequency range of 3 to 50 Hz.

#### ADVANCED TRANSPONDER STUDY CONTRACT

During this reporting period, a contract to assist in the development of an advanced transponder was issued to Motorola. The total price of the contract was \$89,300, with \$5,000 being supplied by this work unit. Since major funding was obtained from NASA Work Unit 125-21-09-05-02-55, the contract is covered in detail in the report for that work unit.

A basic transponder (complete in itself) will be developed with adaptive tracking loops for multi-purpose application. The transponder will be designed with monolithic ICs which will undergo extensive qualification at JPL.

High-accuracy ranging and angle tracking electronics functions, which will not be required for all missions, are to be designed into separable units, thus reducing the cost and increasing the reliability for missions not requiring the additional hardware.

The design goal for the receiver is reliable operation for  $10^5$  hours. A high-reliability, high-efficiency, dynamic phase lock loop with maximum flexibility and low intermodulation distortion under multi-channel operation will be investigated during the contract.

#### IMPLEMENTATION OF COMPUTER-AIDED CIRCUIT DESIGN

Since reliability is one of the prime objectives of this study, all transponder circuits will be thoroughly analyzed and optimized by the most useful computer programs available. During this reporting period, the Electronic Circuit Analysis Program (ECAP) and two new circuit design programs - Performance Analysis of Electrical Networks (PANE) and Diminishing Error Method for Optimization of Networks (DEMON) - have been used on in-house design problems.

Because of the emphasis on reliability in our designs, a search for a way to incorporate a Monte Carlo analysis into the ECAP program was made. The IBM Corporation provided JPL with the PANE program which will perform a 10,000-case Monte Carlo analysis of an arbitrary circuit or set of equations in addition to a regular ECAP-type circuit analysis.

#### PUBLICATIONS

None.

TDRSN SIGNAL DESIGN AND TELECOMMUNICATIONS  
SYSTEM ANALYSIS

NASA Work Unit 164-21-12-03

JPL 362-10501-1-3390

C. E. Gilchrist

## OBJECTIVE

The objective of this work unit is to accomplish signal design, telecommunication system analysis, and system demonstrations to meet certain difficult functional requirements of a Tracking Data Relay Satellite Network (TDRSN) anticipated for a program start in FY 1971 or 1972.

## PROGRESS

Analysis has now been completed in:

- (1) Effects of various types of bandpass and band reject filters on transponder correlation functions.
- (2) Search and acquisition times.
- (3) Generalized analysis of spread spectrum techniques.

From the range of parameters expected in the TDRSN system, it has generally been concluded that the effects of bandpass and band reject filters will not cause major difficulties. Additionally, synthesis of search and acquisition techniques has been made which is expected to be superior to that in the original proposal and more nearly satisfies system constraints. The generalized analysis of spread spectrum techniques has served to convincingly prove that spread spectrum techniques are the optimum TDRSN system choice.

Construction of the first model as outlined in the proposal was complete and testing had begun at the time of the last report. The results of the tests revealed RF leakage problems that prevented the system from performing as expected. Considerable effort has been required to reduce these leakage problems which has caused a one month delay in the system demonstration.

Tests utilizing hard wired pseudo-noise and clock synchronization have indicated a RF phase lock sensitivity near the predicted level. The leakage problem has apparently been solved.

Measurements of autocorrelation and cross-correlation functions of the system have been made. To obtain the desired functions required compensations for expected system delays caused by the RF bandpass filtering. Additional circuitry has been constructed for these delay compensations and to facilitate more complete testing. Search and acquisition has been accomplished for both the RF and code loops; however, careful measurements have not been made of sensitivity and acquisition times.

As previously stated, synthesis of an alternate search and acquisition technique has been made that is expected to be superior to the original proposal. This system utilizes integer-related frequencies for the RF VCO and the pseudo-noise clock. Not only does this reduce the time jitter in the pseudo-noise loop, but also it facilitates search algorithms, constructed from digital hardware, which are much more predictable and should achieve faster acquisitions than the original system. Procurement delays for a digital logic designer (Tam Research Associates) caused a 5-week delay of the hardware parts definition. Acquisition of hardware is in the immediate offing, and demonstration of the system utilizing this method should be accomplished by September.

## FUTURE PLANS

A delay of the demonstration by 2 months is required by the problems outlined above. At this writing, the polarization diversity combiner discussed in the previous report is not expected to be part of this demonstration; however, work will continue on this system as soon as the acquisition system has been adequately tested.

## PUBLICATIONS

### JPL Publications

1. Horttor, R. L., "Cyclic Search Algorithms for Synchronizing Maximal Length Shift Register Sequences," SPS 37-63, vol. III, 1970.

## GEODETIC SATELLITE SYSTEMS ANALYSIS

NASA Work Unit 164-43-01-01

JPL 362-30101-0-3910

J. P. Brenkle  
D. W. Trask

## OBJECTIVE

The objectives of the Geodetic Satellite Systems Analysis task are to: (1) apply deep space lunar and planetary program tracking data analysis and navigation technology to the National Geodetic Satellite Program and (2) apply geodetic satellite technology to deep space planetary orbiter missions.

## STATION LOCATION COMPARISONS

The postflight analysis of the DSN tracking data for the Mariner VI and VII spacecraft has been completed by N. A. Mottinger, and improved DSN station locations have been established. Initial efforts to remove the tropospheric, ionospheric, and interplanetary charged-particle effects have improved the DSN and SAO station location comparisons. The comparisons are within the stated station location uncertainties except for an approximate 21-m longitude bias. This bias continues to confuse the comparison between the DSN station locations determined from deep space mission tracking data and geodetic satellite tracking data. Methods of resolving this discrepancy under consideration include:

- (1) Very Long Baseline Interferometry tracking of distant radio sources. This technique would remove the planetary ephemeris from the intercomparison and brings in questions related to star and radio source catalogues.
- (2) Lunar laser corner reflector tracking analysis. This technique includes the JPL lunar ephemeris in the system but also raises questions concerning the geodetic survey of the laser telescopes and the geodetic tie between the telescope, DSN stations, and SAO stations.

- (3) DSN tracking of the GEOS C satellite. The technical feasibility and schedule implications of this are being investigated.

#### VERY LONG BASELINE INTERFEROMETRY

Very Long Baseline Interferometry (VLBI) is being studied for its capability to determine geophysical parameters. The ability to measure changes in UT1, polar motion, and the orientation of the Earth's spin axis has been considered. VLBI should be able to measure these quantities in the near future as accurately as the existing systems. The use of near-zero declination radio sources with well known positions will strengthen the solution for geophysical parameters when the solution is heavily dependent upon phase data (see Refs. 2 and 3).

A catalogue of about 150 known or suspected small-diameter radio sources has been compiled for VLBI use.

The future of VLBI promises a technique of measuring earth tides and continental drift. If hydrogen masers become available as frequency standards, the major error source will be the atmosphere and ionosphere. Various calibration or modeling schemes to remove these errors will be considered.

A computer program is under construction that will allow the determination of these geophysical parameters along with baseline coordinates, radio source positions, and clock errors. The program will also do error analysis.

This analysis and programming will continue. When the computer program is completed, realistic error analysis will be performed. Plans are being made to perform a VLBI experiment in the fall of 1970. If the experiment yields data, the data will be analyzed with this program.

Plans for a cooperative experiment involving SAO, MIT, Caltech and JPL are being developed to demonstrate the geophysical application of VLBI.

#### EARTH PARAMETER DETERMINATION

The previously published results from the Earth Parameter Determination subtask that G. Pease completed with regard to the GM Earth studies are being

used by C. Thornton in the Satellite Orbit Determination Accuracy Study. It seems that the limiting parameters for the satellite orbit determination accuracy results are the uncertainty in GM Earth followed closely by the other Earth gravitational parameter uncertainties. Therefore, the uncertainty to which the altitude of a satellite can be determined is controlled by the uncertainty in the earth's gravity field model.

Modifications have been completed to the Multiple Link Satellite Program by D. Green to be able to process laser interferometric tracking data. The laser interferometer is being developed by the JPL Telecommunications Division, and as part of the Earth Parameter Determination subtask; analysis is being initiated to determine the usefulness and optimum design of the laser interferometric system for precision orbit determination and geophysical parameter determination.

Analyses will be started soon by G. Pease to determine the potential usefulness of laser interferometric tracking data. These analyses will complement and check the results being obtained in the Satellite Altimetry Data Analysis subtask.

#### SATELLITE ALTIMETRY DATA ANALYSIS

An initial satellite orbit-determination accuracy analysis has been started by C. Thornton to determine the accuracy to which DSN tracking data can be used to determine the GEOS C orbit altitude. Preliminary results from this analysis indicate that the orbit determination accuracy may be of the same order of magnitude as the altimetry data uncertainties. The study is also being expanded to include the orbit-determination accuracy obtainable from MSFN USB stations. Publication of these study results will be started shortly.

After these preliminary studies are completed, the studies will be expanded to include the usefulness of other tracking data types such as C-band radar ranging and laser ranging, optical angle data, and laser interferometric angular rate data.

## SATELLITE-TO-SATELLITE TRACKING DATA ANALYSIS

The geophysical usefulness of synchronous satellite tracking of a drag-free geodetic satellite has been under investigation at JPL by P. Gottlieb and A. Khatib. Simulations indicate that satellite-to-satellite tracking will be able to distinguish between the acceleration profiles obtained from different Earth gravitational models (see Ref. 4). This effort is a natural outgrowth of the Lunar Orbiter tracking data analysis which has led to the lunar mascon discoveries.

## TRAJECTORY PROGRAM DEVELOPMENT

To prepare JPL for real-world altimetry and satellite-to-satellite tracking data analysis, a considerable effort is being made to update the JPL double-precision trajectory and orbit-determination program for this analysis. The following program additions are being made to DPTRAJ, the double-precision trajectory program:

- (1) Spherical harmonic model is being incorporated in the program for the Earth. This will allow more realistic simulations of synchronous satellite-to-geodetic satellite tracking data analysis.
- (2) Harmonic coefficients are being expanded.
- (3) Point mass and disc mascon models are being added to the gravity field model.
- (4) Drag and lift aerodynamic force models are being added to the program (see Ref. 5).

In the future, it is expected that some changes will have to be added to the DPODP, the double-precision orbit-determination program. These may include:

- (1) Use of altimetry data as a measurement type.
- (2) Use of satellite-to-satellite tracking data types.
- (3) Use of other earth-based geodetic satellite tracking data types.
- (4) Solving for atmosphere density and/or satellite ballistic coefficient.

## CARTOGRAPHY

A combined effort has been initiated by S. N. Mohan to use the TV pictures from planetary orbiter missions (i.e., Mariner Mars 1971 and Viking 1975) to fulfill three objectives. The objectives are:

- (1) To use the landmarks common to two or more TV pictures to determine the direction of the Martian polar axis in inertial space.
- (2) To use the TV pictures and orbit-determination results from Mariner Mars 1971 and Viking 1975 to establish control points on the Martian surface for cartographic purposes.
- (3) To use TV pictures of known and unknown landmarks for satellite orbit-determination improvement.

Only the second objective is being partially supported by the Geodetic Satellite Systems Analysis Task. The other objectives are being supported by the Mariner Mars 1971 and Viking 1975 Celestial Mechanics Experiments and satellite navigation research and development tasks.

This task is a continuation of the work initiated under the sponsorship of the Mariner Mars 1969 Cartographic Working Group. Support of this work by the Geodetic Satellite Systems Analysis Task has just begun and no results have been published to date.

## TECHNOLOGY EXCHANGE

At the symposium on VLBI at Charlottesville, Va., held on April 13-16, 1970, P. F. MacDoran and D. W. Trask gave a paper entitled "Very Long Baseline Interferometry: Implications for Deep Space Navigation." This paper dealt with the impact of VLBI on high-precision determinations of Earth platform parameters such as UT1, polar motion, and station locations and indicated its effects on interplanetary navigation.

## REFERENCES

1. Mottinger, N. A., "Status of DSS Location Solutions for Deep Space Probe Missions: Comparison With the SAO Standard Earth 1969 Station Locations", Space Programs Summary 37-62, vol. II, pp 41-45, March 1970.
2. Williams, J. G., "Very Long Baseline Interferometry and Its Sensitivity to Geophysical Astronomical Effects", Space Programs Summary 37-62, vol. II, pp 49-55, March 1970.
3. Callahan, P. S., "Very Long Baseline Interferometry - Expected Correlation from a Finite Bandpass", JPL Section 391 Technical Memorandum No. 87, 8 April 1970.
4. Gottlieb, P., Khatib, A. R., Muller, P. M., Wimberley, R. N., "Geodetic Use of a Tracking Satellite", JPL Section 391 Technical Memorandum No. 93, 23 April 1970.
5. Khatib, A. R. and Brenkle, J. P., "Consideration of Upper Atmospheric and Aerodynamic Force Models for DPTRAJ", JPL Technical Memorandum 392-25, 3 February 1970.

## MEETINGS ATTENDED

1. NASA Headquarters Review of Geonautics Work on Earth Physics and Physical Oceanography Program Studies, January 28-30, 1970.
2. NASA Headquarters Review at GSFC of VLBI Program for FY 1971, June 3-5, 1970.
3. NASA Headquarters Review at GSFC of GEOS II and GEOS C Missions, June 22-24, 1970.
4. NASA Headquarters AAFE Proposal Review at GSFC, June 24-26, 1970.

## PUBLICATIONS

JPL Publications

1. Mottinger, N. A., "Status of DSS Location Solutions for Deep Space Probe Missions: Comparisons With the SAO Standard Earth 1969 Station Locations", JPL SPS 37-62, vol. II, pp 41-45, March 1970.
2. Williams, J. G., "Very Long Baseline Interferometry and its Sensitivity to Geophysical Astronomical Effects", JPL SPS 37-62, vol. II, pp 49-55, March 1970.

## LASER INTERFEROMETRIC SYSTEMS DEVELOPMENT

NASA Work Unit 164-43-05-01

JPL 362-30201-0-3330

M. S. Shumate

## OBJECTIVE

The main objective of this task is the investigation of precision satellite tracking techniques that operate at optical wavelengths. Careful orbit determination from precision tracking of earth satellites should produce large quantities of information with sufficient accuracy to allow several interesting accomplishments in the field of geodesy:

- (1) Location of tracking stations with fractional meter errors, thus permitting determination of continental drift, earth rotation anomalies, etc.
- (2) Determination of earth's gravitational constant and higher tesseral harmonics.
- (3) Determination of earth strain phenomena between widely separated points, possibly permitting earthquake prediction.

In addition, such precision tracking would permit determination of the orbital parameters of synchronous satellites to sufficient accuracy to allow tracking of low earth orbit satellites from synchronous altitudes.

The approach chosen is the study of the carbon dioxide laser, operating in the 10- $\mu$ m region of the infrared spectrum, as a basis for tracking systems that take advantage of the high coherence of such lasers. The system would consist of a transportable ground station made up of a 200-W carbon dioxide laser transmitter and a pair of carbon dioxide heterodyne receivers mounted 100-300m apart and operated coherently with each other as a double-aperture interferometer. The station would track a geostationary satellite that carries a passive retroreflector.

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## STATUS SUMMARY

The first series of tests on a laboratory carbon dioxide laser heterodyne receiver have been finished. The receiver was tested for its ability to detect low-level signals from a non-laser source, in this case a warm black body. (Ref. 1)

The receiver consisted of a liquid helium-cooled, copper-doped germanium detector; a Sylvania Model 948 carbon dioxide laser; and appropriate beam-splitting optics. The local oscillator beam was focused onto the detector through a beam-expanding telescope which permitted adjustment of the local oscillator beam angle. The detector was mounted in a dewar along with a cooled pre-amplifier to improve the system frequency response. The electronic portion of the system consisted of an 0.5-MHz bandwidth IF amplifier, a spectrum analyzer, and a synchronous demodulator.

The receiver was tested using a heated black body as a signal source. The purpose of the tests was to determine the receiver's performance compared to a theoretical quantum noise limited receiver. The results indicate that the receiver was operating within 2.1 dB of the quantum noise limit, and was able to detect a 100°K temperature difference with a signal-to-noise ratio of unity.

The receiver is now being rebuilt in a form that will permit it to be used at the focus of JPL's 24-in. telescope at Table Mountain Observatory. An additional carbon dioxide laser has been procured, and a new dewar/preamplifier system is being designed.

The stability, spectral purity, and power output signature of the Sylvania Model 948 carbon dioxide laser was also investigated. The results indicate that more accurate temperature control will be required to improve the stability; that the spectral purity is adequate (that is, it does not oscillate on more than one rotational order at one time); and that special techniques may be necessary to maintain oscillation on one specific rotational order.

The infrared atmospheric turbulence study is being continued with the aid of James Westphal of the California Institute of Technology's Planetary Science Dept. The data taken during the first six months of FY'70 has been reduced, with the results indicating that there is a good correlation of large-scale effects between the visible and infrared "seeing", but there are small-scale effects that are uncorrelated. Another series of measurements was performed on the 5-Hale telescope at Mt. Palomar in May 1970, with a total of six hours of data collected. For the first time, data has been taken using apertures smaller than 5m, in order to make an approximate determination of the atmospheric coherence diameter at a wavelength of 10  $\mu\text{m}$ . Preliminary inspection of the unreduced data indicates that, during the particular time the data was taken, the coherence diameter exceeded 2.5m. Complete reduction of the data is now under way.

The basic system concept for the infrared interferometric precision tracking system calls for a retroreflector to be installed on a synchronous spacecraft. Since the retroreflector must function best at the carbon dioxide laser wavelengths, and since there are currently no such devices that are space-qualified, we submitted an Advanced Applications Flight Experiment Proposal (Ref. 2) for funding consideration in March.

#### PLANNED ACTIVITIES

During the next reporting period, a detailed error analysis of the infrared double-aperture interferometer will be completed, with an emphasis on determination of the optimum method for counting fringes in the presence of atmospheric turbulence noise. The frequency stability of our commercial carbon dioxide lasers will be studied, including techniques for phase locking them together. Various detector/preamp combinations will be tested, and new detector mounting schemes will be tried. If our AAFE proposal is accepted, procurement action will be initiated for an outside study contract for appropriate space qualifiable infrared retroreflector designs. Another series of infrared seeing measurements will be undertaken at Mt. Palomar, timed to coincide with the usual late summer wind conditions, in the hope of obtaining data during periods of high atmospheric turbulence.

REFERENCES

1. Finnie, C., "10.6 Micron Heterodyne Radiometer," JPL SPS 37-61, vol. III.
2. Shumate, M. S., "Infrared Retroreflector for Geostationary Satellites," AAFE Proposal Submitted by JPL on March 26, 1970.

PUBLICATIONS

None.

## SYNCHRONOUS ORBIT PROPULSION SYSTEMS

NASA Work Unit 164-76-01-02

JPL 362-60201-0-3810

R. L. Bailey

## OBJECTIVE

The objective of this work unit is to investigate solid-propellant motor component areas where performance can be increased and the total motor optimized by the incorporation of advanced composite materials and processes. The current major task is the evaluation of boron composite materials fabricated into motor cases.

## PRESENT STATUS

During this report period, evaluation of contractor proposals submitted in response to the RFP for the fabrication of boron-epoxy cases was completed. Based on technical discussion with selected proposers and the amount of funds available for the contract, Martin-Denver was selected. A CPFF R/D Contract No. 952841 was negotiated with Martin-Denver for a cost of \$22,920. Martin will conduct a development program which will result in the production of three motor cases. During this program, Martin has evaluated the adhesive and its placement, evaluated the fabricability of the vessel, and critiqued the vessel design. The boron-epoxy tape was received by JPL, inspected to assure conformance to the specification, and shipped to Martin-Denver.

The forward and aft metal flange fittings originally designed for maraging steel were redesigned for titanium. The cross-sectional configuration of both flanges was changed to a conic shape and the throat thickness of the aft flange was increased.

The design critique by Martin of the JPL chamber design recommended that a different shape be designed in order to meet the motor performance requirements. Therefore, the computer analysis program was utilized to redesign the case. The new design does not change the original overall length

nor the maximum diameter. However, the shape of the contoured ends changed from a 2:1 to a 3:2 ellipse. The resulting volume is still approximately the same as the original. Also, one extra wrap of material (2 layers) would be required; this increases the weight of the original design (20.2 lb) to 24.4 lb, which is close to the weight of ATS titanium chamber. However, it is believed that the extra wrap is conservative, although it does permit less strain than the ATS chamber. This will be verified when the design is checked by bursting the first case. The second case will be designed based on these results and should result in a lighter weight chamber.

The delivery schedule has slipped because of the redesign of the metal parts and the chamber configuration. Martin-Denver has been supplied the new chamber dimensions and is fabricating the wrapping mandrel. The first chamber is now scheduled for delivery during the first part of August.

#### FUTURE STATUS

A Research and Technology Objective Plan Resume (RTOP) has been submitted for FY'71 to cover the testing of the three boron filament composite cases, and the design of the graphite filament composite case. A test plan will be written for the testing of the three boron filament composite cases, and the design of the graphite filament composite case. A test plan will be written for the testing of the three boron composite cases. It is planned to pressure-test the first chamber in August 1970.

#### PUBLICATIONS

##### Meeting and Symposia Papers

1. Knoell, A. C., and Mullin, J., "Basic Concepts in Composite Beam Testing," presented at SPI Advanced Composites Division Meeting at Washington, D. C., Feb. 1970.

## SATELLITE ADVANCED THRUSTING SYSTEMS

NASA Work Unit 164-76-01-03

JPL 362-60301-0-3840

P. I. Moynihan

## OBJECTIVES

The two specific efforts that were performed under this work unit during this report period were: (1) an in-depth mission-oriented attitude and station-keeping thruster tradeoff techniques study, and (2) a liquid hydrazine thruster technology investigation for thrusts in the range of 0.05 to 0.10 lbf.

## STATUS

The preliminary final report on the mission-oriented thruster tradeoff study was completed and submitted to the NASA 164 office for comment and approval. This study was an attempt to define thruster tradeoff criteria for spacecraft attitude and station keeping and to establish a common parameter from which meaningful evaluations can be determined within the limits of specific missions. The parameter selected as the baseline was "cost-effectiveness", defined as a function of mission value (or worth), mission probability of success, and total mission cost. These three basic functions were further expressed in terms of more specific parameters such as mass, reliability, specific impulse, and power requirements. This technique presents a means whereby uniquely different thruster concepts can be directly compared (e.g., liquid hydrazine vs subliming solid).

Three specific missions were selected as examples for study: (1) an outer planet probe (e.g., TOPS), (2) a synchronous satellite (e.g., ATS, Intelsat), and (3) an earth resources satellite (e.g., OGO, Nimbus). Since the result of any thruster tradeoff study is unique to the specific mission requirements, these three were chosen to demonstrate application of the tradeoff technique and to indicate how the results may differ as the missions differ.

The technology investigation of liquid hydrazine catalytic thrusters in the range of 0.05 lbf precipitated from the general high ranking of these thrusters in the tradeoff study, with specific application to missions utilizing thrusters to unload momentum exchange devices (e. g., momentum wheels) and for station keeping.

Two 0.1 lbf liquid hydrazine thrusters were purchased for evaluation. The results from this and other on-going in-house work units will feed back into the study activity and aid in refining the results.

#### PLANNED ACTIVITIES

The tradeoff study will be published as a JPL technical memorandum as soon as the critique on the preliminary final report is received from the 164 office. An extension to this study to include electric thrusters is planned for next fiscal year. Updating of the report will be an on-going activity.

#### PUBLICATIONS

None.

701-90

## SOLID PROPELLANT UPPER STAGE ADVANCED STUDY

NASA Work Unit 180-06-01-01

JPL 380-60101-0-3810

J. W. Behm

*Handwritten:* 180-06-01-01-40

### OBJECTIVE

The objective of this work unit is to identify future JPL missions which will require the addition of new high-energy upper stages to existing launch vehicles. Attention will be focused on solid rocket stage performance, including the new NASA HEUS beryllium stop-start technology motor.

### STATUS

Mission studies performed at JPL have indicated a need for the development of a new high-energy upper stage to meet future missions using a Titan/Centaur class of launch vehicle. Injection energies range from 90 to 140 km<sup>2</sup>/sec<sup>2</sup> which cover the range of JPL interest; injection weights vary from 1300 to 4000 lb. These missions include Jupiter Orbiter, TOPS, and the Saturn Orbiter.

Titan/Centaur class launch vehicle performance estimates have been made in combination with a wide spectrum of synthesized liquid and solid upper stages. These studies were sufficient to establish optimum gross sizing and mission flexibility characteristics. The family of solid stage configurations considered indicated excellent mission flexibility (optimum payload capability for a fixed stage size) over the energy range noted. The HEUS beryllium stage was characterized by a delivered specific impulse ( $I_s$ ) of 326 sec and an assumed stage propellant mass fraction (SPMF) of 0.88. The resultant optimum stage weight was approximately 3800 lb.

Preliminary results were iterated to confirm performance capabilities. Results of these studies were prepared for use by OART for OSSA presentations. A number of different upper stage configurations were found to be capable of meeting both the Jupiter Orbiter and a TOPS type missions. No launch vehicle

in combination with an upper stage was found to be capable of performing a maximum Saturn Orbiter; however, several higher performing upper stage designs can accommodate minimum or intermediate Saturn missions. The beryllium solid motor appears capable of fulfilling a minimum Saturn mission and would be cost effective relative to developing more expensive liquid stages.

Results of the study were abstracted and included in a joint contractor/JPL technical status paper of the restartable beryllium solid propellant high-energy upper-stage (HEUS-RS) demonstration test program.

## PUBLICATIONS

### Meeting and Symposia Papers

1. Bogart, W., Whetherell, R., and Behm, J., "Development of a High Energy Upper Stage Solid Propellant Rocket Motor with Extinguishment Capability" (Confidential); for 26th JANNAF Solid Propulsion Meeting, July 1970, Washington, D. C.

## ELECTRO-EXPLOSIVE TEST TECHNIQUES

NASA Work Unit 180-24-03-01

JPL 380-40101-0-3810

V. J. Menichelli

## OBJECTIVE

The objectives of this work unit are to develop theory, application technology, and instrumentation for the testing of explosive devices. Nondestructive testing is stressed.

## STATUS AND ANTICIPATED ACTIVITIES

It was previously reported that three nondestructive test techniques used in the evaluation of the bridgewire and bridgewire/explosive interface of electro-explosive devices were developed. Since then, these techniques have been applied to commercial electro-explosive devices. Approximately 10% of the devices studies gave evidence of abnormal responses to the tests.

Of the three techniques used to evaluate the electro-explosive devices, the "transient pulse" test was the most sensitive and yielded the most information. This test consists of introducing a constant current pulse of low magnitude (approximately 0.4 amp) into the bridgewire of the device. The temperature coefficient of resistivity (TCR) of the bridgewire material allows a heating curve to be displayed on an oscilloscope as a change in resistance. From the display and the associated measurements, it is possible to calculate the cold resistance of the bridgewire, the thermal time constant, and the heat loss factor.

In the investigation of the causes of the device abnormalities, the "transient pulse" test technique was used exclusively. The prevalent observed abnormality was a deviation from a smooth exponential heating curve to a heating curve containing an irregular rise and/or a sharp nonohmic irregularity. It is believed that those nonlinearities occurring a short time after the application of power are thermally induced while those that occur at  $t = 0$  are voltage sensitive. The voltage sensitivity is quite likely caused by products such as oxides at the bridgewire weld interface. Several devices exhibiting voltage

sensitive heating curves were carefully dissected and found to contain very poor bridgewire welds. The mechanism of the thermally induced nonlinearities are believed caused by poor intimacy of contact between the bridgewire and explosive. A partial confirmation of this theory has been demonstrated by observing, through a special glass fixture, the behavior of a bridgewire being pulsed by constant current. The effect was that as the bridgewire heats it grows in length due to the thermal coefficient of expansion of the wire and moves with respect to the header. If the posts are rigid, the bridgewire moves with respect to the explosive, creating an unstable interface between the header, bridgewire, and explosive. It was noted that as the loading pressure of the powder is increased, this effect of thermal expansion movement is reduced. Although it would appear that this laboratory test has artificially induced or generated this problem, ordinary thermal cycling can result in similar effects.

Future efforts will be directed toward further understanding the causes resulting in abnormal heating curves. When the causes and their effects are understood, corrective action can be taken to eliminate the deficiency in the squib design. The results of this study will lead to improved design criteria for future generations of squibs.

## PUBLICATIONS

### JPL Publications

1. Rosenthal, L. A., and Menichelli, V. J., "Nondestructive Testing of Insensitive Electro-explosive Devices by Transient Techniques," JPL Technical Report 32-1494, 1970.

SPACECRAFT PROPULSION SYSTEM  
FOR TEN-YEAR MISSIONS

NASA Work Unit 180-31-01-03

JPL 380-10401-0-3840

H. R. Long

## OBJECTIVE

This work unit provides for the determination of the requirements for a trajectory-correction propulsion system capable of multiple firings during a long-duration (one decade) mission, and, based upon the results of a comparative analysis of candidate systems, to design, fabricate, and test a prototype system to demonstrate feasibility and discover any unforeseen system or environmental interactions. The technology evolving from this work unit directly supports the development of the Thermoelectric Outer Planet Spacecraft (TOPS).

## PROGRESS

As previously reported, a monopropellant hydrazine blowdown system was selected for the TOPS trajectory-correction propulsion subsystem. The essential aspects of the propulsion performance specification for TOPS-type missions are multiple firings (5 to 10) and long cumulative firing times (500 to 1500 sec) spread over a 10-year mission. Industry-wide surveys of existing rocket engines, solenoid valves, and squib valves for the TOPS application were made to assess the availability of the required technology for the 70s missions. Several promising engines were identified in the survey for purchase and evaluation in early FY'71. Existing solenoid valves do not appear designed for long-term hydrazine exposure; modification of the existing designs using new materials and fabrication techniques or new designs are required. The explosive valve survey evaluation is not complete.

Exploratory tests with readily available engines in the 25 lbf-thrust class have illuminated several potential problems which will be carefully assessed next fiscal year. First, propellant "washout" of the decomposition reaction in the catalyst bed was observed with propellant that was colder and contained

more water than usual. Second, the upper life limit of 1500 sec could not be met by a borrowed Transtage engine originally built for pulse-mode operation which had undergone 400 sec of pulse testing prior to the TOPS life test. Finally, the higher performance hydrazine mix of 76%  $N_2H_4$ /24%  $N_2H_5NO_3$  severely degraded the commonly used Shell 405 catalyst by virtue of its much higher reaction temperature.

Broader technology areas that affect all components are being studied to provide direction and emphasis for on-going research. The areas of most importance are propellant/material compatibility and RTG and Jovian radiation effects. The feasibility of advanced hydrazine-based monopropellants, such as blends with hydrazine nitrate or hydrazine azide, will be greatly influenced by this work.

The propulsion system baseline configuration selected during the first half of FY'70 has guided the TOPS component and system technology work. Extensive reliability/mass tradeoff studies were conducted to determine the optimum final configuration. Two important conclusions were drawn. First, 10-year reliability studies of propulsion systems are not possible at this time because the failure rate as a function of time is unknown for most components. Therefore, our reliability studies were based on short-term experimental data assuming the results provided a valid relative ranking of competing configurations. There was no significant difference in mass or reliability between the quite different competing configurations, so the baseline configuration has been retained.

The interfaces between the TOPS trajectory-correction propulsion subsystem and the attitude propulsion, pyrotechnic, control computer, measurement processor, and power subsystems have been established through active participation on the TOPS design team. These interface definitions provide the operating environment of the propulsion system which is important in system design. Technical conferences held with industry teams responsible for Intelsat III (5-year design life), Intelsat IV (7-year design life), and Pioneers F&G (Jupiter flyby craft) have contributed to our technology assessment, system optimization, and system design efforts.

## PLANS

Component procurement will be initiated for key components such as the rocket engine, valves, and filters for component-level evaluation and then system-level tests. Where component-level evaluation shows a weakness, modifications in the system-level test components will be sought if funds permit. Other components such as tanks and fill valves will be borrowed or purchased "off-the-shelf".

The detailed design of the propulsion system will be completed early next fiscal year. A full-scale model will be constructed to demonstrate the design and illustrate interface connections with the rest of the TOPS subsystems.

## ANTICIPATED PUBLICATIONS

Journal Articles

1. Baughman, L. E., "Spacecraft Propulsion System," to be published in Astronautics and Aeronautics as part of the August 1970 issue devoted to TOPS.

## PUBLICATIONS

None.

701-90

## HIGH-THRUST, THROTTLEABLE HYDRAZINE ENGINES

NASA Work Unit 180-31-07-01

JPL 380-10301-0-3840

T. W. Price

### OBJECTIVE

The overall goal of this work unit is to advance the technology of high-thrust, throttleable monopropellant reactors. Specific objectives include the design, fabrication, and testing of two reactor designs and the evaluation of several electromechanical throttle valves.

### APPROACH

Several mission studies have recommended the use of monopropellant hydrazine reactors. Throttleable, high-thrust (300 to 1000 lbf) reactors are particularly attractive for planetary lander missions, and in fact such devices have been selected for use on the Viking Mars lander. The general technology areas of high thrust and throttling of hydrazine reactors are being explored by means of a simultaneous in-house program and a contracted effort.

### PROGRESS

All competitors, including the winner (TRW), bid higher than the planned amount. The total cost of the TRW contract, even after negotiation, was greater than originally planned. In order to meet these increased costs, the in-house program was reduced in scope during this reporting period and no testing beyond that reported previously was performed. The principal activity this period has been management of the TRW contract, planning for the FY'71 program, and analysis of the data already gathered. The last item has been pursued at a low level of effort but is nearly complete and will be reported soon in the JPL Space Programs Summary.

Because of the greater than planned costs mentioned earlier, the scope of the TRW contract also was reduced during this period, but most of the program

has been completed as originally planned. The major omissions were vacuum testing and life testing of the thrust chamber. A more detailed discussion of the contract status is given in the paragraphs that follow.

As reported earlier, TRW was instructed to procure two throttle valves; one from Ling-Temco-Vought (LTV) and one from Moog. Both valves were to be of similar design and were to use a linear displacement pintle linked to a 28-VDC electromechanical actuator by a ballscrew transmission assembly. A comparison of these two valves would result in data directly applicable to the Viking lander. However, Moog could not deliver hardware in a timely manner because of the long lead time required for the ballscrew. Therefore, it was decided to buy from Moog a radically different design which, while in the early stages of development, showed promise of a significantly smaller response time as compared to the ballscrew concept.

The LTV valve was received on schedule and has been bench tested, sterilized, and used for all tests of the engine. The valve purchased was slightly different from the basic LTV design in that a soft bellows was incorporated. The bellows protects the actuator motor both from exposure to hydrazine and from any loss of lubrication that could result from extended exposure to a space environment. The valve met all requirements (except a linearity requirement) and in particular exhibited a response time of 60 ms (65 ms was the requirement).

The Moog valve is significantly different in concept from the LTV design. Flow is metered by a vane that operates directly off of the motor shaft and, hence, the motion of the metering component is rotary as opposed to linear. The vane covers or uncovers a shaped slot in a sleeve in order to throttle the fuel flow. In addition to better response (see next paragraph), this design also offers the advantages of reduced pressure losses and the elimination of all dynamic seals. The latter is achieved by submerging the rotary torque motor and the position indication device directly in hydrazine.

The rotary valve has been fabricated, but could not be delivered in time for engine testing. However, the valve was bench tested at Moog (tests witnessed by TRW personnel), met all requirements (again, except for the linearity requirement), and exhibited an excellent response time of 35 ms. Moog

has elected to rework the valve metering slot so as to eliminate the nonlinearity and will deliver the valve directly to JPL for further testing during FY'71.

As reported earlier, an engine design had been approved by JPL. Some of the more pertinent features of the design include an elliptically shaped chamber, a conical thermal barrier, use of a TZM catalyst support plate, and a single element, 91 orifice injector. The engine was fabricated and assembled without incident. During the initial checkout firings, however, an unstable decomposition process was discovered. The instability was characterized by a  $\pm 25\%$  variation in chamber pressure at a frequency of  $\sim 15$  Hz. Several short tests then were conducted to eliminate causes such as feed system coupling; but all evidence pointed still to the catalyst bed.

After a review of all the test data it was decided to change the interior catalyst bed design. The unstable design contained a cylinder of 14-18 mesh catalyst which extended the length of the catalyst bed. The area between the cylinder and the chamber wall was filled with  $1/8'' \times 1/8''$  pellets. The new configuration selected was one with which TRW has had more experience although considered marginal with respect to meeting the response requirements. This design contains the fine mesh catalyst between two hemispherical screens and decreased the mass of fine catalyst by about one half. The fine catalyst eliminated was replaced by  $1/8'' \times 1/8''$  pellets.

The engine was opened by machining away the girth weld. The interior of the engine was in excellent condition and the catalyst attrition was nil. The changes noted above were made and the two engine halves were rejoined by an electron beam weld. Subsequent limited testing of this configuration revealed that the instability had been eliminated. Because of the cost problems noted earlier, the 300 sec combined life and dynamic response test was eliminated, but enough sea level testing, including some dynamic throttling was accomplished to verify that the engine will meet the contract response requirements.

#### PROJECTED ACTIONS

Both the TRW and JPL designed engines will be tested further during FY'71. Both throttle valves, but particularly the Moog valve, will undergo

further bench testing at JPL before mating with an engine and will be used for engine tests. After both engines and throttle valves have been characterized, a second in-house engine, incorporating the best features of the previous hardware will be designed, fabricated, and tested.

#### CONTRACTOR PERFORMANCE

The contractor performed in a satisfactory manner during the report period.

#### PUBLICATIONS

##### Meeting and Symposia Papers

1. Kenny, R. J., and Reaves, D. F., "Throttleable Thruster System Design, Fabrication, and Test Verification, "presented at the AIAA 6th Propulsion Joint Specialist Meeting, San Diego, June 17, 1970.

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SOLID PROPELLANT SYSTEMS FOR LONG  
TERM SPACE MISSIONS

NASA Work Unit 180-32-04-01

JPL 380-20201-0-3810

W. L. Dowler

*270-394-05*

OBJECTIVE

The objective of this work unit was to determine, through analysis, the trade off between specific impulse and solid propellant motor mass fraction for propulsion requirements needed for outer planet orbit insertion motors.

STATUS

The funding of \$27K was expended during the first 6 months and thus additional work was not accomplished during this report period. The results of that work formed a portion of the basis for the recommendation and selection of a low acceleration motor containing berylliumized propellant combined with a hydrazine monopropellant vernier engine for the baseline propulsion system in the JPL Jupiter Orbiter study. The results of the solid/mono option will be included in the Jupiter Orbiter design study report.

PUBLICATIONS

None.

## MATRIX TEST OF STERILIZABLE PIECE PARTS

NASA Work Unit 186-58-13-08

JPL 384-80401-0-3540

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 - Phase II (See Tables I, II and III.)

Test results at the completion of 6000 hours of life testing:

Code 1 - Sprague 350D, 39 $\mu$ f, 35V, solid tantalum.

There have been two random catastrophic failures. One failure was in Group AI and one was in Group CL.

The degradation failures by groups are as follows:

	<u>Group</u>	<u>No.</u>	<u>Group</u>	<u>No.</u>	<u>Group</u>	<u>No.</u>
Capacitance:	AF	1	BF	1		
DF:	AC	1	AD	1	AE	2
	AF	2	AJ	2	BJ	1
	CC	1	CF	1	BF	1
	AB	1	BB	1	BG	1
	BI	1	CJ	1		

	<u>Group</u>	<u>No.</u>	<u>Group</u>	<u>No.</u>	<u>Group</u>	<u>No.</u>
Leakage Current:	AA	4	AL	3	AD	2
	AE	1	AF	4	AJ	2
	AK	7	AL	5	BJ	4
	BK	2	BB	3	BC	1
	BD	2	BF	1	CC	2
	CD	3	CE	5	CF	2
	CH	1	CI	3	AG	1
	AB	1	AC	2	BL	1
	CB	1	CJ	1	CL	3

Code 2 - Aerovox V423XP, 1 $\mu$ f, 200V, Mylar

There have been three random catastrophic failures. One failure was in Group AB, one was in Group BB and one was in Group CD.

There was one random DF failure in Group CI. There have been no capacitance or IR failures since the last report.

## CONCLUSIONS

Number of temperature cycles matrix:

Code 1 - There have been no significantly different effects for capacitance or DF.

There were significant differences in leakage currents for the two 15-cycle and two 18-cycle groups (AE, AK, AF and AL) but this is far above the three or four cycles that would be used in actual practice and is not considered pertinent. These higher number of cycle groups were included for engineering information.

Code 2 - There have been no significant differences in capacitance DF or IR.

Rate of temperature change matrix:

There have been no significant parametric differences for Code 1 or Code 2.

**Storage time-temperature matrix:**

There have been no significant parametric differences for Code 1 or Code 2. With the exception of Groups AF and AL, the catastrophic and parametric failures are of a random nature with no significantly different effects within the matrix cells. Within the scope of this test, there is no significant evidence that the number of cycles (below 15), the rate of temperature change, or the length of storage is critical to the sterilization effort.

It must be emphasized that these results and conclusions are based on only 6000 hours of a 10,000 hour test, and, consequently, they are subject to revision during the remainder of the test program.

**PUBLICATIONS**

None.

TABLE I. Number of Temperature Cycles Matrix

(Number of Cycles)

		3	6	9	12	15	18	
36 Hrs at 145°C	AA 30 parts each cell (typical)	AB	AC	AD	AE	AF		Control Group
	92 Hrs at 135°C	AG	AH	AI	AJ	AK	AL	

TABLE II. Rate of Temperature Change Matrix

(Minutes to Reach Temperature)

		120	90	60	30	15	7-1/2	3	
Final Temp	145°C	BA 30 parts each cell (typical)	BB	BC	BD	BE	BF	BG	Control Group
	105°C	BH	BI	BJ	BK	BL	BM	BN	

TABLE III. Storage Time-Temperature Matrix

(Hours Storage)

		36	92	200	300	400	500	
Storage Temp	145°C	CA 30 parts each cell (typical)	CB	CC	CD	CE	CF	Control Group
	135°C	CG	CH	CI	CJ	CK	CL	

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FLIGHT COMPUTERS AND SEQUENCERS ADVANCED DEVELOPMENT

NASA Work Unit 186-68-02-08

JPL 384-63701-0-3610

G. R. Hansen

J. J. Wedel

OBJECTIVE

The long-range objective of this work unit is the development of advanced circuit techniques and computer technology and the evaluation of new computer technologies. This work supports the requirements of technology for the Central Computer Subsystem (CCS), formerly the Central Computer and Sequencer (CC&S), for future planetary spacecraft. Development of low power circuitry and circuitry tolerant to harsh environments contributes to the objectives. The development of circuit design techniques, such as computer-aided analysis programs, also supports the objective.

PROGRESS AND PLANS

During the present fiscal year, work has primarily concerned the technology for the CCS, which is a unit of the Central Data Subsystem (CDS) for the Thermoelectric Outer-Planet Spacecraft (TOPS) project. This computer has a very long required lifetime and limited available power and weight, together with a complex design and functional requirements which include monitoring of other spacecraft subsystems and limited reconfiguration of them in case failures are observed. Work on the computer-aided circuit analysis program (MTRAC), which is the only known program capable of handling magnetic core circuits, has also continued.

MTRAC Program

The MTRAC is now operational on the Scientific Computer Facility at JPL which consists of a UNIVAC 1108 computer. This report will conclude mention of this work. The program is being submitted to COSMIC, but it has caused such interest that several copies of it have been sent to organizations requesting it in advance of the COSMIC submission.

The Stanford Research Institute contract for measuring magnetic core parameters to obtain statistical core data for use in the MTRAC program has been concluded, and average core data has been obtained on a sample of 11 cores. The data obtained agreed quite well with the single core whose measured parameters had previously been used in the MTRAC program.

### TOPS Technology

Because of a reorganization at the Laboratory, the large scale integration (LSI) contract with Radiation, Inc. will be transferred to another work unit and reported in the future under 186-68-56-04.

This contract, which is in three phases, is concerned with the development of a Customized Metallization Multigate Array (CMMA) in which the final layer of metallization for the chip may be varied through use of one of several different masks. The particular mask used determines the connection of the various gates and thus the logical functions performed by the chip.

Phase I was completed on schedule and the results were presented at a design review held at JPL. Certain problem areas resulting from a combination of speed, power, temperature specifications and noise immunity requirements were encountered. Resolution of these problem areas required JPL direction in the form of priority guidelines necessary to effect the engineering trade-off decisions. The JPL review board supplied these guidelines and the problem areas were resolved early in the Phase II effort.

A review board recommendation to subject CMMA test structures to the TOPS radiation environment is being pursued during this period and will be continued into the following period.

Initial layouts of the four types of CMMA devices have been accomplished and the primary purpose of the Phase II effort, the fabrication and test of a number of engineering models, is well under way. In parallel with the development of the CMMA engineering models, a CMMA Product Assurance Plan is being developed and is also proceeding on schedule.

The Phase II effort will be completed with the presentation of the design documentation to a JPL review board(s) on or about 1 November 1970. The Phase III effort, the fabrication and test of a quantity of 400 prototype CMMA devices, is scheduled for completion 1 July 1971.

Testing on the plated wire memory stack is continuing. Owing to resource limitations, it has not been possible to purchase electronics for this stack as indicated in the work unit schedule. The stack does operate satisfactorily and, according to specifications, over the temperature range. Present plans are to use waveforms which are more nearly marginal or outside of the satisfactory range and observe performance. This work will not be continued in FY'71 except to follow industry developments on a cursory basis, unless additional resources can be found.

A problem encountered in the TOPS CDS is the input/output interface structure for connecting the CCS with the other subsystems. The interface should be very reliable, have a long lifetime, and in addition should be relatively unaffected by the failure of a peripheral subsystem it is connecting to the CCS. It should not result in a great proliferation of cables and interconnections. During the reporting period a new magnetically coupled bus has been developed. This device uses magnetic cores for coupling the peripheral subsystems to a coaxial bus structure. A Patent application and a New Technology brief have been filed. Work will continue on this bus with special reference to incorporating the CMMA device as the associated electronics.

The JPL Self-Testing-And-Repairing (STAR) computer is being used as a model for the TOPS CCS as has been mentioned in previous progress reports. It now appears that limitations in funding will necessitate using the STAR breadboard itself for feasibility model testing. This computer is being developed under the 125-23 program and is reported in the -12 RTOP. In FY'71 it will be transferred to the -17 RTOP. The power switch used for connecting (automatically) various redundant functional units of the STAR computer is a vital part of the computer and will be required in any CCS making use of STAR concepts. Thus, it is of interest to the present work unit. The original power switch was developed for the STAR computer by the Stanford Research Institute.

During the present period, three additional designs, all possessing various merits and defects, have been developed. The primary selection criteria are efficiency, failure modes which cause the switch to go "off" rather than "on", and ease of manufacture. Two of the switches are magnetic, and the last criterion chiefly is concerned with the coil winding techniques required. During FY'71 the switch evaluation will be continued and a selection made.

#### TOPS Functional Requirements and Subsystem Design

This work unit has continued support to the TOPS design team and Data Handling design team. Work Unit 186-68-02-17 (Central Processor for Spacecraft Control) also contributes to the CCS for the TOPS. An RTOP entitled Central Data Subsystem for Outer-Planet Missions (186-68-56) has been written which includes these two work units among others and will be applicable to the work in FY'71. The number of the present work unit will change to 186-68-56-02 and the title will be Spacecraft Computer Technology.

#### Central Timer

Initial studies of the TOPS central timer or Frequency Synchronizer (FS) have been made. A redundant oscillator will be used and some experimental work will be done for testing of redundant oscillators with various methods of combining outputs in order to determine the response when an oscillator fails. Following these experiments, work on the FS will be interrupted because of lack of resources until late in FY'71 when the detailed design will be started.

#### PUBLICATIONS

None.

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## CENTRAL PROCESSOR FOR SPACECRAFT CONTROL

NASA Work Unit 186-68-02-17

JPL 384-68501-0-3610

J. J. Wedel

### OBJECTIVE

The objective of this work unit is to increase the effective utilization of the Central Computer Subsystem (CCS), formerly the Central Computer and Sequencer (CC&S), for the spacecraft control functions and to provide designs for implementing present and new uses. Because of the increasing complexity of the traditional sequencing load of the CCS, it has become more and more like a general purpose computer. The work unit objective will permit mission planning teams and detail design teams to fully use these computing and logical capabilities. A central general purpose computer is considered to be necessary to support the long duration and sophisticated missions planned during the late 1970s.

During this reporting period, the work unit has exclusively concentrated on support to the Thermoelectric Outer-Planet Spacecraft (TOPS) project. The CCS, which is a unit of the Central Data Subsystem (CDS) for this project, will monitor various spacecraft subsystems and undertake certain automatic repair actions as well as perform the traditional sequencing and computing functions.

### PROGRESS AND PLANS

Support to the TOPS design team and Data Handling design team has continued along with refinements in the Functional Specifications for the CCS. This work will continue for the next period.

The previous report noted that funding limitations have required that the STAR breadboard being developed under the 125-23-12 RTOP be used in the feasibility model demonstration for the TOPS CDS. No breadboard of a CCS specially designed for the TOPS will be built in FY'71, as had originally been

planned. The STAR computer will be augmented with the shared (two-port) memory which is a common memory for interfacing the STAR and the Measurements Processor (MP).

A major amount of effort has been spent in designing the interface between the CCS and other subsystems. Flow charts of the actions of the CCS in normal circumstances are now available. During FY'71 these interface specifications will be expanded to include actions when the state of the spacecraft is observed to be abnormal, i. e., the monitoring and repair functions. This work has included sizing of the computer memory to perform necessary computations and estimates on timing.

The flow diagrams allow STAR computer programs to be written to implement the various actions to be done by the CCS and some programs have been written. Although this work was to be continued to provide programs for the feasibility model demonstration, it now appears that resource limitations will not permit this to be done during FY'71.

The block diagrams and logic design of a special computer for TOPS using STAR concepts have not been done and will be postponed until FY'71, again due to resource limitations. The interface work described above will permit block diagrams to be developed relatively early in the fiscal year, but actual logic design will be postponed until later and will depend on pressure of other events concerned with the feasibility demonstration.

The shared memory has been completely designed, is being constructed, and will be finished early in FY'71. Construction start was delayed because of lack of parts funds. It will then be integrated with the STAR breadboard as fast as resources permit. A STAR computer program for simulating the MP has been written by personnel associated with that processor, and after the shared memory is operational with the CCS, it will be possible to test the performance of this major part of the CDS with a simulated MP.

Support to the TOPS project in the CCS development is also provided by Work Unit 186-68-02-08 (Flight Computers and Sequencers, A. D.) which is primarily concerned with technology. In the report on that work unit, mention is made of a new bus structure for connecting peripheral subsystems to the CCS. Continuation of the work on the bus will consider its connection to the STAR computer. No work has been done in the present work unit on the STAR I/O unit listed in the Work Unit Schedule. Unless additional resources are found, this unit will not be constructed and the feasibility model interface with other subsystems will be limited to interaction with the MP through the shared memory.

In FY'71 all of the work units supporting the CCS for TOPS, as well as other work, are included in an RTOP entitled Central Data Subsystem for Outer-Planet Missions (186-68-56). The title of the present work unit will change to Spacecraft Central Computer (186-68-56-03).

During FY'71 the work on the shared memory will largely consist of debugging the interface and integrating it with the STAR computer. A new work unit, Shared Memory for STAR Computer (125-23-12-06), has been established under the Advanced Digital Data Systems for Deep Space RTOP (125-23-12) for continuing this work.

#### PUBLICATIONS

None.

## OPTICAL SENSOR TECHNIQUES AND COMPONENTS

NASA Work Unit 186-68-02-19

JPL 384-64601-0-3440

W. C. Goss

## OBJECTIVE

This work unit is for the development of attitude control optical sensor technology and components which are needed for future spacecraft missions. The objectives for the two tasks comprising this work unit in FY'70 were:

- (1) Development of an improved image dissector tube to be used in future attitude control star trackers.
- (2) Identification of the critical mechanization problems of a star tracker for a multiple outer planet mission.
- (3) Measurement and evaluation of the effects on a star tracker of the radiation environment which will exist aboard an RTG-powered spacecraft.

## PROGRESS

The contract initiated with EMR-Photoelectric in Princeton, New Jersey on the development of an advanced image dissector, has progressed through the completion of the Phase I effort. The technical analysis, a detailed drawing set, a Fabrication and Process Plan, an Environmental Test Plan and a Functional Test Plan have been completed and transmitted to JPL for approval. The Phase II effort to fabricate, test, and deliver advanced image dissectors is well under way. First unit delivery is projected for early August 1970. Technical progress on this contract has been very encouraging. A brazed ceramic and stainless steel assembly has evolved utilizing a high temperature-tolerant tri-alkali photocathode and a standard product line focused electron multiplier. The electron optics and electrostatic deflection structure utilized

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in the earlier design image dissector have been incorporated in the new design with some changes to improve characteristics and to simplify fabrication. It appears probable that all the technical requirements and many of the design goals will be met or exceeded.

The contract amount, as awarded, is \$169,332 including fee, and the Statement of Work was written to obtain delivery of four tubes. Action has been taken to reduce a projected overrun by reducing the delivery of tubes to a quantity of two and deleting requirements for certain tests and documentation. An overrun in the amount of \$29,000 is still anticipated and is principally attributable to a change in contractor burden rates.

No effort was expended during this period on the second objective of identifying the critical mechanization problems of an outer planet mission star tracker. An unexpectedly high level of interaction on the image dissector contract was given priority over this objective.

Neutron and gamma irradiation tests have been made to determine the effects of a simulated RTG radiation environment on a Mariner star tracker. Neutron irradiation was performed at the Battelle Northwest facility in Richland, Washington and the gamma irradiation at JPL. Figure 1 tabulates dose rates and total dosage estimated for an RTG-powered spacecraft (TOPS) on a mission to the outer planets and the test values.

Radiation Type	TOPS Estimated Rate	Tested Rate	TOPS Estimated Dose	Tested Dose
Gamma	1 mr/hr	1 mr/hr 10 mr/hr	80 r	6.2 r
Neutron	50 n/cm <sup>2</sup> .sec	130 n/cm <sup>2</sup> .sec 1300 n/cm <sup>2</sup> .sec	1.5 x 10 <sup>10</sup> n/cm <sup>2</sup> .sec	9 x 10 <sup>10</sup> n/cm <sup>2</sup> .sec

Figure 1. Radiation Test Levels

No effects of any type were observed either due to radiation flux density or to total integrated dose. Note that a wide margin was established in the neutron test, but that total integrated dosage was not achieved for the gamma test. This was due to a low flux rate and a limited availability of the source for test.

#### FUTURE WORK

The fabrication and test phase of the image dissector contract is expected to be completed during the next reporting period. In-house evaluation of the delivered tubes will be undertaken utilizing an image dissector test rack fabricated at JPL. Further radiation tests planned for FY'71 have been deferred to FY'72 due to funding limitations. These tests include gamma radiation dosage to a full ten year equivalent level and tests on the new image dissector. In addition, in FY'73, evaluation of both the image dissector and the complete tracker will be made in a simulated Jupiter radiation belt; i. e. , high energy electron and proton flux fields.

#### PUBLICATIONS

##### JPL Publications

1. Willis C. Goss, "Advanced Development Electrostatic Image Dissector", SPS 37-63, Vol. III.

##### Contractor Reports

1. T. J. Hovick, "Phase I Final Technical Report of the Baseline Design of an Image Dissector Tube", Weston Instruments, Inc., EMR Division - EMR Photoelectric, May 4, 1970, JPL contract 952519.

GUIDANCE AND CONTROL SUBSYSTEM INTEGRATION  
FOR FUTURE MISSION

NASA Work Unit 186-68-02-21

JPL 384-65201-0-3430

T. C. Duxbury

## OBJECTIVE

The objective of this work unit is to develop and maintain a capability for functional analysis and design of guidance and control subsystems, including the guidance, attitude control, and power subsystems. A near-term objective is to provide the analysis and design support to the Thermoelectric Outer Planet Spacecraft (TOPS) Project necessary to develop and demonstrate the approach guidance capability required to perform the Grand Tour type mission. This objective applies for the duration of the TOPS Project and is within the discipline area defined by the more general, long-range objective.

## PROGRESS

Thermoelectric Outer Planet Spacecraft (TOPS) Project

The TOPS approach guidance functional requirements document has been updated during this reporting period. More detailed information on the mechanization characteristics, including interfaces with other subsystems on the TOPS spacecraft, and on the on-board data processing requirements have been included.

Approach Guidance Sensor Subsystems (AGSS) geometric error models have been derived based upon a vidicon (TV) sensor approach. Analyses of calibrating the modeled errors during flight have been completed. As a result of the geometric calibration analyses, a requirement has been placed on the TOPS AGSS to have an 11 x 11 reseau grid. This grid will allow electromagnetic measurement distortion to be removed to a level below 2.0 arc-sec (1 $\sigma$ ). The reseaus are also required to be brighter than the space background.

to insure their detection in the video data. Also, the geometric distortion analyses revealed that a total of 50 star images (not required to be in the same picture) are needed to reduce the optical measurement distortion below 4.0 arc-sec ( $1\sigma$ ).

A navigation study of five multiple-outer planet missions has been completed. Included in the missions studied were the Grand Tour (4 planet) missions with inner and outer ring passages at Saturn, a 1977 Jupiter-Saturn-Pluto mission, and 1978 and 1979 Jupiter-Uranus-Neptune missions. Under TOPS midcourse fuel loading constraints, spacecraft-based measurements are required to meet the navigation requirements.

In the navigation study it was determined that measurements of natural satellite direction during planetary approach could give a navigation capability for even more demanding missions. Viewing the planet offers a backup to viewing the satellites, however, a degraded navigation performance would be obtained.

Preliminary software requirements for gathering and processing spacecraft-based navigation data for the outer planet missions have been completed.

The Approach Guidance and Science Imaging (AGSI) Committee documented an interim report based on data obtained from the science, guidance and data handling discipline areas. A preliminary investigation of areas of compatibility and incompatibility between a guidance and science instrument was defined. A partial integration of the science and guidance instruments appears possible based on this preliminary study because of the areas of compatibility defined. Possible mechanization alternatives for science and guidance are being investigated.

## PLANS

Future effort in this unit will be concerned with the development of the AGSS functional design. Geometric calibration studies will be continued during the next reporting period with emphasis on applying the existing calibration

analysis to Mariner Mars 1969 flight TV calibration data and Mariner Mars 1971 ground TV calibration data.

An effort will be completed to determine the effects of planet atmosphere, size, shape and spin axis uncertainties in determining the direction to the center of mass of the large, gaseous outer planets.

The AGSI Committee will define tradeoff criteria for evaluating alternate mechanization approaches for science and navigation instruments or combined instruments. Also, a more detailed study of the areas of compatibility and incompatibility will be made before a final selection is made on guidance and science instrumentation.

## PUBLICATIONS

### Journal Articles

1. Breckenridge, W.G., and Duxbury, T.C., "Defining a Spacecraft-Based Navigation System", Aeronautics and Astronautics, vol. 8, no. 6, June 1970.

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APPROACH GUIDANCE SUBSYSTEM DEVELOPMENT

NASA Work Unit 186-68-02-23

JPL 384-66101-0-3440

Dr. G. Paine

OBJECTIVE

The principal goal of this work unit is to develop the technology necessary to make optical measurements from a spacecraft and to use the data obtained to improve interplanetary guidance in the vicinity of a planet. Specifically, this task supports the Thermoelectric Outer Planet Spacecraft (TOPS) Project. Major emphasis is placed here on spacecraft optical measurement instrumentation referred to as the Approach Guidance Sensor Subsystem (AGSS).

The AGSS is used to determine the positions of a planet's natural satellites against a star background. A sequence of these measurements can be used to augment ground based tracking station radio-doppler data in estimating the spacecraft's position relative to the planet being approached. In fact, in a backup mode, the optical measurements could be used without the radio-doppler data. The addition of optical data will improve trajectory estimates, which in turn will permit a more precise pre-encounter maneuver to be made. Optical measurements permit more exact spacecraft control in orbit injection and capsule missions. On some multiple planet missions, large weight savings, by reductions in the fuel carried for trajectory corrections, can be achieved. On a "Grand Tour" type of mission to Jupiter-Saturn-Uranus-Neptune the use of an AGSS enables a spacecraft weight savings of several hundred pounds. The projected weight savings depend primarily on the projected radio guidance accuracy.

Specific objectives for FY'70 included: (1) A thorough evaluation of existing image tube technology to ascertain which sensors are most suitable to the AGSS. Factors of sensitivity, reliability, aging effects, and drive requirements were considered. (2) A study of the celestial references available

to bound the AGSS problem. (3) A study of possible optical systems to determine the tradeoffs between optical and imaging components. In any optical system considered emphasis will be placed on size, weight, mechanical stability, and ease of calibration. And (4) the generation of a revised functional requirement document.

## PROGRESS

In the latter half of FY'70 our specific objectives, listed above, were met. (1) An evaluation of image tube technology revealed a device, the channel plate image intensifier, which has characteristics that are well suited to the AGSS. In particular, its saturation properties should help meet the stringent dynamic range requirements of the AGSS. This device had not been under consideration previously. Further study of its characteristics is underway. (2) A study of the properties of the satellites and planets under consideration was coupled with a study of the general distributions of stars near the encounter dates. As a consequence it became apparent that the dynamic range required of the AGSS could be minimized with a narrow field of view system and that this was one of the most stringent requirements; one that eliminated many candidate sensors from consideration. (3) Several brief tradeoff studies were made to determine the impact of the optical system on the imaging requirements. In addition, some particular examples were examined in depth: e. g., the optical system required by the channel plate intensifier is readily met by state-of-the-art design: a light weight system with a  $0.7^\circ$  field of view, a diameter of 9 cm, a focal length of 147 cm, and an f/number of 16. (4) A revised functional requirements document based on the use of a channel plate image intensifier with the optical system described above has been prepared.

In addition to meeting the FY'70 objectives, active interaction with the Approach Guidance/Science Imaging Committee has taken place and the committee has been continually apprised of the developments mentioned here. Also, an investigation into the types of tests to be performed on any AGSS was begun.

## FUTURE WORK

The primary tasks for FY'71 are concerned with advancing the definition of the requirements on the AGSS, the definition of a mechanization which can meet the requirements, and the tradeoffs between the two. The tasks include: further study of sensor capabilities, including data on the behavior of various sensors to point sources and other special optical inputs; determination of the best way to readout the proposed channel plate device, e. g. , image dissector, vidicon or other means; further definition of the system test requirements; continued study of the celestial references and possible optical systems; as well as studies of reliability factors.

As the work advances the definition of interfaces will become necessary, and a basic design for a breadboard AGSS will be developed. Emphasis will be placed on the needs for long life, reliability, and redundancy (both within the AGSS, and possibly with other spacecraft imaging devices). Emphasis will also be placed on continued support of the Approach Guidance/Science Imaging Committee.

## PUBLICATIONS

None.

701-90

REMOTE OPERATION OF A ROVING VEHICLE

NASA Work Unit 186-68-02-25

JPL 384-66701-0-3430

J. W. Moore

OBJECTIVE

The objectives of this task are to analyze, design, 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 systems; and to produce designs, specifications, and recommendations directly applicable to planetary exploration missions.

PROGRESS

University Grants

Technical monitoring of the progress of Cornell University and Rensselaer Polytechnic Institute (RPI) engineering research grants was maintained throughout the reporting period.

The work performed at both universities emphasized the development of subsystems, including associated analysis and hardware designs, for an unmanned Mars surface roving vehicle mission. The integration of these subsystems into a total vehicle system capability has been emphasized throughout the entire fiscal year.

The task areas at RPI include terrain modeling and path selection, navigation, vehicle configuration, power systems, mobility and a gas chromatograph. At Cornell the task areas are laser obstacle detection, navigation, soil sampler-tester, vehicle motion control, mechanical obstacle detection, telemetry and command and vehicle mechanics. The majority of work at RPI involves analyses, computer simulation and modeling; the exception to this is the work on the gas chromatograph system, where a hardware system has been

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developed, and has been subjected to preliminary testing. Cornell has directed most of its effort toward the development of hardware in the above task areas, with analyses aiding in the determination of hardware parameters and substantiation of test results.

### RPI Progress

Considerable technical progress has been made in all areas of activity at RPI. In the terrain modeling and path selection area, a mathematical technique has been developed for determining the "value" (in terms of energy requirements and vehicle safety) of the terrain in a sector in front of the vehicle. Only first-order effects have been incorporated in the path selection algorithm, but the results obtained appear promising. Future activity will include the addition of second-order effects and improving the mathematical terrain models.

Most of the navigation work has been concerned with mathematical modeling and simulation of a vehicle navigation method requiring surface landmarks and an orbiting satellite. A preliminary error analysis indicated that the navigation error is dependent upon sensor accuracy and the number of measurements of satellite and landmark positions. A more detailed error analysis and better sensor accuracy data is needed before realistic accuracy predictions can be made.

During the second half of FY'70, RPI developed a roving vehicle configuration. An extremely small model (approximately 10 inches in length) was constructed to illustrate the proposed configuration. A movie, demonstrating the RPI configuration, was made. In the fourth quarter, a 1/3-scale model was constructed with suspension, battery power and the capability to be driven. Small motors provide the drive force. This vehicle will be used for vehicle dynamic and mobility tests in FY'71.

In the power systems area, progress has been made in determining the vehicle power requirements and evaluating the tradeoff between battery and RTG. The RTG is considered the primary power source for vehicle operation on the surface of Mars.

The gas chromatography test facility has been completed. The facility is now ready to be used for experiments in FY'71. The final parts were received in the fourth quarter, installed, and the chromatograph operation tested.

### Cornell Progress

Cornell continued its design and development of subsystems for a Mars roving vehicle during the second-half of FY'70. The entire activity was directed toward a vehicle system test during the fourth quarter. However, unforeseen hardware difficulties, coupled with underestimates of the effort required, forced a delay until FY'71 for the system test.

Hardware difficulties were encountered in the laser obstacle detector, navigation and the on-board computer. The laser obstacle detector prototype was completed late in FY'70 and a significant reduction in power output occurred while the detector was undergoing bench tests. The power dropped by a factor of ten and the range capability was significantly reduced. The initial weeks of FY'71 will be spent correcting this difficulty.

The navigation subsystem was not completed because of a failure in the directional gyro in the third quarter. The gyro was sent to the manufacturer for repair and it was not received until late in the fourth quarter, thus contributing to the system test delay.

The on-board computer which is needed for vehicle guidance and control was completed late in the fourth quarter. Bench testing was completed but the critical interfacing with other on-board subsystems was not initiated. The computer appears ready for system integration and test in FY'71.

The mechanical obstacle detector and the soil sampler-tester were modified during the second half. Subsystem tests on these devices have substantiated the modifications made.

A limited-capability telemetry and command subsystem was completed in the fourth quarter. This subsystem has the capability for transmitting 32 different commands to the vehicle and telemetering a limited amount of vehicle data. The subsystem, however, will be adequate for the system test.

Joint Presentation

A joint presentation on these two research grants was held on May 19, 1970, at Cornell University. Students from RPI and Cornell were selected to present a summary of the work performed in various subsystem areas. The format of the presentation was similar to a technical conference. The presentation appeared to be well received by those in attendance from NASA and JPL.

## FUTURE PLANS

During the next reporting period technical monitoring of the university grants will continue. RPI will concentrate their activity in the areas of vehicle design, systems analysis, navigation and path selection and gas chromatograph test and evaluation. Cornell will complete the necessary subsystem development and system integration functions for performing the vehicle system test.

## MEETINGS ATTENDED

1. Lewis, R. A., "Roving Vehicle Navigation Subsystem Feasibility Study," presented at 3rd Hawaii International Conference on System Sciences, University of Hawaii, January 13-17, 1970.

## ANTICIPATED PUBLICATIONS

Contractor Reports

1. Annual progress reports by Cornell and RPI.

## PUBLICATIONS

Contractor Reports

1. Frederick, D. K., Lashmet, P. K., Sandor, G. N., Shen, C. N., Smith, E. J., Yerazunis, S. W., "Analysis and Design of a Capsule Landing System and Surface Vehicle Control System for Mars Exploration," RPI, March 1, 1970.

## GSE ADVANCED DEVELOPMENT

NASA Work Unit 186-68-02-27

JPL 384-66901-3430

R. Williamson

## OBJECTIVES

The general objective of this work unit is to develop Guidance and Control (G & C) Ground Support Equipment (GSE) technology for application to future planetary missions. The specific objective is to develop a unified support equipment approach centered around a small general-purpose computer in support of the Thermoelectric Outer Planet Spacecraft (TOPS) project.

## PROGRESS

At the end of December, 1969, the effort of this work unit was assigned to two work units. The responsibility for the development of a computerized test set (CTS) to support spacecraft computer subsystems was transferred to the Astrionics Division under work unit 186-68-02-27-03. Included in the transfer was the responsibility for the prototype CTS which was developed around a small general-purpose computer, a DDP-124, leased from Honeywell, Inc. The development of the prototype CTS to check out spacecraft computer subsystems had been the primary emphasis of the GSE Advanced Development task to the date of the transfer.

The Guidance and Control Division retained the responsibility for the development of a CTS to support the G & C spacecraft subsystems (Electrical Power, Attitude Control and Scan, and Approach Guidance) under work unit 186-68-02-27. The CTS for the G & C subsystems requires the performance of a number of functions different from those required for spacecraft computer subsystems. The capability to adapt to both analog and digital circuits is required. Increased consideration of manual and semi-automatic modes of operation is required in addition to automatic test modes. The CTS technology base developed for spacecraft computer subsystems, however, will be utilized

in applying the CTS concept to the G & C subsystems. The computer leased from Honeywell, Inc. will be used by both divisions.

The progress of the CTS development for the G & C subsystems was limited during this reporting period due to the large budget reductions. Preliminary test requirements for the Attitude Control and Scan subsystem have been determined. The preliminary design of the CTS and interface equipment is in process.

#### PLANS

During FY'71 the effort will include: (a) development of test requirements and test techniques for the TOPS G & C Subsystems, (b) preliminary and functional design of the CTS and interface units for the G & C Subsystems, and (c) start of the detail design of the interface units.

In FY'72, the interface unit designs will be completed and the units will be fabricated, the CTS hardware and software will be developed and checked out, and the complete test system will be tested with breadboards or prototypes of the TOPS G & C Subsystems.

#### PUBLICATIONS

None.

GSE ADVANCED DEVELOPMENT  
NASA Work Unit 186-68-02-27-03  
JPL 384-66903-0-3610  
M. Ebersole

## OBJECTIVE

The general objective is to develop the Guidance and Control Ground Support Equipment (GSE) technology to meet the requirements of future planetary missions. The specific objective is to develop a unified support equipment approach centered around a small general-purpose computer.

## PROGRESS

The primary task for this reporting period has been the continuation of the development and fabrication of a prototype of the computerized test system for the unified support equipment. In order to demonstrate the basic capabilities of the test system a Mariner Mars 1969 Central Computer and Sequencer (CC&S) is being interfaced and tested with the prototype test system. Progress towards the completion of the prototype test system since the last reporting period includes:

- (1) Completion of fabrication and checkout of test system hardware assemblies required to interface the general-purpose computer with the CC&S.
- (2) The test system software has been completed and is in the process of being debugged. Test system software includes the following capabilities:
  - (a) Manual Mode Operation. Manual mode operation whereby the CC&S under test is controlled by operator typewriter input of discrete commands to the CC&S.

- (b) Automatic Mode Operation. Automatic operation of the CC&S under test whereby the CC&S is automatically controlled and monitored and the monitored CC&S outputs are verified by comparison to a predicted list of outputs generated by a CC&S software simulator which runs concurrently with the CC&S.

The CC&S simulator may be run independently of the CC&S as a tool for generations of CC&S sequences expected as a result of particular CC&S machine language programs.

Input to the automatic test mode may be via cards or magnetic tape.

- (c) Test Recall. Test routines may be stored on magnetic tape and recalled for later use if desired.

At present the test system and CC&S are completely integrated and the various test modes available in the test system are being exercised. Test system software improvements and changes are being incorporated as they become necessary in the course of the integration tests. It is planned to culminate the integration test activities with a test system demonstration which will demonstrate all test modes.

## PLANS

No funds are currently planned for the continuation of this work unit for FY'71. However, it is planned to continue development efforts on the computerized test system in the next fiscal year under VO'75 project funding and to apply the computerized test system techniques developed to date to checkout of a Viking Orbiter 1975 Computer Command Subsystem (CCS). The computerized test system was also planned as the first step in support equipment for the JPL Self-Testing-And-Repairing (STAR) computer. Suspension of the work unit will make it impossible to continue the development for this application.

More specific plans are:

- (1) To expand the test system capabilities to include operation with a CRT display device to develop the test system man-machine interface.
- (2) Modifications to the test system software and hardware for eventual use in testing the Viking CCS breadboard system.
- (3) Modification to the test system software and hardware for eventual use in testing Viking CCS subassemblies and modules.

#### PUBLICATIONS

None.

## CONTROL SYSTEMS FOR ADVANCED SPACE PROGRAMS

NASA Work Unit 186-68-02-39

JPL 384-71101-0-3440

L. S. Smith/T. Kerner

## OBJECTIVE

The long-range objective of this work unit is to develop and mechanize control systems for spacecraft to be used in the future missions of space exploration. The design will be evolved with emphasis placed on reliability, low power consumption and ease of integration with other spacecraft systems.

A breadboard model of the design will be constructed and the design will be verified through a single axis simulation.

## PROGRESS

During the January 1 to June 30 period, the detailed electronic design of the control system was completed. Simultaneously, work has progressed in the implementation of the single axis simulator.

The design features a hybrid attitude control electronics (ACE) with the largest portion of the implementation being digital. The ACE is excited by a digitized gyro and sun sensor on its input lines and is designed to drive into momentum wheels and gas system actuators to produce the torques required to maintain the spacecraft attitude. The analog portions of the design are primarily in the implementation of the momentum wheel and gas system actuator drives. The ACE features a central processor unit performing the required arithmetic operations in a serial manner. The system is designed to sample the sensors at a 10 times per second repetition rate; a complete processing cycle is accomplished during each sampling period. A clock rate of 6.4 KC is used. The system has been designed to perform in the several modes that are characteristic of a space flight. Attitude control can be maintained either through the processing of sensor inputs, providing precise position information and coarse rate information, or the processing of the gyroscope outputs, providing rate and position information.

The design has been implemented using the low power TTL 54L/74L family of IC's and MSI's where appropriate. The ACE has been breadboarded and is currently in checkout.

Design activity is close to completion on the electronics required to support the single axis simulator test. A capability to command the ACE into any one of its several modes is being implemented. The single axis simulation is accomplished by placing the electronics and its associated equipment on a gas bearing table. Communications with the table will be maintained via capacitive coupling.

#### FUTURE WORK

The breadboard construction checkout of the ACE will be completed and the necessary design modifications incorporated. Integration with the digital sun sensor (NASA Work Unit 186-68-02-44-00) and the actuators will be performed. The design and mechanization of the single axis simulation support equipment will be completed. The system integration will be completed by mating the hot gas system to the electronics. Comprehensive testing of the single axis attitude control system will be undertaken.

#### ANTICIPATED PUBLICATIONS

##### JPL Publications

1. Smith, L. S., "TOPS A/C Single Axis Simulator Momentum Wheel Tachometer Circuit", JPL SPS 37-63, vol. III.

#### PUBLICATIONS

##### JPL Publications

1. Smith, L. S., "TOPS A/C System Simulation Instrumentation", JPL SPS 37-61, vol. III.

## OUTER PLANET CONTROL SYSTEM DESIGN STUDY

NASA Work Unit 186-68-02-41

JPL 384-72101-0-3440

W. E. Dorroh

## OBJECTIVE

The long-range objective of this work unit is to complete the system design for the spacecraft control systems required for missions to the outer planets. This basic objective includes two important considerations: The first is the functional design of control systems that are capable of meeting the special requirements imposed by outer planet missions, e. g., long life, extreme radiation, and extreme temperature environments. The second is the functional design of the control systems as an integrated part of the complete spacecraft system.

## PROGRESS

Several studies and analyses were initiated to complete the definition of single axis simulator requirements.

Reaction Wheel Controller Simulation

A computer model of the wheel controller was used to simulate the performance of the system during the various modes of operation. The results indicate a need for increased rate damping in the acquisition and commanded turn modes. These changes are being incorporated into the breadboard hardware for the single axis simulation.

Reaction Wheel Unloading Simulation

The wheel controller model was used in conjunction with several unloading algorithms in an attempt to minimize the attitude error during unloading. Preliminary results indicate that a peak error of twice the reaction wheel deadband should be achievable.

Reliability Studies

A study was performed of stand-by redundancy with imperfect error sensing and switching. This resulted in a set of general reliability functions which can be used to determine the required level of redundancy to achieve the maximum overall system reliability.

Design Team Support

Integrating the subsystem design into the overall spacecraft design was continued by participation in the TOPS Design Team, obtaining design constraints and supplying required information on the attitude control subsystem.

## FUTURE WORK

Activities for the first half of FY'71 will involve simulation of the single axis air-bearing test hardware such that the test results may be evaluated.

## ANTICIPATED PUBLICATIONS

Journal Articles

1. Dorroh, W. E., Jr., "An Attitude Control Subsystem for a Thermo-electric Outer-Planet Spacecraft, " Astronautics and Aeronautics.

JPL Publications

1. Lin, Ho-sen, "TOPS Attitude Control Reliability Study, " JPL Space Program Summary.

## PUBLICATIONS

JPL Publications

1. Lin, Ho-sen, "An Analysis of TOPS Science Package Pointing Error Due to Structural Vibration of the Supporting Booms", JPL SPS 37-62, vol. III.

701-90

INERTIAL DEVICES FOR LONG-LIFE MISSIONS

NASA Work Unit 186-68-02-42

JPL 384-72201-0-3440

P. J. Hand  
T. C. Lear

OBJECTIVE

The objective of this work unit is to provide inertial devices and their companion electronics for use on the single axis simulator being developed for the Thermoelectric Outer Planet Spacecraft (TOPS) Project. Gas bearing gyroscopes with digital rebalance electronics and momentum wheels are both being supplied.

This work unit also includes an investigation of nuclear radiation effects on gyroscopes and accelerometers, as well as a low noise gyro study contract. In addition, the final work on sterilizable inertial sensors is conducted under this work unit.

PROGRESS

Gas Bearing Gyros

The procurement action with Honeywell, Inc., for a type GG134S gyro has been suspended due to a re-allocation of FY'70 funds. However, arrangements are under way to borrow a GG134S from Manned Spacecraft Center to check for compatibility with the JPL Phase II digital gyro rebalance loop, reported on under NASA Work Unit 186-68-02-44.

Low Noise Gyro Study

The 6 month study program with Honeywell, Inc., was extended to 9 months to cover additional fabrication and testing on a modified GG334 type gyro. This was performed without any cost increase in the contract value of \$49,900. The final report was received in March 1970 and the contract was

closed-out in April 1970. Results were highly successful with all design goals being met. The program has resulted in demonstrating a design approach to be used in reducing the output noise of single-axis gas bearing gyros.

### Sterilizable Inertial Sensors

#### Bell Aerosystems Model VII Accelerometer

The contract with Bell Aerosystems, in the amount of \$124,331, for the development of a sterilizable accelerometer was concluded in January 1970 with the delivery of the final report. No additional accomplishments, beyond those covered in the last semi-annual report, were made.

#### Honeywell Type GG177 Accelerometer

Evaluation of the GG177 accelerometer has been concluded. The last tests, following shock, were completed in February 1970. Performance was essentially the same as that reported on in the last semi-annual report. The unit was returned to the vendor for additional testing. In general, the unit was quite satisfactory prior to sterilization, but exhibited degraded performance after exposure to the sterilization environment.

### Momentum Wheels

Two A. C. powered momentum wheels have been received and are in life test. No degradation of the bearings has been observed to date, with approximately 1000 hours running time on each. One of the motors has been selected for use on the TOPS single axis simulator, but will continue in life test until needed for this application.

### Nuclear Irradiation Tests

Irradiation of the Kearfott 2565 gyro to the full TOPS radiation dose of 7000 rads gamma and  $1.4 \times 10^{12}$  neutrons/cm<sup>2</sup> was completed. No change in the gyro parameters which can be attributed to radiation exposure were noted. The previously reported change of 3.8% in the damping coefficient was due to poor repeatability of the test method. Refinement in the test techniques is now yielding results with better than 1% repeatability.

The planned evaluation of the organic solids and bearing lubricants has been accomplished for the gamma exposure, but the neutron exposure has been delayed to conserve funds. This neutron testing is expected to be done on the JPL Dynamitron, as soon as it can be made available for this mode of operation.

## PUBLICATIONS

### Contractor Reports

1. Kraus, G. M., "Gyro Noise Study Program," Honeywell, Inc., Final Report, JPL Contract 952575, Report 21367-FR, dated March 1970.
2. Toth, T. A., "Development of a Sterilizable High Performance Accelerometer," Bell Aerosystems Co., Final Report 60007-035 on JPL contract 951492, dated 30 January 1970.

## LONG LIFE ATTITUDE CONTROL THRUSTER SYSTEM DEVELOPMENT

NASA Work Unit 186-68-02-43

JPL 384-72301-0-3440

J. D. Ferrera

## OBJECTIVE

In January 1970, the objectives under this task were changed from those reported in the last Semi-Annual Report under this work unit in order that this task would support more directly the Thermoelectric Outer Planet Spacecraft (TOPS) Attitude Control Single Axis Verification (A/C SAV) testing. As such, the revised objectives are:

- (1) Provide the A/C Single Axis Simulator (A/C SAS), consisting of a combination radial and thrust gas bearing, a table (sized to the correct inertia), and a support for the bearing and the sun simulator which is required for the A/C SAV testing of the TOPS attitude control system (momentum wheels plus hydrazine thrusters).
- (2) Continue the valve testing as time permits.
- (3) The low leakage seals study will be discontinued.

## PROGRESS

During this report period the air bearing was specified, procured, and delivered on June 16, 1970. The table and supports have been designed and are currently being fabricated in-house. Completion is expected by July 15, 1970. This work is progressing on schedule.

A very small amount of valve testing was completed during this period. This activity will be transferred to another work unit for the next report period.

## PLANNED ACTIVITIES

During the next report period the telemetry and position pickoffs will be installed on the bearing. Following this installation, the bearing, the table,

and supports will be assembled and balanced in the JPL celestarium with the A/C system mounted on the table.

In addition to the TOPS simulator work, a second task concerned with studying a pulsed plasma discharge system, designed to replace the momentum wheel system, at a much lower weight and power penalty, is being undertaken. Specifically, the required system analysis, development of test procedures, and development of proper logic and electronics will be performed in order to incorporate the pulsed plasma system into a single-axis A/C simulation scheduled late in FY'71.

#### ANTICIPATED PUBLICATION

##### JPL Publications

1. SPS on gas bearing performance.

#### PUBLICATIONS

None.

## DIGITAL SYSTEMS FOR INERTIAL SENSORS

NASA Work Unit 186-68-02-44

JPL 384-73301-0-3440

P. J. Hand

## OBJECTIVE

The objective of this work unit is to develop and fabricate the digital gyro rebalance loop that will be used with the Thermoelectric Outer Planet Spacecraft (TOPS) attitude control system single axis simulator.

## PROGRESS

The digital gyro loop development, which was to be in two phases, has been delayed to some extent pending the receipt of an optimum digital gyro such as the GG134S. The Honeywell GG134S gyro procurement previously planned for FY'70 was suspended due to re-allocation of funds (see NASA Work Unit 186-68-02-42). Therefore, an existing GG334S gyro will be used for the simulation tests. Of the five GG334S gyros remaining at the conclusion of the sterilization program, only one demonstrated adequate stability for use with the TOPS single axis simulator. Unfortunately, this gyro developed an internal short during testing with the Phase I digital system. This gyro (SN A-4) has been returned to Honeywell, Inc., for repair under contract FD-525681, in the amount of \$4,560. This work will take 9 weeks and the gyro will be returned to JPL by the end of July. The gyro will then be retested and calibrated using the Phase I electronics for installation in the TOPS single axis simulator.

The Phase I electronics breadboard is being repackaged for use on the simulator as it is believed that a strongly corrosive ammonia atmosphere from the warm gas jets will be present. The electronics and gyro will be housed in a gasket sealed metal box to protect the electronics. The plugboards from the breadboard will be used with only minor changes. Fabrication and testing of this unit are on schedule.

A digital computer simulation of the Phase I gyro rebalance loop has been performed and has confirmed the stability of this digital rebalance concept. The program as written will accept the parameters of other gyros in substitution to check out the design changes necessary to accommodate other possible candidate gyros for the TOPS attitude control system.

During the next 6 month period, the fabrication of the simulator package will be completed. Calibration with the rebuilt GG334S will be performed and long term stability information obtained. In addition, some preliminary fabrication work on the Phase II digital gyro system will be started in anticipation of the loan of a GG134S gyro from Manned Spacecraft Center.

#### ANTICIPATED PUBLICATIONS

##### JPL Publications

1. Hand, P. J., "TOPS Inertial Reference Unit," JPL Space Program Summary, 37-63, vol. III, July, 1970.

#### PUBLICATIONS

None.

## DIGITAL SUN SENSOR DEVELOPMENT

NASA Work Unit 186-68-02-45

JPL 384-73401-0-3440

L. F. Schmidt

## OBJECTIVE

The long-term objective of this task is to develop a cruise sun sensor which meets the requirements of the Thermoelectric Outer Planet Spacecraft (TOPS). The Ranger and Mariner spacecraft sun sensors produced an analog error signal which was required to be accurate only near the deadband switching points. The outer planet missions require that the spacecraft orientation, with respect to the sun, be varied continuously in flight in order to provide accurate pointing of the high gain antenna toward earth. This technique requires that the sensors be accurate over a large field of view so that a variable bias can be applied to the sensor output to turn the spacecraft to the desired position.

## PROGRESS

Sensor Testing

The predicted performance of the sensor was verified through testing of the pitch axis breadboard. These test results indicate that the design concept formulated to meet the TOPS requirements is satisfactory. The principal problem encountered is related to the detector characteristics. The problem of non-uniform detector characteristics over the entire sensitive area indicate that improved detector fabrication techniques must be developed to obtain flight quality detectors. Only one of the four detectors procured can be made to function properly over the entire 6 degree field of view.

Single Axis Test Support

The optical mechanical portion of the pitch breadboard sensor will be used for the single axis tests scheduled for verification of the complete attitude control system. The signal processing electronics have been redesigned for

this test. Instead of using the method described in SPS 37-60, Vol. III, the Gray code output word will be fed into the attitude control electronics in a parallel manner.

### Sun Simulator

A sun simulator is required to provide a stimulus for the sensor during the single axis tests. The design of the simulator is approximately 30% complete. The simulator uses a xenon arc lamp for the radiation source and is designed to provide various solar diameters to simulate the conditions of sensor operation at several distances from the sun.

### Solar Disc Simulator

The construction of the solar disc simulator is complete. The unit will be assembled at the Table Mountain test facility after the optics are anti-reflection coated.

## PLANNED ACTIVITIES

The planned activities for the first half of FY'71 are as follows:

- (1) Fabrication of pitch breadboard signal processing electronics to support the single axis attitude control tests.
- (2) Completion of the design and fabrication of the sun simulator required for the single axis test.
- (3) Initiation of a procurement for a yaw detector having improved output characteristics.

## PUBLICATIONS

### JPL Publications

1. Schmidt, L. F., "Digital Sun Sensor," SPS 37-60, vol. III. p. 103, December 13, 1969.

## TRAJECTORY SUPPORT TO THE TOPS PROJECT

NASA Work Unit 186-68-02-46

JPL 384-72501-0-3920

J. Ball  
W. Stavro

## OBJECTIVE

The objective of this work unit is to provide the trajectory and navigation support required by the Thermoelectric Outer Planet Spacecraft (TOPS) Project.

## TRAJECTORY ANALYSIS

Using the PEGASIS computer program, detailed encounter parameters were determined for the TOPS '77 J-S-P, '79 J-U-N, and '77 Grand Tour A baseline missions. Trajectory analyses were also performed for a possible 1975 Jupiter-Pluto mission and a 1975 Jupiter/Out-of-Ecliptic mission. An article based on this work will appear in a special issue of Astronautics and Aeronautics devoted to the TOPS Project.

## MISSION ANALYSIS

Preliminary mission analysis studies were made in support of the TOPS project and the outer planet mission design effort. A navigation analysis for the J-S-P, Grand Tour A, Grand Tour B, '78 J-U-N and '79 J-U-N missions was performed. The mean  $+3\sigma$  total velocity correction requirements for these missions were estimated. These preliminary values were based on estimates of navigation errors from ephemeris, station location and execution errors. The computations included results based on Earth based radio tracking both alone and in conjunction with various on-board measurement systems. Limitations to the various on-board measurement systems were reviewed.

ANTICIPATED PUBLICATIONS

Journal Articles

1. Draper, Divita, Frewing, and Stavro, "The Spacecraft and the Missions," *Astronautics and Aeronautics*, August, 1970.
2. Ball, J. E., Duxbury, T. C., "Navigating the Grand Tour," *Astronautics and Aeronautics*, August, 1970.

PUBLICATIONS

JPL Publications

1. Stavro, W., "Possible 1975 Jupiter-Pluto Gravity Assist Trajectories," SPS 37-63, vol III.

## SPACECRAFT DATA STORAGE

NASA Work Unit 186-68-03-01

JPL 384-60901-0-3630

J. Hoffman  
E. Bahm  
D. Bergens

## OBJECTIVE

The objective of this work unit is to devise and develop reliable large capacity spacecraft ( $10^6 - 10^{12}$  bit) data storage subsystems for future deep space missions. The FY'70 effort has been directed toward storage components and techniques to meet the requirements of the Thermoelectric Outer Planet Spacecraft (TOPS) as applied to missions of up to 12 years duration. Work during the last half of FY'70 has involved the following subtasks:

- (1) TOPS Data Storage Subsystem (DSS) design,
- (2) Buffer storage development,
- (3) Tape transport development,
- (4) Tape transport components design, and
- (5) Metal base recording tape feasibility.

## SUBTASK 1 - TOPS DATA STORAGE SUBSYSTEM DESIGN

Objective

To support the TOPS Design Team and develop a conceptual design for the Data Storage Subsystem.

Progress

Studies conducted in early FY'70 resulted in the decision that the TOPS should employ a Centralized Data System (CDS). The Data Storage Subsystem presently planned for the CDS comprises the following basic elements:

- (1) a  $2 \times 10^9$  bit fixed rate serial access mass memory,

- (2) a  $2 \times 10^6$  bit variable rate serial access buffer memory, and
- (3) a controller to manage memory assignment, input-output operations, etc.

Investigations carried on to this time suggest that the  $2 \times 10^9$  bit memory requirement can best be satisfied with an improved magnetic tape recorder (see subtask 3). The serial access buffer memory requirement may best be satisfied with either a core (see subtask 2) or an improved plated wire configuration, depending on system size, weight, and power characteristics.

### Plans

The mass memory will be designed to store both encounter and cruise data. The buffer memory will provide data rate conversion for the mass memory as well as storage for computer programs and execution of data compression. More detailed design and performance requirements for the complete TOPS DSS will be established during the next 6 months.

## SUBTASK 2 - BUFFER MEMORY DEVELOPMENT

### Objective

The objective of this subtask is to develop a long life, serial, buffer memory for TOPS. It is intended to serve as a data rate buffer for the spacecraft tape recorder during planetary encounters and to be the primary data storage mechanism during interplanetary cruise. In the latter mode, it would store a weeks collection of engineering and science data. The original requirements of the buffer memory were: 8 million bits, block oriented with random access to each block, requiring 10 watts, 36 pounds, and 1600 cubic inches.

### Progress

A survey of memory techniques revealed that no memory made today met all of the requirements. Semiconductors appeared to be a good choice, but needed some development to achieve low power, small size, and radiation hardening. A block size of 32,768 bits is practical for such a memory.

An RFP was initiated in January for development of a semiconductor memory module (SMM). An 8 million bit memory would use 244 SMM's.

The RFP brought three proposals. All far exceeded the budget estimate, the outstanding technical proposal being the highest. The decision was made to terminate the solicitation due to the high cost and other factors. The data storage requirements for the early outer planet missions are being re-evaluated and an applicable limited scope technology SMM development has been proposed.

### Plans

Any future semiconductor memory development work will proceed under NASA Work Unit 186-68-56-10. Present plans are to proceed with the TOPS buffer memory development employing magnetic techniques. The nature and extent of this effort will depend upon DSS requirements and resource availability.

### SUBTASK 3 - TAPE TRANSPORT DEVELOPMENT

#### Objective

The magnetic tape recorder continues to be the prime candidate to satisfy the TOPS bulk storage requirements. The immediate objective of this effort is to develop a suitable tape transport design to meet the requirements of the early outer planet missions.

#### Progress

During this report period, development of an attractive three motor transport design has proceeded. This concept uses two DC motors for moving the tape in a reel-to-reel configuration and for tape tensioning. A third motor is employed for control of tape speed. A breadboard model, including motor control electronics and feedback servos, has been fabricated in-house. Its performance characteristics are currently being evaluated.

Investigation of two other direct drive tape transport configurations has been performed on a low level basis. One, employing the peripheral belt technique, incorporates a slave tape capstan for precise tape control. The other employs the magnetic tape itself as a peripheral self-drive medium.

Another concept being given serious consideration is that of a fluid-filled transport. Such a design could incorporate hydrostatic bearings and provide a fluid controlled head/tape interface. Discussions have been held with industry personnel regarding these techniques. This approach appears attractive for TOPS in view of the long life and difficult environmental requirements.

General investigation of tape transport performance characteristics has led to preparation of a mathematical model of a previously developed Engineering Test Model (ETM) transport. This current effort is expected to provide a valuable tool for transport design optimization.

### Plans

The ensuing 6 months will see concentrated evaluation of the performance characteristics of the three motor transport. Continued study of the fluid-filled transport concept will be performed and preparations will be made for the development of this item in FY'71. Efforts to develop and evaluate the feasibility for TOPS of hardware demonstrating the designated life and performance requirements will proceed.

## SUBTASK 4 - TAPE TRANSPORT COMPONENTS DESIGN

### Objective

The objective of this effort has been to investigate the more critical elements of tape transport systems, i. e., bearings, lubricants, tape, heads, and drive belts, to improve performance integrity and reliability. Resource priorities have limited work during this report period to evaluation of transmission drive belts.

### Progress

Testing and evaluation of polyimide material belts was continued and additional fatigue life statistics were acquired. That fatigue life is highly dependent on belt physical condition is apparent. Also, statistics indicate that actual life substantially exceeds that predicted from existing models,

being primarily a function of bending stress level. Data were obtained on the effects of time and temperature cycling on installed belt tension and belt life. Some preliminary data on the effect of length to width ratio and run-in periods on fatigue life were obtained.

### Plans

Investigations in the area of component design and materials selection will continue as required to optimize the TOPS DSS. This will include work related to bearings, lubricants, magnetic tape, and heads.

### SUBTASK 5 - METAL BASE RECORDING TAPE

#### Objective

The objective of this effort is to determine the feasibility of employing a chemically and physically stable metallic base material with a suitable magnetic coating as a precision high environment magnetic recording tape. Such a tape would be a significant aid to the success of the TOPS DSS development effort.

#### Progress

A contract (No. 952619) for 23K was awarded in June 1969 to the Kinelogic Corporation to investigate the feasibility of using metal foil as a tape base. Since then, the physical characteristics of various candidate metal foils have been evaluated. Two materials have been selected - Havar and Beryllium copper.

Preliminary plating experiments were performed to apply a magnetic coating to samples of the metals chosen. Inspection equipment was designed and fabricated to test the magnetic characteristics of the plated samples. A tape transport is being modified to facilitate evaluation of tape handling characteristics. Preparations for lapping to width of the wound tape packs are in process.

No significant progress has been made on this program during the last 3 months due to the temporary unavailability of contractor personnel and a reassignment of the JPL cognizant engineer to a higher priority project.

Plans

The work on the Kinelogic contract will be resumed.

PUBLICATIONS

None.

## SCIENCE DATA SYSTEM IMPLEMENTATION

NASA Work Unit 186-68-03-04

JPL 384-61601-2-3620

R. H. Nixon

## OBJECTIVE

The objective of this task is to develop the hardware and component technology for science data subsystem equipment for deep-space missions where reliability and long lifetime are of paramount importance. The general goal has been to develop new circuit and logic techniques, qualify new component technology, and develop the physical hardware necessary to make maximum use of the new technology.

The near-term goals have been directed to supporting the Thermoelectric Outer Planet Spacecraft (TOPS). This support includes the development and qualification of a large-scale integrated-circuit counter shift register (CSR), the evaluation of series 54L integrated circuits, and support to the TOPS micro-electronic parts committee.

## PROGRESS

Counter Shift Register

The development contracts (No. 952267 and 952535) with Honeywell Aerospace Inc., St. Petersburg, Florida, have been completed. Twenty-eight circuits of metal mask 1, and twenty-seven circuits of metal mask 2 have been received. Testing of these devices at the contractor's facility has shown that they will not meet the full JPL specification. The following is a summary of some of the measured parameters and the number of devices which met the specification:

1. Output Saturation Voltage: 35%
2. Leakage Current: 70%
3. Power Consumption: 60%
4. Operating Speed: 22% shift; 58% count.

There was not any one device that met all specifications. This is attributed to the specification being too tight for the basic circuit design, and not to lack of control in processing. A slight relaxation in some of the specification parameters would result in a fairly high total device yield.

The contractor's microelectronic facility has been closed down as a result of a corporate decision to consolidate these activities at their research center in Minneapolis. This leaves JPL without a source should they decide to use the CSR in any flight equipment. Because of the complexity of the device and the extremely tight tolerances on mask alignment and registration, it is felt that most commercial semiconductor houses would be either reluctant or unable to build a hi-rel CSR. JPL intends to discuss the possibility for future CSR fabrication with some of the smaller, more technology-oriented companies.

Honeywell has made recommendations for improving the yield and performance of the device should a new fabrication effort be initiated. These are listed here briefly:

1. Increase  $V_{cc}$  limits.
2. Relax layout ground rules to increase spacing by 25 - 50%. This would increase the die size and require a new package.
3. Redesign the basic cell:
  - eliminate bias diodes;
  - eliminate pinched resistors;
  - insert  $T^2L$  gating;
  - reduce internal noise margin from 1.4 volts to 0.7 volts.

The 55 devices received under the subject contract are being prepared for evaluation and characterization. This work has slipped from the original schedule due to a slip in the receipt of components. A program has been written for the Teradyne tester, and testing will begin as soon as test fixtures are completed.

The multilayer board for evaluating the CSR in an operating system has been received. Parts are being prepared for mounting and evaluation testing should begin early next fiscal year.

### Committee Support

Support to the microelectronics committee has continued. The evaluation of semiconductor memory technology will be covered under a new task during FY'71; Semiconductor Memory Development, NASA Work Unit 186-68-56-10.

The microelectronics committee is considering the development of either an analog-to-digital converter (ADC), or a multiplexer. Evaluation of these devices is being conducted under this task. It is expected that a recommendation will be presented during the first quarter of FY'71. If either of these devices should be developed, it is likely that it would be handled under this work unit.

### ANTICIPATED FUTURE WORK

A new work unit title will be introduced in FY'71. The new title is Microelectronic Device Implementation. This title more accurately describes the true nature of the work being conducted.

A working relationship will be developed with the DOT microelectronics facility (formerly ERC) whereby they will serve as a contractor to JPL for the development of one or more custom circuits. The specific circuits and the exact relationship will be determined early in the fiscal year.

The evaluation of an ADC vs multiplexer development will be made during the first quarter of next fiscal year. If a decision is made to go ahead, procurement action will be initiated.

The evaluation and characterization of the CSR will be conducted and completed. This will include series 54L components.

Participation with the microelectronics committee will continue.

PUBLICATIONS

Contractor Reports

1. Ten-Bit Counter Shift Register, Final Report, Honeywell, Inc.,  
May 22, 1970, Contract Number 952535.

## ADVANCED RECORDING TECHNIQUES DEVELOPMENT

NASA Work Unit 186-68-03-07

JPL 384-67401-0-3630

J. C. Ashlock

## OBJECTIVE

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

## PROGRESS

With the understanding of quasi-linearity in digital tape recording as developed on this work unit and discussed in previous reports, the structure of the optimum (maximum likelihood) detector for use on detection of playback signals has been found using communication theory techniques. The form of a simpler, suboptimum (but still attractive) detector employing a transversal filter has been defined and this detector has been breadboarded; this design has been extended to a self-adaptive, time-variable detector which has also been breadboarded. The adaptive approach allows the detector to automatically adjust to the nearly optimum structure as tape recorder parameters change throughout a reel of tape or with age, wear, environment, etc. Breadboards of these detectors now have a demonstrated capability of operating at 10,000 bits per inch (bpi) on each track; furthermore, the adaptive detector has operated successfully at 20,000 bpi (40,000 flux reversals per inch maximum). Using computer simulation programs developed previously under this work unit, the adaptive detector has been studied in detail by computer simulation in order to establish the stability and accuracy of the adaption process.

This newly devised technique for the detection of tape recorder signals has been described in a new technology report and is being evaluated for patent action. A descriptive article has been submitted for publication in the Space Program Summary (see PUBLICATIONS).

Progress under this work unit has now reached the point where it is possible to design a detector for use on high density, digital tape recorder playback signals using a logical step-by-step process which takes into account all significant parameters of the tape transport and the record process. Limited work has been initiated on the problem of simplifying the resulting design to make it adaptable to Flight Data Storage Subsystems. In the time available, there was no significant return in this area.

#### PLANS

This work unit is being terminated and will not continue into FY'71. Application of the techniques developed to date will be supported by the appropriate flight project or, in the case of TOPS, by 186-68-56-09.

#### PUBLICATIONS

##### JPL Publications

1. J. C. Ashlock, "Quasi-Linearity of the Digital Record/Reproduce Process on Magnetic Tape Recorders", SPS 37-62, vol. 3, pp. 203-206, April 30, 1970.

## TOPS VIDEO DATA PROCESSING EQUIPMENT

NASA Work Unit 186-68-03-11

JPL No. 384-71001-0-3620

R. Rice

## OBJECTIVE

The objective of this task is to define the hardware and software requirements for image processing on the TOPS (Thermoelectric Outer Planet Spacecraft), and to detail the design of the imaging processor. Design of image processing for TOPS includes consideration for both science and approach guidance. Specific goals are: 1) The logical design and breadboarding of a science video data compression system, now called "the Rice Machine" (the wiggle algorithm is the principal element of this compressor). 2) The development of computer programs to regenerate the original data set from the compressed data including the capability to overcome the effects of some channel errors. The programming will also have the capability of interfacing with the breadboard. 3) The specification of on-board processing requirements for approach guidance.

## PROGRESS

A highly efficient information preserving coding algorithm was developed to handle PCM TV data with difference entropies in the principal operating range of 0 to 4 bits/pixel. The name "code word wiggle" assigned to it was descriptive of a particular tabular construction procedure used. Because of the uncertainty in camera parameters, it was felt desirable to extend efficient coding beyond the principal operating range. This was accomplished using split-pixel modes and a backup PCM option (previously reported). The combination of these additions with the wiggle algorithm makes up the complete compressor (Rice Machine). The performance of the Rice Machine has been thoroughly investigated, although complete documentation is still in progress. A graph of performance vs data entropy is shown for 8-bit data in Figure 1.

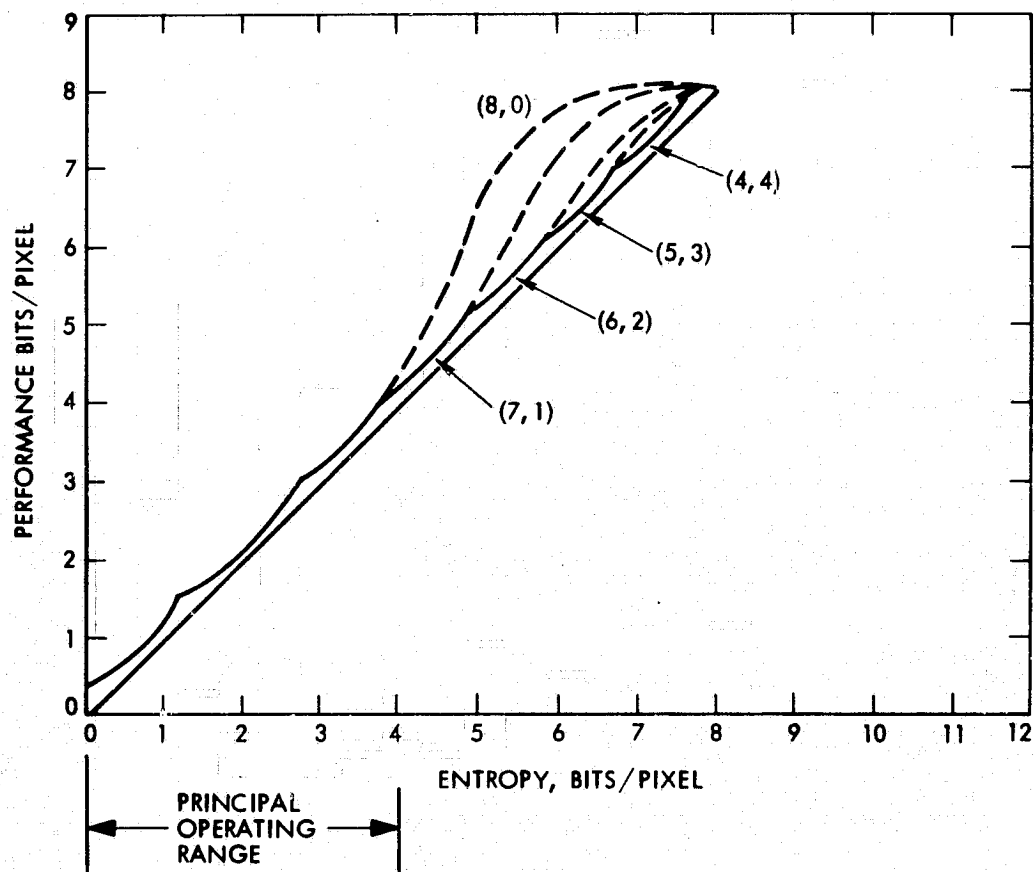


Figure 1. Performance vs Data Entropy (8-Bit Data)

The notation  $(n, k)$  describes curves for different modes. The  $(8, 0)$  curve extends into the principal operating range. Note that at least one mode always performs within 0.2 or 0.3 of the entropy. A very simple near-optimum mode switching algorithm was developed from these graphs on the basis of line-to-line correlation. Split-pixel modes other than those shown in the figure contribute additional flexibility to the system. For instance, if sensor noise increases after 5 years in space so that the least significant bits become useless, these bits may be deleted without affecting the compressor's near-optimum performance on the remaining bits.

The logical design of a breadboard model of the Rice Machine has been completed. Construction and testing of this breadboard are expected by the end of September 1970. The design of the most critical equipment necessary to interface an XDS-930 computer with the breadboard has been completed.

Considerable effort has been applied to define the interacting variables which affect on-board approach guidance (A/G) processing requirements. It has been determined that under a worst case situation the Rice Machine would be capable of transmitting back an adequate number of full A/G pictures to provide accurate coordinate estimates. Data compression of A/G pictures theoretically does not need to be information preserving. However, the fact that a system already on-board can do the job has a strong impact on the necessity for a more powerful compressor. Thus, future consideration will deal with the need and specification of this second on-board compressor.

#### FUTURE PLANS

In addition to the completion of a breadboard model of the Rice Machine and the approach guidance studies, plans call for a ground-based software decoding package by early calendar year 1971. Although very low channel error rates are anticipated for the TOPS mission, this decoding package will include some capability for the isolation and correction of errors. It will be possible to interface the breadboard with these programs via an XDS-930.

It should be noted that because of the versatility of this information preserving data compression system, its applicability, either all or in part, extends beyond TOPS data. Some preliminary investigation of additional applications will be pursued.

#### ANTICIPATED PUBLICATIONS

##### Contractor Reports

1. Rice, Robert F., "Television Data Compression for a Grand Tour of the Outer Planets", Symposium on Picture Coding, North Carolina State University, Raleigh, North Carolina, September 10-12, 1970.

#### PUBLICATIONS

None.

## TOPS SCIENCE DATA SYSTEM DEVELOPMENT

NASA Work Unit 186-68-03-12

JPL 384-72601-0-3620

D. Lee

## OBJECTIVE

The objective of this work unit is to design and develop the units that interface the TOPS Measurement Processor (MP) with the science instruments.

The interface units, also commonly referred to as Control and Conditioning Logic (CCL), will be designed to satisfy the science data, engineering data, and control requirements for each scientific instrument.

Present goals are: 1) to establish functional and interface requirements for each CCL on the basis of the proposed TOPS Science payload; 2) to design the CCL logic to the extent necessary to specify control and measurement data functional requirements on the MP; and 3) to prepare sample programs which generate science data formats in order to evaluate their ability to be reprogrammed.

## PROGRESS

The Central Data Subsystem (CDS) on the TOPS was based on the Computer Accessed Telemetry System (CATS) concept. The MP within the CDS performs the functions of controlling and formatting all the science and engineering measurement data. The special Control and Conditioning Logic units are necessary to interface the specific science instruments with the standard interface of the MP. This standard interface, which has been studied extensively and is now defined, makes use of shared data buses over which the MP sends command/control information to all the CCL's and accepts measured data from the CCL's. It provides the flexibility necessary for TOPS to accept changes in its science payload.

A total of 12 instruments has been proposed as the TOPS baseline payload. Their names and adopted acronyms are listed below:

1. Vector Helium Magnetometer (VHM)
2. Plasma Wave Experiment (PWE)
3. Infrared Multiple Radiometer (IMR)
4. Micrometeoroid Detector (MD)
5. Charged Particle Telescope (CPT)
6. Trapped Radiation Detector (TRI)
7. Trapped Radiation Instrument (TRI)
8. Ultraviolet Photometer (UV)
9. Plasma Probe (PP)
10. Radio Emission Detector (RED)
11. Meteoroid Astronomy Detector (MAD)
12. Science Imaging Subsystem (SIS)

The CCL functional requirements for these instruments are being formulated on the basis of preliminary release documents in the proposed instrument functional description. Functional interface design assumption documents have been completed for the first five instruments listed above.

Formatting of science data is accomplished with stored programs. These will be stored in the memory and accessed by the MP which executes the instructions and issues appropriate instructions to the CCL's. The sequence of CCL instructions corresponds to the sequence of data words in the format. A typical TOPS cruise science data format using the CCL instructions has been generated. This format was then deliberately altered to evaluate the reprogramming capability of CATS. Alterations made on the format include addition and deletion of certain science measurements, variation of instrument sampling rate and sampling sequence. The result indicated that programming flexibility is characteristic of the CATS. It is possible to generate a variety of science data formats from a single format by making small changes in its program.

Further, it is feasible to generate overlapping science formats and select one format from among them with minimal change in the program. This allows substantial saving in memory requirements, since it is possible to store several significantly different formats in only slightly more memory locations than required for one format.

#### PLANS

The functional and interface requirements for the remaining CCL's will be defined and updated during the next 6 months. Preliminary logic will start around October 1970.

A standard interface between the CCL and the MP will be designed and fabricated in house with the 54L series logic elements. This interface will be tested around the end of FY'71 with the MP breadboard to verify their compatibility and the desired flexibility.

#### PUBLICATIONS

None.

RF POWER AMPLIFIERS  
(ESFA DEVELOPMENT AND TUBE EVALUATION)

NASA Work Unit 186-68-04-09

JPL 384-63401-0-3360

L. Derr  
M. Hanna

OBJECTIVE

The objectives of this work unit are to develop a 20 to 100 watt S-band electrostatically focused amplifier (ESFA) with high efficiency and radiation cooling for spacecraft applications and to provide for ESFA and TWT evaluation, environmental testing, and life testing for purposes of increasing our knowledge of these devices and determining their application to deep space exploration missions.

PROCUREMENT OF LIFE TEST ESFA  
(JPL Purchase Order No. Z-509366 to Varian)

During this period, the radiation cooled ESFA to be delivered under this fixed price contract was constructed, pumped, and tested. While on the pump cycle, several leaks in the vacuum wall were detected and repaired. During the RF testing, an equipment failure caused the collector element to be disconnected. The charge accumulating on the collector turned the electron beam back into the output cavity, melting copper from its inner surface. The evaporated copper deposited on the sapphire radiation window. As the tube was reconnected to the test set, the clouded window heated and fractured. This ruined the tube.

At that point a new project engineer was assigned who has recommended numerous fabrication changes to improve the reliability of the ESFA. These changes are being made to both the radiation and conduction cooled tubes.

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Because of the failure mentioned above, it was necessary to reschedule the contract delivery dates to the following:

One Radiation Cooled ESFA:	October 15, 1970
One Conduction Cooled ESFA:	November 30, 1970
One Conduction Cooled ESFA:	January 15, 1971

#### LIFE TEST PROGRAM AT JPL

Life tests have been continued on four S-band traveling wave tubes. A Hughes 10-watt TWT, Model 216-H, has been operated for 43,000 hours. Its RF output power has degraded only 1.0 dB during this time.

Three Watkins-Johnson 25-watt TWT's are also undergoing life tests. Two of these are from the 33% efficiency W-J 274-1 series. The other is a Model W-J 274-6, which has shown an overall efficiency of 41%. The series -1 tubes have accumulated 20,800 and 21,400 hours of testing, respectively, and have shown an output power drop of 0.15 and 0.25 dB, respectively. The series -6 TWT has been life tested in a vacuum environment for 17,100 hours and has shown a loss of less than 0.03 dB during this time. All other tubes are being tested in air.

In addition, a W-J 395-3 SN/9 was placed on life test 1 May 1970. This 100-watt tube has shown no output change in its 440 hours of testing, however, the anode and helix currents do show pulsations at approximately a 2 Hz rate. These pulsations do not appear in the RF output.

#### EVALUATION OF LIFE TEST MODELS OF THE 100 WATTS S-BAND TWT (JPL Purchase Order No. 486972 to Watkins-Johnson Company)

The tubes were returned to JPL by Watkins-Johnson after mechanical modifications and prepared at JPL for continuation of the life test preevaluation. Tube SN/9 was placed in life test on 1 May 1970. Tube SN/10 underwent vibration testing to the Mariner '71 specifications during which test slight transients were observed. The tube was then placed in a vacuum chamber to begin thermal vacuum testing. After vacuum was established, the tube was energized. Five minutes later a power loss of 6 dB concurrent with a drop in

helix current was noted. A subsequent increase in pressure tripped the safety circuits and shut off the tube. This was thought to be due to outgassing, possibly in the potting compound used in this tube. Further attempts to energize the tube produced the same results. The tube was then removed from the chamber and examination indicated that an apparent ionization breakdown had occurred as a result of air entrapment during mating of the output connector. As this breakdown had occurred in the output cable, the cable was replaced, and again power was applied to the tube, and again excessive currents were noted. The test was then postponed, and an investigation (including X-ray examination of this tube, SN/10, and a control tube, SN/3) is now underway to determine the exact failure.

## PUBLICATIONS

### Meetings and Symposia

1. Hughes, R.S., "Spacecraft S-Band 10-100 Watt RF Amplifier Tubes," Presentation to the AIAA 3rd Communications Satellite Systems Conference, Los Angeles, California, April 6-8, 1970.

## ADVANCED SPACECRAFT TELECOMMUNICATION SYSTEMS

NASA Work Unit 186-68-04-11

JPL 384-63201-0-3390

J. P. Eyraud  
P. L. Parsons

## OBJECTIVE

The objective of this work unit is to provide telecommunications system design and system analysis for the Thermoelectric Outer Planet Spacecraft (TOPS) Project.

## PROGRESS

A preliminary analysis of the numerous parameters that predict the performance of the communications link between a TOPS and the DSIF tracking stations has been completed for a typical Jupiter-Uranus-Neptune (JUN) mission. Supporting investigations for the JUN mission include: Solar Noise Effects, R. F. Power Allocated to the Carrier and Data Subcarriers, and DSIF Weather Considerations. Other preliminary investigations conducted within the objectives of this work unit pertain to: Design Goal Summary of Real and Non-Real Time Data Rates, and a High Gain Antenna Polarization Study.

Additional investigations were conducted to support an outer planet mission analysis activity. These investigations pertain to proposed missions for: 1) a Jupiter Flyby/Out-of-Ecliptic; 2) a Jupiter Flyby with Entry Probe; 3) a Jupiter Orbiter; and 4) a Reduced Capability Spacecraft.

A Typical Jupiter-Uranus-Neptune Mission

The JUN mission was selected for study since it typifies a worst case analysis as both Jupiter and Neptune encounters represent worst case communications distances when compared to the corresponding encounters in a JSP trajectory. Typical telemetry link performances for the JUN trajectory are estimated to be: 1) at X-band: Jupiter = 60 kbps, Uranus = 5 kbps and Neptune = 1.7 kbps, and 2) at S-band: Jupiter = 10 kbps, Uranus = 500 bps and Neptune = 166 bps.

### Solar Noise Effects

The effects of the sun on the spacecraft receiver noise temperature was investigated. The noise increase through the low gain antenna is negligible at all times. Degradation of the receiver, when connected to the high gain antenna, starts at about 6 dB shortly after launch and decreases to 0.5 dB at Jupiter encounter.

### R. F. Power Allocated to the Carrier and Data Subcarriers

An in-depth analysis of the R. F. power allocated to the carrier and data subcarriers was performed for the JUN mission. Given a transmitter output power of 20 watts, the 20 watts is distributed as follows: carrier = 1.74 watts, science data subcarrier = 17.38 watts, engineering data subcarrier = 0.07 watts, and the power lost due to intermodulation products = 0.81 watts. For this mode of operation the modulation efficiency was determined to be 95.95% and is the mode used in the derivation of the data rates for the typical JUN mission above.

### DSIF Weather Considerations

A preliminary investigation of the weather effects upon the DSIF tracking station performance was conducted for wind, cloud cover and rain. At Goldstone, California, the wind effects are reasonably well understood, however, the wind statistics for other DSIF sites are not yet available. The final report of a DSN funded study pertaining to cloud effects has been obtained and data from it are being utilized in current analyses. Rain will be a negligible problem at Goldstone and adequate data are not yet available from the other sites.

### Design Goal Summary of Real and Non-Real Time Data Rates

A typical TOPS mission has been divided into twenty mission operational phases and a "first-look" examination of the desired data rates that would be required has been completed. A critical examination of the desired data rates versus each mission phase is yet to be conducted so as to verify the compatibility of the communications link(s).

### High Gain Antenna Polarization Study

An investigation of the feasibility of interfacing a linearly polarized spacecraft high gain antenna (with S- and X-band feeds) with a DSIF tracking station was conducted. It was determined that the DSIF tracking stations would have extreme difficulties in providing the necessary polarization tracking feed (rotatable) for the downlink carrier and at the same time provide a transmitting power of 400-KW and linearly polarized. To circumvent these problems, a spacecraft high gain antenna with circular polarization at S- and X-band will be used as the baseline design.

### Outer Planet Mission Analysis Activity

The four potential missions examined as part of this study were: 1) a Jupiter Flyby/Out-of-Ecliptic, 2) a Jupiter Flyby with entry probe, 3) a Jupiter Orbiter, and 4) a Reduced Capability Spacecraft. The objective of this study was to examine the impact and design modifications that would apply to the baseline TOPS spacecraft design in order to be adapted to meet the objectives of the four previously mentioned missions.

### INVESTIGATIONS IN PROCESS

Currently the spacecraft command subsystem is being studied. The culmination of this study will yield a functional requirements specification with particular emphasis on Functions, Parameters and Interfaces.

### FUTURE PLANS

1. Complete investigation in process.
2. A study and resulting functional requirements specification will be prepared for the spacecraft telemetry, radio and antenna subsystems.
3. Update the telecommunications design control tables that provide estimates of the communications link performance.
4. Provide support to the TOPS Design Team as required.

ANTICIPATED PUBLICATIONS

Journal Articles

1. Couvillon, Jr., L. A., Eyraud, J. P., Kermode, A., Paulos, L. B., and Woo, K. E., "Communications with Outer Planet Spacecraft," Astronautics and Aeronautics, September 1970.

PUBLICATIONS

None.

## TOPS DUAL FREQUENCY TRANSMITTER DEVELOPMENT

NASA Work Unit 186-68-04-21

JPL 384-68601-0-3360

L. Derr  
R. Dickinson

## OBJECTIVE

The objectives of this work unit are to develop long life, high efficiency S-band solid state transmitters and X-band tube RF amplifiers for the Thermo-electric Outer Planet Spacecraft (TOPS) Project and deep space outer planet missions.

## DEVELOPMENT OF AN X-BAND, O-TYPE, LINEAR BEAM AMPLIFIER TUBE

Four development proposals to build this X-band device were received and evaluated during this period. The contractor selected is the Watkins-Johnson Company and a CFFF contract for this work will be initiated by the end of this reporting period. This vendor submitted two development plans in response to the 12-year life requirement specified for this electron tube. He first proposed a single cathode TWT which would meet all the requirements except the 12-year life. He also proposed a multiple cathode TWT (similar to the multiple cathode electron gun (MEG) TWT now being developed for JPL with NASA Program 125 funding on Contract No. 952784 at S-band) as being more capable of reaching the 12-year life. Due to the fact that the MEG design has not yet been fully developed and that a considerably higher cost was involved, the single cathode TWT design was selected. It is felt that this device should be capable of a 6-year life with some possibility of more years at a higher risk factor.

The negotiated price for this work was \$388K to be funded by \$80K in FY'70 and \$258K divided between the fiscal years 71 and 72. The work under this plan will begin in mid-August 1970, and run for 18 months. During this time, six experimental and one prototype tube will be constructed and evaluated. The prototype tube will be delivered to JPL as the final item. Formal quarterly reporting has been arranged under the contract.

## SOLID STATE 20 WATT S-BAND POWER AMPLIFIER DEVELOPMENT

Based upon continuing microwave power transistor developments, it appears that for launches in the 1975 and beyond that time period a solid state S-band transmitter with an amplifier-type output stage can be as efficient as a varacutor multiplier type of output stage. Thus, the approach of this subtask will be to develop a power amplifier using the combined output of several S-band (2295 MHz) power transistors to achieve 20 watts of output power. Power combining will be required in order to adequately derate the S-band transistors for the required 12-year lifetime.

An investigation is underway to develop rational derating factors for transistor operating conditions such as allowable junction temperatures and breakdown voltage safety factors. Additionally, expected passive component value changes and active device parameter changes (gain, input/output impedances) due to aging and radiation effects during the 12-year lifetime design goal will be estimated for use in optimum reliability circuit design.

Breadboard studies of medium power coaxial transistor (RCA 2N5470) resonant cavity amplifier configurations are nearly complete. Fifty-three percent collector efficiency and 5 dB gain has been achieved at a 1 watt output level. Modifications to the cavities will now be made to use 5 watt (RCA TA 7205) transistors in a maximum efficiency amplifier mode. Also, micro-strip circuit configurations will be investigated.

## PUBLICATIONS

None.

## TOPS RF SYSTEM DEVELOPMENT

NASA Work Unit 186-68-04-26

JPL 384-71701-2-3360

J. F. Boreham  
A. W. Kermod

## OBJECTIVE

The objective of this work unit is to provide radio frequency system (RFS) support for the Thermoelectric Outer Planet Spacecraft (TOPS) Project in two specific areas: (1) Participation in the TOPS Design Team, with a goal to define the RFS and to describe its estimated characteristics and capabilities, and (2) to develop technology and hardware necessary to reduce the losses associated with antenna pointing inaccuracies and transmission components which connect the spacecraft power amplifiers to the antenna. The TOPS requirements for both types of loss exceed present hardware capabilities.

## TOPS DESIGN TEAM ACTIVITIES

Continued support was provided to the TOPS Design Team. This effort has included the continuation of a radio system design and several formal presentations covering the current RFS design status, including a TOPS Project Design Review. Design tradeoff iterations have included a preliminary study of the impact on the RFS of Spacecraft-Orbiter and Spacecraft-Probe type of missions.

The transmitter reliability studies that were previously reported have been extended to include a range of failure rates bounding the optimistic and pessimistic failure rates expected for RF hardware in the 1975 time period (assuming aggressive advanced development). A reliability study was also performed for the dual-level X-band traveling wave tubes (TWT's) that will be used to provide the periodic high data rate downlink channel. The results of the study indicate that two units (one unit in standby redundancy) will be sufficient to provide the necessary reliability for the TOPS mission.

An auxiliary oscillator reliability study was performed for the use of single, dual, and triple auxiliary oscillators using mission lifetimes ranging from  $10^3$  to  $10^5$  hours. For a  $10^5$  hour mission, triple redundancy would be recommended for this critical function.

Receiver and overall RFS reliability studies will be performed during the next reporting period.

#### ANTENNA POINTING ELECTRONICS

Closed loop RF pointing will be used to maintain the high gain antenna X-band pointing loss to less than 0.3 dB (0.09 degrees for a 14 foot parabola). This will be accomplished through the use of an S-band monopulse antenna feed, which is currently being developed under "TOPS High Gain Antenna and Feed," (186-68-04-27), coupled to the redundant tracking electronics. The antenna pointing electronics will be compatible with the receiver being developed under "Multi-Mission Spacecraft Radio Research," (125-21-09-05-02).

Two companies (Motorola and TRW) responded to an RFQ for the development of the tracking electronics in conjunction with an advanced transponder receiver. Motorola was selected for the 6-month study and development contract effort at a price of \$89.3K (\$35K from 186 funding and the remainder from 125 funding). The study effort, expected to commence on 6 July 1970, calls for a design study of an advanced transponder with multi-mission, deep space application. Emphasis is to be placed on (1) high reliability, (2) simplicity of design, (3) cost minimization based on multi-mission capability, (4) cost effectiveness analysis for all basic tradeoff decisions, (5) improved performance characteristics, including improved threshold and adaptive phase tracking loops, (6) low DC power consumption, and (7) insensitivity to the operating environment.

The tracking electronics portion of the study will consist of a tradeoff study and selection of the monopulse RF angle tracking system to be used in conjunction with the basic transponder receiver. The tradeoff studies and analyses will include the following: (1) block diagram studies; (2) tracking electronics signal-to-noise ratio analysis to determine overall antenna pointing

capabilities and limitations versus received power level; (3) phase and amplitude error analysis for the RF, IF, and detector portions of the system for each mechanization studied; (4) the effects of doppler offset, doppler rate, and signal-to-noise ratio on overall performance; (5) cross coupling effects between channels and receivers; (6) modulation analysis to determine cross modulation and interference resulting from the uplink command modulation, ranging modulation frequencies; (7) tracking electronics RF pre-selector filter requirements; and (8) determination of the transfer function for the tracking electronics with specification of the angle error channel(s) accuracy and resolution capability for the range of receiver parameters specified in the contract.

#### LOW LOSS RF COMPONENT DEVELOPMENT

Solid state and electromechanical S-band RF switches have been under development and evaluation as previously reported. The AIL SPDT 100 watt diode switch failure previously reported was repaired after some difficulty. With the installation of the replacement PIN diode, it was necessary to clean all previous potting material out of the cavity in order to obtain satisfactory repotting, using the low loss dielectric material. High power testing was resumed at the 25 and 50 watt power levels. The insertion loss performance characteristics for the repaired side of the switch were degraded from the previously reported 0.26 dB maximum to 0.36 dB, and the VSWR increased to 1.33 from the previous 1.10 maximum. The isolation remained greater than the previously reported 37.5 dB minimum. The change in performance characteristics is attributed to the parameters of the replacement diode as well as the mechanical tolerances of the structure upon reassembly. The switch failed at the 75 watt power level; a failure analysis revealed that the replacement diode had shorted. The switch was operating in the low loss mode (diode reversed bias) at the time of failure.

The diodes utilized in the AIL switch design have a breakdown voltage specification of 400 volts minimum, which is marginal for the design. Replacement diodes with a breakdown voltage of 1,000 volts have been ordered from two different manufacturers. An in-house switch redesign effort will incorporate the higher breakdown voltage diodes.

A purchase order was placed with Computer Metrics to perform an evaluation of the X-band electromechanical switches, utilizing a computerized microwave network analyzer. The evaluation was performed over a frequency range of 1.0 to 18.0 GHz and for temperatures of -10°C, +25°C, and +75°C. The evaluation included 10 SPDT and 5 transfer switches. The measurements have been completed and the data are being analyzed. Upon completion of data analysis, switches will be selected for vacuum power tests.

## ANTICIPATED PUBLICATIONS

### Journal Articles

1. Couvillon, Jr., L. A., Eyraud, J. P., Kermode, A. W., Paulos, L. B., and Woo, K. E., "Communications with Outer Planet Spacecraft," Astronautics and Aeronautics, September 1970.

## PUBLICATIONS

### JPL Publications

1. Kermode, A. W., "TOPS Radio Frequency Subsystem," SPS 37-61, vol. III, May 31, 1970.

### Meetings and Symposia

1. Kermode, A. W., "Deep Space - Outer Planet Communications," IEEE 1970 International Conference on Communications, June 8-10, 1970.

## TOPS HIGH GAIN ANTENNA AND FEED

NASA Work Unit 186-68-04-27

JPL 384-71401-0-3330

K. E. Woo

## OBJECTIVE

The objective of this work unit is to develop new technology required for the antenna subsystem of the Thermoelectric Outer Planet Spacecraft (TOPS). The primary objective is to develop a dual frequency (S- and X-band), high efficiency feed system for the TOPS high gain antenna. A second objective is to reduce the TOPS antenna pointing loss. A third objective is to evaluate the prototype TOPS antenna system.

## PROGRESS

During the second half of FY'70, the RF design of the prototype TOPS S/X band feed (linearly polarized) has been completed. Test results show that the feed meets TOPS RF requirements at all operating frequencies. The feed efficiency reaches about 73% at 8448 MHz, 64% at 2295 MHz, and 51% at 2115 MHz, without including the losses due to aperture blockage. The mono-pulse provides boresight null depth of more than 40 dB below the peaks of the difference channels. The fabrication of the feasibility model of the feed is expected to be completed at the end of FY'70.

The RF evaluation of main reflector surface materials for the TOPS unfurlable high-gain antenna has also been completed. It has been found that, in general, the gold-plated Chromel-R mesh exhibits less reflectivity loss than that of the copper-coated Dacron Mesh. The reflectivity loss at 8448 MHz of the gold-plated Chromel-R mesh provided by Prodesco, Inc. is in the range of 0.03 to 0.08 dB, which is compatible with TOPS RF reflectivity requirement (<0.1 dB).

Using the techniques developed in the related work unit 125-21-09-02, "S/C Antenna and Propagation," the geometry of the TOPS high-gain antenna (14 ft diameter) has been determined. The focal-length-to-diameter ratio of the main reflector is 0.420, a selection based on RF performance, feed location, and the desirability of latching the ribs of the main reflector to the subreflector when the antenna is in furled condition. Based on latest feed patterns, preliminary design of the subreflector calls for a 29.7-in. diameter hyperboloid with a small extension flange for minimizing the diffraction loss of the hyperboloid. Refinement of the subreflector design is in progress.

Based on the techniques developed in the same related work unit, the defocusing effect of the TOPS high-gain antenna has been investigated. It is found that the gain reductions at 8448 MHz, due to a defocusing of quarter, half, and one wavelength are approximately 0.25, 1.0, and 4.3 dB, respectively. The comparison of RF performance between focalpoint and Cassegrain antenna systems has also been investigated. It is found that for the TOPS 14-ft diameter high-gain antenna, the Cassegrainian system will provide slightly higher aperture efficiency than that of the focal-point system, in addition to providing in-flight refocusing and beamsteering capabilities.

#### FUTURE WORK

The feasibility model of the S/X band feed will be RF tested and delivered to TOPS during the first quarter of FY'71. A short investigation of circularly polarized and switchable circular/linear type feeds will be conducted during the same period. In the remaining period of FY'71, a non-flight type TOPS subreflector will be fabricated and tested, RF performance of TOPS antenna system will be evaluated, and beamsteering by tilting the subreflector will be studied.

#### ANTICIPATED PUBLICATIONS

##### Journal Articles

1. Couvillon, Jr., L. A., Eyraud, J. P., Kermode, A., Paulos, L. B., and Woo, K. E., "Communications with Outer Planet Spacecraft," Astronautics and Aeronautics, September 1970.

JPL Publications

1. Woo, K., "Further RF Test Results of Reflector Surface Materials for Spacecraft Antennas," SPS 37-63, vol. III.

## PUBLICATIONS

JPL Publications

1. Woo, K., "High-Efficiency S- and X-band Telemetry and Tracking Feed," SPS 37-60, vol. III, pp. 36-41, December 31, 1969.
2. Woo, K., and Otoshi, T. Y., "An RF Study of Reflector Surface Materials for Spacecraft Antennas," SPS 37-61, vol. III, pp. 99-106, February 28, 1970.
3. Holland, R., "Large Spacecraft Antennas; Optimization Criterion for Illuminating Circular Antenna Apertures," SPS 37-61, vol. III, pp. 111-120, February 28, 1970.

## TELEMETRY DATA SYSTEM IMPLEMENTATION

NASA Work Unit 186-68-04-29

JPL 384-73101-0-3620

R. Easton

## OBJECTIVE

This work unit is a companion to 125-23-12-13, "Efficient Telemetry Data Systems," now terminated. Together, these work units address the problem of efficient, reliable data systems for advanced outer planet missions of the Thermoelectric Outer Planet Spacecraft (TOPS) class. The companion 125 account concentrated on the discovery and analysis of basic algorithms. This 186 work unit accomplishes the detail design, development, and application of the new idea generated under the OART(125) sponsorship.

## PROGRESS

During the past 6 months, substantial progress was made in the design and development of a fast, flexible, and reliable data system for the TOPS. This system, called CATS (Computer Accessed Telemetry System) represents a significant departure from the Mariner telemetry system organization and implementation. Under the auspices of this work unit, the CATS has been simulated on a general-purpose computer, and the operation of its major logic paths has been verified. This milestone was completed on schedule. A new structure for an analog commutator has been designed, built from hybrid technology, and tested. The new "tree" structure has been shown to have substantial reliability, power, weight, and volume advantages over the "deck" structure used for the Mariner missions. Studies have been made of the application of the CATS concept to a centralized data processor for the TOPS, and this organization has been formally adopted in the TOPS system design.

A simplified version of CATS having programmable sequencing, but no data processing capability, has been constructed and tested during this report period. Software for automatic programming, monitoring, and testing of the breadboard using a small general-purpose computer is virtually complete.

A 256 channel tree-type analog commutator incorporating internal redundancy and hybrid circuitry, based on the prototypes tested during the last reporting period, is expected to be completed in July. This 2-month delay in meeting the milestone results from delays in obtaining the electronic components for mounting in the hybrid substrates, and should not impact future milestones.

The detailed logic design of the full scale CATS measurement processor breadboard for TOPS is 50% complete and should be completed within the next 6 months, to be followed by construction and testing. The hardware and software interfaces for efficient interaction with an on-board STAR control computer have been defined and partially designed. This computer will be able to backup CATS in the event of a CATS hardware failure and the two units will share a common memory to conserve hardware and facilitate the efficient transfer of data between them. The STAR computer development is funded by OART.

The interface with the science instrument control and conditioning logic (CCL) has been defined. The CCL's are being developed under companion work unit 186-68-03-12. We are progressing on choosing the most effective formatting method for the transmission and storage of CATS data.

A study of the command data processing function was initiated during this period. The characteristics of earlier command subsystems were reviewed, and a general approach to the TOPS command function was outlined. The use of error-correcting codes to assure reliable performance was considered; many alternatives are available, but further study is needed to establish the required level of performance.

## PLANS

The CATS logic design is expected to be completed within the next 6 months, with construction and testing the following 6 months. Tests will continue on the breadboarded sequencer and tree switch and their computerized support equipment described above. In addition, studies of the advantages to be gained for TOPS by the use of the data processing and formatting schemes under consideration, using data from recent Mariner shots, will be made.

During the next 6 months, the studies should lead to the establishment of the functional requirements of the Command Decoder Subsystem so that detailed design can be started. This work will be accomplished under a companion work unit 186-68-56-03, Spacecraft Control Computer.

## PUBLICATIONS

### Meeting and Symposia Papers

1. Easton, R., Efficient Spacecraft Data Systems, IEEE 1970 National Telemetry Conference Proceedings, April 1970.

## TOPS SCIENCE INSTRUMENTS RADIATION EFFECTS STUDIES

NASA Work Unit 186-68-06-11

JPL 384-72701-0-3250

R. H. Parker

## OBJECTIVE

The objective of this task is to determine the maximum allowable radiation levels of the science instruments of TOPS consistent with acceptable radiation interference of the experiments and to design internal shielding where necessary to achieve acceptable radiation levels. The radiation environment includes gammas and neutrons from the RTG and natural radiation from planetary trapped radiation, the solar wind, solar flares, and cosmic rays.

## PROGRESS

The design restraint radiation levels for charged particles have been reiterated several times in the last six months with the last change being dated June 16, 1970. The radiation damage thresholds for electronic components as reported in the JPL contract #952565 to Boeing together with the design indicates a severe proton problem. Boeing reports permanent damage thresholds beginning as low as  $10^8$  protons/cm<sup>2</sup> for 20 MeV protons while the design restraint indicates  $9.6 \times 10^{11}$  p/cm<sup>2</sup> for  $10 \leq E_p \leq 30$  MeV and even larger fluxes at higher energies. In fact the fluence for  $E_p > 1$  MeV is  $6.5 \times 10^{12}$  p/cm<sup>2</sup>.

For the various detectors listed in Table I damage problems also exist, but more critical are the interference levels which are indicated in the table. Solutions to the problems being considered range from ignoring the severest models all the way to altering the trajectories to avoid the peak flux areas at Jupiter. Direct experimenter contact to determine acceptable radiation levels is continuing and those contacted are indicated in Table I.

Experiments are underway at JPL to examine radiation effects on selected components. Electron effects on UV enhanced Si photodiodes and continuous multipliers are being investigated with Sr<sup>90</sup>/Y<sup>90</sup> beta sources. Si surface

barrier detectors, GM tubes, Photomultipliers and Si vidicon tubes are being or will be tested for RTG gamma and neutron interference in the simulated RTG facility. Additional tests for these and other devices are planned using facilities such as the Dynamitron accelerator.

Radiation tests off-Lab are being conducted through the Quality Assurance and Reliability Division which has a commitment with GSFC for both electron and proton irradiation tests which will be accessible for several science instrument component radiation tests.

The literature search is continuing at a reduced level to complement the Boeing report previously mentioned.

The report on the gamma scattering and wall albedo experiment is in final editing and should be published in July 1970.

The TOPS Radiation Environmental Testing Working Group has completed radiation test results and is recommending standardized test levels and reporting procedures for all spacecraft components including science instrument components.

Simplified spacecraft model shielding calculations have been reported by the Engineering Mechanics Division. These give a three order of magnitude decrease in RTG fluxes in the science area over the bare RTG calculations. More realistic spacecraft model calculations, expected in early FY'71, will allow accurate determination of the configuration and weights of the base line science instrument shields.

Summarized in Table I is the current position of the TOPS Science Instruments Radiation Effect Studies.

#### PUBLICATIONS

None.

Table I. Science Experiments Maximum Radiation Environment

Experiment Base Line Instrument Model	Sensitive Component	Acceptable Radiation Level	
		RTG (Y, n)	Charged Particles
Charged particle telescope J. A. Simpson-U. of Chicago-P	LI drifted solid state detector and photodiode and a silicon cylinder	To rads (total mission) $5 \times 10^{10}$ n/cm <sup>2</sup>	--
Vector helium magnetometer E. J. Smith - JPL-P	Electronics	<10 <sup>4</sup> rad* (γ) (95 mr/hr)  <10 <sup>12</sup> n/cm <sup>2</sup> (U <sup>235</sup> fission spectrum)	<10 <sup>8</sup> p/cm <sup>2</sup> (1 MeV)  <10 <sup>11</sup> e/cm <sup>2</sup> (1 MeV)
Imaging (TV) M. Smokler JPL-O	Visible E & M radiation detector (e. g., vidicon)	Designing component tests	
Infrared multiple radiometer P. Schaper-JPL-O	Cooled bolometer (contains germanium foil)	Designing component tests	
Meteoroid astronomy detector R. K. Soberman-GE-P	Photomultiplier (interference of sensitivity)	<10 <sup>4</sup> rad (γ) <10 <sup>11</sup> n/cm <sup>2</sup>	<4 X 10 <sup>8</sup> p/cm <sup>2</sup> <10 <sup>12</sup> e/cm <sup>2</sup>
Micrometeoroid detector W. H. Kinard-LRC-P	Electronics	<10 <sup>4</sup> rad* (γ) (95 mr/hr) <10 <sup>12</sup> n/cm <sup>2</sup>	<10 <sup>8</sup> p/cm <sup>2</sup> <10 <sup>11</sup> e/cm <sup>2</sup>
Plasma probe H. Bridge-MIT-VM C. Snyder-JPL-VM	Channeltron	<10 <sup>10</sup> counts (all radiation) Component testing in progress	

\*Does not include SCR's which show damage at levels as low as 500 rad.  
P-Pioneer F/G instrument; VM - Mariner Venus Mercury proposed instrument;  
O other proposed instrument

Table I. Science Experiments Maximum Radiation Environment (Cont)

Experiment Base Line Instrument Model	Sensitive Component	Acceptable Radiation Level	
		RTG ( $\gamma, n$ )	Charged Particles
Plasma wave F. L. Scarf-TRW-VM	Electronics	$<10^4$ rad* ( $\gamma$ ) (95 mr/hr)	$<4 \times 10^7$ p/cm <sup>2</sup>
		$<10^{12}$ n/cm <sup>2</sup>	$<10^{11}$ e/cm <sup>2</sup>
Trapped radiation experi- ment R. W. Fillius-UCSD-P J. A. Van Allen-U. of Iowa-P	Cherenkov, totally depleted surface barrier, and single element solid state detectors two element solid state telescope and a photomultiplier	Designing tests and testing in progress	
Ultraviolet photometer D. L. Judge-USC-O	Channeltron	Component testing in progress	
Radio astronomy J. K. Alexander-GSFC-O	Electronics	$<10^4$ rad* ( $\gamma$ ) (95 mr/hr)	$<4 \times 10^7$ p/cm <sup>2</sup>
		$<10^{12}$ n/cm <sup>2</sup>	$<10^{11}$ e/cm <sup>2</sup>
X-Ray K. A. Anderson-UCB-O G. Garmire-CIT-O	Proportional counters	$<21$ rad ( $\gamma$ )	$<10^8$ (p+e)/cm

140

701-90

\*Does not include SCR's which show damage at levels as low as 500 rads.

P-Pioneer F/G instrument; VM - Mariner Venus Mercury proposed instrument; O other proposed instrument

## TOPS - PHOTOSCIENCE SUPPORT ACTIVITY

NASA Work Unit 186-68-06-12

JPL 384-72801-0-3210

Terrence H. Reilly  
Leonard Larks

## OBJECTIVE

The objective of this activity is to provide support to the TOPS Design Team in the areas of science objectives, mission planning, and instrument development for the imaging experiment.

## PROGRESS

Completion of Preliminary Science Objectives Manuscript

A preliminary statement of science objectives for outer planet imaging experiments was prepared during the previous reporting period. This manuscript has now been edited and published as a JPL Technical Memorandum.

Continuation of Science Survey

The effort to revise and refine our understanding of the imaging science objectives was continued. This was done through meetings with individual scientists, surveys of the literature, and participation in a seminar on the exploration of the outer planets at the California Institute of Technology. One outcome of this continuing study has been an increased emphasis on photographing the outer planet satellites.

Preliminary Experiment Profiles

Some preliminary profiles for the imaging experiment were prepared. This was done by first choosing a candidate imaging system, data storage system, science telemetry rate, trajectory, etc. Next, the number, timing, and quality of the photographs which can be obtained under the assumed conditions are tabulated. This procedure is then repeated for other choices of

hardware and trajectory. These profiles are one source of guidance to the Design Team in making hardware and trajectory decisions.

#### Support for Preparation of Imaging System Functional Requirements

A preliminary functional requirements document has been prepared for the imaging system. Photoscience support was provided in the areas of required image quality, number and timing of pictures required, weight estimates for optical components, etc.

#### Support for Star Simulator Design

A requirement exists for an imaging system capable of photographing the outer planet satellites against a star field for the purpose of approach guidance. Little is known about the response of imaging sensors to point sources of light (stars), so tests must be undertaken to determine this response. A suitable view of the stars is not easily available for these tests, so a star simulator is being built for laboratory use. Photoscience support has been provided in the design of and procurement of parts for this simulator.

### PLANNED ACTIVITIES

#### Revision of Science Objectives

The effort to keep current our understanding of the imaging science objectives will continue. This should result in a revision of the science objectives document early in the second quarter of the fiscal year.

#### Photometry and Colormetry Review

A summary of earth based photometry and colormetry of the outer planets will be prepared and evaluated for use in planning the imaging experiment.

#### Performance vs Reliability Trade-off

Because outer planet flight times are on the order of 10 years, the imaging sensors used may represent a compromise between high performance and long life. An assessment of the reduction in scientific return should be made for any such compromises that are identified.

Preparation of APO Material

It is anticipated that an advisory group of scientists will be appointed at some early date to assist in mission planning. A description of our present concept of the imaging experiment will be prepared for use in connection with the Announcement of Planning Opportunity.

Science Requirements Document

A document stating mission requirements for the successful completion of the imaging experiment will be prepared.

Design Team Support

General photoscience support to the Design Team will continue.

PUBLICATIONS

JPL Publications

1. Reilly, T. H., "Scientific Objectives for Imaging Experiments at the Outer Planets - A Discussion," JPL TM 33-454, June 15, 1970.

TOPS IMAGING SYSTEM  
NASA Work Unit 186-68-06-13  
JPL 384-72901-0-3210  
M. I. Smokler

## OBJECTIVE

The objective of the TOPS Imaging System task is to provide a sound basis for the design and development of an imaging system which meets the experiment requirements of the outer planet missions within the limits of spacecraft constraints. The outer planets missions place more stringent requirements on the imaging system than have been levied by any previous planetary mission. More sensitivity is required because of the low level of solar irradiance at the far planets. Radiation effects are of concern for the first time because of the use of a radio-isotope thermal generator (RTG) for spacecraft power, but more particularly because of the flux of high energy electrons and protons expected during transit of the Jovian radiation belts. But the most severe problem is introduced by the long life required. Operating life will be long because of the many planets and satellites to be photographed and because of the need to initiate far encounter sequences early enough to match the scale of earth based photographs. Storage life, before launch and in flight, is also a serious obstacle for some components.

The activities in pursuance of the objective include system design and tradeoff studies, liaison with approach guidance activities, and study and evaluation of sensors. One activity previously reported, the definition of a video simulator for the TOPS Feasibility Model spacecraft, has been eliminated because of this spacecraft has been dropped from the TOPS plan.

## ACCOMPLISHMENTS

### Functional Requirements

A major item of work completed consists of Document No. TOPS-4-2048, Functional Requirements for the TOPS Science Imaging Subsystem. This

document has been submitted to the spacecraft design team for system level review. It includes experiment requirements, experiment profile, imaging system requirements, a baseline system design and interface definition. The baseline system consists of two cameras, with narrow and wide field angles. The narrow angle camera is designed to yield resolution of 10 kilometers or better at each planet and is designed around a silicon intensifier target (SIT) vidicon. The wide angle camera has ten times a large a field angle and is designed around a silicon vidicon.

### System Design

The system design effort has included design calculations on line scanner systems, photographic film systems, and electron imaging tube systems. A complete set of parametric design curves has been developed to expedite system design. Performance tradeoff curves have been prepared to show theoretical limitations and sensitivity-resolution interdependency.

### Approach Guidance

Liaison with approach guidance activities has been maintained by participation in the Approach Guidance/Science Imaging working group. System studies and sensor investigations have included consideration of approach guidance requirements. Work has been started on design of equipment needed to measure the response of various imaging sensors to simulated stars; this will provide a basis for predicting performance of the science imaging system in the approach guidance function.

### Imaging Sensors

Thorough investigations have been undertaken of a variety of imaging sensors, with particular emphasis on the Mariner vidicons, silicon vidicons, silicon intensifier target (SIT) vidicons, and dielectric tape cameras. Commercially available silicon vidicons have been purchased for evaluation. Arrangements have been made for radiation testing of these vidicons. An order has been placed for two special silicon vidicons, one with a cooled faceplate and one with a charge storage layer at the target. These will be used to investigate storage and slow scan potential of the silicon vidicon.

The imaging sensor requirements revealed by system design, the limitations of sensors revealed by the sensor investigations, and the lead time required for imaging systems have lead to the conclusion that support is needed for sensor development in the immediate future. A sensor development plan has been prepared which supports this conclusion and proposes a specific development program.

#### FUTURE PLANS

System tradeoff studies will continue in order to determine the effects of significant design changes on the imaging experiment. Particular attention will be devoted to design approaches which promote reliability. The tradeoff studies will include investigation of the various combinations of data rates, buffer storage, bulk storage, and operating sequences. As data become available for the intensifier-vidicon being developed for the Viking Orbiter, the possible use of this tube in an outer planet imaging system will be investigated. Data from investigation of response to subaperture images (of stars) and from other sensor evaluation experiments will be used to refine the system design.

Design and development of a star simulator and special electronic circuitry related to star imaging will be continued. Measurement will be made of the response of various sensors of interest to point source images. Field tests of a Mariner camera performing star imaging will be supported.

Several silicon vidicons will be submitted to evaluation experiments, including evaluation of the effects of radiation. The special silicon vidicons on order will be tested for storage and slow scan capabilities. Investigation of possible solutions to sensor problems will continue. If support is provided, the sensor development plan will be implemented.

#### PUBLICATIONS

None.

## ADVANCED SYSTEM TECHNOLOGY/SCIENCE PAYLOAD INTEGRATION

NASA Work Unit 186-68-06-14

JPL 384-72702-0-2960

P. C. Theisinger

## OBJECTIVE

The objective of this work unit is to integrate a science payload onto the Thermoelectric Outer Planet Spacecraft (TOPS). Identify and resolve specific problems associated with that baseline payload and investigate alternate instruments for inclusion in the payload. Investigate problems of instrument reliability and redundancy associated with a Grand Tour Mission.

## PROGRESS

Functional requirements have been written for all instruments. Those instruments which are slight modifications of previous designs have functional requirements which go into significant detail. Those instruments which are more conceptual have very gross functional requirements. Significant progress has been made in obtaining information on temperature requirements and special requirements.

Although no detailed reliability and redundancy studies have been done, the areas of reliability concern for the instruments have been identified. A continuing liaison with the Space Science Division has been established concerning their work in the radiation susceptibility of selected science detectors. Inputs to the Space Science Division have also been made on a science management plan that would assure the production of reliable science instruments.

## PLANS

During FY'71 this work will continue. Liaison will continue with the TOPS Design Team. Functional requirements will be generated for a revised science payload based on inputs from the Space Science Division, and this revised payload will be integrated into the TOPS design. Detailed reliability studies will be initiated to cover the radiation susceptibility of those instrument

detectors not currently being investigated, and other areas of reliability concern that have been identified.

**PUBLICATIONS**

None.

## MULTIMISSION SPACECRAFT COMMAND TECHNIQUES

NASA Work Unit 186-68-09-02

JPL 384-73201-0-3390

A. Couvillon

## OBJECTIVE

This work unit accomplishes the design and development of flexible, reliable, high-performance command detection systems for advanced missions to the outer planets.

## PROGRESS

The development of the all-digital command detector invented in early FY'70 has progressed very well. A breadboard system has been constructed and various tests have been run. The breadboard embodies two variations of the basic algorithm; Mark I, with 15 subcarrier cycles per data bit, and Mark II, with 225 subcarrier cycles per data bit, which is better suited to low bit rates.

The breadboard system accomplishes all the required functions of acquisition, tracking, data detection, and lock detection. Its performance in each of these respects is substantially in accordance with theory, as shown in Figures 1 and 2. Figure 1 is the data detection performance of the new system; the experimental points are seen to be within about 0.4 dB of the theoretical limit representing a perfectly synchronized optimum receiver. Figure 2 shows the experimental static tracking error performance compared to a theoretical bound. Similar results have been obtained for system acquisition and lock detection.

This new system offers substantial performance, weight, power, volume, reliability, and cost advantages over the analog command systems which have been used on the Mariner missions.

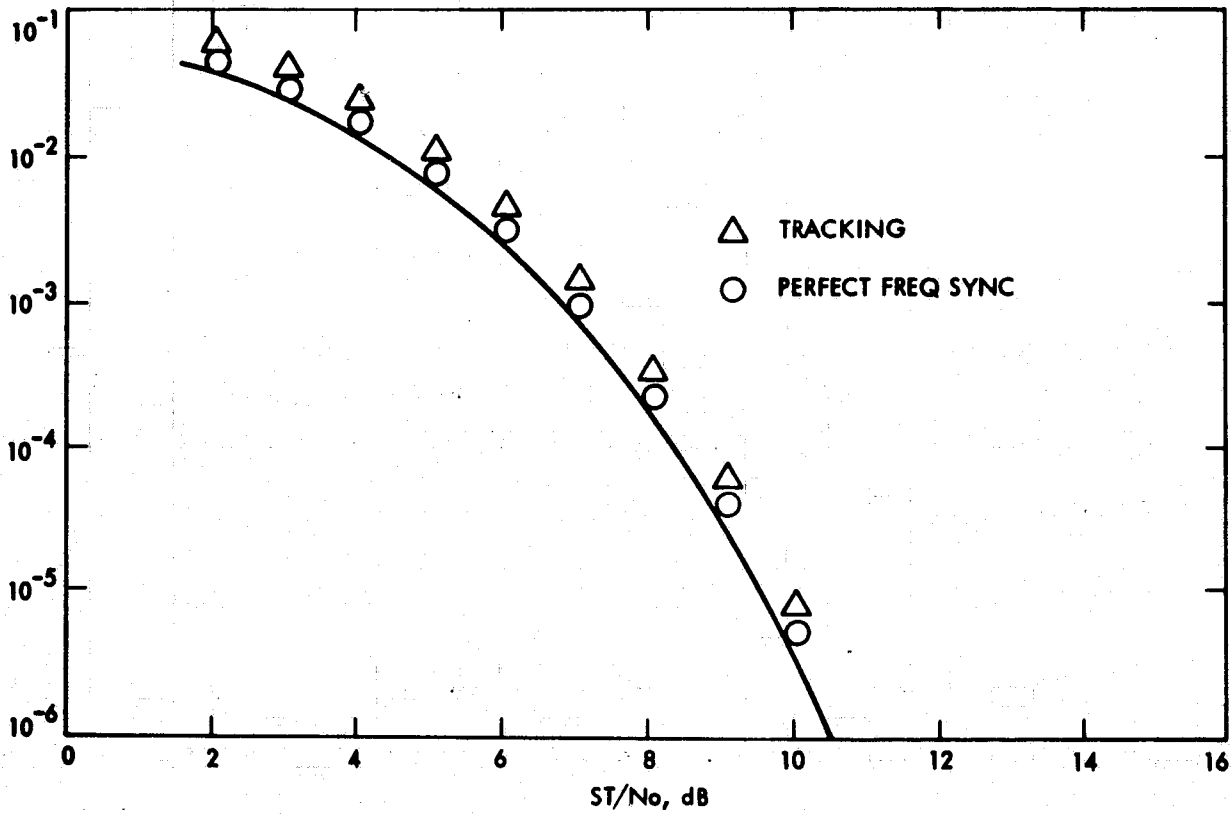


Figure 1. Command Bit Error Rates - Theoretical Limit and Experimental Measurement

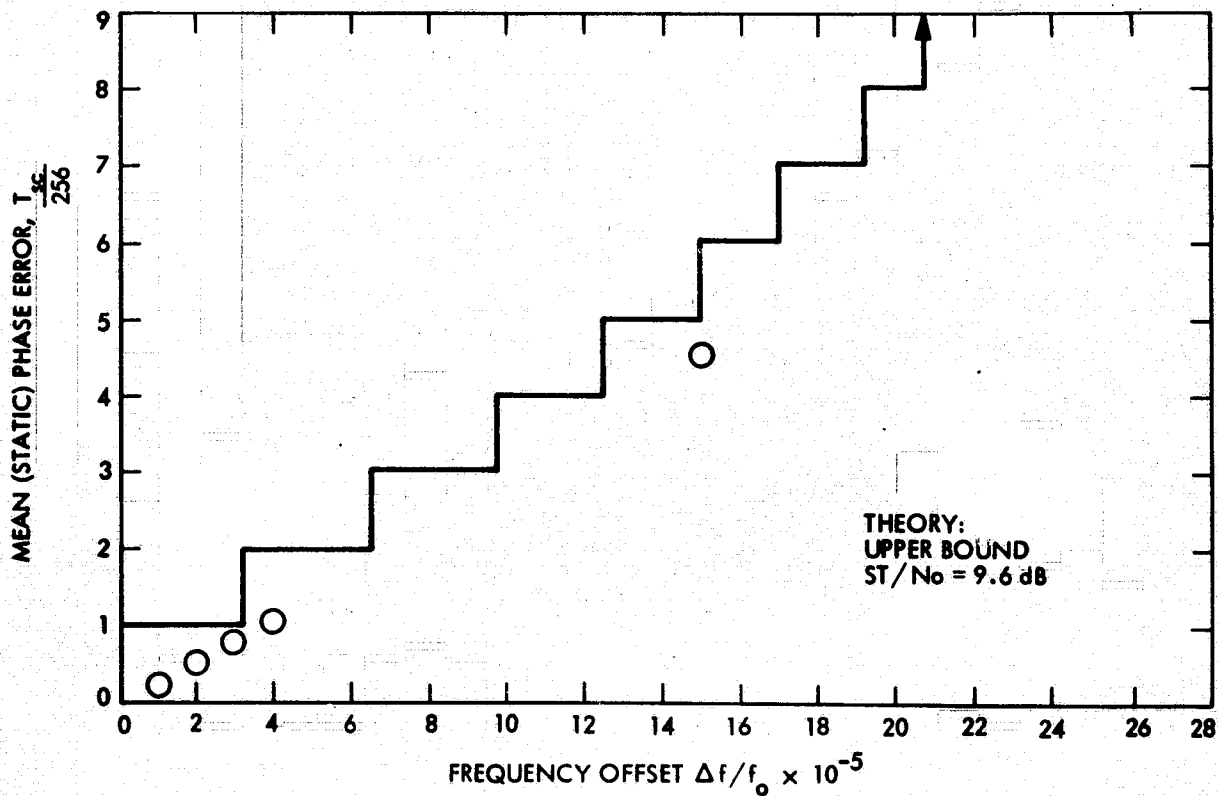


Figure 2. Command Subcarrier Tracker Error - Theoretical Bound and Experimental Measurement

## ANTICIPATED PUBLICATIONS

Journal Articles

1. Couvillon, Jr., L. A., Eyraud, J. P., Kermode, A., Paulos, L. B., and Woo, K. E., "Communications with Outer Planet Spacecraft," Astronautics and Aeronautics, September 1970.

## PUBLICATIONS

Meeting and Symposia Papers

1. Couvillon, L.A., "Microelectronic Spacecraft Command," paper for the NASA Microelectronics Conference, February 1970, Hampton, Va. (Conference was cancelled, but proceedings were published.)

JPL Publications

1. Couvillon, L.A., "Spacecraft Command Techniques," SPS 37-59, vol. III.
2. Tegnalia, C.R., "Digital Command System Development," SPS 37-60, vol. III.

THERMOELECTRIC OUTER PLANET SPACECRAFT  
ADVANCED SYSTEM TECHNOLOGY

NASA Work Unit 186-68-09-09

JPL 384-70604-0-2940

E. L. Divita  
R. F. Draper  
G. W. Haddock  
W. S. Shipley

## OBJECTIVE

The purpose of the Thermoelectric Outer Planet Spacecraft (TOPS) Project is to demonstrate the capability to perform missions to the outer planets, specifically the Grand-Tour-type mission, and to develop necessary system design capabilities through the design and testing of a feasibility model spacecraft.

A major objective of the TOPS Project is to perform design and developmental testing of the spacecraft system, subsystems, and subassemblies using the technologies critical to this type of mission. The interactions of the subsystems in the integrated system will be evaluated so that realistic performance, reliability, and cost estimates can be made. The spacecraft design will emphasize the use of advanced system technology. Detailed objectives are presented in the TOPS Policies and Requirements Document (Ref. 1) and were previously listed in the FY'69 Semiannual Review of Research and Advanced Development, December 1968.

The objective of the environmental requirements work is to support TOPS by developing new environmental definitions and test requirements to evaluate the feasibility of the Outer Planet Spacecraft and long life missions.

In addition to the system design and environmental requirements efforts, this work unit supported TOPS Project Management, mission engineering, and nuclear operations evaluations.

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## PROGRESS

### System and Subsystem Design

#### System Design

The system design is essentially complete from the standpoint that major functional approaches have been agreed to by the system design engineers and cognizant subsystem engineers. The nature of the advanced system technology task, however, requires system iteration with new ideas and approaches so that appropriate changes may be made throughout the project. The TOPS design team has produced Functional Requirement (FR) Documents; many of which have been approved and the remainder are in the process of being approved. These FR's indicate the agreement areas and define the system, subsystems, and their interfaces.

The weight and power tables, the flight sequence, S/C command and telemetry lists, and spacecraft functional block diagrams have been updated to reflect the results provided by additional investigation in all areas.

System interface meetings have defined how the failure-sensing and switching logic is to be divided between each subsystem and the Control Computer Subsystem (CCS). Also, these meetings have established the sizing of the CCS memory and processors.

#### Spacecraft Configuration Design and Selection

Spacecraft configuration studies have continued and small changes were incorporated in the basic design. Coordination of the AEC's multihundred watt RTG study with JPL activities has resulted in using their baseline design and a modification to the 2 parallel and 2 series arrangement of the RTG's. This was done primarily to make installation of the RTG's as simple and quick as possible; thereby, minimizing personnel radiation dosage. The Radio Emission Detector (RED) science experiment has been integrated into the baseline payload. Attitude propulsion thrusters have been configured as couples in roll and moments in pitch and yaw. This maintains the least amount

of plumbing, no additional heater requirements, and ease of installation into the spacecraft. The number of thrusters is small enough to allow a complete standby set of thrusters.

### Reliability

(Reliability analyses have continued in the subsystem areas by system engineers.) An analysis was made of the number of Command Detector Subsystem standby units required to complete the mission. The Measurement Processor Subsystem has determined that the STAR coding methods can be used on at least 50% of the functions. Check steps can be put in the software to validate the remaining steps. The Control Computer Subsystem reliability analysis was completed with the existing design. The simplified detailed design will use these results. A system reliability model was worked for selected allocation for each subsystem. The results of subsystem reliability models will be used in the model in the future. A reliability implementation plan was developed to achieve the needed long life capability.

### Buffer Memory Module

The development of the semiconductor memory module (SMM) indicated the approach was beyond the funds available to TOPS.

### High Gain Antenna

A review of the high gain antenna was held. Evaluation was made of several structural designs, reflective materials, and results expected of in-house or contracted efforts. A radial rib (48), unfurlable, Chromel R mesh reflector, in-house design with a large central hub antenna, will be built.

### Approach Guidance and Power Distribution

Extensive trade-off analysis by a special study team will establish compatibility between the science imaging and the approach guidance imaging during the next quarter. Power hardware has been built for both the AC distribution as well as the DC systems. Selection of the distribution approach will be made during the next quarter.

## Environmental Requirements

During FY'70 this work unit accomplished preparation of an advanced copy of an Environmental Estimates Document, Environmental Design Characteristics and Restraints Document, and a Preliminary version of a General Developmental Environmental Test Specification for Piece-Parts, Components and Subassemblies.

The estimates document was used by the designers early in the study to account for environmental influences. The subsystem and system environmental design characteristics and restraints document is currently being used to provide a basis for the design of the spacecraft system and subsystems compatible with the environments.

The modifications to the test requirements covering both proton and electron tests (identified in the previous progress report as the TOPS Environmental Test Specification for Jupiter Trapped Radiation Belts) have been made. The new test levels and requirements were derived based on the most recent estimates of these Jovian Radiation Belts (NASA Monograph). These test requirements initially will be used for piece-part developmental testing.

The general piece-part test specification will include the new proton and electron test requirements as well as the RTG neutron and gamma radiation test requirements. Additional information on temperature test requirements at this level of equipment are being incorporated in the piece-parts test specification. As an initial step in piece-parts developmental testing, a Radiation Test Program is currently being implemented. This test program will provide radiation effect information and data for the development of selected new radiation sensitive piece-parts, and as well provide evaluations of alternate test procedures. In addition, the new test results will be compared with radiation effects data recently provided by a literature search as a first step toward eliminating large uncertainties in threshold levels. The testing (which will include use of in-house and out-of-house facilities) is being coordinated through the Radiation Working Group and the Microelectronics Committee to facilitate standardizations. Gamma and neutron radiation test levels will be simulated using CO-60 sources, test reactors and accelerators, if necessary,

to do parametric accelerated radiation testing. Electron and proton radiation test levels which are derived from the design restraints in TOPS-3-300 will be simulated using high energy accelerators. As part of this initial program, developmental high and low energy testing will be performed to verify the adequacy of the test levels and use of energy equivalency.

#### Mission Engineering and Nuclear Operations

Launch vehicle and aerodynamic shroud candidates have been identified for outer planet missions that would utilize the TOPS spacecraft capabilities. Initial performance estimates have been obtained for each and liaison is being subsequently conducted with the appropriate NASA Centers and industrial sources to maintain an awareness of the status of each candidate.

The spacecraft/launch vehicle integration requirements are in the process of being identified. The new requirements, occasioned by incorporating RTG's in the spacecraft design, and attempting to encapsulate the Burner II stage with the spacecraft in the Explosive Safe Area, are in the initial stages of study; the objective being to assess the magnitude of the problems prior to the authorization of a flight project.

The impact of the RTG's on the ground handling and system testing of the spacecraft both within JPL and at ETR is being evaluated. The initial estimates of the radiation levels in the immediate vicinity of the RTG's are sufficiently high that the potential exposure of test and handling personnel needs to be carefully studied and procedures planned to minimize the total exposure time for these personnel.

These several areas of mission engineering and nuclear operations will be studied during the next reporting period.

#### Project Management

The third TOPS Project Review was held April 9 and 10, 1970. The completed system design was presented and the subsystem reviews stressed reliability analysis and evaluations of available data to substantiate achievement of project objectives. The primary efforts involved support to ensure

major component development (e.g., CMMA, SMM and X-Band TWT) consistent with TOPS requirements and to the development of selected subsystems which will be used to demonstrate feasibility. Some of these subsystems include data handling, (CCS and MPS elements), antenna, power, attitude control and propulsion.

Certain developments required have been identified as beyond current funding. Such special purpose component developments include tape recorders, image sensor and approach guidance sensor. The equipment desired for feasibility model spacecraft beyond funding include representative data handling, structure, packaging and cabling, and RTG's (schedule implications). Status of all TOPS development was identified. Technical information as well as programmatic details (summaries of deliverables and current schedules) are given in the April Review Document.

#### PLANS

For FY'71, this work unit has been divided into several separate work units to cover the disciplines of: Program Management, Mission Engineering, System Design, System Testing, Environmental Requirements, and Science Integration. These disciplines will continue to pursue the TOPS activity in accordance with Reference 1 as may be modified by current funding levels and programmatic redirection.

#### PROBLEMS

Following is a list of technical problems, with the most difficult shown first. Subsystem development problem areas are listed under Item 4 in order of difficulty. Each of these problem areas are being studied.

- (1) Life - System Design to achieve life; through redundance, self-test and repair, and advanced parts technology.
- (2) Power - RTG development
- (3) Environmental - Jovian Van Allan Radiation Design Restraints and Test Requirements (protons and electrons).

RTG neutron and gamma radiation design restraints and test levels (accelerated radiation testing).

Solid particle fields and influence on mission and spacecraft design.

(4) Subsystem Development

- (a) Data Storage
- (b) Imaging Sensors
- (c) Self-test and Repair Computers
- (d) Deployable Antenna
- (e) Attitude Control, Use of Digital Sensors, Digital Logic, and Momentum Wheels
- (f) Approach Guidance
- (g) Propellant Acquisition
- (h) Magnetic Field Control

(5) Mission Engineering and Nuclear Operations – RTG nuclear operations and ground handling during integrated system tests and launch.

#### JPL DOCUMENTS RELEASED

1. Shipley, W. S., "Policies and Requirements for Thermoelectric Outer Planet Spacecraft", JPL 701-24, TOPS Project Document No. 1, February 14, 1969.

#### ANTICIPATED PUBLICATIONS

##### Journal Articles

1. McDonald, R. R., and Shipley, W. S., "Outward Bound" Astronautics and Aeronautics, September 1970.
2. Divita, E. L., Draper, R. F., Frewing, H. K., and Stavro, W., "The Spacecraft and the Missions", Astronautics and Aeronautics, September 1970.

#### PUBLICATIONS

None.

NUCLEAR RADIATION FIELD MAPPING  
FOR RTG-POWERED SPACECRAFT

NASA Work Unit 186-68-09-10

JPL 384-73501-0-3530

W. A. Hagemeyer

F. Wolf

## OBJECTIVE

This task has the general objective of obtaining analytical methods and computer codes to determine the radiation environment within and adjacent to a spacecraft equipped with an RTG power plant. These analytical methods are to be applied to the Thermoelectric Outer Planet Spacecraft (TOPS). The resulting radiation intensity levels will be provided to other project personnel.

A modification of the "Faster-II" code, called "RAMPART", developed by the ART Research Corp., Los Angeles, was used to obtain a preliminary map of the radiative environment of the TOPS spacecraft version 12j, due to the presence of the RTG. Both gamma and neutron flux in the payload region and near the spacecraft bus have been calculated for a simplified vehicle structure, which uses the correct component weights and materials, however, assumes a homogeneous mass distribution for the propulsion compartment and the electronics. The radiation source was simulated by adopting the "Multi-Hundred Watt" radioisotope thermoelectric generator, developed by G. E., in a linear arrangement of 8 fuel capsules of approximately 8800 W (th) total power and a generator jacket of homogeneous mass distribution. The numerical results show a strong shielding effect in the main payload region where dose rate levels for gamma radiation are more than two orders of magnitude lower than in an empty field. The antenna forms a source of scattered radiation bypassing the spacecraft bus and delivering up to 40% of the total dose received in the payload center.

Repeated runs of the computer program provided more details in the map and an opportunity for important sampling of the radiation sources.

Preparations are made for improvements of the input options of the RAMPART program which will provide greater flexibility of spacecraft geometry. This will permit rotating the RTG relative to the rest of the structure, which is defined within an orthogonal coordinate network. The TOPS 12K version will be treated with this improved form of the RAMPART code in the next step of the environmental mapping effort.

#### PUBLICATIONS

None.

MODULAR ELECTRONIC PACKAGING  
ADVANCED DEVELOPMENT

NASA Work Unit 186-68-10-09

JPL 384-66601-0-3570

R. H. Dawe  
R. M. Jorgensen  
J. T. Rice

## OBJECTIVE

The objective of this task is to develop and qualify to anticipated environments, including those of long term missions such as the Thermoelectric Outer Planet Spacecraft (TOPS), practical modular packaging configurations utilizing IC, MSI, and LSI monolithic; hybrid thick film, and conventional discrete electronic components. Development of a method to package a representative TOPS STAR computer module is a specific objective. Included also is the continued development and improvement in module interconnect techniques including resistance welding, reflow soldering, unheated electrode welding-through-wire insulation and discrete multilayer as electronic component joining techniques.

Development of a family of reliable, non-magnetic, radiation resistant microcircuit hermetic packages was initiated.

## CONDUCTOR JOINING

Reflow soldering or "sweat soldering" is a joining process in which two or more solder coated items are joined together by heating the items to the melting point of the solder and allowing the solder coatings of the items to flow together. Reflow soldering was evaluated for the attachment of flat pack leads to terminals of the molded stick module. The variables studied were coating material and thickness and method of heating the coating to melting temperature. Coating of tin (plated from acid tin baths), and solder (plated from fluoborate baths and oil bath fused) were compared in thicknesses of 0.0005, 0.0010, and 0.0020 inches on brass terminals (QQ-B-613 comp 22). The heating processes evaluated consisted of pulse heating of various geometries of heating elements for use as conductive mode heat sources and resistance soldering.

Both resistance soldering and pulse heated soldering "iron" techniques were successfully demonstrated to reflow solder flat pack leads to the stick terminals. Resistance soldering produced the more consistent sample joints in appearance and peel strength values. Joints had the same degree of peel strength for all joint thicknesses although the 0.0005 plating thickness did affect consistency of the process appearance. The tin plating showed its effect not in the reflow soldering of flat pack leads, but in soldering of wire on the other end of the terminal. The joint of the wire to the tin plated terminal has less desirable flow characteristics and requires higher skill levels than the joint to the solder plated terminal.

A Process Bulletin is in preparation to cover the use of reflow soldering for attachment of flat packs to stick modules.

Development of film insulated wire and wire welding equipment using X-Y table is being done in conjunction with NASA OART 125 program, Microelectronic Packaging Advanced Development and Advanced Development of Electronic Interconnections. Equipment Procurement and Development is proceeding on those units. Development of application techniques on this work unit will proceed when the equipment development and process have progressed sufficiently for application development.

The contract to study the effects of impurities in nickel was completed and the contractors report received. The evaluation showed that the most significant difference in high purity nickel and nickel with high trace impurities was in tensile strength, a fact that would influence organization of welding processes in which absolute values of strength (in pounds) were used. Second, the effect of differing conductivities was not pronounced in the smaller wire sizes (0.016 and 0.020 dia) but was of sufficient magnitude in larger wire sizes that a weld process chosen for the high purity wire (0.025 dia and larger) would prove inadequate for use with the maximum impurity wire.

It is planned to add additional information and alter the presentation of the data to be more definitive and useful and report it.

## MICROCIRCUIT AND HYBRID HERMETIC PACKAGE DEVELOPMENT

Package failures have been a major problem on microcircuit component procurements. These failures plus requirements to provide a non-magnetic and radiation resistant package established the need for a reliable hermetic package. With these requirements plus additional inputs of the micro-part committee and package manufacturers, a draft of specification CS50539 and drawing of a 14 lead package for 54L series logic devices were generated. The specification covers the detail requirements for a family of microcircuit packages and includes design guidelines, mechanical and electrical requirements, materials, acceptance criteria, and qualification requirements.

A design review of the specification was held and review inputs were incorporated into the documents. The document package was then reviewed with engineering representatives of eight package manufacturers. The document was updated based on these manufacturers conferences and is now completing final review prior to release.

It is planned to release this specification, procure parts to the documentation in conjunction with NASA Work Unit 186-70-02-01 and test and evaluate the parts to establish specification adequacy for obtaining reliable parts.

## CONNECTOR AND WIRE EVALUATION

Connector procurement for modular development was completed. Parts procured on this work unit were included in the connector and wire evaluation added to the NASA Work Unit 186-68-10-13, Packaging and Cabling Support to TOPS, as part of a mid-year reprogramming of TOPS.

## MODULE DEVELOPMENT

Studies were continued in development of a composite module and interconnection system. Documentation of various existing modular interconnect techniques and fabrication of samples of these techniques in the previously developed composite module frame was initiated. This will help define the family of techniques available and provide the means of developing comparative data between existing and new techniques such as the discrete multilayer.

Development support of the hybrid thick film tree switch and driver prototype modules was provided in conjunction with the TOPS Measurement Processor developed on NASA Work Unit 186-68-04-29, Telemetry Data Systems Implementation, and NASA OART 125 Program, Hybrid Packaging Advanced Development. Of particular interest was the input/output connections and their interaction with the next level of interconnect that would be found in the composite module.

The documentation and/or development of several systems of modular packaging will provide a choice for the most reliable and efficient packaging of the STAR computer processor planned for end of the FY'71.

Completion of the samples of modular interconnects including the discrete multilayer interconnect is planned. Also planned is the development of the electronic assembly interconnect concept proposed for TOPS using these sample modules.

## PUBLICATIONS

### Contractor Reports

1. "Analysis of Weldability of Two Grades of Pure Nickel," Report Number WVS-170-2591-03, Walter V. Sterling, Inc., December 1969, JPL P.O. EI-510325.

## TOPS MECHANICAL SUPPORT

NASA Work Unit 186-68-10-12

JPL 384-73601-0-3550

J. O. Lonborg

## OBJECTIVE

The purpose of this work unit is to provide general mechanical support to the Thermoelectric Outer Planet Spacecraft (TOPS) Project. Specific mechanical advanced development tasks, including TOPS configuration design, are performed under a companion work unit, 186-68-12-05.

## PROGRESS

Design and fabrication of the TOPS Feasibility Model structure is no longer planned. Rather, interface control drawings for the interfaces of the structural subsystem with the electronics compartment, the propulsion module, the RTG assembly, and the high gain antenna are being prepared. These will be substantially complete in FY'70.

For several reasons, including the desire to incorporate configuration changes resulting from further design team activities, construction of the full-scale TOPS spacecraft model was deferred to the first half of FY'71. It is now planned that this model will be such a sufficiently close simulation of the spacecraft that it could serve as a meaningful Radiation Test Model (RTM) for the verification of nuclear radiation mapping techniques. The high gain antenna for the model is under construction. It will be a closer simulation than was originally planned; it being recognized that this is an opportunity to gain experience that will be of value in the fabrication of the actual TOPS antenna, which is being developed under work unit 186-68-12-05-55.

The general TOPS Project and design team support will continue through FY'71. The full-scale model will be completed and a spacecraft positioner will be provided for it.

## PUBLICATIONS

None.

## PACKAGING AND CABLING SUPPORT TO TOPS

NASA Work Unit 186-68-10-13

JPL 384-73701-0-3570

R. H. Dawe  
J. C. Arnett

## OBJECTIVE

The objective of the Packaging and Cabling Support to TOPS has been grouped into three general areas. The first consists of the establishment of the packaging and cabling goals and concepts in support of the system design and the configuration development. The second consists of the development of the mechanical design of the Electronics Compartment including the Electronic Assembly and interconnection interfaces. This includes the review of the existing technology and development in the other work units for the methods to most efficiently and reliably perform this function. The third area consists of those necessary housekeeping activities required for the systems assembly, tests and operations that must be performed to obtain a functioning system but do not require new technology or development.

Packaging and Cabling Goals and Concepts in Support of the System Design and Configuration

The TOPS functional requirement specifications TOPS-3-220, Flight Equipment, Electronic Packaging; and TOPS-4-2009 Flight Equipment Cabling Subsystem were completed and released. These specifications depend heavily on supporting packaging and cabling documentation and Mariner '71 documents currently referenced. There is no plan to update these documents for TOPS. It is intended to have updated, new and/or additional technology and requirements needed for TOPS considered and incorporated where possible when these documents are updated or revised for other project needs.

Support to the system design team was provided to review impacts on packaging and cabling of several types of missions plus variations for those missions. Packaging systems were reviewed considering the possibility of

electronic equipment operating at low temperatures (below 40°F). Electronic equipment can be designed and fabricated to operate at low temperatures with extensive engineering and testing of all the details. However, the following problem areas were summarized in a memo to the Design Team: increased stress on components of embedments, glass transition of polymers causing component joint stress, internal stresses caused by on-off operations of equipment during its lifetime, the large number of thermal cycles required to produce and test units, unknown metallurgy of complex electrical conductors and interconnects, lack of adequate existing instrumentation and test methods, insufficient and difficult correlation of data on low temperature operations. A comprehensive evaluation and test program would be required to assure reliable operation of equipment at low temperature.

Packaging and cabling status was presented in the TOPS April Design Review.

Planned activities are to provide continued support to the spacecraft design team and subsystem areas.

#### Electronics Compartment, Assembly and Interconnect Development

Design of the TOPS electronic compartment is progressing and the spacecraft and electronic assembly interface is nearing completion. Finalization requires selection of the connector required for this interface.

The connector and wire development included completing the collection and organization of parts procured on various work units, preparation of test plans and initiation of the testing program. Significant delays in delivery of most of the orders, in spite of minimal certification and specification requirements, pointed up the importance of long lead procurement policy for this type of hardware. Only one of fifteen orders was delivered on time and many were three to four times the promised delivery period,

The tests on connectors and wires include general screening, detailed testing of mechanical and electrical characteristics, and exposure to environments which might be encountered by future spacecraft systems such as TOPS.

Figures 1 and 2 show most of the connectors being tested. The test included ten different manufacturers in four classes of connectors. The evaluation of these connectors continued to the end of FY'70.

Planned activities include additional evaluation of connectors and wires to determine their suitability in the use and application areas preparatory to formulating procurement documentation. Radiation testing of potential candidates of connector and wire is desirable, and attempts will be made to get these parts included in a radiation test program. Interface definitions between the spacecraft, electronic compartment and electronic assemblies will be finalized and information to fabricate the mock-up electronics compartment developed.

#### Housekeeping Activities Support

Based on the last revised TOPS schedule, the initiation of documentation and fabrication of System Test Complex cabling is not planned until the latter part of FY'71.

#### JPL DOCUMENTS RELEASED

1. Dawe, R. H., "Thermoelectric Outer Planet Spacecraft Electronic Equipment", 701-60, TOPS Document No. TOPS-3-220, January 30, 1970.
2. Dawe, R. H., "Thermoelectric Outer Planet Spacecraft Cabling Subsystem", 701-69, TOPS Document No. TOPS-4-2009, March 16, 1970.

#### PUBLICATIONS

None.

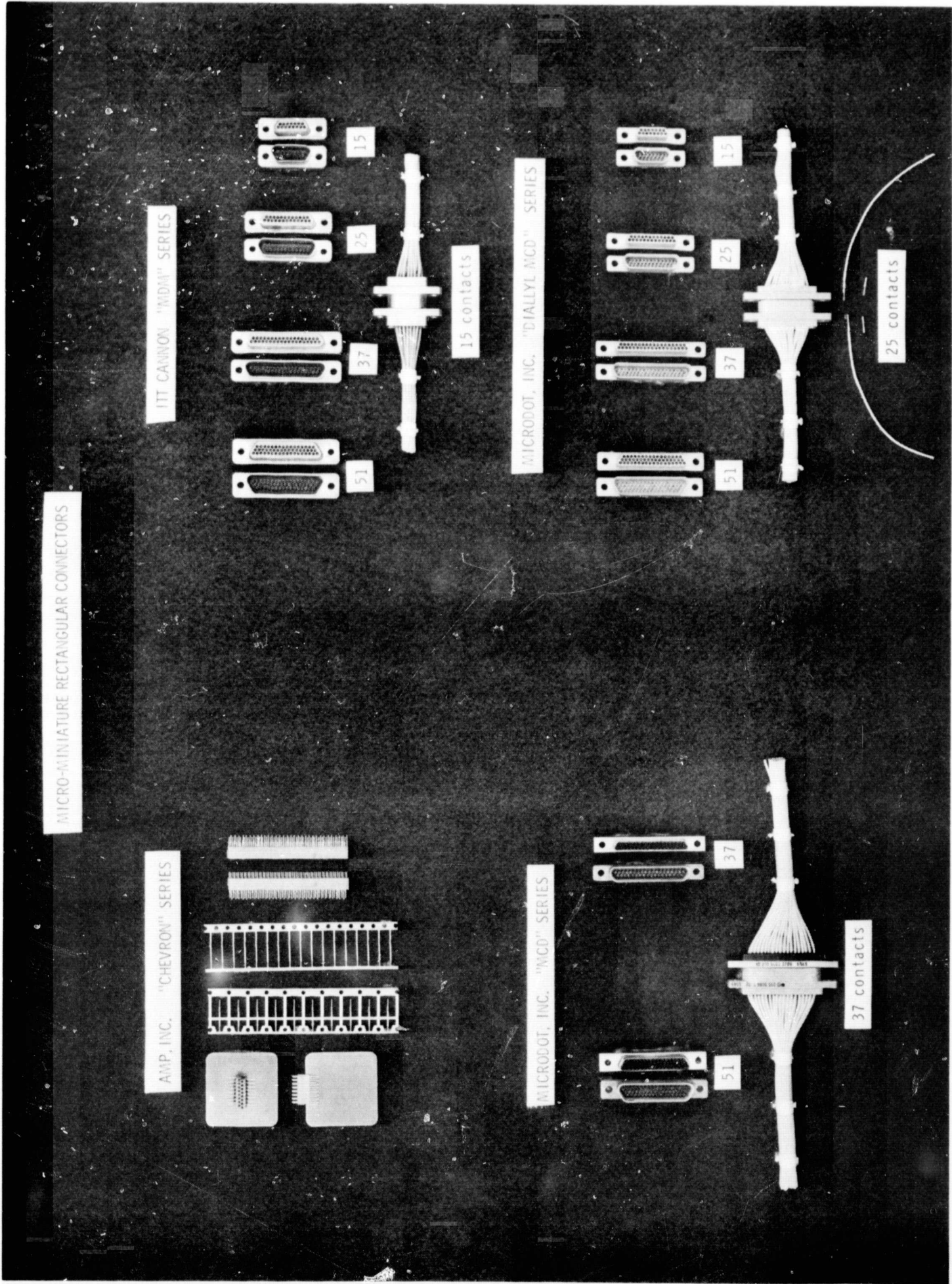
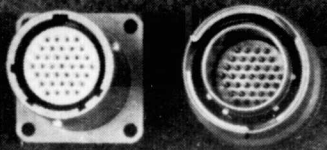


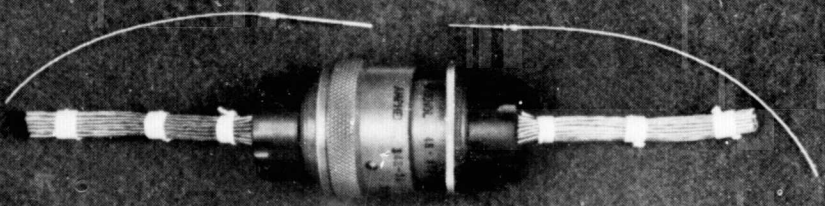
Figure 1. Microminiature Rectangular Connectors with 50 MIL Center Contacts in Evaluation Program

SUB-MINIATURE CIRCULAR CONNECTORS

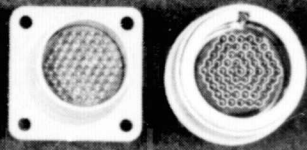
Amphenol "348" Series



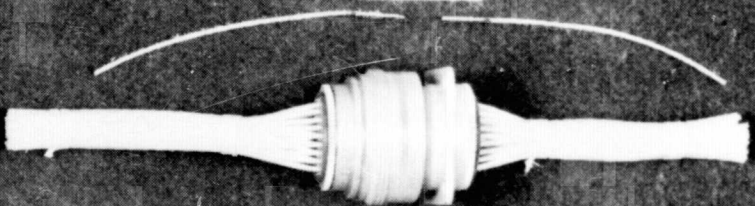
37 contacts



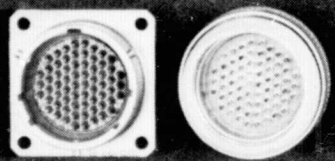
Deutsch "UR2" Series



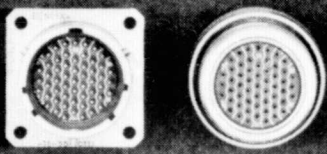
61 contacts



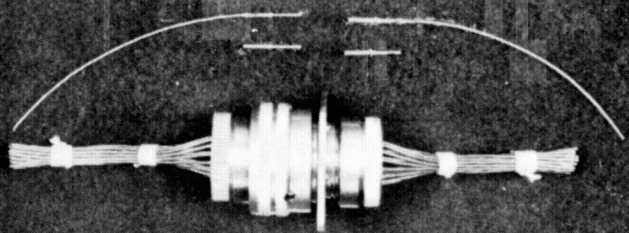
66 contacts



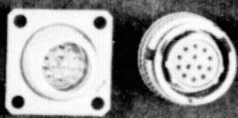
Bendix "JT" Series



55 contacts



13 contacts



22 contacts

175

701-90

Figure 2. Subminiature Circular Connectors in Evaluation Program

## SPACECRAFT MECHANICAL TECHNOLOGY

NASA Work Unit 186-68-12-05

JPL 384-68201-0-3550

J. O. Lonborg

## OBJECTIVE

The primary goal of this work unit is to ensure that critical mechanical advanced development is accomplished on a schedule consistent with future project needs. It includes certain aspects of configuration, structures, structural elements, and mechanisms. The current effort is entirely devoted to satisfying the requirements of the Thermoelectric Outer Planet Spacecraft (TOPS) Project in these areas, and consists of the following four subtasks.

TOPS Deployable Antenna

The objective of this subtask is to develop a 14-foot diameter deployable paraboloidal antenna for the TOPS project. Operation at S- and X-band is required; hence, the reflector surface must be accurate to about 0.030 inches rms. The Telecommunications Division, through work unit 186-68-04-27, is providing RF assistance and is developing the feed.

A status review was held in January 1970. Its purposes were to review the in-house antenna development in progress, to assess the impact of a similar antenna development that JPL had learned of, to re-evaluate several other concepts, and to define the continuing program. This review concluded that the overall objectives of the TOPS project are best met by continuing the in-house development. In the interim, the following have been accomplished:

- (1) It has been determined that 48 ribs will yield an acceptable geometric approximation error of 0.023 inches rms.
- (2) A tapered tubular rib has been designed and the optimum as-manufactured rib shape has been computed.
- (3) An antenna design review was held in April 1970. As one of the results, the hub design is being modified for better manufacturability.

- (4) Rib temperatures and gradients, as functions of sun-spacecraft range and other parameters, have been calculated and are being used to compute thermal distortions.
- (5) A deployment system employing redundant Negator springs acting on each rib was designed. Rate control methods are being evaluated.
- (6) RF reflectance measurements and scanning electron microscope observations were made on samples of several candidate materials for the deployable reflector surface. Gold plated, Chromel-R mesh, like that used on the RCA ALSEP and other deployable antennas, has been ordered for the TOPS antenna. Since there appear to be some fundamental problems in obtaining a well adhered gold plating and there is thus some concern regarding the adequacy of this material for a 10-year flight, the feasibility of knitting a suitable mesh from an alloy that would not require plating is also being investigated.

The remainder of the antenna hardware will be procured in the first quarter of FY'71 and the assembly will be completed early in the third quarter. Mechanical tests and measurements are to be completed and the antenna is to be available for RF testing by the end of FY'71.

#### TOPS RTG and Science Boom Deployment Mechanisms

On the TOPS spacecraft, the RTG's and the science instruments are mounted on hinged rigid booms, which are deployed after spacecraft separation. The objective of this subtask is to develop the required deployment mechanisms.

During the previous reporting period, studies were made, a concept was selected, and an actuator/damper was designed. Fabrication and testing were deferred to permit completion of the thermomechanical fluid pump investigations. The latter task having been completed, a preliminary model of the actuator/damper has been constructed, and the test set-up is being built. It is now planned that this work will be concluded in the first quarter of FY'71.

### Thermomechanical Fluid Pump

The TOPS project is considering the use of a pumped fluid loop for transporting waste heat from RTG's to science instruments and other cold equipment. The objective of this subtask was to explore the feasibility of substituting for the electric pump one operating directly from thermal energy extracted from the warm fluid.

This task has been completed. In addition to accomplishing analysis and design, two feasibility model pumps were built and tested under simulated operating conditions. Numerous sealing difficulties were experienced with the first, but a set of operating conditions was found such that it did execute seven complete cycles of operation. Operation then ceased, presumably due to leakage of the temperature control fluid past the piston, with resulting contamination of the Freon expansion chamber.

A second model was designed and constructed to remedy the known defects with the first. Bellofram rolling diaphragms were used as piston seals to prevent leakage. An improved heat exchanger employing parallel, finned, thin-wall tubes was designed. This model could not be made to exhibit sustained oscillation and the difficulty was traced to excessive mechanical losses due to hysteresis in the Belloframs. Sufficient testing was done to verify improved heat exchanger performance and to indicate the margin by which the pump failed to operate.

This work is being reported more fully in SPS 37-63, Volume III and in a paper delivered to the 5th Aerospace Mechanisms Symposium. Because of changing temperature control requirements and in light of its now known performance limitations, this work is not being continued at the present time. Necessary improvements to create an operable device are known or can be calculated.

TOPS Configuration

TOPS configuration and mechanical integration work was continued through this period and resulted in version 12K. Significant changes from the previous baseline, 12J, are:

- (1) A fourth RTG has been added and the assembly has been reconfigured such that the structural attachment weight is reduced and the accessibility to the individual RTG's is improved.
- (2) Propellant tanks have been resized consistent with the change in mission design from a four planet to a three planet trajectory.
- (3) Whereas roll and pitch maneuver capabilities were formerly provided by a common set of thrusters, these functions have now been separated. Roll thrusters are so located as to produce a couple about the spacecraft center of gravity, thus minimizing the adverse effects that would result from the loss of one.
- (4) The superstructure has been reconfigured. The support structure is now biaxially symmetric for improved monopulse tracking.
- (5) The following science changes have been made: radio emission detector antennas were added, the meteoroid astronomy detector was resized, the micrometeoroid detector was relocated, and the IR radiometer was updated.

This subtask will be continued in FY'71.

## PUBLICATIONS

Meeting and Symposia Papers

1. Sabelman, E. E., "Thermo-Mechanical Piston Pump Development", 5th Aerospace Mechanisms Symposium, June 15-16, 1970.

JPL Publications

1. Sabelman, E. E., "TOPS Boom Deployment Mechanisms", SPS 37-60, vol. III, pp. 177-179.
2. Mack, T. H., "Development of Mechanisms for a Planetary Landing Parachute System", TM 33-441.

SPACECRAFT ADHESIVES FOR LONG LIFE  
AND EXTREME ENVIRONMENT

NASA Work Unit 186-68-13-09

JPL 384-73901-0-3510

W. Roper

## OBJECTIVE

The long-range objective of this task is to investigate the field of high and low temperature polymers for application as adhesives for near-sun and outer planet (Grand Tour) missions. The proposed outer planet missions impose on the spacecraft adhesives conditions of extreme cold ( $-375^{\circ}\text{F}$ ) for extended periods (10-12 years). The near-sun missions (e.g., Mercury/Venus, solar probes) impose conditions of extreme heat ( $400^{\circ}\text{F}$  and greater). It is, therefore, necessary that new adhesive materials which can function in these extreme environments be found and their performance thoroughly characterized.

The specific objective for FY'70 was to complete a state-of-the-art review of all new polymer and adhesive systems and, from this review, select those materials which show promise as potential spacecraft adhesives. Following this review and selection phase, some limited laboratory testing of the candidates was planned. This was planned in order to further characterize the materials with respect to their performance in future spacecraft environments.

## PROGRESS

The specific objectives of FY'70 have been essentially reached in this task. The materials state-of-the-art review was completed and a selection of candidate materials was made. This review involved both a thorough literature survey as well as the contacting of over 40 organizations or companies concerned with new materials and adhesives development. The results of this review have been presented in detail in a recently published Space Programs Summary report (see publications). As a result of the review, three polymer systems have been found to have good potential as future spacecraft adhesives. These include the polyimide, the polybenzimidazole and the

polyquinoxaline polymers. During the last half of FY'70, a test program for evaluating the thermal shock characteristics of these selected materials was planned. Some specimen preparation was completed but actual testing was not accomplished due to a decrease in task funding at mid year. It was originally estimated that the adhesive materials would be evaluated for thermal shock resistance between the temperature levels of 400°F to -300°F. The current estimate of the best temperature range to evaluate thermal shock resistance is +400°F to -100°F. This temperature range at a thermal shock rate of 40-60°F/min is typical of a worst case condition for the future Grand Tour and Mercury/Venus missions. It is planned that this thermal shock testing will be completed during the FY'71 period.

Also during the last half of FY'70, the concluding work of the previous "Sterilizable Polymers" work unit (186-58-13-2) was completed. During this period the work was summarized in a final published report (see publications).

#### FUTURE PLANS

In FY'71 it is planned that the thermal shock testing of the adhesive candidates will be concluded. In addition, further laboratory testing is planned. This testing will include long term (4000 hours) thermal aging at 500°F. The adhesive systems which survive this elevated temperature exposure should be good candidates for low temperature exposure. Long term aging at very low temperatures (-375°F), which was originally planned for FY'71, will be postponed until FY'72 because of funding limitations. While the long-term low-temperature exposures are very important for the outer planet missions, they are more costly than the long-term high-temperature exposures needed for the near-sun missions.

#### PUBLICATIONS

##### JPL Publications

1. Roper, W. D., "Spacecraft Adhesives for Long Life and Extreme Environments," SPS 37-63, vol. III, June 30, 1970.

2. Roper, W. D., "Spacecraft Polymeric Materials Interactions during Decontamination, Sterilization and Thermal Vacuum Exposures," Technical Report 32-1491, June 15, 1970.

## LONG LIFE SPACECRAFT PRESSURE VESSEL MATERIALS

NASA Work Unit 186-68-13-10

JPL 384-73801-0-3510

J. C. Lewis

## OBJECTIVE

The objective of this work unit is to develop material property design data for highly reliable, highly efficient pressure vessels for advanced long term planetary exploration missions. In FY'70, development was begun to obtain stress corrosion data for Ti-6Al-4V alloy in combination with nitrogen tetroxide ( $N_2O_4$ ) and monomethyl hydrazine (MMH) for future missions to Venus, Mercury, Mars, and the outer planets. In FY'71, development of  $N_2O_4$ /MMH data will be completed and selection of materials for long term storage of oxygen difluoride ( $OF_2$ ) and diborane ( $B_2H_6$ ) will begin.

## PROGRESS

All equipment has been installed and all test procedures have been developed for testing Ti-6Al-4V alloy with  $N_2O_4$  and MMH. Limited testing was accomplished to determine the relative reactivity of the two propellants with Ti-6Al-4V alloy. Conclusive data as to which is the more reactive was not obtained due to a reduction of funding. This reduction of funding also delayed the start of testing to determine the optimum heat treat level for this alloy.

Because isopropyl alcohol is used as a cleaning fluid to flush MMH from the cracks and the pressurization tubing, the effect of isopropyl alcohol on cracks in Ti-6Al-4V alloy was determined. No such data were available from other investigations. From limited testing, a threshold stress intensity of approximately 60 percent of  $K_{Ic}$  was determined for isopropyl alcohol in Ti-6Al-4V alloy of 150 ksi yield strength. This knowledge allows a test procedure to be used which precludes crack growth due to the isopropyl alcohol cleaning process.

A reduction of the work load from other space programs on the in-house electrical discharge machining (EDM) units negated the need to rent such a machine.

## PLANS

In FY'71, the relative reactivity of  $N_2O_4$  and MMH on Ti-6Al-4V alloy will be conclusively determined and the optimum heat treat level for welds, heat-affected zones, and wrought metal will be determined. Tests of 1000 hours duration will be made on the optimum heat treat condition. Enough different heats of Ti-6Al-4V alloy will be tested to permit efficient statistical evaluation of the stress corrosion threshold for use in design of propulsion subsystems for future long term planetary exploration missions.

Plans for pressurized storage of preflawed Ti-6Al-4V pressure vessels in  $N_2O_4$  and MMH in FY'71 have been cancelled due to limited funding.

Also in FY'71 testing equipment for  $OF_2$  and  $B_2H_6$  will be installed at JPL's Edwards Test Station. Some limited screening of materials in  $OF_2$  and  $B_2H_6$  is planned for the last quarter of FY'71.

## PUBLICATIONS

### JPL Publications

1. Lewis, J. C., "Long Life Spacecraft Pressure Vessel Materials," SPS 37-61, vol. III (1970).

## ESTABLISHMENT OF POWER PULSE SCREENING CAPABILITY

NASA Work Unit 186-70-01-04

JPL 384-00401-0-3540

W. Bartel

## OBJECTIVES

The objective of this work unit is to establish a power pulse method for screening resistors which are used in spacecraft systems. This method will replace the current method of screening which typically consists of a temperature cycling, power burn-in, and three parameter measurements. The benefits derived from the power pulse method will be increased effectiveness in detecting defective parts, a screening cost reduction by about a factor of five to ten, and reduced screening time.

## APPROACH

The current effort on this work unit is a follow-on to a feasibility study completed in fiscal 1968. The power pulse concept for screening was developed by Dale Electronics for screening power wirewound resistors which they manufacture. The feasibility study which we performed was to extend this method of screening to all categories of resistors including power and precision wirewound resistors, as well as carbon and metal film resistors.

Because feasibility was demonstrated, it is the purpose of the current effort to establish safe and effective power levels for screening by this method and to prepare the necessary screening procedures.

Screening by the power pulse method consists of applying a short power pulse to the resistor and monitoring the resistance change on an X-Y recorder during the pulse period. A defective part manifests as a perturbation in the resistance curve. The pulse period is typically of five seconds duration and the pulse power level varies from about 10 to 50 times the rated power of the part. The power level to be utilized for a given part type is based upon the

rated power of the part and is a function of its physical volume, materials, and configuration. Because of the wide variation of these factors, it is necessary to investigate each type of part individually to arrive at the appropriate pulse level.

The approach consists of investigating a sample of 10 parts for three values of each combination of power rating and part type. Part types included are those having high volume usage in spacecraft applications. The method for establishing the pulse levels is to measure the static resistance change between room temperature and the rated temperature of the part. Using this resistance change as a limit, the resistor is pulsed at increasing power levels until the resistance change resulting from the pulse applied is equal to the resistance change previously determined. The average pulse level for the sample of parts is then selected as the required pulse level. After the pulse level is determined, a second sample is taken and subjected to the selected pulse level and then followed by a life test to determine if the pulse had any detrimental effects on the part.

The original plan was to also verify the pulse level with an infrared radiometer temperature measurement. However, this proved to be very time consuming and the available equipment provided poor repeatability. Consequently, this verification has been abandoned.

## PROGRESS

A power pulse test set was purchased from Dale Electronics for \$17,000 and was delivered in March 1969. Testing was started about two months later. Completion of the effort was rescheduled from January 1, 1970 to July 1, 1970 due to some testing anomalies requiring retesting and because the effort was initially underestimated.

Four series of resistors from four vendors were investigated. The test data provided the pulse levels for screening three of the series. The fourth series, which are precision wirewound units, exhibited temperature coefficients which were too low. This made it impossible to establish screening

pulse levels for this series with the instrumentation available. However, this does not rule out screening this type of resistor by the power pulse method. Another approach for establishing pulse levels is indicated.

A final report is in progress and will be released upon completion of the analysis of the life test data. This report concludes the effort on this work unit.

#### PUBLICATIONS

None.

## ELECTRONIC PARTS FOR LONG DURATION MISSIONS

NASA Work Unit 186-70-01-09

JPL 384-72401-0-3540

L. W. Wright

## OBJECTIVE

The objective of this work unit is to support the development of Thermo-electric Outer Planet Spacecraft (TOPS) hardware as well as lay the ground-work for future flight projects by (1) developing qualification and screening criteria for discrete and microelectronic devices consistent with the long life and environmental characteristics of outer planet missions, (2) participating in development of complex microcircuits, (3) performing evaluation and failure analysis of devices of interest to TOPS, and (4) developing a preliminary parts list and parts acquisition and control plan for a flight project.

## ACTIVITIES DURING REPORT PERIOD

The following is a brief summary of the activities pursued during the report period.

1. Device Evaluation

Device evaluation efforts can be considered in three parts as follows:

- a) The accelerated test program for a digital IC was continued to completion. All testing was completed in February and the contractor's final report was received near the end of March. Preliminary analysis of the data indicates that approximately 10% of the devices were potentially defective and that high stress testing was able to remove these defective devices in less than 1000 hours. The data further suggest that high stress levels which will remove defects while not degrading normal devices can be selected. Additional analysis of the data is still being performed at JPL.

- b) Due to late delivery and scheduling problems, testing of the TI developed photon switch was not resumed until June, 1970. Initial tests have been performed for the new devices and the previously received devices were subjected to retest. All tests were performed with both the Fairchild 4000 and the new Terradyne J259 test system; correlation between instruments was good. In the future, the Terradyne J259 will be used in lieu of the Fairchild 4000 which was used at the outset of the effort. The new test system provides improved accuracy and its output format allows more convenient data analysis.
- c) Testing was performed on a variety of devices at temperatures as low as  $-150^{\circ}\text{C}$  to cursorily investigate the feasibility of operating spacecraft electronic subsystems at such temperature extremes. The results indicated that even though no devices failed catastrophically as a result of the low temperature exposure, some devices would not perform at the extremes and that large parametric shifts occurred in most others. Based on these results, it was concluded that it would be extremely difficult to design complex electronic subsystems operable at  $-150^{\circ}\text{C}$  and that even if such a subsystem were designed it would still require a limited temperature range of operation. That is, a subsystem might be operable (over the range of  $-100$  to  $-150^{\circ}\text{C}$  but might not be operable) at temperatures warmer than  $-100^{\circ}\text{C}$ .

## 2. Failure Analysis Support

Failure analysis support has continued to be provided on devices of interest to TOPS. Primarily the analyses have been related to the 54L series of IC's available commercially from both TI and National. A smaller amount of analysis work has been performed in relation to an optoelectronic pulse amplifier manufactured by TI.

### 3. Radiation Technology

The radiation literature search and study performed by Boeing under JPL contract 952565 has been completed and the final report was received in June 1970. After submittal of the final report, a detailed verbal presentation was given to JPL TOPS designers by Boeing. From the study, it can be concluded that: 1) for the present state-of-the-art many active components will be seriously degraded by radiation during interplanetary missions, 2) in many cases data are inadequate to do more than make gross estimates of degradation of part type performance, 3) data evaluating proton damage are not available for many part types, 4) for most part types hardening and screening procedures are not known or are in a developmental stage, 5) although part degradation can be estimated for each environmental component, there are no data indicating how to assess the total degradation due to combined environments, and 6) using currently available data, system reliability in a radiation environment would be difficult to assess, particularly for part types for which the radiation levels are near the threshold for damage.

### 4. Participate in Device Development

The development of the custom metallized multigate array has been supported through participation as reliability representative. Several review meetings have been held with the contractor, Radiation, Inc., and guidance has been provided as appropriate. The contractor's Product Assurance Plan has been prepared in final outline form and subjected to review. The final Product Assurance Plan is now being generated as a part of Phase II.

The semiconductor memory module development has been supported through participation in (1) preparation of the reliability portion of the statement of work, (2) evaluation of proposals received, and (3) assessment of vendor facilities and capabilities during fact finding visits.

PUBLICATIONS

Contractor Reports

1. Final Report on an Accelerated Life Test Program for Monolithic Integrated Circuits, Boeing Company, March 11, 1970, Contract 951978.
2. Final Report on a Literature Search and Radiation Study on Electronic Parts, Boeing Company, May, 1970, Contract 952565.

## TOPS RELIABILITY AND QUALITY ASSURANCE PROGRAM

NASA Work Unit 186-70-01-10

JPL 384-01001-0-1500

T. Gavin  
P. Chelson

## OBJECTIVE

The objective of this work unit is to provide a reliability and quality assurance effort to facilitate achievement of the TOPS purpose and objectives and by the foundation for future outer planet missions assurance programs.

## PROGRESS

Reliability

In support of the TOPS Design Team, predictions were performed for the Digital Command Subsystem; analysis of the standby redundant auxilliary oscillators for the RF subsystem; as well as tradeoffs of solid state transmitters vs TWT for 4 and 5 year missions as well as 12 year missions. Assistance was also provided for the failure mode and effects analysis of the fluid loop. The TOPS recommended failure rates were upgraded through the inclusion of Mariner 69 and Pioneer Flight data. In studying the significance of the constant failure rate assumptions for the reliability predictions done on TOPS, a study of the effects of using an increasing failure rate (the Wiebul function) was performed using the Digital Command Subsystem of TOPS as an example.

In the development of reliability analysis techniques, the math modeling computer program for handling very large classes of complex redundancy is nearing completion and will be published in early FY'71.

In support of the development of an integrated failure mode analysis and assessment technique, an algorithm and computer program for handling the mathematics of fault trees is near completion and will also be published early in FY'71.

## ERC COORDINATION

The closing of the ERC as a NASA center and the subsequent takeover by the DOT has had some impact on the activities of ERC in support of TOPS.

The ERC Microelectronic capability will be retained by the DOT and sustained by NASA in 1971. A meeting was held at ERC in May with Headquarters, ERC and JPL to discuss FY'71 support by ERC to TOPS. The following is the status of the ERC effort:

1. Improvement of Screening Methods/NAS-12-2197.
  - a. Contractor: Philco Ford Microelectronics  
Division Blu Bell, Pennsylvania.
  - b. Status: This program has been delayed at least four months due to process control difficulties in the Contractor's lines. The Contract has been assigned to NAPO for monitoring by JPL.
2. Automatic Visual Inspection of Microcircuits/NAS-12-2151.
  - a. Contractor: Arthur D. Little  
Cambridge, Massachusetts.
  - b. Status: Phase I is complete. A design review was held with the Contractor, ERC and JPL June 16, 1970. A decision to continue or cancel this activity is pending.
3. Metallization Survey. This was originally to be contracted to industry and will now be accomplished in house by ERC.
4. LSI Qualification. Cancelled - will be done by JPL.
5. Radiation Effects. Cancelled - arrangements have been made for the GSFC to support this work.
6. Beam Lead Technology. As a result of the May 1970 meeting, ERC will conduct a study on the reliability aspects of nonhermetically sealed beam lead technology in FY'71.

7. Device Development. ERC has offered to conduct a device development for TOPS in FY'71. At the present time discussions are being conducted with ERC on this matter.

PUBLICATIONS

None.

## DEVELOPMENT AND EVALUATION OF MSI/LSI

NASA Work Unit 186-70-01-11

JPL 384-01101-0-2940

W. S. Shipley

## OBJECTIVE

The objective of this task is to gain experience in the selection, application and procurement of Microelectronic Devices available in the 70's suitable for Outer Planet Missions such as the Grand Tour.

## APPROACH

The approach to this task has been previously reported in JPL Document 701-66, "Semi-Annual Review of Research and Advanced Development," July 1 - December 1, 1969, Volume I - OSSA Activities During Report Period.

## PROGRESS

During the report period effort has been directed in the following areas:

(1) Counter Shift Register (CSR) — The CSR development was completed at Honeywell, Inc., Florida. The CSR is a bipolar monolithic 10 bit Counter/Shift Register which can be used as a Counter and Shift Register or as an independent counter or shift register. Fifty devices have been delivered and characterization is scheduled to be initiated in the near future.

(2) Custom Metallized Multigate Array (CMMA) — The CMMA is currently under development at Radiation Inc., Melbourne, Florida. This device is a digital logic array employing two layer metallization. During this reporting period Phase I of the Contract was completed, and a detail design review was conducted at JPL with the Contractor. As a result of this design review, recommendations were made to continue with some modifications in the Phase II efforts. Phase II will be complete in November 1970.

(3) Semi-Conductor Memory Module (SMM) -- An RFP was issued for the development of the SMM to be used in a  $8 \times 10^6$  bit buffer memory. Proposals were received and have been evaluated. The estimated costs in the proposals were well in excess of available resources and as a consequence the entire TOPS memory situation is being re-examined. A decision on the SMM is expected by August 1970.

(4) Hi-Rel Packages -- Packages are a major cause of quality problems in Integrated Circuits. Recognizing those problems, the Microelectronic Committee authorized the development of a high reliability package.

A preliminary review of the package specifications was held and expressions of interest from various package houses was solicited. An RFP for the package will be issued in July, 1970.

#### PUBLICATIONS

None.

## DESIGN APPRAISAL METHODS FOR ELECTRONIC PARTS

NASA Work Unit 186-70-02-01

JPL 384-00901-0-3540

P. Pietrokowsky

## OBJECTIVE

The long-range objective of this task is to develop and implement an engineering approach to the understanding of electronic parts which will lead to maximum space flight reliability compatible with state-of-the-art semiconductor technology. The latter is to be accomplished by an in-depth analysis and evaluation of technology utilized in semiconductor microcircuits. Design appraisal methods are interdisciplinary in nature. Studies are directed so as to discover low yield steps in fabrication technology. Results of investigations aid in the identification of unreported semiconductor device degradation and failure mechanisms. The application of information derived from this task will be of value in the development and selection of parts for flight qualified electronic systems.

## APPROACH

The objectives of this task will be pursued through literature surveys as well as in-house and contracted studies. The in-house studies will be of a laboratory nature. The purpose of the latter will be to obtain additional information on process technology beyond that available through conventional channels of information. In addition, laboratory analysis will serve as a means of resolving contradictory data. Technology interchange will be pursued with commercial device manufacturers, government agencies, institutes sponsored by departments of the government, and educational institutions. This task is based on in-depth investigation and understanding of electronic parts. The latter will produce critical analysis of integrated circuit technology, resulting in elucidation of low yield processes and failure modes associated with these processes.

## PROGRESS

The Circuit Characterization and Design Appraisal Procedure, developed during the previous fiscal year, was applied to an integrated circuit of considerable interest in systems application — the National Semiconductor DM70L20. The latter is a dual four input NAND gate TTL. Results of this study were compared with a previous analysis of a similar device made by Texas Instruments — SN54L20. A complete topological analysis was not completed due to a lack of diffusion depth information. These devices are fabricated by the use of extremely shallow diffusions. Conventional optical techniques are extremely difficult to apply to these measurements. For this reason it has been necessary to find more accurate methods of device sectioning. The development of these techniques is essential because newer generations of integrated circuits do employ narrow layers of epitaxial silicon and shallow diffusions. An electronic circuit analysis program was utilized to evaluate the DM70L20 circuits with regard to the electrical stresses involved and the tolerance of the circuit to minor deviations of gain, leakage currents and resistance. The program utilized is called ECAP and was appropriate for this DC analysis. The model used for the active transistors included a dependent current generator of a specified gain ( $\beta$ ) with series input impedance and a shunting conductance. The diodes were represented by an appropriate battery representing a voltage drop. The inactive transistors were represented by low conductance resistors. The output of the program was nodal voltage and branch currents which allowed accurate determination of the states of the circuit elements. In the case of the transistors, an "on" or "off" state was determined, also the amount of current through a transistor, diode or resistor was available.

Technology analysis was performed on ceramic integrated circuit packages and aluminum lead wires used in integrated circuit packages. Ceramic packages from four different vendors were sectioned by metallographic techniques. Analysis of the sections indicated that some of the packages contained a glass-to-conductor seal. Other packages employed a ceramic-to-low thermal expansion metal seal. Factors considered in package evaluation included: hermeticity, lead strength in fatigue, thermal shock, solderability, and electrical insulation. Measurable criteria observed were plating, area of

conductor islands, lead end contamination, case flatness and internal radii. Data and information obtained from this study were included in sections of a ceramic package specification prepared for the TOPS program. Aluminum wire used for die-to-package bonds was studied. Aluminum-silicon and aluminum-magnesium alloys from four different commercial vendors were investigated for homogeneity and uniformity of structure. A total of eight different wire types were tested. Electron microprobe analysis indicated the aluminum-silicon alloy wires to be more heterogeneous than the aluminum-magnesium alloys. Tensile tests of the as-received wires indicated a wide variation in breaking strength - of the order of two to one. The latter is an indication that thermal-mechanical history varied from one wire batch to the next. Tensile test gauge length was also investigated. A 4cm gauge length series was compared with a 25cm gauge length series. A one-to-one correspondence was not observed between the two series of tests. These results indicate the caution necessary in acceptance of aluminum alloy wire and suggest standardization of tensile testing techniques for small diameter wire. The final technology analysis was a critical analysis of literature pertaining to low temperature glass deposition. Important applications of this technology are to be found in thick film MOS techniques and highly controlled diffusion of bipolar devices. The latter is evidenced in precision diffused resistors. A final report has been written.

An analysis of transient radiation in microelectronic active devices (diodes and transistors) was made. The analysis is valid for both primary and secondary ionizing radiation, providing the energy-loss law is known. The importance of secondary radiation, as a means of producing ionizing photocurrents, follows from this study. Secondary radiation in the kilovolt energy range is extremely productive of photocurrents. A report of this study was submitted to the Fourth NASA Microelectronics Symposium.

A study of MOS technology was initiated. The first phase of this study included an examination of test patterns used by commercial vendors. The test patterns were for the purpose of defining various processes used in MOS transistor fabrication. The different test patterns span a period of MOS technology of about five years. Various elements of the test patterns show a

considerable increase in complexity of device processing. The latter indicates relative importance of oxide process control in MOS technology.

## PUBLICATIONS

### Meeting and Symposia Papers.

1. "Interaction of Kilovolt Energy Electrons of Semiconductors," paper submitted for the Fourth NASA Microelectronics Symposium, January 1970. P. Pietrokowsky. (Conference cancelled, but proceedings were published.)

701-90

PLANETARY ENVIRONMENT SIMULATION TECHNOLOGY

NASA Work Unit 186-71-02-02

JPL 384-10501-0-3750

N. Morgan

OBJECTIVE

The objective of this work unit is to identify, plan for, and develop environmental simulation test capabilities to support projected planetary missions. During this reporting period, this work unit has continued to support activities directly related to the Thermoelectric Outer Planet Spacecraft (TOPS) Project. The major activity has been in the area of radiation environment simulation while efforts in other areas have been essentially completed.

PROGRESS

Conceptual Design of a Helium Cooled Shroud for Antenna Testing

This effort is essentially complete and a Section Report 701-73, "Thermoelectric Outer Planet Spacecraft (TOPS) High Gain Antenna Thermal Simulation" is in the process of publication. A brief summary of this report follows.

A thermal analysis was made with the antenna both in space and in the space chamber to determine system requirements and to estimate system simulation performance. Two antenna configurations were assumed, 1) uninsulated, and 2) insulated from the RTG.

A light weight aluminum shroud designed for cooling by dense gaseous helium and for temporary installation inside of an existing LN<sub>2</sub> shroud simulates the thermal properties of deep space.

Either an open loop refrigeration system or a closed loop refrigerator may be used for shroud cooling. These systems are described and the cost of providing the systems and services for measuring the antenna surface are determined.

The lowest cost system is an open loop system using commercially obtained bulk liquid helium from 500 or 1000 liter dewars. The estimated costs include the environmental system, standby during test setup, operation of the system and six antenna measurements of 350 antenna surface points for a simulated flight from Jupiter to Neptune. Estimated cost for testing the insulated antenna configuration is \$147K. For the uninsulated antenna with an RTG simulator (infrared radiation only) the cost increases to \$181.4. The costs assume installation of the system in an existing large space simulator.

#### Study of Micrometeoroid Simulation Facilities

A Section Report 701-62, "Survey of Meteoroid Simulation Facility Capabilities" has been published and was distributed to several NASA personnel at the Program 186 Spring Review. Some effort will continue in this area to keep abreast of new developments. Since the last semi-annual report, there have been some changes (which have been incorporated in the Section Report) and these include the deletion of the recommendation for further multi-staged rocket studies and the addition of recommendations for MHD system studies and laser-accelerator studies. It should be noted that NASA, through centers such as Ames, is supporting development of micrometeoroid simulation capabilities in some of the areas recommended.

#### Simulation of RTG Radiation

During this reporting period work commenced on modifying existing test cells to allow testing of materials exposed to radioactive sources. One test cell modification will allow testing of piece parts and components wherein the effects of cumulative radiation dosage both in real time and at accelerated rates can be determined. Another test cell contains a vacuum chamber wherein combined environment tests will be conducted. In addition, the small Molsink chamber modification is essentially complete and combined environment testing can be performed upon delivery of a radioactive source.

ANTICIPATED PUBLICATION

1. Miller, C., and Parker, R., "Results of Radiation Backscat t Experiments Performed in JPL 10-Ft and 25-Ft Space Simulators".

PUBLICATION

JPL Publication

1. Miller, C.G. and Truscello, V.C., "Compatibility and Shielding Analysis of Science Instruments in Spacecraft Containing a Radio-isotope Thermoelectric Generator", JPL Technical Report 32-1427.

70-39416

DECONTAMINATION PROCEDURES  
(FORMERLY DEVELOPMENT OF ETO PROCESS  
SPECIFICATIONS AND PROCEDURES)

NASA Work Unit 191-58-21-02

JPL 392-82301-0-2940

A. S. Irons

## OBJECTIVE

The objective of this work unit is to develop the necessary information and procedures that will permit the successful application of cleaning and decontamination processes to space hardware. Success will be evaluated in terms of bactericidal and sporicidal activity and compatibility with typical spacecraft materials.

## INTRODUCTION

Orbiting missions may require hardware cleaning or decontamination to decrease the viable microbial load on spacecraft to an acceptable level. An examination of decontamination compounds and procedures is required to determine their effectiveness in reducing the number of viable particles resident on space hardware.

## APPROACH

The approach of this task is to complete the contracted ETO effort to determine the effects upon process efficiency of varying the process parameters: temperature, relative humidity, ethylene oxide concentration, pressure, carrier gases, and duration of prehumidification phase. The effects of gas flow volume and velocity during all phases of the cycle are being evaluated and tests are being carried out on inoculated test pieces that simulate flight hardware. Cognizance is being maintained on current work in the field of decontamination and development of equipment and processes that utilize various cleaning or decontamination agents.

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## ACCOMPLISHMENTS TO DATE

During the past six months of FY'70, the following was accomplished:

1. The inoculated test pieces that had been exposed to a vacuum of  $1 \times 10^{-6}$  torr for two weeks were exposed to ambient conditions while waiting for exposure to ethylene oxide. The pieces were checked periodically for die-off of spores.
2. The ethylene oxide chamber was delivered to Becton Dickinson (B-D) Research Center, Raleigh, North Carolina, by the fabricator, S. Blickman Company.
3. A series of trial runs was initiated to determine whether the desired operating characteristics necessary to conduct parametric exposures could be achieved.
4. The parametric evaluation was expanded to include exposure to ETO of test pieces not previously preconditioned at increased temperature and humidity. These data will be required if it becomes necessary to decontaminate unpreconditioned hardware. The inclusion of this important experimental condition required an extension of the period of effort. Becton Dickinson agreed to perform the additional tests at no additional cost to JPL if the period of effort called for in the contract could be increased. Approval was given in the form of a Supplemental Agreement which changed the program completion date from 12 March 1970 to 1 September 1970, but did not increase cost.
5. A shakedown of the chamber revealed that some alterations had to be made to meet the contract objectives. These alterations, which required more effort than originally anticipated, have been completed.
6. Assays of test pieces indicate excessive die-off of the inoculum since exposure to vacuum and storage at ambient for approximately 4 months. Some test pieces have been or are being reinoculated.
7. Operating instructions for the chamber have been prepared.

## FUTURE ACTIVITIES PLANNED

Future activities in this task effort will be to determine the microbial reduction capability and material compatibility of chemicals to be used for cleaning of spacecraft. This will include the development of a preferred cleaning methods and materials chart for all spacecraft subsystems and an evaluation of these procedures for cleaning of surfaces on the Mariner-Mars 1971 back-up spacecraft.

Continued activities on the ethylene oxide chamber studies will be as follows:

1. Test pieces will be assayed for die-off prior to ETO exposure. Test pieces showing excessive die-off; i. e., greater than 1 log from the original  $1 \times 10^6$ , will be reinoculated and dessicated under vacuum.
2. Test pieces will be subjected to various conditions of relative humidity, temperature, time, and ethylene oxide concentration to determine their effect on decontamination process efficiency.
3. The test pieces will be assayed after exposure and attribute data (positive or negative) as well as enumeration data (number of survivors) will be acquired and used as the basis for determination of efficiency.
4. A final report will be prepared which will present a summary of data generated in all phases of the study. This report may furnish the basis of ethylene oxide cycle recommendations and determination of the most efficient cycle under the terms and conditions of the tests.
5. Constant communication will be maintained between cognizant JPL and B-D personnel in an effort to keep the period of effort at a minimum.

## PUBLICATIONS

None.

## REVIEW OF HEAT SPECIFICATIONS

NASA Work Unit 191-58-21-06

JPL 392-80601-0-2940

M. D. Wardle

## OBJECTIVE

The objective of this task is to develop procedures and acquire information necessary for the definition of appropriate flight acceptance and terminal sterilization cycles for flight hardware. To accomplish this objective, the dry heat resistance of micro-organisms exposed to typical spacecraft prelaunch environmental conditions will be determined in conjunction with an investigation into those factors affecting the manifestation of dry heat resistance.

## INTRODUCTION

Studies presently in progress which are concerned with micro-organism heat resistance are the following: 1) determination of the effect of various environmental factors on heat resistance and 2) the estimation of decimal reduction times (D values) of micro-organisms indigenous to spacecraft assembly environments.

## APPROACH

The following tasks have been developed to evaluate the effect of various parameters on the heat resistance of micro-organisms:

Heat Resistance of Natural Contaminants

Using the swab-rinse technique, spore isolates were acquired from the Mariner '69 spacecraft. Heat resistance studies of spore crops from these isolates were conducted.

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### Heat Resistance of Spores Located Between Mated Surfaces

The Thermal Joint Conductance apparatus is used to conduct studies of the relationship between the pressure to which spores are exposed and their heat resistance expressed as  $D_{125^{\circ}\text{C}}$  values. The description of this device appears in a previous report.

### Determination of Effect of Water on Heat Resistance of Spores

Using a Quartz Crystal Microbalance (QCM), sensitive to mass changes in the nanogram range, bacterial spore mass is measured and changes in this mass are studied in relation to the environmental conditions seen by the spores. Environments emulating those experienced by a typical spacecraft prior to launch are invoked.

### ACCOMPLISHMENTS TO DATE

#### Heat Resistance of Natural Contaminants

Further testing of the Mariner '69 spore isolates reported on during the last period has been completed. These tests were designed to determine the effect of replication, sporulation medium, and suspension menstruum on  $D_{125^{\circ}\text{C}}$  values. The latter two factors were found to significantly affect the heat resistance of the spores. A complete report on the dry heat resistance of the Mariner '69 isolates is in preparation for publication in the open literature.

#### Heat Resistance of Spores Located Between Mated Surfaces

Spore heat resistance (at  $125^{\circ}\text{C}$ ) in earth,  $\text{GN}_2$ , and helium (He) atmospheres at pressure levels from ambient to 10,000 psi was determined. The spores were located on stainless steel surfaces placed in a mated configuration. Tests at ambient pressure showed that earth atmosphere produced the highest  $D_{125^{\circ}\text{C}}$  (26 minutes) followed by  $\text{GN}_2$  (18 minutes) and He (13.5 minutes) atmospheres. Increasing pressure to 10,000 psi appeared to raise the heat resistance of the micro-organisms in all three atmospheres. At 10,000 psi the

earth atmosphere tests exhibited a  $D_{125^{\circ}\text{C}} = 41.5$  minutes, while  $\text{GN}_2$  and He atmosphere tests showed  $D_{125^{\circ}\text{C}}$  values = 21 minutes. The statistical significance of this increase has not yet been assessed.

#### Determination of Effect of Water Content on Heat Resistance of Spores

A quartz crystal microbalance (employing eight crystals) for the detection of mass changes in bacterial spores exposed to various environmental conditions, has been fabricated and physically tested. The physical tests have shown both temperature and relative humidity to be critical parameters in the accurate measurement of spore mass. Efforts have been made to define these parameters more accurately in the context of biological experimentation with the microbalance. Biological testing to date has indicated the ability to estimate spore mass on the crystals in a vacuum. Using a micrometer syringe, spores were placed on the crystals and their mass was measured. Concurrent tests using plate count and counting chamber estimates of the number of spores present in the inoculum indicated the mass measurement made by the microbalance to be realistic.

#### FUTURE ACTIVITIES PLANNED

##### Heat Resistance of Natural Contaminants

Future efforts in this task area will be directed towards determination of the heat resistance of bacterial spores recovered from the Mariner-Mars 1971 spacecraft.  $D_{125^{\circ}\text{C}}$  values will be estimated in both atmospheric and  $\text{GN}_2$  environments. Comparison between the '69 and '71 dry heat resistance studies will be made.

##### Heat Resistance of Spores Located Between Mated Surfaces

Future experiments will be directed toward more accurately defining the effect of different relative humidities on the heat resistance of spores located between mated surfaces.

Determination of Effect of Water Content on Heat Resistance of Spores

As a result of a curtailment in the funding of this task, no further work is projected for FY'71.

PRESENTATIONS

The following presentations were given at the semiannual Sterilization Symposium:

1. "Thermal Resistance of Microbial Populations Occurring in Hardware Assembly Areas," presented by M. Wardle.
2. "Study of Surface Mating Pressures and  $D_{125^{\circ}\text{C}}$  Values," presented by C. Hagen.
3. "Quartz Crystal Microbalance," presented by M. Wardle.

Another paper concerning this task was given at the ASM meeting in Boston, Massachusetts. This paper was entitled, "The Effects of Various Cure Cycles Upon the Viability of Bacillus Subtilis var. Niger Spores Within Solid Propellant," and was prepared by W. Brewer, W. Paik, C. Robillard and R. Green. It was presented in Boston by W. Brewer.

ANTICIPATED PUBLICATIONS

Wardle, M. D., Brewer, W. A., and Peterson, M. L., "Dry Heat Resistance of Bacterial Spores Recovered from the Mariner-Mars '69 Spacecraft," in preparation.

PUBLICATIONS

None.

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## PLANETARY QUARANTINE ANALYSIS

NASA Work Unit 191-58-22-04

JPL 392-80101-0-2940

M. Knittel

R. Green

D. Taylor

### OBJECTIVE

The objective of this work unit is to perform analyses necessary to (1) define Planetary Quarantine constraints; (2) perform sensitivity studies to determine the effect of specific contamination events on the terminal sterilization cycle or probability of contamination allocation; and (3) perform research necessary to establish valid numbers for use in analytical studies.

### INTRODUCTION

The Planetary Quarantine analyses are being performed with emphasis being placed on problem areas delineated for flight programs, present and future. A systems approach based on planned mission profiles is used to identify contaminating events. A logic diagram constructed for these events facilitates calculations and probability allocations. Sensitivity studies will be performed to determine the effect of a specific contaminating event on the overall probability allocation and/or sterilization cycle.

### APPROACH

The work unit has been divided into two subtasks, Planetary Quarantine Analytical Studies and Research Activities. Analytical studies of the planetary quarantine constraints relative to future flight projects are being continued so that these constraints can be evaluated at the conception of a proposed project.

Research tasks will be identified as necessary to provide valid numbers for use in analytical studies. Current research activities include: (a) Molsink Studies (determination of the effect of a simulated deep space environment

on survival of vegetative bacterial cells; (b) probability of release studies and (c) studies to determine if microorganisms can survive prolonged exposure to the lunar environment by performing a microbiological assay of parts of the Surveyor III spacecraft returned by the Apollo XII crew.

## ACCOMPLISHMENTS TO DATE

### Molsink

The Space Molecular Sink facility has been used to determine the effect of simulated deep space vacuum and heat. Pressures of  $10^{-10}$  torr and temperatures of 30 to 60°C were used to determine the survival of vegetative bacterial cells. The test bacteria were a Staphylococcus sp. and a Micrococcus species.

It was determined that 1% of the population of either the Micrococcus sp. or the Staphylococcus sp. could survive at 60°C during a 14-day exposure. At 30°C, 11% of the Staphylococcus sp. cells survived 14 days while 24% of the Micrococcus sp. cells survived this temperature for the 14-day period. Twenty percent of both test bacteria survived the -105°C exposure for 14 days. As a point of comparison, these same bacteria were exposed to ambient pressure (760 torr) at a temperature of 25°C for 14 days. The Staphylococcus sp. lost viability completely (0% survival) and the Micrococcus population dropped to 2.9% of the initial inoculum.

Recently the time of exposure has been increased to 28 days and the results show that with the Micrococcus sp. 1% survived 60°C, 8.7% survived 30°C and 7.1% survived -104°C. A repeat of this experiment is now in progress to establish the validity of these results.

### Microbiological Assay of Surveyor III Parts

Microbiological sampling of the Surveyor III camera was completed in cooperation with personnel at the Manned Spaceflight Center Lunar Receiving Laboratory. One organism (Streptococcus mitis) was recovered from a piece of polyurethane foam used as insulation for a circuit board in lower housing of the camera.

Microbiological sampling of the returned Surveyor III cabling has been initiated. The Sealed Environmental Sampling Container (SESC) not only contained the cable samples but also a sample of painted aluminum strut. This strut and samples of the mylar wrapping from the cable had to be transferred from the SESC to other sample containers in a controlled atmosphere of argon containing less than 10 ppm of water, CO<sub>2</sub>, and oxygen and with only red light illumination. During the transfer, microbial contamination of the cable samples was prevented by a strict protocol of aseptic procedures.

The microbiological sampling of one piece of TV cable has been completed and the cultures are incubating. At this time, 14 days have elapsed and no positive cultures have been found. Incubation of the samples will continue for at least 4 more weeks before the final readings will be made.

#### Probability of Release

The microbial release studies conducted under contract by the Boeing Company were completed during this reporting period. These studies were designed to obtain information for use in determining the probability of survival and release of viable microorganisms from the interiors of solids after a hard planetary landing. This was accomplished by impacting internally contaminated projectiles into stainless steel collection canisters. Parameters that were studied included materials impacted (methyl methacrylate and Eccobond 55), number of organisms, impact velocity and surfaces impacted, i. e., stainless steel and sand.

The results show that less than one percent of the spores were released, and that the total number of organisms surviving impact decreases as the velocity increases. This decrease in total survivors with an increase in velocity offsets an otherwise expected increase in released viable organisms as fracturing of materials increases. The data obtained during this study indicate that the probability of microbial release should be re-evaluated and reduced.

## FUTURE ACTIVITIES

Studies using the Molsink facility will continue with exposures of up to 56 days. Based on the results from the 56-day exposure, an experiment will be planned to expose vegetative bacterial cells for 6 months to understand better the rate of bacterial vegetative cell and spore die-off in simulated space.

In the near future, the second piece of TV cable from Surveyor III will be subjected to Microbiological Assay. If any positive cultures are obtained from the sampling these will be classified and tested for ability to survive in simulated extreme environments.

A contract has been negotiated with the Boeing Company for further studies or probability of release of bacterial spores from solids by aeolian erosion.

## MEETINGS ATTENDED

1. A presentation based on this task was given at the semi-annual Sterilization Symposium by R. Olson, entitled "Microbial Release from Solids After Simulated Hard Landing."
2. Hagen, C. A., J. F. Godfrey, R. H. Green, and C. W. Craven, "Survival of Microorganisms in Deep Space Environments," Extreme Environments: Mechanisms of Microbial Adaptations, Ames Research Center, June 24-26, 1970.
3. Mitchell, F. J., W. L. Ellis, and M. D. Knittel, "Microbiological Analysis of the Surveyor III TV Camera," Extreme Environments: Mechanisms of Microbial Adaptation, Ames Research Center, June 24-26, 1970.

## PUBLICATIONS

### Meeting and Symposia Papers

1. Paper read before the Thirteenth Plenary Meeting of COSPAR in Leningrad, USSR, May, 1970.

2. Fraser, S. J., R. L. Olson, and R. H. Green, "Microbial Release from Solids After Simulated Hard Landings."

## STERILIZATION SUPPORTING ACTIVITIES

NASA Work Unit 191-58-23-02

JPL 392-81101-0-2940

D. M. Taylor

## OBJECTIVE

The objectives of the Sterilization Supporting Activities include the following:

1. Maintenance of in-house microbiological laboratory 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 program.

## INTRODUCTION

The Sterilization Supporting Activities serve as laboratory and technical support for each of the existing JPL tasks. Study of new problem areas as well as development of a state-of-the-art awareness of potentially applicable technologies are included under this task.

## APPROACH

The Sterilization Supporting Activities have been divided into tasks, the accomplishments of which are summarized below.

## ACCOMPLISHMENTS TO DATE

Microbiology Laboratory Operations

The Microbiological Laboratory Operation task has continued to provide the necessary laboratory support for the various other tasks requiring microbiological experimentation including technical assistance in developing

experimental procedures. Most of these tasks are reported as separate NASA work units. The Microbiology Laboratory in Building 233 has been reactivated and all equipment brought into specification in order to carry out the SR&T Spacecraft Monitoring task. This laboratory will also be used to assay microbiological samples from the Mariner '71 spacecraft and for carrying out research tasks requiring a biologically controlled environment.

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. A short discussion of some of these is presented below.

#### Monitoring of Fungi in Spacecraft Assembly Areas

Initial recoveries of micro-organisms from environmental fallout strips and Reyniers air samples in Building 179, Spacecraft Assembly Facility, revealed the presence of high numbers of fungi, primarily molds. Preliminary studies were initiated to record the incidence of fungi recovered on Sabouraud agar from additional fallout strips placed in the environment. The results from this study will be reported at a later date.

#### Lunar Rock Crusher

Two additional lunar rock crushers were cleaned and sterilized for the Manned Space Center. The same procedures which were reported in the last semiannual report were used.

#### FUTURE ACTIVITIES PLANNED

Activities in support of JPL's Planetary Quarantine Program will be continued. This task will be continued to provide the microbiological laboratory support required to carry out microbiological research necessary to support the other NASA work units. A study will be initiated to determine the feasibility of developing a direct detection and assay method for micro-organisms on spacecraft surfaces.

JPL participation in NASA-sponsored activities such as the planetary quarantine advisory committee and NASA document reviews will be continued.

Furthermore, as new problem areas are identified, studies will be initiated to obtain preliminary information or a better definition of the problem areas.

#### MEETINGS ATTENDED

1. Green, R. H., Biological Contamination Control. Presented at the Dusseldorfer Hygienetag in Dusseldorf, West Germany.

#### ANTICIPATED PUBLICATIONS

1. Brewer, W. A., Paik, W. W., Robillard, C., and Green, R. H., "The Effects of Various Cure Cycles Upon The Viability of Bacillus Subtilis var. Niger Spores Within Solid Propellant," submitted to Applied Microbiology.

#### PUBLICATIONS

None.

MICROBIOLOGICAL MONITORING OF SPACECRAFT ASSEMBLY  
FACILITY OPERATIONS

NASA Work Unit 191-58-23-03

JPL 392-80401-0-2940

D. Taylor  
R. Koukol  
M. Christensen

## OBJECTIVE

The objectives of the Monitoring Study are: (a) to continue developing and documenting the procedures and techniques necessary to estimate the spacecraft surface microbial burden on specific locations of the vehicle, during any phase of assembly or testing; and (b) to provide data to update the input histograms of the Microbial Burden Prediction Model.

## INTRODUCTION

The Planetary Quarantine Studies require both an accurate estimation of the number of microorganisms and the precise location of the organisms on the spacecraft. This information is necessary to determine if a particular flight would contaminate a planet or what time/temperature is needed to sterilize the spacecraft.

## APPROACH

The program approach is to use the Mariner '71 Project Monitoring Plan as a control and by taking supplementary samples on specific areas, do sensitivity studies which will provide a confidence limit on the microbial burden estimate. This task will also be used to investigate the criteria for: (a) selection of surfaces; (b) number and location of samples; and (c) data handling.

Input histograms to be updated for the Microbial Burden Prediction Model include histograms for environmental fallout, initial burden on all subzones entering the assembly flow and the microbial burden at different assembly stages. The data for these parameters will be obtained under this

subtask effort. Emphasis will be also directed towards development of sampling procedures for problem areas such as cabling, thermal blankets, solar panels, etc.

#### ACCOMPLISHMENTS TO DATE

The M'71 spacecraft has been partitioned into major assembly zones (17) and subzones (66). The surface area has been computed with a total of 1800 ft<sup>2</sup> - 700 exposed, 1100 occluded and 30 mated. On the basis of this breakout, 25 subzones have been selected for use in the monitoring of the spacecraft, and sampling sites have been selected for these 25 subzones.

The monitoring program has been determined and is scheduled with 13 monitoring events. At each event the subzone burdens are determined by taking 250 microbiological samples of 4 in<sup>2</sup> each, combining all the subzone burdens and extrapolating to the total spacecraft. The first scheduled sampling has been initiated on the PTM and this data has been programmed and entered into the Bioassay Data Storage and Retrieval Program. Monitoring of the Mariner '71 assembly environment has also been initiated.

#### FUTURE ACTIVITIES

In the future, the monitoring program for the PTM and flight spacecraft will be continued and the data used in updating the math model. Through a detailed analysis of the data it will be possible to develop criteria for:

- (1) selection of surfaces
- (2) number and location
- (3) data handling

Monitoring procedures for problem sampling areas such as cabling, thermal blankets, and solar panels will be developed.

MEETINGS ATTENDED

A presentation of this task was given at the semi-annual Sterilization Symposium by M. Christensen under the title, "Microbiological Monitoring of Spacecraft Assembly Facility Operations."

PUBLICATIONS

None.

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STOCHASTIC MATH MODEL  
NASA Work Unit 191-58-23-06  
JPL 392-80201-0-2940  
A. R. Hoffman

## OBJECTIVE

The objective of this task is the development of a mathematical model and associated computer programs capable of accurately predicting burden on various surfaces of a space vehicle during systems assembly and test.

## INTRODUCTION

The model is intended (1) to supplement the biological assays of the planetary vehicle by simulating the microbial accumulation processes during periods when assays are not taken, (2) to reduce the number of biological assays that are required to be taken, and (3) to predict the microbial loading on the spacecraft in support of the planetary quarantine analysis and the design of terminal sterilization processes.

## APPROACH

The approach is to write a computer program code, to improve the code logic and the input histograms by emulating test and assembly sequences from previous flight projects, to convert the model from a theoretical tool to a control tool and demonstrate the manner in which it could be applied to an ongoing program, and to compare predictions to the results of the assay data in real time.

## ACCOMPLISHMENTS TO DATE

During the reporting period, Phase VIII of JPL contract 952532 was completed. The Input Translator Program (ITP) was developed during this phase to facilitate preparation of input data. The ITP performs much of the repetitious and time-consuming work involved in preparing input data. In addition, it also performs bookkeeping chores such as maintaining the current

status of all parts. The ITP was programmed so that only minor revisions were necessary to the previously developed portions of the program. The ITP has been used to prepare input data based on the Mariner Mars 69-3 spacecraft for use on the burden prediction model.

Also, during this reporting period, a series of sensitivity studies were performed using the MV 67-2 emulation. The results indicate that increases in environmental fallout levels give significantly larger increases in microbial burden on the spacecraft than similar increases (factors of 10 to 100) in average lifetime.

The Mariner Mars '71 planned sequence emulation has been completed.

#### FUTURE ACTIVITIES

An analysis of the Mariner Mars '71 (MM'71) planned sequence will be performed to verify conclusions from the MV 67-2 sensitivity studies and to evaluate input parameters not considered in the earlier study.

The actual assembly of MM 71-2, beginning in August, will be emulated. The model will generate burden predictions that will be compared to estimates based on the assay data while the assembly is still in progress.

#### PUBLICATIONS

None.

## DEVELOPMENT OF AN ULTRASONIC/VACUUM SAMPLING DEVICE

NASA Work Unit 191-58-23-08

JPL 392-82801-0-2940

H. W. Schneider

## OBJECTIVE

The objective of this task was to develop an ultrasonic vacuum device that can be used to remove and recover either particulate materials or microorganisms from space hardware.

## INTRODUCTION

The device has been designed to utilize both ultrasonic energy and vacuum in a synergistic mode. The entire system is comprised of a vacuum head, an oscillator, a piezoelectric transducer, a vacuum source and a sample collection device.

## APPROACH

Before the device can be employed on space hardware, a systematic study of the operational parameters must be completed. The device has to be compatible with spacecraft material and operational constraints.

## ACCOMPLISHMENTS TO DATE

The first test with the device was conducted in January 1970. Four 10 x 14-inch aluminum trays were seeded with a known amount of B. subtilis var. niger spores and treated with the probe according to prescribed procedures, leaving designated control areas untreated. Without utilizing the crystal, at a flow rate of 1 CFM, removal efficiencies of 39, 25, 19 and 19% were obtained.

Following this, the 49 kHz crystal was incorporated, and the device was tested on particulate matter of a known size. Monolayered 1.1, 7.5 and 30 micron size polystyrene, styrene divinylbenzene and polydextran particles

with a fluorescein tag were prepared for this test. At maximum flow rate and power output, the device was not efficient in the removal of the test particles. The operation of the 49 kHz crystal did not produce an appreciable increase in particle removal, although a sound pressure level of 117 db was measured underneath the crystal in the sampling plane. The flow velocity measured at the inlet of the device was approximately 900 to 1000 FPM.

Concluding that the device would not be more efficient than available techniques for removing spore size viable particles, all further testing was discontinued.

#### FUTURE ACTIVITIES PLANNED

No future activities are planned under this task.

Analytical work based upon literature data to assess the capability of other conceivable concepts for the removal of small particulates from surfaces is in progress. These studies indicate that acoustic energy levels, which are potentially lethal to microorganisms and incompatible with delicate spacecraft surfaces, are necessary to break the adhesive bonds.

#### PUBLICATIONS

1. Christensen, M. R. Presentation at Semi-Annual NASA Sterilization Technology Seminar in Atlanta, Georgia, April 15 and 16, 1970, p. 124-131.

A final report is in progress.

## PLANETARY QUARANTINE OPERATIONS

NASA Work Unit 191-58-23-09

JPL 392-81301-0-2940

G. F. Ervin

## OBJECTIVE

It is the objective of this work unit to provide direct support to the NASA-HQ Planetary Quarantine Officer and his staff in order to provide assurance that the quarantine requirements of NHB 8020.12 are being met by unmanned planetary projects.

## APPROACH

This task will consist primarily of providing various technical services to the Planetary Quarantine Officer. The technical services to be provided by JPL will be requested by the Planetary Quarantine Officer through the JPL Office of Research and Advanced Development. The services to be provided by JPL will be largely devoted to the review and critique of various documents submitted by unmanned planetary projects to satisfy NHB 8020.12 requirements. The support to be provided by JPL will be primarily on-site (at JPL) and may involve the disciplines of microbiology, mathematical analysis, mission design and analysis, component reliability, and others.

## STATUS

During this reporting period, draft versions of the Viking '73 and Mariner Mars '71 Planetary Quarantine Plans were reviewed and comments given to the NASA Planetary Quarantine Officer. With the delay of Viking until 1975, it is anticipated that the Viking Planetary Quarantine Plan will be modified, updated, and again submitted for review at a later date. The Mariner Mars 1971 Planetary Quarantine Plan has been formally approved by representatives of the JPL Project Office, the NASA-HQ Program Office, and the NASA-HQ Planetary Quarantine Office and was released April 13, 1970.

A presentation was made to the Planetary Quarantine Advisory Committee on April 14, 1970, in Atlanta, Georgia. This presentation was an introduction to various outer planet missions that are under consideration and explained the basic scientific rationale associated with such missions. Its purpose was to stimulate members of the Committee toward a consideration of Outer Planet Planetary Quarantine problems and requirements.

Also, as a part of this work unit, various discussions have been held with representatives of the George Washington University Biological Communication Project. These discussions were aimed at determining mechanisms whereby the JPL Planetary Quarantine library could be reproduced on microfiche and entered into GWU's system. These discussions were generally favorable and resulted in a preliminary agreement which would allow the start of categorization, screening and reproduction activities about September 1970.

#### FUTURE ACTIVITIES

The activities of this work unit in the near future will be those associated with:

1. A review of Microbiological Assay and Monitoring Plan, Planetary Quarantine model, prelaunch analysis documents and any modifications that may be proposed to the approved Mariner Mars '71 Planetary Quarantine Plan.
2. Updating and resubmission of the Viking '75 Planetary Quarantine Plan.
3. A review of the Mariner-Venus-Mercury '73 Planetary Quarantine Plan, if required.
4. A continuation of the coordination activities with GWU.

#### PUBLICATIONS

None.