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FLEXIBLE ROLLED-UP SOLAR ARRAY

NINTH QUARTERLY REPORT

OCTOBER 1970

PREPARED FOR:
Air Force Aero Propulsion Laboratory
Research and Technology Division
Wright-Patterson Air Force Base, Ohio 45433

PROJECT NO. 682J/DATA NO. HS207-205(9)/CONTRACT NO. F33615-68-C-1676

PREPARED BY:
Hughes Aircraft Company / Space Systems Division
(Under Contract F33615-68-C-1676)

AUTHORS: E. O. Felkel
G. Wolff
Et al.

Hughes Ref. No. 70(22)-10798/B3532-018

SSD 00501R

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FOREWORD

This report was prepared by Hughes Aircraft Company, Space Systems Division, El Segundo, California, under Contract F33615-68-C-1676. The work was administered under the direction of L. D. Massie, APIP-2, Air Force Aero Propulsion Laboratory.

The period covered extends from 29 June 1970 to 27 September 1970. Contributors to this report include E. O. Felkel, G. Wolff, M. C. Olson, W. N. Turner, R. E. Daniel, G. P. Steffen, D. Plummer, R. K. Geiser, G. Lindenman, C. Duncan, and D. Lane, all of Hughes Aircraft Company, Space Systems Division, El Segundo, California.

The work covered herein was accomplished under Air Force Contract F33615-68-C-1676, but this report is being published and distributed prior to Air Force review. Publication of this quarterly, therefore, does not constitute approval by the Air Force of the findings or conclusions contained herein. It is published for the exchange and stimulation of ideas.

ABSTRACT

The main activities on the Flexible Rolled-Up Solar Array (FRUSA) program during the ninth quarterly reporting period consisted of assembly of the development /qualification model of the orientation mechanism, solar array, drum mechanism, control electronics unit (CEU), and solar cell electronics unit (SCEU).

Cells, simulated blanks, and busses were bonded to the two qualification model panels. The panels were connected to the drum mechanism, which had been assembled without the interface wiring, and water table deployment/retraction tests on the complete assembly successfully conducted. Functional acceptance testing of the CEU and the SCEU have been initiated. The instrumentation conditioning unit (ICU) is still awaiting the two hi-reliability capacitors before acceptance tests can be initiated. Fabrication of detailed parts for the power conditioning unit (PCU) and battery/charge controller are nearing completion, and detailed parts drawings and the schematic have been released for the load bank assembly.

An updated FRUSA/Agena wiring diagram, Space Experiment Plan, and Flight Model Design and Test Specification have been completed and submitted to Wright-Patterson Air Force Base.

The fourth semiannual FRUSA system review was held on 15 September. Attendees included representatives of the Air Force, NASA, Aerospace and Hughes organizations. Several working group meetings were held between SAMSO /Aerospace/LMSC and Hughes to resolve interface problems, the most serious of which are interference between the orientation mechanism drum axis shaft, and a spacecraft antenna dipole. Additional tasks implemented during the reporting period were a shading, EMI/EMC, and a structural dynamics analysis.

CONTENTS

ILLUSTRATIONS

TABLES

SECTION I

INTRODUCTION AND SUMMARY

This document reports progress in the ninth quarter (29 June to 27 September 1970) on AFAPL contract F33615-68-C-1676, Flexible Rolled-Up Solar Array, Project Number 682J.

The main activities on the Flexible Rolled-Up Solar Array (FRUSA) program during the ninth quarterly reporting period consisted of assembly of the development/qualification model of the orientation mechanism, solar array, drum mechanism, control electronics unit (CEU) and solar cell electronics unit (SCEU).

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The format of this quarterly report is designed to present the status of each major system element in a separate section.

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SECTION II

PROGRAM STATUS

The Flexible Rolled-Up Solar Array (FRUSA) program is divided into five phases, as described in the paragraphs that follow. The current program schedule and status are shown in Figure 1.

PHASE I - PROGRAM DEFINITION

Major milestones associated with this phase and scheduled during this period have been completed. Included in this category are all the program requirements, design, and test requirements.

PHASE II - DESIGN STUDY AND ANALYSIS

The study phase of the program has been completed and a firm baseline design established. Design packaging details have been completed. Additional analysis tasks defined during the interface working group meetings are being initiated at this time. These tasks include the installation of a support axis position indicator assembly/sensor element to be provided by the mission integrating contractor; a Thorad/Agena structural dynamics

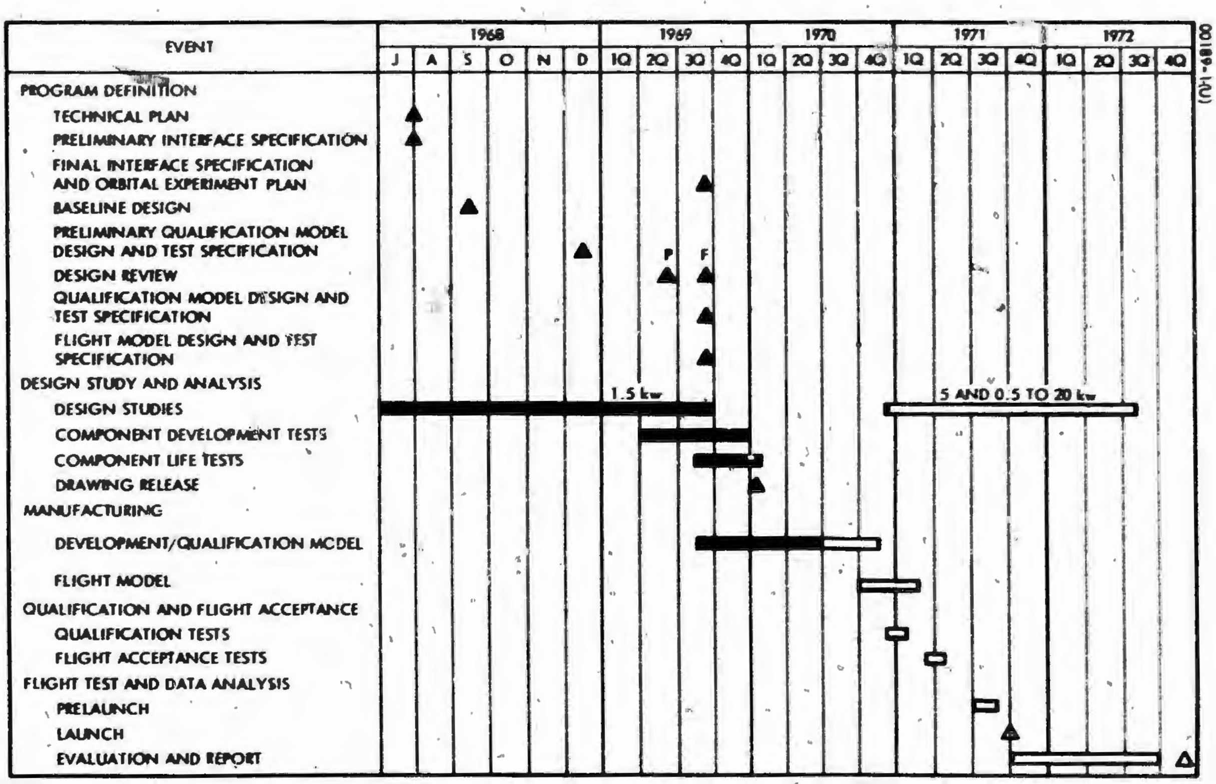

Figure 1. Program Schedule

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analysis to define ascent structural excitation levels and frequencies for the three-point attachment to the vehicle forward rack; a shading analysis to determine power output variations occurring during eclipse season light-time transient shading of the flexible array experiment solar panels by the SESP 71-2 vehicle fixed rigid solar panels; and an electromagnetic compatibility study to determine the potential interference effects to the Agena and the effect of the Agena payload and telemetry on FRUSA.

PHASE III - MODEL FABRICATION

All engineering drawings have been released. Fabrication of the engineering/qualification model is proceeding. Assembly operations on the qualification panel and orientation mechanism are nearing completion. Numerous Air Force/Aerospace/Hughes/LMSC working group meetings to resolve interface problems have been held and more are scheduled during the next reporting period.

PHASE IV - QUALIFICATION AND FLIGHT ACCEPTANCE TESTS

Qualification and flight acceptance tests will be conducted according to the test plan.

PHASE V - FLIGHT TEST AND DATA ANALYSIS

The flight test and data analysis phase will include prelaunch checkout and countdown procedures as well as in-orbit operation and analysis.

SECTION III

SYSTEMS ENGINEERING

SUMMARY

The systems engineering activity during this period included:

- Updating of FRUSA documentation
- Command modification
- Penumbra transition study and modifications
- FRUSA/Agena power interface switching logic
- Updating eclipse power summary
- Updating weight summary

ORBITAL OPERATIONS

The integrating contractor presented an Orbit Operations Plan during his 30 percent design review. This included the deployment of the FRUSA under the control of a sequencer/timer. Initially, Hughes requested that the FRUSA be deployed to its operational position by a real time pyro command for maximum operational flexibility and not be dependent upon the proper operation of the Agena timer. LMSC informed Hughes that for safety reasons all Agena pyro commands are sequencer controlled to prevent inadvertent ground command transmission of these critical events. Hughes is still somewhat apprehensive about the operation of the sequencer and would prefer to have all FRUSA functions performed by real time ground commands. The operation of this sequencer must still be thoroughly reviewed with LMSC to assure that no interference with the proper deployment of FRUSA occurs.

The LMSC Orbit Operations Plan specifies that during the 13th orbit the sequence timer will pitch down the Agena vehicle and transfer to a wideband pneumatic mode (from ± 0.2 to ± 3.0 degrees). The Agena rigid array, FRUSA, and ONR antennas are then deployed. Approximately 6 minutes are allowed for stabilization before activation of the control moment gyros. The pneumatic system continues to operate, reinforcing the action of the gravity gradient mode control moment gyros. The vehicle torques are monitored to verify that they are low enough to allow capture of the vehicle attitude by the control moment gyros. If performance of the gyros is satisfactory, the pneumatics are deactivated during the 14th orbit. Data readouts for SAMSO-002 are scheduled to continue through the 16th orbit, with the last readout obtained from the Kodiak Tracking Station.

FRUSA array extension is planned for the 16th orbit after control has passed from Kodiak to the Hula Tracking Station. Sun acquisition is scheduled for the 17th orbit during the Kodiak pass.

A recent analysis by LMSC has indicated that the FRUSA drum mechanism, in its initial deployed position, will interfere with the Agena horizon sensor. The horizon sensor is used until the pneumatics are deactivated in the 14th orbit. Therefore, it may be desirable to command sun acquisition immediately after deployment to move the FRUSA from its initial position. If there is insufficient time to acquire the sun during the 13th orbit (this may require as long as 9 minutes), it may be desirable to torque about the support axis for only a few minutes to move the drum mechanism away from the horizon sensor field of view, turn the CEU off again, and complete the sun acquisition sequence in accordance with the present schedule (on the 17th orbit). This matter must be reviewed thoroughly with LMSC to arrive at a mutually satisfactory solution.

Manual slewing of the array to the +Z side of the spacecraft is scheduled for the 19th orbit in the LMSC plan to prevent interference with the ONR-001 experiment. This maneuver also is not scheduled in the Hughes Space Experiment Plan. Manual torquing commands were included in the FRUSA only to accommodate emergency situations if binding would occur in the orientation mechanism. Manual torquing must be done with extreme care because it is not rate limited. The OFF command must be sent within a few seconds after the ON command to prevent generation of excessive disturbance forces on the spacecraft. Also, it is not possible to repeat the OFF command many times to ensure an OFF condition, because manual slewing is performed by toggle commands. The ON and OFF conditions must be confirmed by telemetry. The matter of manual slewing is still being reviewed by Hughes and LMSC. Hughes would prefer not to use the manual torquing commands in an operational mode, only under emergency conditions.

DOCUMENTATION

The FRUSA/Agena wiring diagram was updated to reflect the latest design changes in the electrical interfaces between the FRUSA and Agena telemetry, command, and power subsystems. The drawing has been furnished to the integrating contractor who is responsible for fabricating the flight harness.

The FRUSA Space Experiment Plan has been completed and published. Some minor modifications will be made at a future date to synchronize the FRUSA mission sequence with the LMSC Orbital Operations Plan.

The Flight Model Design and Test Specification has been updated to reflect the latest FRUSA design changes.

SEMIANNUAL REVIEW

The fourth semiannual FRUSA system review was held at the Hughes Aircraft Company facilities in El Segundo, on 15 September 1970. Attendees included representatives of the Air Force, NASA, Aerospace and Hughes organizations.

The main theme of the review was the overall status of the FRUSA program. (See Fourth Semiannual Review booklet for details.) After the oral presentation, the qualification model hardware, consisting of the following, was exhibited.

- Orientation mechanism
- Solar panels and drum
- Control electronics unit
- Instrumentation conditioning unit
- Solar cell electronics unit

MEETINGS

A technical group meeting with LMSC was held at Hughes El Segundo on 2 September 1970. The major technical points discussed were:

(1) Use of the FRUSA sun lock-on signal to be combined with the SAMSO-002 "on" signal for FRUSA slew disable. During eclipse periods when the FRUSA would normally be slewing about the support axis, it is possible that the FRUSA panels could interrupt the 002 experiment operation. LMC proposed to utilize the sun lock-on signal plus the 002 "on" signal to disable the FRUSA slewing during eclipse. It was agreed that LMSC could use the FRUSA sun lock-on signal if they provided the proper buffering.

(2) LMSC would like to control the interface relay which is located within the FRUSA PCU. This would eliminate the need for a second large relay, which could be used to remove the Agena loads from the FRUSA. This is desirable in case of a malfunction within the Agena experiments. It was agreed that Hughes would bring the interface relay control wires out to spare pins on the PCU J1 connector.

Updated schematics were furnished and sundry items of future planning were discussed.

COMMAND MODIFICATION

The load bank was originally designed to operate with four ON commands and one common OFF command for all four load resistors. However, it was determined that the Agena command decoder can not supply the 0.25 ampere required by the four command latching relays. Its maximum load capability is 150 ma. Therefore, it became necessary to provide two OFF commands to reduce the current requirement to 125 ma.

PENUMBRA TRANSITION OPERATION

A detailed analysis of FRUSA operation during the transition from sun illumination to total eclipse was conducted. To understand the transition or penumbra conditions more clearly, an orbital analysis was performed. The results were somewhat surprising. The SESP-71 spacecraft will be launched into a twilight orbit. Because the SESP-71-2 orbital inclination at launch will be close to 90 degrees, the spacecraft, initially, upon entering eclipse, only grazes through the penumbra. After approximately 1 month in orbit, the first penumbra condition is reached. Its time increases with each successive orbit to approximately 400 seconds and the depth of penetration also increases with each succeeding orbit. A short umbra or total eclipse is reached on the 18th orbit after start of the penumbra (see Figure 2). The period of partial and full eclipse (umbra and penumbra) continues to increase thereafter, with the penumbra time slowly decreasing. Eclipse time increases to approximately 36 minutes at the noon orbit and the penumbra reaches a minimum value of approximately 8.5 seconds at the same time. Therefore, the penumbra region can be any value between 8.5 to 400 seconds.

Power bus transfer from the solar array to batteries during the penumbra transition was designed to be accomplished by an undervoltage sense circuit. As solar illumination decreases, the solar array voltage bus also decreases until the undervoltage sense circuit is triggered at 21 ± 1 volts. The array is then unloaded and all spacecraft loads are transferred to batteries. This arrangement has one major flaw, however. When the solar array is unloaded, its voltage rises to a high value that re-triggers the undervoltage sense circuit and transfers the loads back to the solar array. The loads force the solar array voltage down again to a value below the trigger point and an oscillatory condition results.

This condition was corrected by eliminating the undervoltage sense circuit and allowing the solar array voltage to decrease until the sun lock-on signal goes low (approximately 10 volts). This means that the FRUSA unregulated bus, which is provided to the orientation mechanism CEU also drops to this value before transfer to the battery bus. This bus provides excitation to the torquer motors and switching latches. A low torquer voltage bus for a short period of time will have no harmful effects, but the latches could change their operational state unless a continuous voltage greater than 20 volts is provided. For this reason it was decided to provide two separate unregulated buses to the CEU. The unregulated bus that

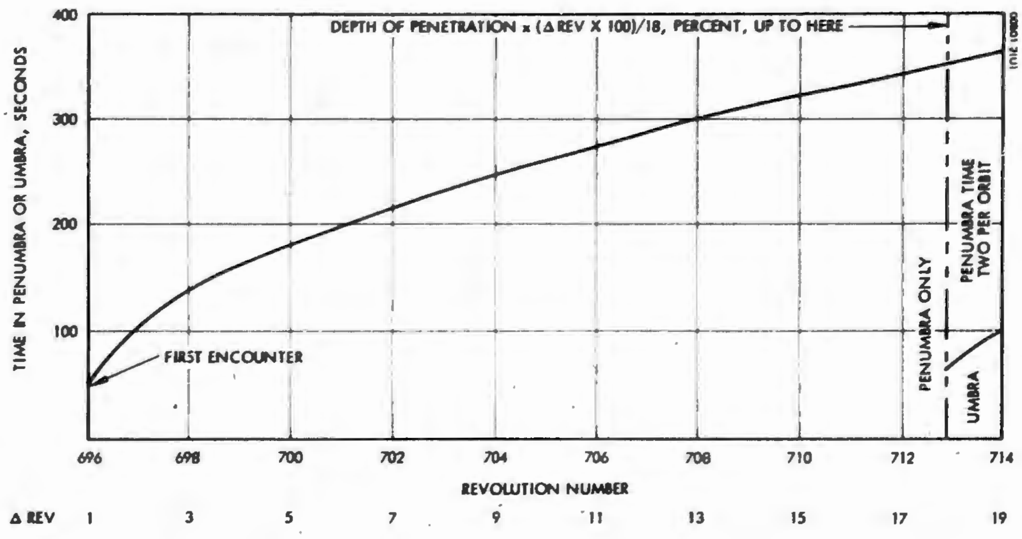

Figure 2. Post-Twilight Penumbral Encounter Durations 400 N. M. Orbit; i = 94 Degrees

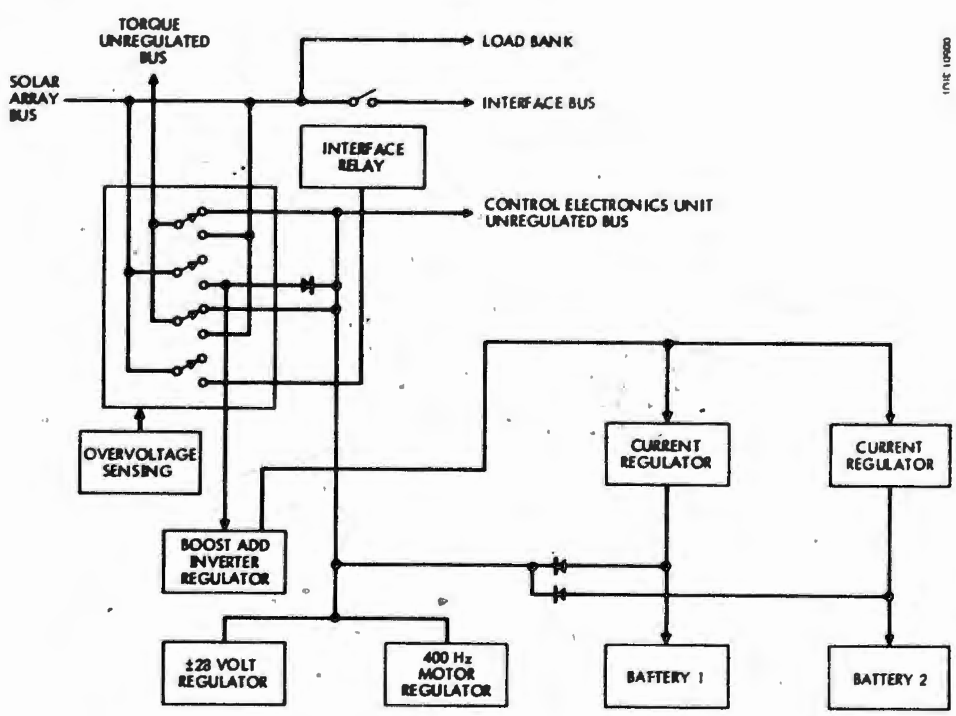

Figure 3. Modified Power Conditioning and Storage Subsystem

provided all unregulated power to the CEU now provides excitation to the torquers only. The second or new unregulated bus, which is called the CEU unregulated bus, will power the CEU latches only. This bus is connected to the FRUSA batteries at the same point where the ±28 volt PCU regulators receive their excitation from the batteries during eclipse and from the battery charge controllers current regulators during solar illumination periods (see Figure 3).

In summary, two changes have been made to the FRUSA system. The undervoltage sense circuit of the PCU has been eliminated to prevent PCU relay oscillation. A new CEU unregulated bus was added to prevent momentary drop-out or undervoltage to the CEU latches.

FRUSA/AGENA POWER INTERFACE

A minimum of 940 watts of FRUSA power will be provided to the Agena power conditioning equipment at the start of the mission to operate the SAMSO-002 cooler and recharge the SAMSO-002 batteries. It is important to be able to isolate this large load from the FRUSA under certain operational conditions, especially if a malfunction occurs in the SAMSO-002 experiment or its associated power equipment. It was therefore decided that the integrating contractor would provide logic that will maintain the FRUSA interface relay in an OFF condition until a ground ON command is received. In addition, the integrating contractor will provide a ground command that will open the FRUSA interface relay and remove all external FRUSA loads.

FRUSA WEIGHT SUMMARY

Current system weights by individual units are listed in Table 1. Actual weights represent approximately 65 percent of the total anticipated system weight.

ECLIPSE POWER SUMMARY

The eclipse power summary has been updated as shown in Table 2.

WORK TO BE PERFORMED DURING NEXT PERIOD

Work to be performed during the next reporting period will include:

- Continue to update FRUSA documentation to reflect current design and mission planning
- Continue coordination with integrating contractor
- Start electromagnetic compatibility analysis and test planning
- Update power summary utilizing measured power dissipation from unit and system test data

TABLE 1. FRUSA FLIGHT WEIGHT SUMMARY

Subsystem	Weight, pounds
Orientation	
Orientation mechanism* (including sun sensors)	56.0
Control electronics*	12.5
Solar sensor group	1.0
Subsystem total	69.5
Solar array	
Solar array panel*	34.0
Storage drum mechanisms*	35.8
Subsystem total	69.8
Power conditioning and storage	
Battery/charge controllers	42.0
Power conditioning	13.5
Subsystem total	55.5
Instrumentation*	7.1
FRUSA system total	201.9
Test auxiliary units	
Reference cell/module electronics*	7.5
Load bank for I-V tests	35.0
Subsystem total	42.5
Contingency	5.6
Total experiment weight	250.0

*Actual weight

TABLE 2. ECLIPSE POWER SUMMARY

Unit	+28 Volt Regulated Loads, amperes	-28 Volt Regulated Loads, amperes	Unregulated Loads, amperes
Solar Array			
Commutators (2)	0.100		
Accelerometers (10)	0.200		
Strain gage amplifiers (3)	0.150		
ICU	0.025	0.014	
Sun sensors	0.010	0.010	
Subsystem totals	0.485	0.024	
Orientation Mechanism			
CEU regulated	0.129	0.070	
CEU unregulated (including torquers)			0.248
Commutator	0.050		
Subsystem totals	0.179	0.070	0.248
Total regulated load	0.664	0.094	
Power Conditioning and Storage			
Power conditioning unit (PCU) ±28 volt regulator			1.010
Miscellaneous			0.035
PCU unregulated input current			1.045
Total unregulated current from batteries			1.293

Table 2 (cont'd)

<u>Battery Energy Computations</u>

Orbit period:	99 minutes
Maximum eclipse time:	36 minutes
Sun acquisition time:	6 minutes
Maximum battery discharge time:	36 + 6 = 42 minutes
Minimum battery charge time:	99 - 42 = 57 minutes
Eclipse energy required:	(42 minutes) (1.293 amperes) 54.3 amp/min

Charge current required to replenish battery:

$$Ic = \frac{W}{TE}$$

where

W = energy removed during eclipse

E = battery charge efficiency = 74 percent

T = charge time

$$Ic = \frac{54.3}{(57)(0.74)} = 1.29 \text{ amperes or } 0.645 \text{ ampere /battery}$$

Charge current = 1 ± 0.05 ampere

$$\text{Energy margin} = \frac{0.95 - 0.645}{0.85} \times 100 = 32.2 \text{ percent}$$

SECTION IV

SOLAR ARRAY SUBSYSTEM

SUBSYSTEM DESCRIPTION AND STATUS

The solar array subsystem consists of two flexible solar cell arrays that are stored, deployed, and retracted by the drum mechanism. During the ninth quarter of the program, the following major tasks were accomplished.

- Completion of water table functional tests of solar array subsystem qualification model
- Preparation of complete set of I-V and P-V curves for temperatures between -300° and +200°F
- Successful completion of 781 thermal cycles on representative sector of solar array
- Completion of full panel coverage design changes and analysis
- Completion of qualification model solar arrays and start of fabrication for flight units
- Completion of tooling and fixture design for solar array subsystem assembly and test

DESIGN AND ANALYSIS TASK

The drawing changes required to implement the full live cell coverage on the flight solar arrays have been completed. In addition, all discrepancies uncovered during qualification model fabrication have been incorporated in the drawings. These discrepancies include such items as dimensional inconsistencies, additional views required to clarify the configuration, and revisions required to reflect product and/or assembly procedure improvements.

The I-V and P-V curves for the currently planned flight panel, at start of life, have been completed for temperatures between -300° and +200°F. A typical set of curves for 170°F are shown in Figures 4 and 5. A curve of power (at maximum power point) versus temperature is shown in Figure 6.

An analysis has been started to evaluate the effect of shading by the LMSC rigid panel on the FRUSA arrays. This analysis will consist of two parts; one to determine if permanent damage will be incurred and the other to evaluate the reduction in panel output power. The primary effort so far has been on the permanent damage aspect. In particular, studies and tests conducted on other Hughes programs have been reviewed and compared to the

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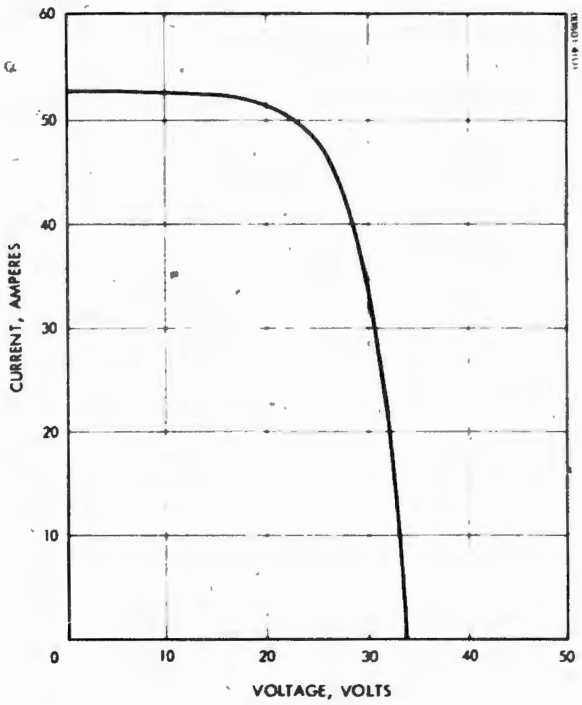


Figure 4. Flight Solar Array Current-Voltage Characteristics at 170°F

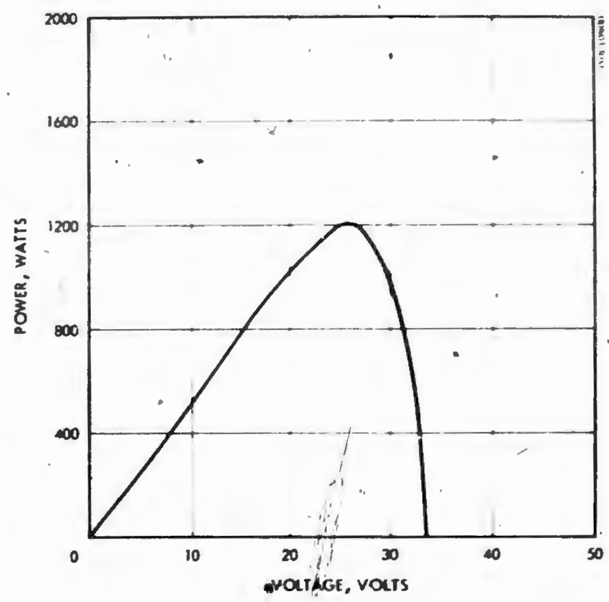


Figure 5. Flight Solar Array Power - Voltage Characteristics at 170°F

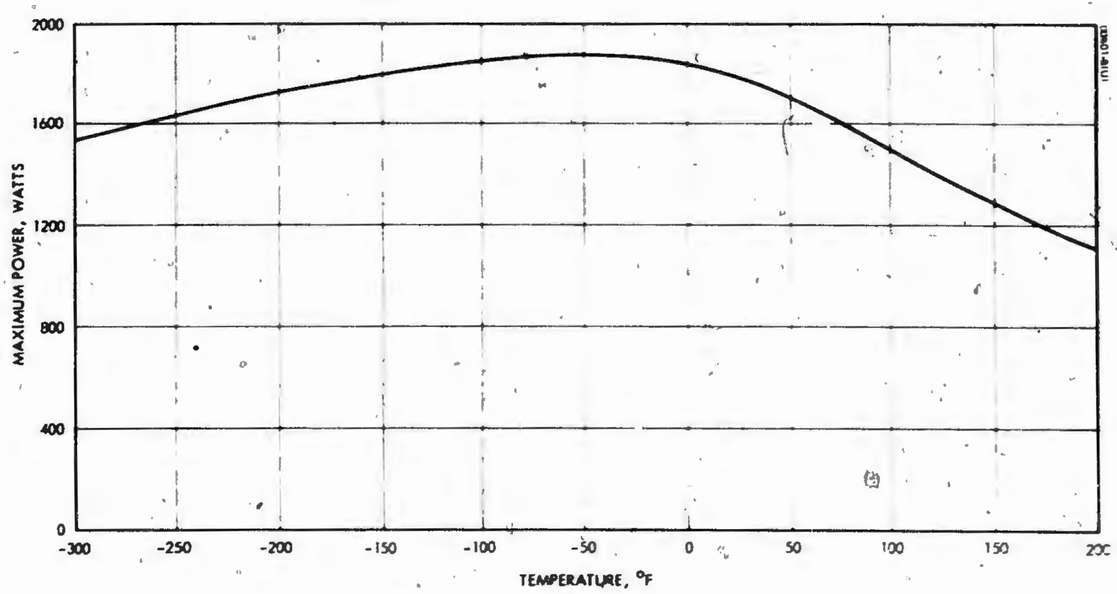


Figure 6. Flight Solar Array Maximum Power Versus Temperature

FRUSA conditions. Tests to determine the 8 mil cells' reverse voltage characteristics have been conducted. A thermal analysis is in process to determine cell temperature rise during shading. Following completion of the "hot spot" analysis, the reduction in panel power output will be computed.

ENGINEERING TEST PROGRAM

The qualification model of the solar array subsystem has been assembled, without electrical wiring in the drum and across the interfaces, and subjected to functional tests on the water table (see Figures 7 and 8). These tests have consisted of 20 complete cycles with the following data and information obtained:

- Motion picture coverage at various locations to evaluate deployment characteristics of booms, panel, etc.
- Qualitative data on panel and cushion roll-up features
- Specific information on size, number of turns, etc. for panel drum and cushion reel
- Operation of 400 Hz drive electronics with boom actuator motor
- Evaluation of water table and float insertion procedures
- Static measurements of boom synchronization

In general, the system operated extremely well with no significant design changes anticipated. The following are specific observations on the functional performance:

- Boom synchronization appears to be excellent - on the order of ±1 inch maximum
- Cushion and panel windup is satisfactory with only a small amount of "walking" noted during panel windup
- Float insertion and water table operation is quite smooth, with only minor changes required in table and/or procedure
- Best movie location for evluation of deployment characteristics is above the geometric center of each fully deployed panel

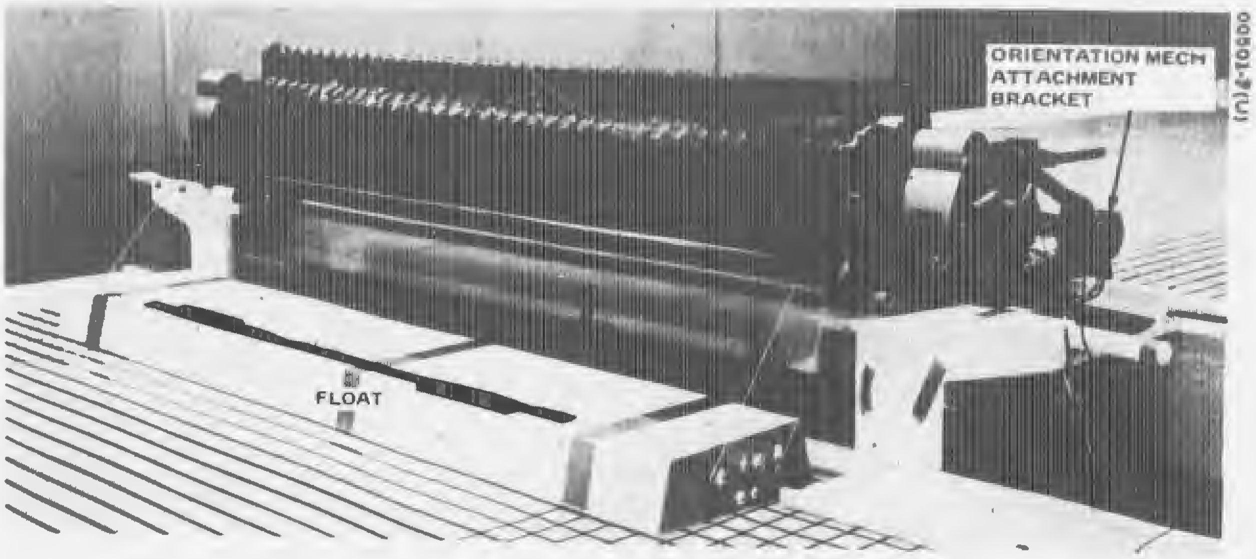


Figure 7. Solar Array Subsystem Mounted on Water Table for Engineering Tests

(Photo ES97028647)

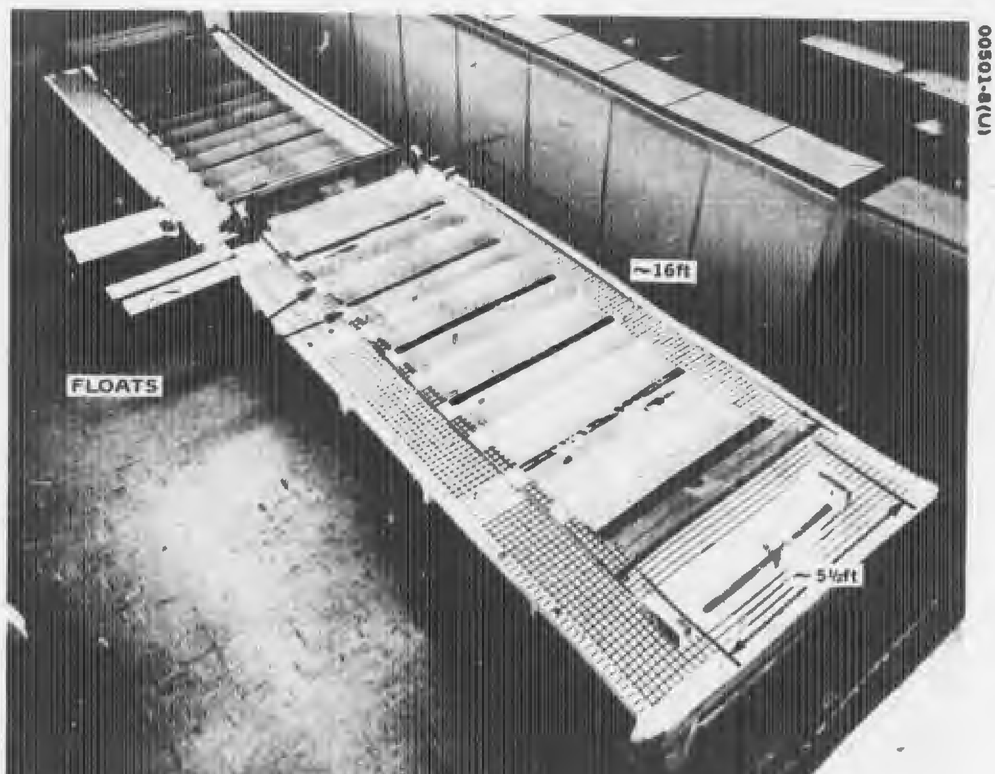


Figure 8. Solar Array Subsystem Deployed on Water Table for Engineering Tests

(Photo ES97028646)

- Operation of limit switches in boom actuator unit is not proper and redesign has been initiated by the vendor. Modification will be incorporated prior to start of the qualification test program

- Booms have a tendency to self-extend about 6 inches after full retraction. To prevent a possible oscillatory mode, a slight modification in motor drive electronics has been incorporated.

Pulsed zenon simulator tests have been conducted on about 40 percent of the 3 x 81 flight model cell groups. A marked improvement in output over the qualification model groups has been achieved. The fabrication losses have averaged about 2-1/2 percent compared to about 7 percent for the qualification model groups.

A representative panel segment, as shown in Figure 9, was exposed to 100 thermal shock cycles over the temperature range of about +200 to -300°F. These tests indicated some electrical degradation from mechanical damage believed to be the result of excess solder on the contact areas of the cells. After establishing tighter inspection procedures, additional samples of a similar configuration were fabricated for tests at the NASA Lewis facility. At the present time these samples have been subjected to 781 cycles between +189 and -163°F at pressures of 1 x 10^{-7} Torr. A typical cycle is 55 minutes at +189°F, followed by cooling to -163°F in 30 minutes. No mechanical or electrical degradation has been noted in the test samples.

FABRICATION STATUS

The qualification model solar array subsystem was assembled less contour cables and other electrical wiring and used in an engineering test program. Following the completion of the tests, the system was disassembled and is currently being refurbished and wired for the qualification test program. The principal parts being refurbished are the boom actuator units supplied by SPAR Aerospace in Toronto, Canada.

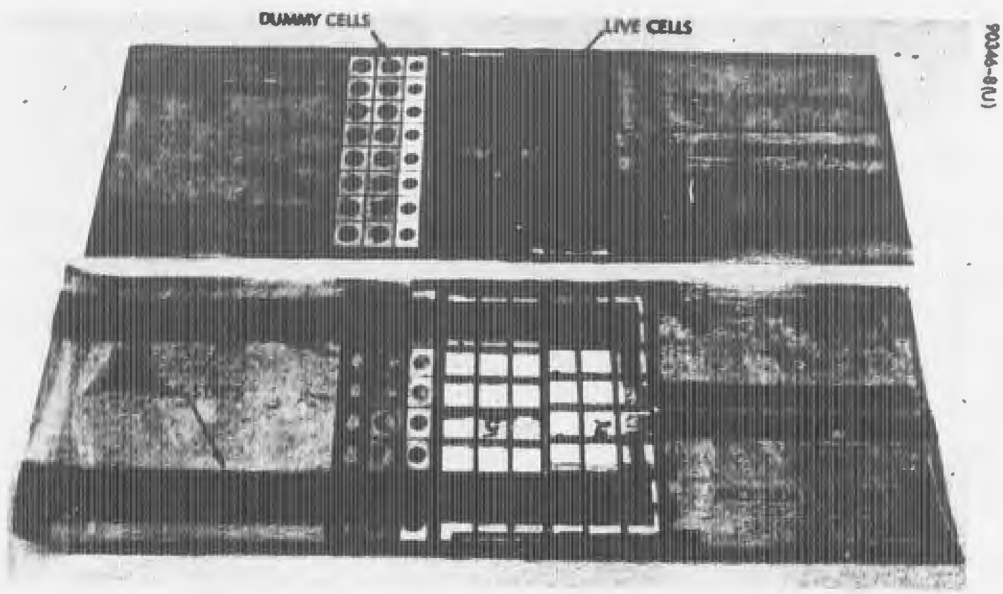
The following items have been accomplished on the flight model of the solar array subsystem:

- Fifty percent of the flight cell groups have been fabricated, tested, and are ready for bonding to the substrate

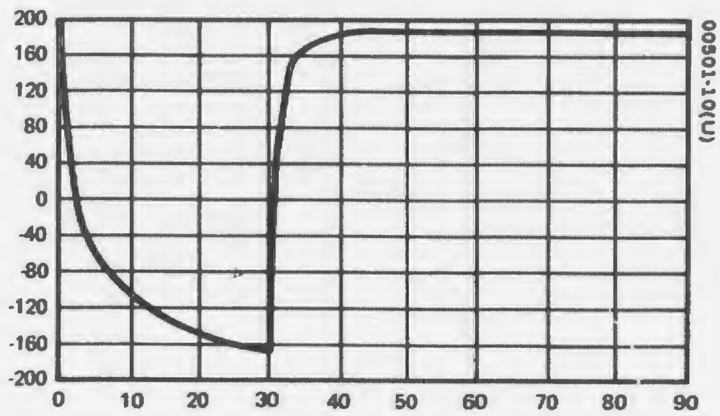
- Substrate fabrication has been completed

- Buss fabrication has been started

- All orders for drum mechanism detail parts have been placed and fabrication is underway



a) Thermal Shock and Cycling Test Specimen



b) Typical Thermal Cycle of Solar Panel Specimen

Figure 9. Thermal Cycling Test

The fixture for supporting the panels in a vertical plane during electrical tests with the solar simulator has been completed (see Figure 10). This fixture will also be used during the panel assembly for work in areas that are difficult to reach with the panel in a horizontal position on the table. Assembly operations that will require use of this fixture include final wiring of reference cells, reference modules, and temperature sensors and rework, if required, of conventional cells located in center portion of panel. Since the fixture will be employed during the initial panel assembly operations, it will accommodate panels by themselves or attached to the drum.

WORK TO BE PERFORMED NEXT QUARTER

- Completion of solar array shading analysis
- Completion of solar array subsystem for qualification test program
- Continuation of fabrication and assembly of flight model
- Completion of solar array thermal cycling tests

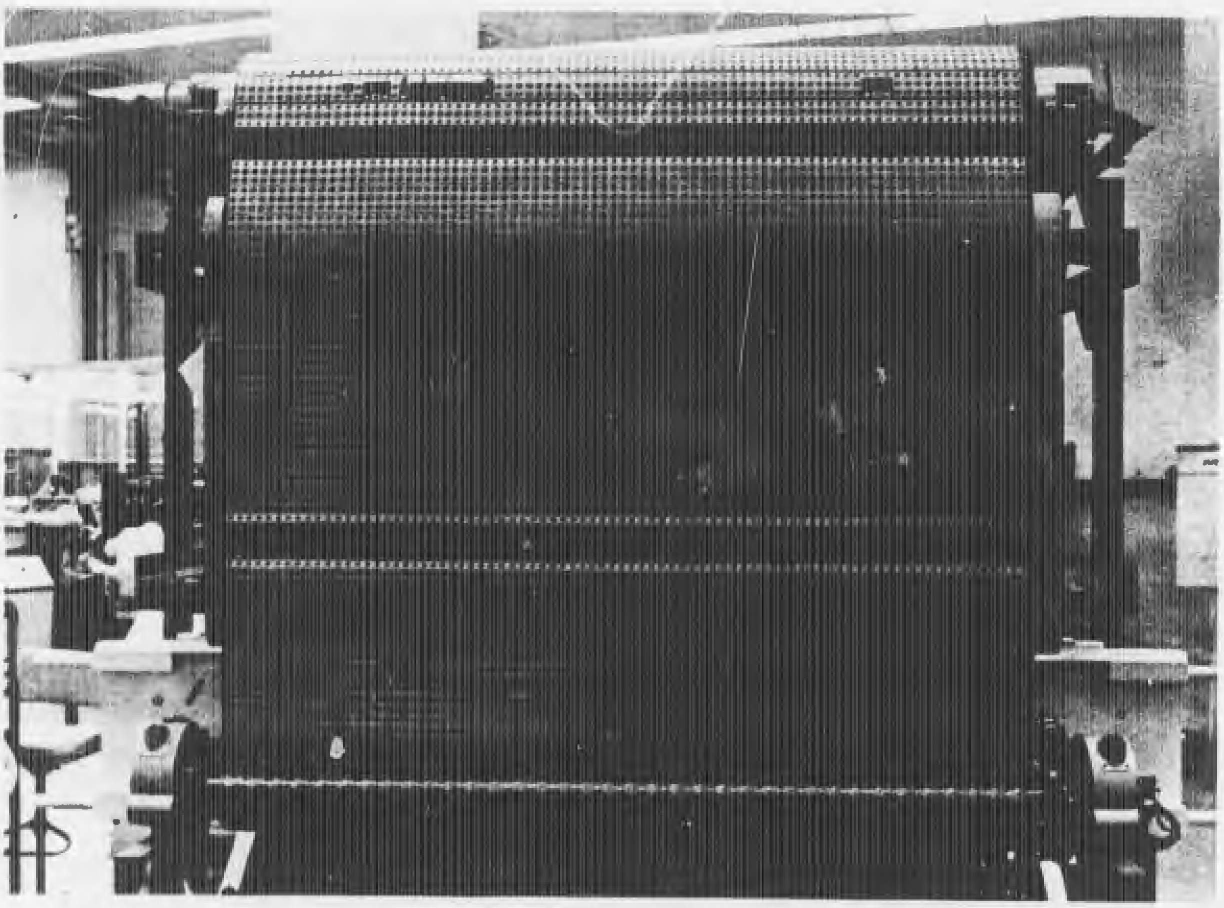


Figure 10. Solar Array Vertical Handling and Test Fixture
(Photo A28668)

SECTION V

ORIENTATION SUBSYSTEM

SUMMARY

The orientation subsystem consists of three components; the control electronics unit (CEU), the orientation mechanism (OLSCA), and the sun sensor group. The subsystem acquires the sun and then maintains the solar panel normal to the sun. It also provides signal and power transfer from the panel to the spacecraft. An integral part of the orientation mechanism is the deployment mechanism which deploys the stowed array to its normal operating position.

Functional acceptance testing of the CEU is underway and will be completed shortly. Several possible modifications to the CEU have been investigated in response to the integrating contractor's inquiry.

The orientation mechanism assembly has been completed (see Figure 11). The drawings are being updated to eliminate minor problems encountered during first assembly and wiring. The power brush design has been revised to allow for initial fit tolerance buildup and the possibility of component shifting after assembly.

Functional testing of the mechanism has begun and data is being obtained to determine the performance of the unit.

A coordinating meeting was held with integrating contractor personnel to discuss a possible mechanical interference problem of the orientation mechanism drum axis shaft and a spacecraft antenna. A number of alternatives that would eliminate the problem were considered.

MECHANISM

The orientation mechanism was assembled during this last quarter. The components were assembled initially without the wiring for a fit check. This operation indicated a number of minor problems that could be expected with a complex mechanism of this type. The assembly was completed and then partially disassembled to permit wiring.

During the assembly, a problem with the power brushes indicated a need for a design revision in this area. The essence of the problem is that a precise geometric relationship was required between the brush, the brush holder, and the slipring to ensure proper seating of the brush on the rings. It is difficult to achieve this precise relationship initially because of tolerance buildup. Extensive run-in would be required to achieve the desired relationship and would be uneconomical if the tolerance buildup was more than a few thousandths. Even if the assembly could be precise, shifting of components during launch and thermal exposure could possibly cause problems during

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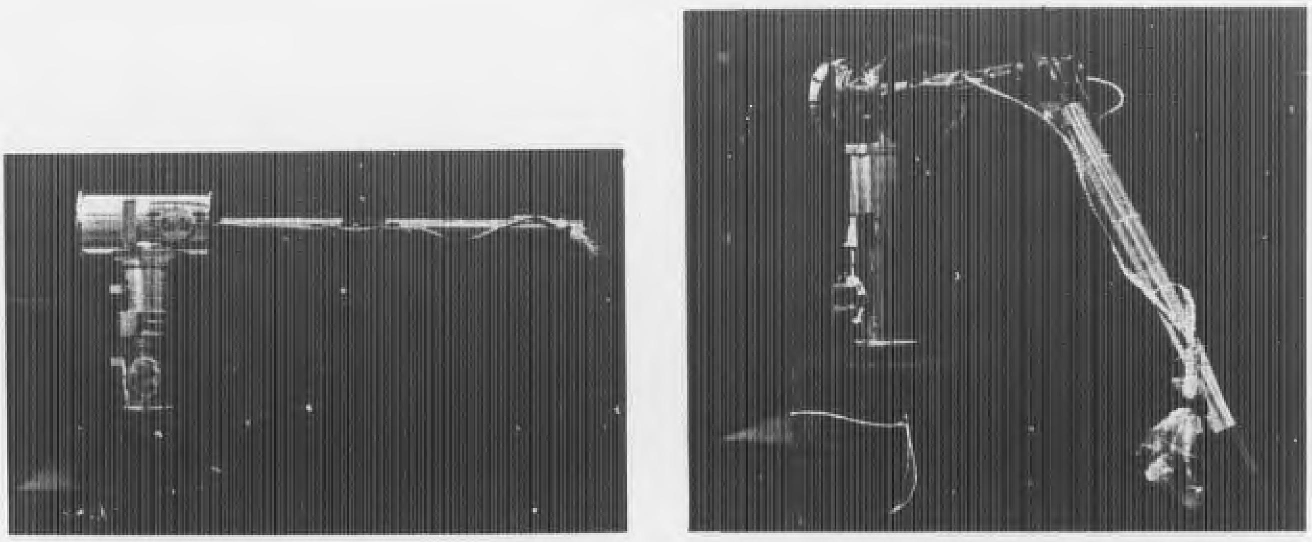

a) Deployed in Normal Operating Condition (Photo A28782)

b) Unlatched (Photo A28781)

Figure 11. Orientation Mechanism

flight. Therefore, the design has been altered to include flexibility for initial tolerance buildup and/or shifting of components during flight. The modified design has been tested and results indicate the modification is satisfactory.

Minor revisions have been made to the orientation mechanism drawings to eliminate problems encountered during first assembly.

Functional testing of the mechanism has been initiated. Both the drum and the support axis have been powered in both directions indicating that both motors are performing satisfactorily. The mechanism is presently undergoing "run-in" to attain seating of the brushes on their mating surfaces.

SENSOR GROUP

The cadmium sulfide cells are undergoing screening tests. A screening test specification has been released describing the testing to be performed and the procedures to be used.

CONTROL ELECTRONICS UNIT

The completed CEU is presently undergoing functional acceptance testing.

Assembly was completed during the reporting period. Power transistors which were the pacing item in the assembly were obtained from another Hughes program, since the original source could not deliver acceptable items.

The accepted CEU will be used in conjunction with the mechanism to determine their compatibility and performance in the near future.

In coordination with changes in the power control subsystem, which eliminated the undervoltage sense circuit, power for the CEU latches was moved from the array side to the battery side of the PCU relays. This precludes any possibility of latch instability due to low supply voltage.

MEETINGS

Several meetings were held with spacecraft integrating contractor personnel to coordinate the orientation mechanism hardware and spacecraft interface.

A number of CEU modifications have been investigated by Hughes to determine the feasibility of:

1) Replacing CEU on/off toggle switching to discrete command switching
2) Determine the effect of rate limiting the manual torquing

An interference problem was recently discussed with the integrating contractor. Interference between the drum axis shaft and antennas located on the spacecraft was discussed in terms of alternatives to eliminate the interference. The most probable solution at this point in time appears to involve one of the following design changes:

1) Lowering the CEU on the support axes shaft

2) Lowering the antenna installation

3) Restricting the service loop of the harness at the deployment mechanism

Other alternatives investigated required more major modifications to the orientation mechanism or the spacecraft.

A simplified thermal model was developed to assist the integrating contractor in his analysis of the total system thermal balance. Copies were transmitted separately to AFAPL, SAMSO/Aerospace, and LMSC.

PLANS FOR NEXT QUARTER

The orientation subsystem functional testing and refurbishment of the orientation mechanism in preparation for qualification test will be completed in this next period. Completion of the sensor group fabrication and flight acceptance tests is planned.

Additional coordination with the spacecraft integration contractor will be required.

Hardware for the flight unit is being fabricated and assembly of the second orientation subsystem will begin in the next reporting period.

SECTION VI

POWER CONDITIONING AND STORAGE SUBSYSTEM

BATTERY/CHARGE CONTROLLER

All drawings including schematics have been released for the battery/charge controller. Fabrication of detail parts for the qualification model is essentially completed and assembly has been started. High reliability components are on order and the battery cells are undergoing acceptance testing. The individual battery cells will be released to production in October for fabrication into the two 12-cell battery packs required for the qualification unit. Delivery dates on several hi-reliability components are presenting a serious problem with respect to qualification model delivery schedules.

Engineering tests are being performed with the breadboard charge controller and a small number of the cells from the qualification lot. These tests are designed to demonstrate margins in the energy balance at temperatures between 30° and 90°F.

Several charge controller circuitry changes have been made to improve the overall performance. The most significant of these are listed below:

1) Increase in charge control loop gain to maintain desired charge rate at cold temperatures.

2) Addition of a "select" resistor to increase battery/charge controller output current capacity (2.25 amperes maximum)

3) Addition of capacitors to reduce susceptibility to extraneous noise spikes

4) Addition of telemetry outputs to provide verification signals

POWER CONDITIONING UNIT

The PCU circuits have been modified because of a possible oscillation of the PCU relays during the transition period between the sunlit and eclipse portions of the orbit. (Reference Section III of this report.) The modification made to correct this problem is the elimination of the under-voltage sense circuit and some revisions to the regulated and unregulated power bus circuits (see Figure 12). Other circuit changes incorporated to improve overall performance are as follows:

1) Increased the output filter capacitors on the 42-volt boost regulator/inverters to decrease output ripple

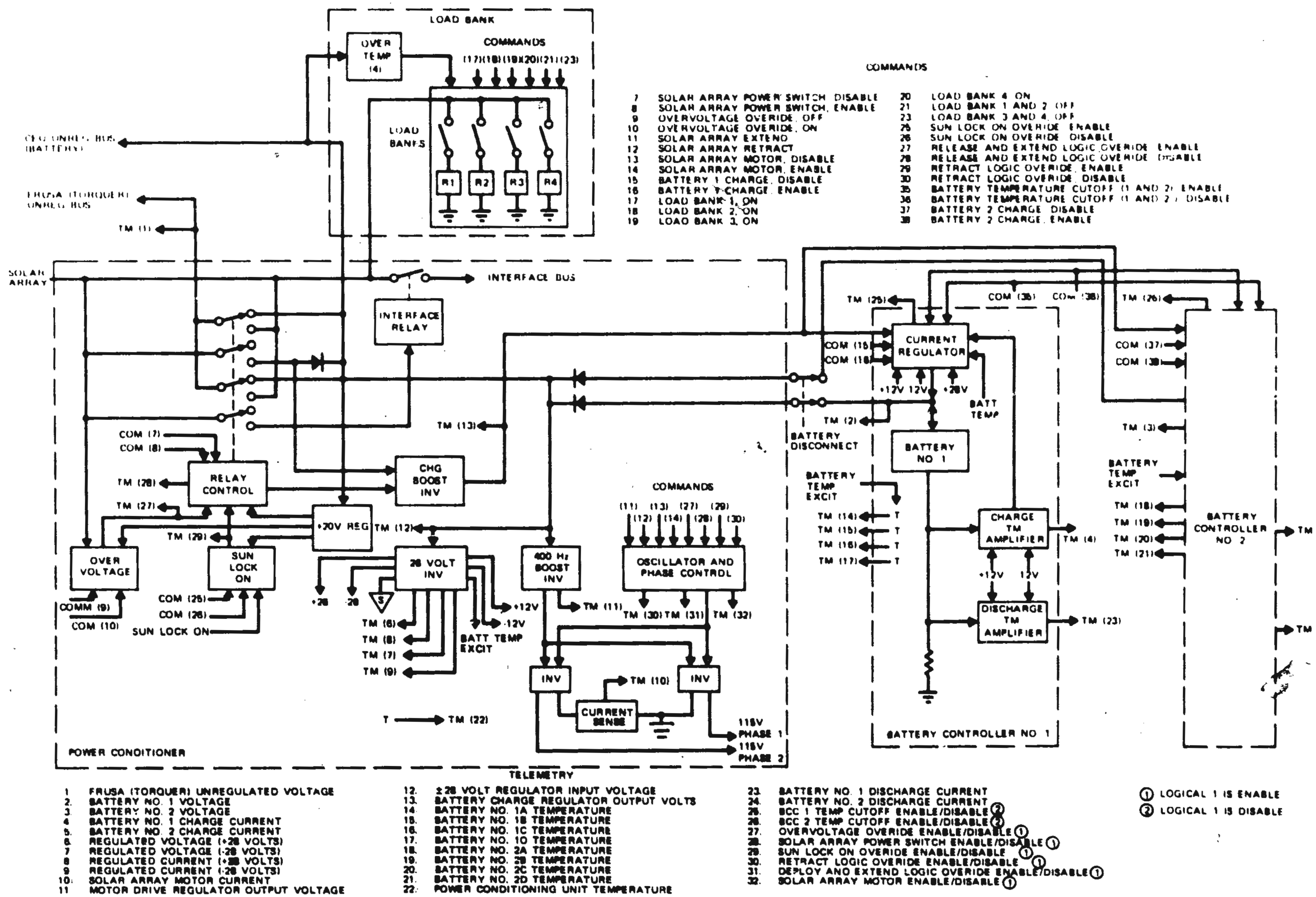

Figure 12. Power Conditioner and Storage Subsystem Functional Block Diagram

2) Separated power and signal grounds to reduce system noise

3) Modified motor control logic to prevent undue motor wear at the "fully retracted" point

4) Added telemetry signals to verify status of commands

5) Reassigned connector pins to share load bank currents more equally

All detail and assembly drawings (including changes listed above) have been released. In addition, breadboard tests have been performed to confirm the adequacy of the changes.

Fabrication of detail parts for the qualification and flight PCUs is continuing with the qualification parts essentially complete. Because of component delivery problems, however, schedule slip in the qualification unit delivery is anticipated. A preliminary acceptance test specification has also been prepared for this unit.

The 400 Hz motor drive breadboard has been used with the solar array subsystem for extending and retracting the booms. Performance was satisfactory, but some minor changes were required in the limit switch turnoff circuit.

LOAD BANK

The detail parts drawings and the schematic have been completed and released for the load bank assembly. The assembly drawing and wire list have also been completed and released. A preliminary acceptance test specification has been prepared.

Because of the solar array change to full live cell coverage, the load bank resistances have been changed. The new values, shown in Figure 13, will be incorporated in the flight unit design.

WORK TO BE PERFORMED NEXT QUARTER

- Complete units for the qualification test program
- Continuation of the fabrication and assembly of flight units

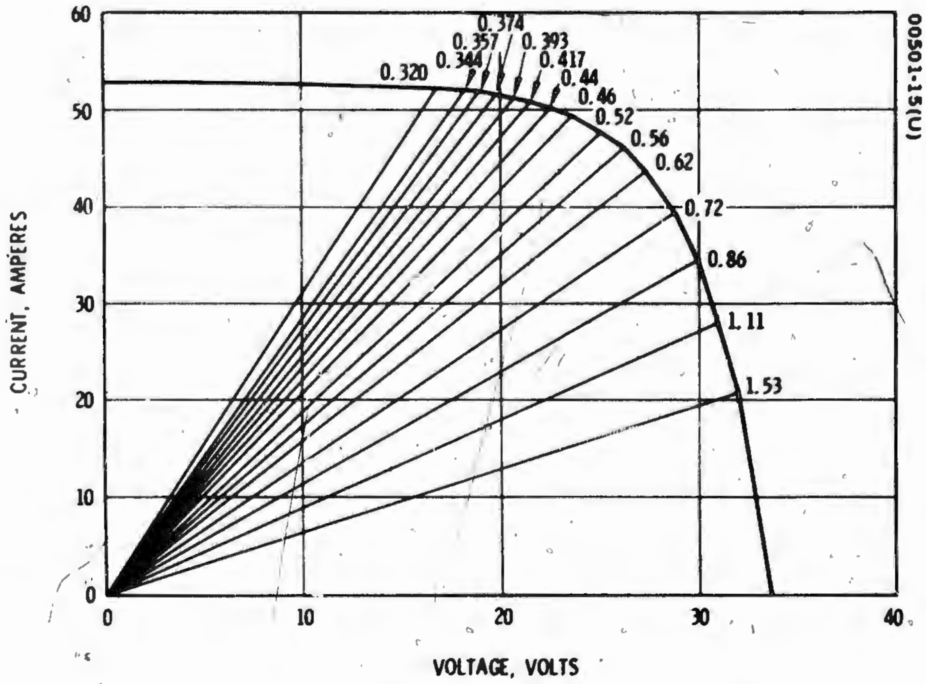

Figure 13. New Load Bank Load Lines

SECTION VII

INSTRUMENTATION SUBSYSTEM

WORK PERFORMED DURING REPORTING PERIOD

The instrumentation activity during this period included:

- Addition of new telemetry channels
- Strain gage measurement calibration
- Study of FRUSA telemetry frame size changes
- Fabrication and test of SCEU printed circuit boards
- Commutators, strain gage amplifiers, and accelerometers for qualification model received from vendors

NEW TELEMETRY SIGNALS

It was determined that many of the commands sent to the PCU and battery/charge controllers (BCC) were difficult or impossible to verify with the telemetry channels provided. Therefore, the following bilevel telemetry channels were added to provide this necessary capability:

C-25	BCC1 temperature cut-off enable/disable
C-26	BCC2 temperature cut-off enable/disable
C-27	Overvoltage override enable/disable
C-28	Solar array power switch enable/disable
C-29	Sun lock-on override enable/disable
C-30	Retract logic override enable/disable
C-31	Deploy and extend logic override enable/disable
C-32	Solar array motor enable/disable

STRAIN GAGE MEASUREMENTS

There are three strain gage measurements on the FRUSA solar array subsystem. Each panel has a strain gage bridge network to measure the tension in the boom length compensator which indirectly measures the tension of the panel substrate. Another strain gage measures the loading at the base of one of the inboard booms. Since the output level of this network is of the order of a few millivolts, a high gain strain gage amplifier is used to amplify this signal to the standard 0 to +5 volt format.

One of the boom length compensator tapes was instrumented with bonded foil type strain gages. It was electrically connected to a strain gage amplifier and tension in 1-pound increments was applied to the tape to obtain a calibration curve. The data obtained was in very close agreement with the theoretical computations.

A tape for the other solar array was also instrumented and calibrated with its associated amplifier. The data again was satisfactory.

The boom length compensator strain gage measurement requires a gain of 500, whereas the boom loading strain gage measurement requires a gain of only 100. To minimize the cost of the strain gage amplifiers, it was decided to purchase three identical amplifiers with a gain of 500, and to desensitize one of them by a factor of 5. It was determined that the best way to accomplish this was to provide two external resistors in series with the bridge excitation supply. This reduces the excitation voltage to the bridge network from 15 volts to 3 volts and reduces its sensitivity by a factor of 5. This modification will be incorporated prior to assembly on the solar array subsystem.

PROPOSED AGENA TELEMETRY MODIFICATION

Hughes has been informed by LMSC that the present SCF computer software will not be able to process the FRUSA data in real time during the mission. This is due to the fact that presently they cannot handle the FRUSA 45-word commutator format. The SCF software is configured to function with commutator sizes based on a binary progression (16, 32, 64, etc.). Therefore, LMSC initially suggested that 19 idling words be added to our 45-word commutator to convert it to a 64-word format. Hughes rejected this proposal because it would reduce the sampling rate to an unacceptable value and it would result in uneven sampling intervals for the super commutated data. LMSC subsequently modified its initial suggestion to add idling periods of 6, 6, and 7 words after the 15th, 30th and 45th FRUSA commutator words and to double the present sampling rate by providing three additional main frame telemetry words. This proposed solution was approved by Hughes and is now under evaluation by the SESP 71-2 project office.

SOLAR CELL ELECTRONICS UNIT

Fabrication and assembly of the qualification model SCEU has been completed. Checkout and test of the printed circuit cards has been completed and units tests have been started. Testing will be completed by 15 October.

INSTRUMENTATION CONDITIONING UNIT

Fabrication and assembly of the qualification model ICU has been completed with the exception of two capacitors. Delivery of the capacitors has been postponed a number of times by the vendor. The new promised delivery data is the first week of October.

COMMUTATORS

Three PCM compatible commutators for the qualification model have been received from Teledyne.

ACCELEROMETERS

The ±0.1 g force balance accelerometers for the qualification model have been received.

STRAIN GAGE AMPLIFIERS

Three strain gage amplifiers for the qualification model have been received.

WORK TO BE PERFORMED DURING NEXT PERIOD

- Complete SCEU and ICU and install on qualification model
- Install strain gage amplifiers, commutators, and accelerometers on qualification model
- Verify proper operation of instrumentation in system test operations

SECTION VIII

SYSTEM TEST

Systems test activity during the period includes:

- Initiation of vibration fixture parts procurement
- Initiation of solar-thermal-vacuum test fixture design
- Generation of systems test procedures
- Completion of fabrication of the solar array interface brackets
- Completion of design of the solar array support harness
- Initiation of procurement and fabrication of the system test electrical harness
- Continued activity screening for standard test equipment
- Evaluation of the LMSC general test requirements

The design and drawing effort on the four vibration fixtures has been completed; two fixtures for the solar array, one for orientation mechanism, and one for power subsystem. Requests for final bids on the fabrication of the fixtures have been received and purchase orders have been placed. Delivery is expected during the first week in November.

Design of the solar-thermal-vacuum test fixtures is in progress. Two test setups are required: 1) Phase I, where the solar array is mounted in the sun volume at 4 feet above the endbell, and 2) Phase II, where the orientation mechanism is mounted in the sun volume at the 17 foot level to allow extension of the actuator booms.

Test procedures for the ambient functional, vibration, and solar-thermal-vacuum tests are being generated and are expected to be completed by 13 November.

A set of solar array interface brackets have been designed and fabricated. The purpose of these brackets is to provide attachment to the solar array during handling and test. The brackets, after attachment to the solar array, are designed to accept the stretcher-type handling fixture and the vibration fixtures.

Design of a solar array support harness has been completed. The purpose of this harness is to provide solar array support attachment during pyro release and deployment tests. The drum assembly will be supported by a cable attached to the 20 foot ceiling at a point directly over the drum shaft hinge point.

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The systems test electrical harness procurement and fabrication cycle has been initiated. A systems interconnect drawing was marked up for use in the fabrication. The flight harness will be fabricated by the integrating contractor, since it is integrated with the Agena payload rack harness. The lengths of the test harness will simulate the lengths of the Agena harness ±12 inches.

A screening effort covering all company and government activities has been initiated by the services division to locate the standard test equipment required for the FRUSA in-house testing. This standard test equipment supplements the FRUSA AGE tester. The required equipments and its minimum capability is as follows:

1) Magnetic tape recorder - 5 channels

2) Power supply - 0 to 50 volts, 60 amperes

3) Chart recorder - 6 channels

4) PAM decommutator

5) Digital voltmeters - four each

6) Oscilloscope - dual sweep

The LMSC general test requirements document is being evaluated to determine what, if any, additional environmental testing is required over and above that presently planned for the FRUSA. The thermal aspects are being examined, as well as the dynamic environment. A coupled dynamic analysis is in progress to determine the vibration characteristics of the combined FRUSA/Agena hardware.

PLANNED ACTIVITIES FOR NEXT REPORT PERIOD

- Complete solar-thermal-vacuum fixture design and initiate fabrication
- Continue test procedure generation
- Combine electrical test harness effort
- Complete standard test equipment screening
- Continue thermal and dynamic study relating to the LMSC general test requirements
- Initiate EMC analysis

SECTION IX

RELIABILITY

The reliability of the FRUSA system has been re-estimated and was found to be .695 for a 1 year, and .856 for a half-year mission. This new estimate was based on the use of a more complete and up-to-date parts list. The program reliability goal had been established at .65 for a 1-year mission life.

The preferred parts list continues to be revised as new parts are added to the list. The quality assurance program plan has been reviewed and revised to include MIL-STD materials such as bolts, nuts, screws, and washers. The source inspection procedure, that is, inspection of parts at the vendor, has been overhauled and revised. In-process inspection of the subsystems continues.

PLANS FOR THE NEXT QUARTER

- Source surveillance for hi-reliability parts
- Incoming inspection and test of parts
- Inspection of the qualification model components
- In-process inspection
- Initiation of TFRs

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13. ABSTRACT

The main activities on the Flexible Rolled-Up Solar Array (FRUSA) program during the ninth quarterly reporting period consisted of assembly of the development /qualification model of the orientation mechanism, solar array, drum mechanism, control electronics unit (CEU), and solar cell electronics unit (SCEU).

Cells, simulated blanks, and busses were bonded to the two qualification model panels. The panels were connected to the drum mechanism, which had been assembled without the interface wiring, and water table deployment/retraction tests on the complete assembly successfully conducted. Functional acceptance testing of the CEU and the SCEU have been initiated. The instrumentation conditioning unit (ICU) is still awaiting the two hi-reliability capacitors before acceptance tests can be initiated. Fabrication of detailed parts for the power conditioning unit (PCU) and battery charge controller are nearing completion, and detailed parts drawings and the schematic have been released for the load bank assembly.

An updated FRUSA/Agena wiring diagram, Space Experiment Plan, and Flight Model Design and Test Specification have been completed and submitted to Wright-Patterson Air Force Base.

The fourth semiannual FRUSA system review was held on 15 September. Attendees included representatives of the Air Force, NASA, Aerospace and Hughes organizations. Several working group meetings were held between SAMSO /Aerospace/LMSC and Hughes to resolve interface problems, the most serious of which are interference between the orientation mechanism drum axis shaft, and a spacecraft antenna dipole. Additional tasks implemented during the reporting period were a shading, EMI/EMC, and a structural dynamics analysis.

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