CARA CORPORATION

The Relation Between Solar Cell Flight Performance Data and Materials and Manufacturing Data

Final Report

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ABSTRACT

The purpose of this study was to examine the flight performance data for solar cell power systems in satellites, and to try to relate the differences in performance to the materials and manufacturing factors of the solar cell system. Because of difficulties encounterd in the retrieval of existing data, a second purpose evolved towards the end of this study. This was to develop methods of data gathering during a satellite project that would simplify data retrieval for a posteriori studies.

The two major conclusions of this work are:

1. Solar cell studies of past flights based on available data are impossible to perform without great expenditures of time and money.

2. A data gathering and storage system can be designed which, if implemented on future flights, would make such a posteriori studies straightforward and fruitful.

As a result of these conclusions, we make the following two recommendations:

1. No a posteriori studies based on flight data and solar cell components information should be funded. Such studies will probably fail because of the difficulties of data retrieval. This recommendation can probably be extended to vehicle components other than solar cells, although our experience is based on the solar cell problem.

2. The implementation of a data gathering and retrieval system to be used for each mission should be investigated. Currently, a great deal of valuable information is lost forever once a mission is completed.

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I. INTRODUCTION AND SUMMARY

A. Purpose and Methods

The purpose of this study was to examine the flight performance data for solar cell power systems in satellites, and to try to relate the differences in performance to the materials and manufacturing factors of the solar cell system. Because of difficulties encountered in the retrieval of existing data, a second purpose evolved towards the end of this study. This was to develop methods of data gathering during a satellite project that would simplify data retrieval for a posteriori studies.

The method of approach in the solar cell study consisted of trying to select a group of flights whose space environments are all similar, for which sufficient flight performance data exist, and for which information on the materials and manufacturing factors is available. For the selected group of flights, an attempt was to be made to relate the differences in performance to specific materials or manufacturing parameters that may be expected to affect performance.

The work was divided into four general phases defined by the following outline:

Phase I:

a. Classify all flights from 1957 through 1967 according to their space environment, so that groups of flights with similar environments can be identified.

b. Ascertain availability of performance data and materials and manufacturing parameters.

c. Generate a coding procedure to facilitate the recording and use of information gathered relative to performance and materials and manufacturing factors.

Phase II: Select a group of flights based on the work in Phase I.

Phase III: Acquire and systematize the actual data needed for the flights selected in Phase II.

Phase IV: Perform analysis to relate materials and manufacturing factors to flight performance of the selected flights.

A space environment classification scheme was devised which permitted the 611 flights examined to be separated into groups of similar environments and preliminary decisions to be made on the suitability of these groups for the purposes of this study.

An initial selection of 77 flights with similar space environments was made for purposes of further study. These flights have orbital parameters below 760 miles, are below the maxima in the first radiation belt, and have appreciable thermal cycles. The final selection was based on the availability of flight performance data. The criterion for this selection was that the telemetry data transmitted by the satellite had to include solar array output voltage, array current and array temperature. It was found that nine flights satisfied this criterion. They were the Pegasus series, numbers 1, 2, and 3; the OSO series, numbers 1, 2, 3, and 4; OGO 4; and Nimbus 2. These were the nine flights for which a detailed search for materials and manufacturing information was made.

The classification of flights according to similarity of environment was done by analyzing the orbital parameters and grouping the flights into classes of similar perigee, apogee, angle of inclination, and period.

The gathering of performance data and materials and manufacturing factors was performed by using computerized literature searches, examining existing documents, visiting manufacturers and government installations, and from correspondence and personal discussions with individuals who had responsibilities for the solar cell systems.

To facilitate the recording and use of the data gathered in this study, a coding procedure and form was designed.

When it became apparent that the data needed to perform a correlation analysis could not be retrieved, consideration was given to the methods of capturing and storing the data at the time of the flight mission. This was done in agreement with the Technical Monitor. Within the time available (the last quarter of this contract), an initial approach to this problem was successfully developed.

B. Summary of Results

The most important result of this study is that it is not possible to perform a posteriori materials studies on solar cell systems without an inordinate expenditure of time and money. The reason for this is that after a mission, the required materials and manufacturing data are placed in dead storage in a highly unorganized fashion. No formal procedure exists for preserving these data in a retrievable form.

The next most important result is that a beginning was made in designing methods of capturing data during a mission that would be readily retrievable for a posteriori studies. In particular, a hybrid form was designed that would permit computerization of significant data and permit its storage on tapes in an indexed, organized fashion.

Another important result of this study is that the appropriate channels were ascertained for determining the existence, and obtaining the type of environmental, performance and materials data for solar cell arrays on satellites. A "name tree" was developed giving the names of individuals having a connection with each flight of interest to this study. This is important because so much of the data exist in contractor quarterly reports, log books, and specifications, all of which generally receive very limited distribution.

C. Conclusions and Recommendations

The two major conclusions of this work are:

1. Solar cell studies of past flights based on available data are impossible to perform without great expenditures of time and money.
2. A data gathering and storage system can be designed which, if implemented on future flights, would make such a posteriori studies straightforward and fruitful.

As a result of these conclusions, we make the following two recommendations:

a. No a posteriori studies based on flight data and solar cell components information should be funded. Such studies will probably fail because of the difficulties of data retrieval. This recommendation can probably be extended to vehicle components other than solar cells, although our experience is based on the solar cell problem.

b. The implementation of a data gathering and retrieval system to be used for each mission should be investigated. Currently, a great deal of valuable information is lost forever once a mission is completed.

Among the most important specific conclusions of this study are those associated with the information gathering process. As stated above, the general result is that the data that can be retrieved for post flight studies represent a small fraction of what was once available.

The computer searches were performed through the facilities of the NASA Scientific and Technical Information Division, and the Defense Documentation Center. While these searches yielded a large number of documents, they were only partially successful. They did serve as indicators of what problems were important, and provided valuable background information; however, they did not yield the comprehensive data needed for this study.

Radiation environment data were sought through the Laboratory for Theoretical Studies at Goddard Space Flight Center. It was determined that such data were available to an accuracy within a factor of 2 or 3 for all flights, upon submission of the appropriate parameters describing the vehicle's orbit and identification.

Detailed thermal environment data for NASA flights and some DOD flights can be obtained from the Thermal Physics Branch at Goddard. Actual panel temperatures have been determined although this information is rarely published.

Personal contacts are an important part of post flight studies. The "name tree" developed for this purpose is given in Table IX.

It was the non-retrievability of the manufacturing and materials information that made it impossible to perform a performance vs. materials analysis. It was found that existing documents were not well organized, and that they were placed in boxes for dead storage with no indexing whatever.

Important specific conclusions with regard to implementing a data capturing process during a flight project are concerned with the structure of data collection forms and with management recommendations.

The forms should be of a hybrid type, in which both check list and narrative information can be entered. They should include names of people and organizations with responsibilities for the solar cell system, design specifications, procedures and materials data, testing procedures, and storage and handling procedures. Examples of such possible forms are given in Tables XIII, XIV, and XV.

Our first management recommendation is that the project manager for the space vehicle mission maintain responsibility for this data collection by assigning an assistant to this task that reports to him. Secondly, a statement of percentage of completion of the data storage forms should be issued with all progress reports. Also, as a "fail safe" mechanism, it should be required that the forms are completed before the data are placed in dead storage. A more detailed description of how this data collection process can be implemented is given in Section IX.

II. THE SELECTION OF FLIGHTS

A. Preliminary Screening

After examination of the Space Projects Log from 1957 to 1968, which included approximately 611 earth satellite flights, it was evident that some of the flights were not useful for the purpose of correlating solar power system performance with materials and manufacturing data. Accordingly, the flights were divided into three classes, which were defined by the following criteria:

Class # 1:

a) In orbit and transmitting data for three months or more

b) Project director NASA or DOD

c) Unclassified.

Class # 2:

a) In orbit and transmitting for three months or more

b) Project director DOD

c) Classified.

Class # 3:

a) Failed to orbit

b) In orbit and transmitting less than three months.

It is clear that Class # 1 was the most promising for our study, and that Class # 3 was unsuitable. Class # 2 may be suitable; however, clearance procedures and the time required to obtain data for classified flights made it desirable to avoid these flights if possible. Fortunately, Class # 1 includes over 200 flights. It was therefore decided to concentrate on Class # 1. These are listed in Table I.

The radiation, thermal and micrometeorite environments of an earth satellite are determined by five orbital parameters (perigee P, apogee A, inclination θ, period T, and calendar year). Ideally, the selected set subjected to detailed study should include only flights for which these parameters are identical. Since this is not possible, it is necessary to choose groups for which the orbital parameters are as close together as possible and lead to similar environments. Since the perigee and apogee determine the radiation environment to a great extent, these parameters were used as an initial basis.

A plot of perigee vs. apogee for the Class # 1 flights (Figure 1) shows a number of clusters along the 45° line, and suggests that a rational starting point for selecting flights with similar environments can be chosen by defining four sets of orbits. In Figure 1, these are labeled I (inside orbit), B (first belt orbit), S (synchronous orbit) and O (outside orbit). I orbits are defined as having perigee and apogee just inside the first radiation belt. The cutoff point was chosen as 760 miles because above this altitude, both electron and proton fluxes increase very rapidly with altitude from negligible to quite significant values.

The B orbits are defined by the cluster in Figure 1 at about 2000 miles. This region is close to the maximum of the first radiation belt and contains a flux of about 10^{10} protons/cm^2 day and 10^{12}-10^{13} electrons/cm^2 day.

The S orbits are those for synchronous geostationary flights, while the O orbits are beyond the radiation belts.

Tables II through V list the Class # 1 flights in the four orbital classes defined above, along with the four orbital parameters for each flight.

For each orbital class, it is necessary to examine the period and inclination in order to search for flights with similar total orbital designation (perigee, apogee, period and angle of inclination). This was done by plotting angle of inclination vs. period in Figures 2 - 6.

A consideration of the flights in each of the orbital classes, based on the classification scheme given above, revealed the following characteristics for each orbital class:

1. I Orbits

a) There are many flights in the inside orbits (sixty-five). This was a decided advantage for our study.

b) Twenty-four of the flights are NASA directed.

c) Particle radiation damage is minimal since the flights are below the maxima in the first radiation belt.

d) Because of the low orbit, the thermal cycle is one of appreciable changes in temperature over times measured in minutes. This may have significant effects on solar cell performances.

e) Because of d), the angle of inclination θ and the period T are important parameters. Any materials study based on I orbits should only include flights whose T and θ are similar.

f) There are two groups of flights with all orbital parameters similar: the group at $\theta \approx 32^{o}$ and the group at $\theta \approx 70^{o}$. The first group contains twelve (12) flights, eight (8) of which are NASA flights; the second group contains fifteen (15), none of which are NASA flights. These groups were labeled I(32) and I(70) respectively.

g) There is a group of seven (7) flights at $\theta \approx 80^{o}$ with T varying from 91 to 105 minutes, and a group of thirteen (13) flights with θ varying from about 48^{o} to 60^{o}. These groups were labeled I(80) and I(55) respectively.

2. B Orbits

a) These are all in a heavy radiation environment.

b) The group contains twelve (12) flights, none of which are NASA directed. Nine (9) are USAF and three (3) are USN flights.

c) Eleven (11) of the twelve (12) flights have similar θ and T, with $\theta \approx 90^{o}$.

d) These polar orbits pass in and out of the maxima of the first radiation belt. Therefore, the radiation environment, as well as the thermal environment, varies during each revolution of the satellite.

3. S Orbits

a) This group contains twenty-seven (27) vehicles, three (3) of which are NASA flights. Sixteen (16) of the flights are at $\theta \approx 0^{o}$ and six (6) are at $\theta \approx 7^{o}$.

b) Philco-Ford is performing a solar cell degradation study of fifteen (15) members of this group. This would be a definite advantage for our study.

c) For at least six (6) of these flights, the thermal environment has been estimated analytically by Hughes Aircraft Company. This also is a definite advantage for our study.

d) Hughes has examined the expected solar cell degradation to be expected from the synchronous radiation environment.

e) For at least six (6) of these flights, the only telemetered data concerning solar cells is the bus voltage. More extensive data would be desirable.

4. O Orbits

a) These all have a flat thermal cycle.

b) There are eight (8) satellites in this group, all of which are nuclear detection test satellites directed by USAF.

c) There is no subgroup with similar θ; the θ values range from 32° to 41°. However, at these altitudes, such a variation in θ is probably not important.

From the above classification scheme, we are led to define the following groups of flights as having similar orbital parameters: I(32), I(55), I(70), I(80), B(90), S(0) and O(36).

The flights in the S orbits have been labeled S(0) to indicate that most of them have an angle of inclination of 0°. We expect that those with $\theta \approx 7^{\circ}$ have environments similar to those at 0° and were included in the S(0) group.

Although the θ values for the O flights vary from 32° to 41°, we expect that this does not produce significant variations among their environments, since these satellites are very far from earth, and all O flights can probably be considered as one environmental group.

In Tables II - IV, the flights of interest for this examination are listed along with orbital data. They include the four subgroups of I orbits with angles of inclination at $\theta \approx 32^\circ$, $\theta \approx 55^\circ$, $\theta \approx 70^\circ$ and $\theta \approx 80^\circ$; the eleven B flights at $\theta \approx 90^\circ$, all S flights $\theta \approx 0^\circ$ - 8°, and O flights ($\theta \approx 32^\circ$ - 41°). These are designated I(32), I(55), I(70), I(80), B(90), S(0) and O(36) respectively.

From the method of selection, it is clear that the choice of the seven sets of flights just mentioned is an optimum one for collecting flights with similar environments, and any other choice would group the flights into environments that were less uniform for each group. However, it must be stressed that for each of the groups defined above, the environment of the solar cell assemblies still vary from one flight to another. This variation depends on time of orbit because of the temporal variations of the radiation environment, the variation of the physical configuration of the solar cell assemblies, and the variations arising from different parking (transfer) orbits. The extent and effects of this variation requires further analysis.

I orbit flights were chosen to be the most likely candidates for this study. These flights can be divided into four subgroupings; thirteen flights with angle of inclination between 28° and 33°; sixteen flights with angle of inclination between 47° and 60°; nineteen flights with angle of inclination between 66° and 71°; and twenty-nine flights with angle of inclination between 79° and 145°. The I orbit flights suffer minimal radiation damage since they are below the maxima in the first radiation belt.

However, because of the low orbit, the thermal cycle has appreciable changes in temperature over times measured in minutes. These flights constitute the largest grouping of flights with similar space environment, and since it is expected that sufficient data will not be available for each flight, this grouping had the highest probability of yielding sufficient data to establish some sort of correlation between materials and manufacturing techniques and performance. Twenty-four of these flights are NASA sponsored; fourteen are USN; fifteen are USAF; one is USA; one is NASA/UK; one is USN/NASA; three are USN/USA; seven are USN/USA/USAF; eight are USAF/USN; one is ARPA; one is ESSA; and one is UK.

The B orbit flights were not chosen because they consist of only twelve flights. These flights are essentially polar orbits passing in and out of the maxima of the first radiation belt, therefore causing both the radiation environment as well as the thermal environment to vary with each revolution of the satellite. Eight of these flights are USAF sponsored, two are USAF/USA, and two are USA/USN.

The S orbit flights, containing twenty-seven vehicles, were not chosen since Philco-Ford is performing a solar cell degradation study of fifteen of these flights, and Hughes has examined the expected solar cell degradation for the synchronous radiation environment. There probably are sufficient vehicles in this grouping to establish a correlation; however, the study would be an essential duplication of the work being performed by these other groups. Also, for at least six of these flights, the only telemetered data concerning solar cells is the bus voltage. Three of these flights are NASA sponsored, three are CSC, twenty-one are USAF, and one is USN.

The O orbit flights were not selected because they are the smallest group with only eight flights. All of these flights are USAF sponsored.

B. Environmental Factors

An indication of the variability of the radiation environment for the I orbits is given in the table below which gives approximate values for the orbital integration flux for protons and electrons of energies greater than 4 MEV and 0.5 MEV respectively for several orbits in units of $(cm^2\text{-day})^{-1}$.

	$\theta = 0^o$		$\theta = 30^o$	
Altitude	ϕ_p (E>4 MEV)	ϕ_e (E>0.5 MEV)	ϕ_p (E>4 MEV)	ϕ_e (E>0.5 MEV)
150 N.M.	0	0	0.3×10^7	2.6×10^8
450 N.M.	0.2×10^8	8×10^9	0.1×10^9	1.4×10^{11}

Orbital Integration Flux Versus Orbital Parameters

This table shows that there is a considerable variation in the radiation environment, even though the level is much lower than in the Van Allen belt.

A theoretical calculation of the effect of radiation at 300 N.M. (Cooley and Barret)* indicates that the radiation field will cause 7% degradation in maximum power in a typical

*W. C. Cooley & M. J. Barrett, Space Environmental Effects in Solar Cell Power Systems, January 1968, (Exotech Report TR-025) solar cell array in one year, while test data for Anna 1B, with an orbit in the 700 mile region, indicated degradations in short circuit current after 400 days ranging from 10% to 45% depending on the cover glass thickness.

There are several conclusions of importance to this study that arise from an examination of the near earth radiation environment. The first is that for orbits above approximately 250 N.M., the radiation effects may still be serious, while below this region, they are less important. This, coupled with the variability of the radiation density with altitude and epoch, means that orbital integrated fluxes must be obtained for each of the flights chosen for study. It is clear that the coarse grained classification of environment based on four orbital parameters is insufficient for the purposes of detailed analysis. However, it may still be true that the angle of inclination is an adequate representation of the orientation of the orbital plane. This is true to the extent that the radiation flux is symmetrical with respect to the orbital plane. For those flights for which the radiation effects are severe, however, the existence of variations in the radiation symmetry (such as those arising from the South Atlantic Anomoly) will require use of the orbital angular parameters completely defining the orientation of the orbital plane relative to the equatorial plane. Because of this, and because of secular variations, it will probably become necessary to use orbital integrated fluxes for each flight as the appropriate radiation environmental parameters.

The available data on the meteoroid environment has been summarized by Lyle in a report by Cooley and Barrett*.

*Ibid.

From the data given in their report, a rough representation of the near earth meteoroid flux in $(m^2 - sec)^{-1}$ for particles of mass greater than 10^{-8} gms, is

$$J_M = e^{1.15 \times 10^{-4}(1-R)}$$

where R is the altitude in kilometers. Thus, the meteoroid flux, within the accuracy of the available data, is essentially constant for all the inside orbits of this study.

Estimates of meteoroid penetration and of cover glass cratering indicates that there are a maximum of about 10^3 penetrations $(m^2\ yr)^{-1}$ and a maximum of about 10^5 craters $(m^2\ yr)^{-1}$. Since penetrations may short circuit a solar cell, and since the erosion associated with cratering decreases transmittance, it is clear that the meteoroid flux must be considered in a materials analysis of solar cell performance.

The thermal environment of the solar cells will be the most difficult to specify. Because the time spent in eclipse is a complex function of the orbital parameters, including those completely defining the orientation of the orbital plane, a complete calculation is required for each orbit even to obtain the black body temperature history of the vehicle. In addition, shadow effects, arising from the solar cell array and vehicle configuration, will complicate the situation further.

Since temperature variations of about 80°C over short periods of time can be expected, and since the thermal stresses thereby induced in the solar cell components are considerable, it is clear that the thermal analysis on the chosen flights must be carefully considered.

The thermal fluctuations for the solar array depend on orbit, time of flight, and vehicle configuration. The solar array temperature fluctuations are different, for example, for body mounted cells as compared to paddle mounted cells, and depend on the nature of the stabilization of the vehicle.

C. Final Flight Selection

The final choice of flights has been based on the availability of flight performance data. If flight data concerning the condition of the solar array is unavailable, then no performance examination can be made. For this reason, the flights chosen for detailed study were those with data transmitted back for the solar array output voltage, array current and array temperature. In many cases, the array temperature and some form of voltage such as the battery voltage was telemetered back. Although this data may be satisfactory for determining in go no-go fashion whether the solar array is functioning, it is inadequate for an analysis of performance degradation.

The vehicles that were finally chosen for study are the Pegasus series, numbers 1, 2, and 3; the OSO series, numbers 1, 2, 3, and 4; OGO 4, and Nimbus 2. There were flights, such as the OV1 series, that did not have a direct measurement of the solar array current, but the battery current was monitored. By knowing the load current, which was known before launch, and the battery current, the solar array current may be calculated. These flights have been discarded, since the indirect current determination multiplied errors and was not satisfactory for our analysis.

The I orbit flights (in the near earth environment) that were examined for possible inclusion in this study are shown in Table VI. The reasons for inclusion or rejection of each of these flights in the final selection are presented in the form of notes to Table VI.

All of the flights chosen for detailed study had their solar arrays mounted on panels or paddles, separated from the main body of the spacecraft. It would have been desirable to include flights with body mounted solar arrays, since these two basic and different types of configurations may have vastly different effects caused by temperature fluctuations.

Within the final group of flights selected for detailed study were solar cells produced by a variety of manufacturers. Contained in the Pegasus series were cells from Texas Instruments and Centralab. The OSO series were supplied by Heliotek and Spectrolab. The OGO 4 cells were manufactured by Centralab and the array was fabricated by TRW. Nimbus 2 had cells and arrays fabricated by RCA.

As was pointed out above, there is a sufficiently large variation in environment, even in the near earth orbits, that each flight had to be examined on an individual basis. It was hoped that this effort might have been reduced by subclassifying the vehicles according to type and looking for correlations. However, the number of vehicles was not sufficiently large to allow this approach to be fruitful.

III. INFORMATION AND DATA GATHERING

A. Initial Steps

An important task in this study was to ascertain the availability of information dealing with environment, procurement specifications, flight performance, testing, and materials and manufacturing data. The availability of this information strongly influenced the choice of the flights to be studied in detail.

The steps by which we pursued the initial information gathering are the following:

1. Search for NASA documents dealing with silicon solar cells using the computer facility at the NASA Scientific and Technical Information Facility.

2. Search for unclassified DOD documents dealing with silicon solar cells using the computer facility at the Defense Documentation Center.

3. Examine lists obtained from the computer searches for documents dealing with flights in the I, B, S, and O groups.

4. Obtain the documents listed from 3 above.

5. Obtain thermal and radiation environmental data as described below.

B. Computer Search of Literature

Two computer search facilities were used to obtain a broad coverage of unclassified reports relating to silicon solar cells in spacecraft.

1. NASA Scientific & Technical Information Division
   P. O. Box 33
   College Park, Maryland 20740
   (Mr. Philip Eckert)

2. Defense Documentation Center
   Cameron Station
   Alexandria, Virginia 22314
   (Mr. Thomas Lin).

Using both NASA and DOD facilities, it was hoped that all significant published documents could be obtained in this way. After considerable discussions with the individuals mentioned above, the following computer searches were performed:

1. A broad coverage search using "Silicon Solar Cell" as an identifier in both facilities

2. A specific search at both facilities in which information was sought on final flight reports, vendor reports on manufacture and testing of solar cell panels and spacecraft power supply, and flight performance.

In the specific computer search, the names of the NASA and DOD flights in the I, B, S, and O flights were submitted and appropriate identifiers were used with the flight name to perform the search.

After careful review of the abstracts of all documents cited, the papers having relevance to this study were ordered through NASA and DDC Clearinghouses.

Table VII shows the number of documents cited, ordered, and received as a result of these searches. These documents, as well as those received from other requests, have been examined and separated into three distinct groups; those that refer to specific flights and have the type of information that is required for this study; those that do not refer to specific flights, but have information that is relevant to this study, e.g., the thermal and radiation effects on cover glasses, and adhesives, etc.; and those that describe some type of problem connected with solar cells but have essentially no specific information that is required for this study. Of the total number of documents received, 58 are in the first class, 150 are in the second class, and 98 are in the last.

These computer searches have been only partially successful, in the sense that they did not yield the comprehensive data that is required for this study. Most of the documents are technical papers, written by authors who are describing special problems. The time involved in sorting and reviewing the documents was enormous, and did not yield the required details. However, it did serve as an indicator of what problems were recognized as significant to solar cell performance, and indicated what techniques were attempted to solve them. In this sense then, they were valuable in providing background data and information.

C. DOD Flight Documentation

A list of all DOD sponsored flights from the I, B, S, and O groups was prepared and sent to Lt. Steve Lacey, SAMSO, Los Angeles, California. We had arranged for Lt. Lacey to provide us with the names of individuals in the DOD or in industry who had responsibility for, or who possessed information relating to, silicon solar cells and solar panels used on these flights.

D. NASA Flight Documentation

A list of NASA sponsored flights for I, B, S, and O orbits was sent to Mr. Robert Ziemer, Deputy Assistant Director of Projects. Mr. Ziemer agreed to supply us with the names of NASA people and vendors who were associated with the solar cell and solar panel development and procurement for these flights. In particular, we asked for the names of people who could supply us with the following kinds of information:

a) detailed manufacturing and materials information

b) test and evaluation data

c) environmental data

d) flight performance data.

K. F. Merten, K. L. Hansen and W. J. Schlotter have prepared a comprehensive document on Nimbus 2, with the same type of detailed information that is required for this study. Therefore, several discussions were held with K. Hansen (G. E. Spacecraft Dept.) to determine where the data exists and how to go about acquiring it. The data exists largely in contractor quarterly reports, log books, and specifications which generally receive very limited distribution. The most effective method of obtaining these sources of information is by personal contact with people who possess a copy. Very effective use of the telephone can be made if names of people to call are available.

E. Radiation Environment Data

For the past eight years, the Laboratory for Theoretical Studies at Goddard Space Flight Center has calculated radiation environments for various flights. The results are available and can be obtained by making a request through appropriate NASA channels. If a flight for which a request is made has not been the subject of a previous radiation environment analysis, it can be performed with the following information:

a) Circular Orbits - altitude, inclination, epoch, vehicle and flight name.

b) Elliptical Orbits - perigee, apogee, period, inclination, epoch, vehicle and flight name.

The accuracy of such calculations is within a factor of 2 or 3.*

Sample data of radiation environments for a sampling of flights from each of the four flight subgroups were requested through our technical monitor for the following reasons:

a) The form of the data can be ascertained at an early stage.

b) The error limits can be determined.

c) The time involved in obtaining the data will be useful in planning Phase III of our study.

d) Verify nature of input data required to obtain these radiation studies.

*E. Stassinopoulos - private communication.

The following flights and information were supplied to Mr. E. G. Stassinopoulos:

FLIGHTS

I Orbits

	Name	Int'l. Desig.	Agency	Launch Date
a)	TIROS 8	1963 54 A	NASA	12/21/63
	Perigee	430 miles		
	Apogee	473 miles		
	Period	99.3 minutes		
	Inclination	58.5 degrees		
b)	NONE	1962Σ1	USAF	5/15/62
	Perigee	180 miles		
	Apogee	401 miles		
	Period	94.0 minutes		
	Inclination	82.5 degrees		

S Orbits

	Name	Int'l. Desig.	Agency	Launch Date
a)	ATS 1*	1966-110A	NASA	12/6/66
	Perigee	22,277 miles		
	Apogee	22,920 miles		
	Period	660 minutes		
	Inclination	0.2 degrees		

*What information is available for the parking orbit of this mission?

	Name	Int'l. Desig.	Agency	Launch Date
b)	IDCSP 16*	1967 66B	USAF	7/1/67
	Perigee	20,509 miles		
	Apogee	20,846 miles		
	Period	1309.8 minutes		
	Inclination	7.2 degrees		

*What information is available for the parking orbit of this mission?

FLIGHTS (continued)

O Orbits

	Name	Int'l. Desig.	Agency	Launch Date
a)	There is no NASA flight in this subgroup.			
b)	VELA 3*	1964 40 A	USAF	7/17/64
	Perigee	63,369 miles		
	Apogee	65,024 miles		
	Period	100.3 hours		
	Inclination	39.5 degrees		

*What information is available for the parking orbit of this mission?

B Orbits

a)	There is no NASA flight in this subgroup.			
b)	LES 1	1965 8C	USAF	2/11/65
	Perigee	1,726 miles		
	Apogee	1,744 miles		
	Period	147.7 minutes		
	Inclination	32.2 degrees		

F. Thermal Environmental Data

The detailed thermal environment for NASA flights and for some DOD flights can be obtained from the Thermal Physics Branch by contacting:

Mr. Milton Schach, Branch Chief
Thermal Physics Branch
Goddard Space Flight Center
Greenbelt, Maryland 20771.

The members of this group have computed solar panel temperatures for many flights. Also, data is available of actual panel temperatures during the mission although this information is rarely published.

A selected group of six flights was sent to the Thermal Physics Branch to determine the nature and availability of these data for reasons similar to those under radiation environmental data. This list was as follows:

	Name	International Designation	Agency	Launch Date
1.	TIROS 8	1963 54A	NASA	12/21/67
2.	NONE	1962 1	USAF	5/15/62
3.	ATS 1	1966 110A	NASA	12/6/66
4.	IDCSP	1967 66B	USAF	7/1/67
5.	VELA 3	1964 40A	USAF	7/17/64
6.	LES 1	1965 8C	USAF	2/11/65

The replies to this request were:

a) TIROS 8 - Contact Mr. Ralph Scott, RCA-AED. (This was done but, the data were not easily available and would require considerable effort to retrieve them.)

b) ATS 1 - Cell temperature 15°C ± 5°C except when satellite is in earth's shadow, then the temperature drops to -80°C in a period of 70 minutes.

c) VELA 3 - Contact Mr. James Moses, TRW Systems. (This was done and temperature as a function of "sun look angle" was obtained with an accuracy of ± 4°C. Although this is not sufficient, complete documentation is available upon furnishing a need-to-know.)

d) LES 1 - Contact Lincoln Laboratories. (This was done through Mr. Donald C. Mac Lelland. We were informed that temperature data is available after we establish a need-to-know.)

e) No comment made concerning numbers 2. and 4. above.

Although the results of this preliminary attempt left something to be desired, it was felt that detailed temperature data could be obtained for the selected group of flights.

G. Personal Contacts

Since a great deal of the information needed for this study could be obtained only through personal contacts, a "name tree" was generated for the flights of interest. This consists of a list of names and locations of individuals who were connected with the flights, who could provide information on the solar cell systems. The list we have generated is given in Table VIII. It was obtained by telephone and correspondence, starting with a group that was known to have the information desired, or who know which individuals were likely to have that information.

Another approach for acquiring the information on solar cells is to go directly to the vendors. Therefore, a list of known vendors for given vehicles is shown in Table IX. It is of interest to note that of the documents received from the computer search relating specifically to the data required for the flights in which we are interested, only one report was prepared by an author employed by the solar cell vendor.

In addition to letter and telephone contacts, personal visits were made to personnel at Centralab, Fairchild-Hiller, G.E., GSFC, Heliotek, Lockheed, NRL, OCLI and TRW. In addition to acquiring detailed information on many flights, an understanding was obtained for the entire manufacturing process of solar cells and solar arrays through these visits.

H. Results of Data Gathering Process

The information and data gathering problem is significant and requires personal contacts. When making these contacts, care must be taken not to abuse them, since these people are often being supported on other programs, and may not be able to spend any significant amount of time in supplying data to others. Therefore, our approach was to acquire as much information as possible from published reports, contractor reports that exist in various libraries, etc., before trying to make any significant and time consuming visits with people. Personal visits were used for two purposes; early in each flight study to see if any special problems had existed, and later to fill in the data we were unable to extract from prepared reports.

Sufficient data had been acquired for the Nimbus 2 and OGO 4 flights to conduct a degradation analysis. (Both vehicles have already had degradation analysis performed.) However, it was not possible to acquire the data for the Pegasus and OSO series of flights.

Pegasus 1, 2, and 3 were included in this study. These vehicles were manufactured by Fairchild-Hiller Corporation of Germantown, Maryland. The personnel at Fairchild-Hiller were very helpful to the extent that they were able. (This contract was not structured to pay for any services rendered by personnel in other firms and agencies. Therefore, their time and assistance on this project were given as favors, and was therefore necessarily limited.) At the end of the Pegasus program, its data were placed in dead storage both in Fairchild-Hiller and at the Marshall Space Flight Center in Huntsville, Alabama. Several visits were made to Fairchild-Hiller, and their dead storage for the Pegasus data was made available to us. These data were stored in several hundred cardboard boxes in the basement of one of their facilities in Germantown, Maryland. These data were not indexed or arranged in an organized fashion. As a result, data could not be retrieved in a logical manner. Time was spent actually going through these boxes in a fruitless attempt to retrieve the relevant data. One of the engineers responsible for the solar array power sub-system did have a personal collection of data that gave some general manufacturing data for the solar array and power system.

The same condition was prevelant at M.S.F.C. Invitations were offered by personnel at the M.S.F.C. to spend some time with the people who were concerned with the spacecraft in an effort to reconstruct from memory as much data as possible. These data could not be documented however, and it did not appear possible to determine any attitude data with the corresponding shadow or albedo effect on the solar array output.

The OSO series satellites were manufactured by Ball Brothers Corporation, with the Goddard Space

Flight Center as the monitoring agency. The data at Ball Brothers Research Corporation is reportedly organized so that it can be retrieved in a logical fashion. Apparently, however, this retrieval still required a considerable amount of manpower, and Ball Bros. was unable to supply this necessary expenditure. They replied that these same data were available through G.S.F.C. and recommended that it be retrieved there. The personnel at G.S.F.C. were anxious to be of assistance, but also were unable to retrieve the data.

The end result is that the manufacturing and analysis data were not obtainable for the Pegasus 1, 2, and 3, and OSO 1, 2, 3, and 4 satellites. These vehicles amounted to seven of the nine vehicles chosen for detailed study. It should be recalled that these nine vehicles (with the exception of the United Kingdom's Ariel III) were the only satellites with sufficient telemetry data for analysis in the total of seventy-seven vehicles chosen on an environmental basis.

The conditions discovered in this study are not unique to a few individual companies or agencies; it is in fact rather common throughout the industry. It is characteristic of all the flights studied that unless a special effort was funded to collect and record data in an organized fashion, it is almost impossible to acquire sufficient data to conduct extensive post flight studies using manufacturing and housekeeping data.

The nature of the projects was to accomplish a primary mission for each vehicle; namely, to conduct scientific experiments. The personnel involved with the vehicle, at the time of the flight, did have sufficient data, or at least a knowledge of its whereabouts to adequately accomplish the primary mission. These housekeeping data may have existed in the form of rough notes and memory, or factual organized reports at their disposal at the time of the flight of the vehicle. It has not been the purpose of these flights to develop a background of operational data that may be used in post flight studies.

At the end of the project, either nothing was done to preserve the data, or these data, in whatever form they existed, were placed in dead storage. This process appears to have been the simple collection of all notes and documents generated during the program, and the bulk storage of them, such as in cardboard boxes. These data were generally not organized or indexed in any way, so it is almost impossible to retrieve from this storage any accurate and readily available information concerning the flight.

For these reasons, post flight evaluative studies on space vehicles will probably not be successful unless it is known in advance that the data are available and can be readily retrieved. Therefore, post flight evaluation studies are not recommended unless the projects for the vehicles to be studied were designed to organize and store data in such a way as to make them available and retrievable.

The performance data, telemetered back, generally exist on computer tapes, and can be obtained in print-out format by direct request to the monitoring agency.

With the performance data that are available for these flights it is not possible to reconstruct the total I-V curve and analyze the degradation with time. If these I-V curves were available, then not only could the amount of degradation be determined, but a strong indication of its causes would also be available. From the data that are available, generally only a small region or single point on the I-V curve can be reconstructed over time. Therefore, in order to make an analysis, it is necessary to develop theoretical I-V curves, and modify them with expected forms of degradation in order to see if a form of degradation can be developed that will match the observed data.

There should be some degradation for each flight due to its radiation environment. This degradation should be predictable, and therefore, the change in I-V characteristics and hence the change in telemetered data should be predictable. If the observed degradation differs vastly from the predicted degradation, then this would be a good starting point for a materials and manufacturing analysis. Variations from expected performance have reportedly been observed for the vehicles selected for detailed analysis in this study.

In making an analysis of the performance of the solar array, it is necessary to know the attitude of the vehicle at the time data is taken. It is not sufficient simply to take "noon-time" data, and expect it to indicate all of the possible types of degradation processes that will occur. Off "noon-time" data are required in order to find some of these processes, such as the partial lifting of cover slides from the solar cells. It is also necessary to know the effects of the earth's albedo and component shadows on the look angle of the solar array with the vehicle's attitude.

Another question that must be considered in analyzing the performance data is the accuracy of the telemetered data. It is necessary to acquire the data which shows the calibration and accuracy of the telemetered data. If the telemetered data are accurate to only 5%, and the degradation amounts to 7 to 10% for one year, then it is very difficult to determine the exact nature of the performance degradation. For these reasons, the data required for interpreting the raw telemetry data are also essential. These data also proved to be unavailable in practice.

IV. CLASSIFICATION CODES

To facilitate the handling and application of the information obtained for use in this study, it was decided to use the device of coded forms. Three different forms were designed for this purpose. The first form, designated C-01, was used to qualitatively record the general availability of data. The second form, designated C-02, is just the dictionary for C-01. The third form, designated C-03, was used for the recording of data, and provides an organized outline of the available pertinent information of each flight. These forms are shown in Tables X, XI, and XII respectively.

The most detailed information available was for Ariel III. This information is presented in the Appendix as an example of the utility of Form C-03. Similar forms are also included in the Appendix for Pegasus 1, Pegasus 2, Pegasus 3, Transit 4B, and TRAAC. It should be noted that the information on the latter forms is much less complete than is the case for Ariel III. This incompleteness is representative of the flights studied, while Ariel III is atypical. The detail of the data is not sufficient, in any case, to establish the correlations intended in this study.

An examination of Forms C-01 and C-02 (Tables X and XI) shows the information required was divided into six major categories. These are: environmental; procurement specifications for cells; procurement specifications for panels; performance; tests for acceptance; materials and manufacturing. Each of these major categories was further divided into appropriate sub-classifications. Simply by circling the corresponding code letters in Form C-01 when availability of particular types of data are ascertained, a graphic display of the amount and type of information is readily obtained.

V. RECAPITULATION OF THE DATA RETRIEVAL PROBLEM

The purpose of this study was to examine the flight performance data for solar cell power systems in satellites, and to try to relate the differences in performance to the materials and manufacturing factors in the solar cell system.

A total of 77 satellite flights were initially selected on the basis of a space-environment classification scheme. These flights were studied in an effort to analyze for correlations between materials and manufacturing techniques and the performance of solar arrays. Study methods included examination of existing documentation, visits to manufacturers and government installations, materials analysis of solar arrays, direct inquiry and discussion with individuals with solar cell system responsibilities for the flights, and direct examination of unpublished data in their files.

It was found that a total of nine flights have sufficient telemetry data for the purposes of this study.

It was also found that, for practical purposes, it is not possible to retrieve the materials and manufacturing information needed for this study. The reason for this is that the purpose of the flight projects was to accomplish a primary mission for each vehicle, and no provision was made for future a posteriori studies. At the time of the flight, the personnel involved with the vehicle had sufficient data, or at least a knowledge of its location, to accomplish the primary mission. Often, these data existed in rough notes, memory, and factual organized reports that were available during the mission. At the end of the project, either nothing was done to preserve the data, or they were placed in dead storage in whatever form they existed. Dead storage often consisted of simply collecting all notes and documents generated during the project and storing them in cardboard boxes. No indexing or organizational scheme was applied in the storage process, so that the required data exists among a large mass of unorganized documents. The retrieval of the needed information to any degree of accuracy and completeness is, thus, prohibitively time consuming and expensive.

The recording of data relating to the design of any vehicle is both a time consuming and, therefore, costly effort, and at the same time a very necessary effort. These data may be of value to future workers on other projects, as well as those personnel actually involved on the present project. The data may be required for as wide a variety of purposes as a statistical analysis of the manufacturing techniques of the past vehicles or the design planning of a new vehicle.

It is, therefore, important to consider how the difficulties we encountered may be avoided in the future. Clearly, if the enormous amount of data generated during a mission is to be preserved for future use, steps must be taken to that end at the inception of the mission. An information system which gathers the data and stores it in readily retrievable, indexed form should be implemented at the start of every mission. In the following pages, some recommendations are made for the type of data, its format, and its capture, that will satisfy the needs of post flight studies.

VI. DATA GATHERING REQUIREMENTS

It is possible to facilitate post flight studies in the future by the design of an organized outline, in generic fashion, to serve as a guide for the recording of data for each vehicle. Then, it should not be very costly or difficult for the individual engineers and project managers who are responsible for the various sub-systems in the vehicle, to record the data in an organized way so that it can be retrieved and used at some future date. As an example of this technique, this study has developed and suggests the use of the forms presented in Section VIII for the solar array sub-system.

The data should not only be recorded, but they should be in a form that makes them most accessible to the widest variety of users. This means that the functional categories of the data should be sensibly designed and organized. This will improve the ease with which the user can extract the data desired, and will also facilitate the documentation of the data.

A meaningful way of accomplishing these objectives is to organize a coded form that allows data for various systems to be entered in a hybrid manner. A hybrid manner is meant to imply that the data is entered in both checklist format as well as free form narrative. For the operation of the computer, a fixed format type of code is preferable. This is almost impossible when engineering items are being recorded, each with its own set of unique requirements and specifications. The easiest method of allowing for any and all types of differences in the data is to enter all of it in free form text. However, the burden on the computer to unscramble the information for future users becomes almost impossible. Therefore, a hybrid approach seems to satisfy both objectives in a reasonable way.

The use of a hybrid form for the storage of data for engineering items also serves the purpose of providing an organized outline for the engineering personnel to use in the recording of their data. This will facilitate the actual recording of the data.

It is also necessary to arrange the physical storage of the data in an organized way, so that the location of the data for the individual sub-systems can be found readily. These processes will then help preserve the technology and data that were generated for any particular vehicle for future analysis and possible application in other programs.

There are problems to this approach other than those presented by the mechanics involved in implementing this suggestion. For example, the availability of information must be considered.

How will the manufacturers of solar cells (or any other proprietary product) react to supplying information to fill out the generic outlines? What kinds of information will they not supply right now? In the past, if they refused to supply information of a proprietary nature, and it then became non-proprietary due to advances in the state of the art, what mechanisms would they find acceptable for supplying the old information to complete the records?

It is characteristic of solar arrays that there are minor differences in construction and manufacturing techniques among individual flights. Some of these variations are determined by the power requirements and the environment in which the vehicle is to be flown. Other differences are manufacturing techniques proprietary to the individual manufacturer of the solar cells and arrays. Since the similarity in the manufacturing techniques and materials used is so great, the data storage may be based on the similarities, with provisions made for specifying the differences.

The manufacturers of the solar cells and arrays have very little feedback from the vehicle manufacturer and/or user, so that they are not aware of the detailed performance of their cells and arrays. It should be profitable to establish a more extensive feedback mechanism between the manufacturer and the user of equipment. Since the manufacturer is interested in improving his product, he would have an interest in developing, over a period of time, the correlation that was funded in this particular study. Therefore, it is recommended that information on the vehicle performance be supplied to the manufacturers of the various sub-systems in that vehicle. This feedback should be supplied in a more formal way than merely by word of mouth to the effect that the vehicle performed well, or that it degraded any given percent over a period of time. Actual housekeeping data should be supplied to the producers of the various sub-systems.

In summary, this study originally intended to determine if a correlation could be established between the materials and manufacturing techniques and vehicle flight performance data for the solar arrays on a selected group of satellites. This study has determined that this correlation was not possible within the approved level of effort due to the practical unavailability of the data. The reasons for this conclusion are documented. It is therefore suggested that methods be adopted for storing data on vehicles so that post flight evaluative studies may be successfully conducted in the future.

VII. FABRICATION OF A SILICON SOLAR ARRAY

A. Fabrication Process

In this section, some important aspects of solar array fabrication are presented in order to clarify the basis of organization for the recommended data collection forms.

The process most commonly used for the production of silicon solar cells and arrays is outlined below.

1. Growth of the Silicon Ingot
2. Slicing and Preparation of the Silicon Blank
3. Formation of the Appropriate Junction
4. Attachment of Contacts
5. Deposition of Anti-reflecting Coating
6. Fabrication of Solar Array
   a) Choice of protective slides and method of construction
   b) Type and method of fabrication of interconnections.

Each step of the process includes different types of handling techniques, storage, and testing procedures. All of these factors must be considered, since they may affect the performance of a solar array in space. Some of the possible effects are described below.

B. Growth of the Silicon Ingot

The fundamental element of a solar cell is the silicon blank into which the appropriate dopants are injected and the appropriate electrical connections are made. The first step in the preparation of this blank is the growth of a silicon ingot. Very high purity silicon is melted in a vacuum furnace and a seed crystal is used to grow a silicon ingot. The seed crystal is oriented, and therefore, the ingot is grown with a preferred orientation. (The crystal is generally pulled in the 100 or 111 direction.) After it is grown, this silicon ingot has a base resistivity that is spatially variable. Typical base resistivity variations are in excess of 100% throughout the ingot.

The base resistivity of the silicon blank is determined by the addition of dopants and the defects generated during this process. The base resistivity of this single crystal of silicon varies along the length of the ingot. (The dislocation density may also vary along this length of silicon. Both the base resistivity and type and density of dislocations may be expected to affect the performance of the solar cell.)

The radiation resistance of the solar cell is affected by the base resistivity. For example, 10 ohm-cm. cells are more radiation resistant than 1 ohm-cm. cells. The radiation resistance increases with the base resistivity. Therefore, it may be desirable to hold closer tolerances on the variations in base resistivity.

Radiation resistance depends on the types and concentration of recombination centers that are caused by the damage due to radiation. Since different dopants affect the radiation resistance, (e.g., lithium doped cells are very resistant) it is probable that the efficiency of these recombination centers are variable for different kinds of impurities.

The process for growing the silicon ingots is a repetitive process. High purity silicon is added with dopants (boron) to a crucible, and melted in a vacuum furnace.

Impurity concentration tends to vary, being richer in the top of the ingot as it is grown. The remaining silicon in the crucible at the end of the growing process is not discarded, since pure silicon is expensive. It is added along with dopants in a prescribed amount to fresh silicon for repetition of the process.

C. Slicing and Preparation of the Silicon Blank

When the silicon blank is grown, it is grown in a preferred orientation, usually the 100 direction or the 111 direction. When the silicon ingot is processed and cut into blanks, the orientation of these blanks is preserved. This has the effect of keeping the normal to the blank in a preferred orientation.

There appear to be two methods now in use for the sectioning and slicing of silicon blanks into wafers that will be used for the production of silicon solar cells. These two methods are distinctly different. One is the slicing of the silicon ingot using a diamond-edged saw blade. The other is slicing the silicon ingot by the use of an abrasive slurry mechanism. (This mechanism consists of stretching tight bands of steel and causing them to move back and forth in an abrasive slurry, cutting through the silicon material via an abrasive technique.) It is probable that both types of slicing cause different types and concentrations of dislocations in the material. These impurities are removed to a great extent by a chemical cleaning after a polishing operation.

D. Formation of the Appropriate Junction

There are different techniques for the diffusion of dopants into the silicon blank to form the n/p junction. One is to present the dopant carried in a gas over the silicon blanks in a furnace allowing the dopants to diffuse into the material. The other technique is to plate the silicon blank with the dopant and allow it to diffuse under the influence of heat in the furnace.

The oxide layer formed during diffusion is removed in another chemical wash, or in conjunction with sand blasting.

E. Attachment of Contacts

The grid type front contacts are applied with an evaporation process. Titanium is deposited first, then silver is deposited, either totally subsequently to the titanium deposition, or beginning toward the end of the titanium deposition forming an intermediate Ag-Ti alloy. These Ag-Ti contacts are sintered to form TiO-SiO with the Si blank, and a good junction for the contact.

A solder dip is used to provide protection to the surface conductors from humidity, and to reduce the tendency for the conductors to lift from the silicon blank.

F. Deposition of Anti-reflecting Coating

An anti-reflecting coating of SiO is evaporated on the cell. This coating is used to gain the most usable sunlight absorbed for the spectral characteristics of the cell, while reflecting the rest. It is characteristic that this coating is applied not in a controlled fashion, i.e., to a specified thickness, but rather to color match the cells in an array. (Thickness monitoring guages may be used; however, color matching is the primary requirement.)

G. Fabrication of the Solar Array

Once the solar cell has been fabricated, it is used as the primary building element in the construction of a solar array. Appropriate supporting substrates are developed, and the solar cells with their interconnections and cover slides are cemented to this substrate. The interconnections must be arranged to accommodate for thermal expansion as well as the generation of the required power and magnetic field cancellations. The cover slides must be carefully chosen to prevent radiation damage. These arrays are balanced and mounted on the spacecraft.

There are various stabilization and orientation devices to provide an adequate area of the solar array facing the sun. The operation of these devices must be documented in order to determine the performance of the solar array in flight.

The monitoring devices on the solar array must be carefully documented in order to measure its performance. It is also extremely important to correlate any measurements of the solar array performance with its orientation to the sun.

VIII. FORMS FOR THE PROPOSED DATA COLLECTION PROCESS TO ACCOMPANY SATELLITE FLIGHTS

The philosophy used in the development of these forms is to provide an organized outline for the storage of data relevant to the design, manufacture, and testing of solar arrays for space vehicles. This outline is based on considerations of solar cell fabrications presented in the previous section.

These organized forms are actually to be completed in two parts. The first part is to be easily computerized so that the data may be readily retrieved and analyzed. This part is organized in hybrid fashion, where most of the data is supplied in check list fashion with provisions for free form narrative, if necessary. By scanning this form, anyone seeking information about the solar array for a particular vehicle can easily locate the type of information that is sought. The second part of the form is a notebook or binder which has detailed information (drawings included) in hard copy form. This notebook should be organized in the same manner as the computer compatible forms so the detailed data may be easily retrieved using part one of the forms as an outline.

In the generic design of the forms for data storage, each element of the sub-system should include:

1. The names of the people and companies responsible in any way for the sub-system
2. The design specifications and reasons for the design
3. Procedures and materials used in the manufacture of the sub-system

4. The testing procedures for the sub-system
5. The storage and handling procedures for the sub-system.

As an example of this type of system, Forms A, B, and C, are the computer compatible forms developed for a solar array sub-system. They are shown as Tables XIII, XIV, and XV. These show the type of data that should be collected, and a method for its organization.

In the development of these forms, provisions must be made to adequately describe the location of data describing any unusual criteria or events, system drawings, specifications on purchased items, quality control procedures, etc.

Table XIII (Form A) shows the nature of the vehicle information that is needed for post flight studies. This information ranges from satellite name, to performance details. The level of detail indicated is necessary to characterize the flight if solar cell studies are to be made.

Forms B and C (Tables XIV and XV) describe the data needed for the solar cell modules and solar cells respectively. It is apparent that these forms capture a great deal of significant information that has been lost on previous flights. The completion of these forms and their storage in an indexed, computer retrievable manner would provide a highly valuable data base on solar cells.

IX. MANAGEMENT RECOMMENDATIONS FOR THE PROPOSED DATA COLLECTION PROCESS TO ACCOMPANY SATELLITE FLIGHTS

The primary responsibility for the completion of the forms should reside in the office of the project manager for the entire space vehicle. He may assign the responsibility for the completion of the various subsections in the vehicle to the individual project managers, who in turn may place the responsibility with the individual project engineers for each sub-system. Therefore, the forms that are designed should be organized to include data relevant to each individual sub-system so the responsibility can be easily handed down the line to the project engineer level.

The project manager may assign responsibility to an assistant for purposes of collecting and policing the completion of the forms.

Whenever progress reports are issued, a statement of percentage of completion of the data storage forms should be included. If there is some problem in the completion of these forms, this should be indicated in the progress reports.

As a "fail safe mechanism", it should be the policy of both the governmental agencies, and private contractors to require the forms to be completed before allowing the relevant data to be placed in dead storage. This should prevent the loss of data in the sense that when they are placed in dead storage, in practice they become inaccessible for future use.

Military specifications should be used wherever possible for the completion of these forms. Standard procedures should be developed to describe some of the complicated processes used in the development of a sub-system. For example, the solar array sub-system has a relatively standard fabrication technique. With these procedures, differences from them can be indicated easily in the data storage forms. This will greatly reduce the time required and difficulties in the completion of the data storage forms.

The forms are completed and designed for ease of computer storage. However, there should be backup documentation in a hard copy loose leaf or other binder. This should include documentation of all types of elements in the sub-system. This will include data received from the manufacturers on the purity of the materials and supplies, any relevant drawings, etc. These binders should be arranged analogously to the same organization and numbering system as the computer compatible forms, so that the general information, detailed as it may be, on the computer compatible forms may be found easily. If more detailed information is sought, then it can be obtained from the hard copy contained in these notebooks or binders.

Whenever there is a delivery of hardware, the forms should accompany that hardware.

The forms for the sub-systems supplied by outside contractors should be sent to both the governmental agencies as well as the prime contractors.

The responsibility for completing these forms should be a dual responsibility. The project manager in the governmental system as well as the contracting project manager should each have the responsibility for the completion of the data storage forms. This redundancy will help to insure the

2

total completion of the forms. However, care must be taken that the responsibility in either one or the other office is not relegated to the other by assumption, thereby creating a situation in which neither, in fact, completes the forms.

In the comments section, associated with each computer compatible form, a brief statement in paragraph form should be included to give a reason for the choice of that particular manufacturing technique or design principle.

X. CONCLUSIONS

The major conclusions of this study are listed below:

1. It is not possible to retrieve materials and manufacturing data for past satellite missions to any degree of detail.
2. Studies that depend on such data are not practical and should not be funded.
3. The wealth of data that has been lost because of inadequate recording and storage is enormous.
4. A data collection, storage, and retrieval system should be instituted to accompany future satellite missions so that data now lost can be preserved.

APPENDIX

Completed Data Outlines for Some Specific Flights Using Form C-03

Form C-03 Pegasus 3 Data

CARA Flight Number
1

Satellite Name
Pegasus 3

International Designation
1965 60A

Sponsoring Agency
NASA

Prime Contractor
---*

Contract Number

Solar Cell Manufacturer
---*

Contract Number
---

* The electrical power system was developed for the Pegasus satellites by Fairchild-Hiller with assistance provided by the Astrionics Laboratory of MSFC.

Orbit Data

Launch Date:
Site:
Vehicle:

Perigee: 323 mi. T: 95.3 min.
Apogee: 336 mi. θ: 28.9°

Solar Cell Data

Type: n/p

Base Material

Type: Silicon

Solar Cell Module

Dimensions: 103.14 x 163.83 cm. (forward panel)
Number of Cells: 6160

Interconnections

Wiring Diagram: (55 parallel strings of 112 in series)

Form C-03 Pegasus 1 Data

CARA Flight Number
2

Satellite Name
Pegasus 1

International Designation
1965 9A

Sponsoring Agency
NASA

Prime Contractor
---*

Contract Number

Solar Cell Manufacturer
---*

Contract Number
---

* The electrical power system was developed for the Pegasus satellite by Fairchild-Hiller with assistance provided by the Astrionics Laboratory of MSFC.

Orbit Data

Launch Date:
Site:
Vehicle:

Perigee: 308 mi. T: 97.0 min.
Apogee: 462 mi. θ: 31.7°

Solar Cell Data

Type: n/p

Base Material

Type: Silicon

Solar Cell Module

Dimensions: 103.14 x 163.83 cm. (forward panel)
Number of Cells: 6160

Interconnections

Wiring Diagram: (55 parallel strings of 112 in series)

Form C-03 Pegasus 2 Data

CARA Flight Number
3

Satellite Name
Pegasus 2

International Designation
1965 39A

Sponsoring Agency
NASA

Prime Contractor
---*

Contract Number

Solar Cell Manufacturer
---*

Contract Number
---

* The electrical power system was developed for the Pegasus satellite by Fairchild-Hiller with assistance provided by the Astrionics Laboratory of MSFC.

Orbit Data

Launch Date:
Site:
Vehicle:

Perigee: 314 mi. T: 97.3 min.
Apogee: 466 mi. θ: 31.7°

Solar Cell Data

Type n/p

Base Material

Type: Silicon

Solar Cell Module

Dimensions: 103.14 x 163.83 cm. (forward panel)
Number of Cells: 6160

Interconnections

Wiring Diagram: (55 parallel strings of 112 in series)

Panel

Size: 103.14 x 163.83 cm. (forward panel)

Deployment Technique: The panels are deployed in orbit in the planes of a regular tetrahedron, giving maximum area utilization efficiency for solar cell panels on a randomly oriented satellite.

Preflight Test Details

Under test conditions at Table Mountain, California, the panel produced 115 watts at 42 volts.

Performance Details

The maximum power per panel is approximately 135 watts, and the average power from all four panels is approximately 110 watts. The average power available during random orientation is 79% of the maximum from one panel. During the sunlit portion of the orbit, the solar cells power the 40 watt load directly while simultaneously charging the batteries. Approximately 48 watts are required for battery charging and about 20 watts are dissipated in the power system electronics.

References

Graff, Charles, "The Electrical Power System for the Pegasus Satellite." #N67-30590

Form C-03 Transit 4B Data

	CARA Flight Number 4
Satellite Name Transit 4B	International Designation 1961 AH 1
Sponsoring Agency USN	
Prime Contractor ---	Contract Number ---
Solar Cell Manufacturer ---	Contract Number ---

Orbit Data

Launch Data:	November 15, 1961	Perigee:	582 mi.	T:	105.6 min.
Site:	Cape Canaveral, Fla.	Apogee:	700 mi.	θ :	32.4°
Vehicle:	Thor-Atlas				

SPECIAL NOTE:

The Transit 4B satellite contained experiments to determine the performance of solar cells in the space environment. Over a period of 236 days from launch until July 9, 1962, the performance of these solar cells indicated a damage rate that was consistent with present knowledge of the proton flux levels of the inner Van Allen Radiation Belt. As a result of the high altitude nuclear weapon test of July 9, 1962, the radiation at altitudes of great interest for earth satellites was changed drastically as to both its character and its intensity.

The following data is for the solar cell experiments carried on Transit 4B, and not for the solar cells used to power the vehicle.

Solar Cell Manufacturer

Heliotek Corporation

Solar Cell Data

Type:	p on n
Dimension:	1 x 2 cm.
Spectral Response:	"Blue Sensitive"

Cover Slide

Material:	Microsheet Glass
Thickness:	Six Mils

Cover Slide Coating

Type: Anti-reflecting Coating & Blue Reflecting Filter

Solar Cell Module

The solar cell panel consisted of twenty series gridded solar cells.

Flight Details

The temperature of the solar panels was monitored on the vehicle. It is estimated that temperature variations encountered when reading solar cell performance at near zero angles of incidence, result in an error of less than one percent, and therefore can be ignored.

The Transit 4B satellite had its symmetry axis stabilized along the local direction of the earth's magnetic field, making it possible to predict the attitude of a solar panel that is perpendicular to this axis. It is estimated that for a magnetically stabilized satellite, a solar panel whose face is perpendicular to the alignment axis of the vehicle will have its attitude determined relative to the sun with an angular accuracy of approximately 3°. This angular measurement accuracy is efficient for measurements on the solar panels with the sun eliminating them at nearly normal incidence. An angular attitude error at normal incidence of 8° would provide an error in the measurement of panel output of only one percent. Therefore, to obtain the best results, measurements were made on the Transit 4B satellite while the sun was illuminating the panel at nearly normal incidence.

Performance Details

The solar cells were operated at approximately 0.2 volts per cell into a 75 ohm resistance, thereby providing a voltage measurement essentially proportional to the short circuit current. A curve* is available showing the short circuit current as a function of time for Transit 4B and TRAAC satellites. This curve has been normalized for a solar constant of 140 mw/cm^2. In the period of 236 days from the launch date, until July 9, 1962, the Transit 4B solar cells showed a deterioration of approximately 17%. In a 20 day period after the high altitude nuclear test, the Transit 4B satellite showed a deterioration of 22%. For a five day period after the explosion, the Transit 4B solar panel showed a decrease of 16%. The deterioration was more rapid at first, and then slowed slightly as is expected for radiation damage to solar cells under a constant or decreasing intensity particle flux.

As the result of the decrease in the power generated by the satellites power system solar cells, the Transit 4B satellite ceased transmitting on August 2nd.

Graphical data* is available showing in detail the degradation of the Transit 4B solar cells after July 9th. Two possible curves have been drawn from the data points. The first curve is for a constant particle flux of 1.9×10^{13} particles/cm^2 per day. The data can be interpreted by assuming a higher initial flux which then tapers off to a steady level. The data can be explained by a steady flux of 1.72×10^{13} particles/cm^2 per day plus an initial flux rate of approximately five times that value which decreased exponentially with a time constant of twelve hours. The fact that the radiation levels were distinctly higher immediately after the explosion is clearly borne out by Ariel satellite data. The value of 1.72×10^{13} particles/cm^2 per day incident upon the solar cells is higher than the omnidirectional flux given by W. N. Hess of the Transit 4B/TRAAC orbit which was stated as 4.5×10^{13} particles/cm^2 per day. There could be a combination of several possible causes for this discrepancy.

* Not included in this report.

1. The particle flux levels in the Transit 4B/TRAAC orbit might be higher than computed from counter data.

2. The solar cells may be more radiation sensitive than a typical "blue sensitive" p on n solar cell.

3. The radiation caused the darkening of the microsheet glass cover slide and/or the adhesive bonding the slide to the glass.

The agreement of Transit 4B and TRAAC solar cell degradation figures indicate that whatever the cause, radiation damage to p on n solar cells in this orbit through the artificial radiation belt is most severe.

Reference

Fischell, R. E., "Solar Cell Experiments on the Transit and TRAAC Satellites", APL, CM-1021 (1962). (Report No. N62-13688)

Fischell, R. E., "Solar Cell Performance in the Artificial Radiation Belt", AIAA Journal 1, 242 (1963) (Report No. A63-11952)

Form C-03 TRAAC Data

CARA Flight Number

5

Satellite Name

TRAAC

International Designation

1961 AH 2

Sponsoring Agency

USN

Prime Contractor

Contract Number

Solar Cell Manufacturer

Contract Number

Orbit Data

Launch Data:	November 15, 1961	Perigee:	562 mi.	T:	105.6 min.
Site:	Cape Canaveral, Fla.	Apogee:	720 mi.	θ:	32.4°
Vehicle:	Thor-Atlas				

SPECIAL NOTE:

The TRAAC satellite contained an experiment to determine the performance of solar cells in the space environment. Over a period of 236 days from launch until July 9, 1962, performance of these solar cells indicated a damaged rate that was consistent with present knowledge of the proton flux levels of the inner Van Allen Radiation Belt. The result of the high altitude nuclear weapon test of July 9, 1962, the radiation altitudes of great interest for earth satellites was changed vastly as to both its character and its intensity.

The following information is for solar cell experiments carried on the TRAAC satellite, and not for the solar cells used to power the vehicle.

Solar Cell Manufacturer

Hoffman Semi-conductor Division

Solar Cell Data

Type:	p on n
Dimension:	1 x 2 cm
Spectral Response:	"Blue Sensitive"

Cover Slide

Material:	Micro-Sheet Glass
Thickness:	Six Mils

Cover Slide Coating

Type: Anti-reflecting Coating & Blue Reflecting Filter

Solar Cell Module

Each module consisted of two cells in series.

Solar Panel

The TRAAC satellite employed four separate solar panels each with two cells in series. (These panels appeared to be mounted on the sides of the satellite.)

Flight Details

The temperature of the solar panels was monitored on the satellite. It is estimated that the temperature variations encountered when reading solar cell performance at near zero angles of incidence result in an error of less than one percent, and therefore can be ignored.

The TRAAC satellite employed independent solar attitude detectors to determine the position of the test solar panels relative to the sun. Measurements to determine solar cell degradation were confined to those cases when the sun illuminated the solar cells at nearly normal incidence.

Performance Details

Curves* are available showing the short circuit current as a function of time for the TRAAC satellite. This curve

* Not included in this report.

has been normalized for a solar constant of 140 mw/cm^2. In a period of 236 days from the launch date until July 9, 1962, the -Y solar panel of the TRAAC satellite showed a deterioration of 22%. For a five day period after the explosion, the four track panels showed decreases as follows: -X, 16%; +Y, 18%; -Y, 12%; +Z, 15%. The deterioration was more rapid at first, and then slowed slightly as is expected for radiation damage to solar cells under a constant or decreasing intensity particle flux.

The last transmission received from the TRAAC satellite was on August 12th.

The agreement of Transit 4B and TRAAC solar cell degradation figures indicate that whatever the cause, radiation damage to p on n solar cells in this orbit through the artificial radiation belt is most severe.

Attitude detectors on TRAAC with 125 mils of quartz showed a decrease in output of not more (and probably less) than 7.8% in the period from day 95 to day 195, when the Transit 4B solar panel showed a decrease of 21%.

Reference

Fischell, R. E., "Solar Cell Performance in the Artificial Radiation Belt", AIAA Journal 1, 242 (1963) (Report No. A63-11952)

Fischell, R. E., "Solar Cell Experiments on the Transit and TRAAC Satellites", APL, CM-1021 (1962) (Report No. N62-13688)

Form C-03 Ariel 3 Data

	CARA Flight Number C-51
Satellite Name Ariel 3	International Designation 1967 42A
Sponsoring Agency UK	
Prime Contractor British Aircraft Corporation	Contract Number ---
Solar Cell Manufacturer Ferranti, Ernest Turnor Ltd. (Module Manufacturer)	Contract Number ---

Orbit Data

Launch Data:	May 5, 1967	Perigee:	306 mi.	θ:	80.2^{o}
Site:	Western Test Range	Apogee:	373 mi.	T:	95.6 min.
Vehicle:	Scout				

Solar Cell Data

Type:	N/P
Dimension:	1 x 2 cm.
Resistivity:	10 Ω - cm.
Efficiency:	10% in sunlight above atmosphere
Spectral Response:	

Base Material

Type:	Silicon
Thickness:	0.014 to 0.016 in.
Purity:	
Method of Preparation:	

Another unusual feature is that the cells are processed in disc form, the last operation being to scribe and break the disc to form two cells. The edges thus formed are not perfectly straight or normal to the surface but give a high shunt resistance.

Dopant

Type:
Diffusion Depth:
Concentration:

Junction depth 0.25 to 0.5μ

Cover Slide

Material: Glass
Thickness: 0.006"
Transmission:
Vendor:

Cover Slide Adhesive

Name & Vendor: G.E. L.T.V. 602
Thickness:
Transmission:
Preparation:
Application:
Cure:

Cover Slide Coating

Type:
Thickness:
Transmission & Spectral Response:
Application Technique:

Front Surface Conductor

Type:
Material:
Resistivity:
Thickness:
Application Technique:

"Finger" Conductors

Type:
Material:
Resistivity:
Thickness:
Dimensions:
Application Technique:

3 fingered grid on the active surface

Untinned nickel/copper/gold

Solder Contact

Material:
Thickness:
Resistivity:
Application Technique:

Untinned nickel/copper/gold contacts which are extremely adherent and easily soldered.

The final design was not achieved without difficulties. The original cells had solder-dipped nickel-plated contacts which gave trouble due to poor adhesion and surplus solder. The cleaved edges sometimes caused the cells to jam in the assembly jigs and occasionally affected the alignment of the connecting strips. These problems were overcome by developing the untinned nickel/copper/gold contact and adjusting the tolerances of the cells, jigs and connecting strips. Thermal mismatch between the connecting strips and the cells was minimized by introducing stress relief loops and making the strips thinner.

At the beginning of the Ariel 3 programme, information on solar cell cements was proprietary, so a comprehensive programme of assessment was carried out on a range of available epoxy and silicone rubber adhesives to select the best materials for this application. The assessment, carried out by R.A.E. in collaboration with Ernest Turner Ltd., High Wycombe (the module contractor) and the Mullard Central Materials Laboratory, Mitcham, covered electron and ultraviolet irradiation, low temperature bond tests, thermal cycling, practical application exercises and the measurement of physical properties.

The cements finally selected were:

Cover: I. C. I. Silcoloid 201 (G.E. L.T.V. 602)

Mounting: Dow Corning Silastoseal A.

A difficulty with the cover cement was that, for this particular application, it had a shelf life of four months, so it had to be purchased and used in small batches.

Solar Cell Module

Dimensions:
Number of Cells: 48, 8 in series x 6 in parallel
Type of Overlays:
Description of Exposed Area:

Interconnections

Wiring Diagram:
Material:
Processing Technique:

Panel

Size:
Deployment Technique:
Location of Spacecraft:
Module Interconnection Details: Five modules in series, for the load array, six in series for the battery array.

Power for the experiments, data handling equipment, tape recorder, telemetry transmitter and command receiver on board Ariel 3 is obtained from two arrays of silicon solar cells. One supplies the loads through converters and regulators, while the other charges a battery for operation in the Earth's shadow.

The load array feeds busbars at the four line voltages, +12V, +6V and -12V, through voltage regulators. As most of the power is required at +12V, this line is fed direct, the other voltages being obtained by a dc to dc converter. The average continuous total load is 6.7W and the peak load is 12.7W.

Isolating converters are inserted in the load and battery circuits to permit the positive terminals of both arrays to be earthed. This was necessary to meet a requirement of the Birmingham experiment that no exposed surface should be positive with respect to the satellite frame.

Fig. 2 (Ref. C-51-3) is a two-dimensional development of the system, in which the modules are shown as small rectangles. Each of the four curved doors carries three panels, load and battery panels alternating to form twelve facets around the body of the satellite. Two of the booms (F and H) each carry four load panels made of double-sided modules, while the other two (E and G) each carry four battery panels.

Thus each array comprises fourteen panels and these are connected in parallel through protective silicon diodes. Altogether, there are 7392 cells on the satellite.

<u>Preflight Test Details</u>

Mechanical:
Performance:
V_{oc}:
I_{sc}:
Vacuum-thermal:
Illumination:

<u>Performance Assessment</u>

A detailed performance assessment of the system was made by a specially developed computer technique which took into account predicted cell temperatures in various attitudes and orbital conditions, the radiation flux expected during the course of the year and the effect of shadows cast on the arrays by the body, booms and aerials. Earth albedo was not taken into account (except when estimating maximum voltages for safety assessments), any extra power from this source being treated as a bonus. The assessment was refined during the course of development, as more accurate data became available and modifications were introduced leading to the final layout. The final assessment showed that the system was capable of meeting all load requirements after one year in orbit, whatever the solar orientation. An initial capability of about 15W was necessary to achieve this.

As examples of the results of this study, curves showing the predicted end-of-life performance of the load and battery arrays in the design attitude are presented in Figs. 3 and 4 (Ref. C-51-3 respectively. Two voltage-current curves are shown in each case, representing the hottest and coldest conditions likely to occur and the load and critical battery requirements are also indicated. The critical battery requirement occurs at the changeover from the constant current to the constant voltage charging mode. As already mentioned, the charging current is automatically reduced at a battery temperature of 40°C. Hence, the locus contains two points at this temperature.

Both load and battery requirements are seen to lie wholly within the output curves.

<u>Module Assembly and Testing</u>

Fig. 7 (Ref. C-51-3) shows the construction of the 48 cell body module. It weighs just under 40 gm. (1.4 oz) and will deliver just over 1W into a matched load in normal incidence sunlight above the atmosphere.

Each row of six cells, called a "sub-module", is connected in parallel by soldering the back contacts to 0.006 in. printed circuit board and the front contact to a narrow copper strip. The sub-modules are series connected in sets of eight to form 48 cell patches which are then cemented to 1/4 in. honeycomb panels and connected to three Teflon insulated terminals at each end. Finally, a 0.006 in. glass cover slip is cemented to each cell to provide a highly emissive surface and give protection against micrometeorites and low energy radiation.

The boom modules are similarly constructed, except that the honeycomb is an inch thick and cells are mounted on both faces.

The assembly process was designed to facilitate rapid production and maintain a consistently high standard of quality and reliability. Special jigs were used for every assembly stage and only the series connections were hand soldered, the other soldered joints being made in heated jigs under a closely controlled time/temperature cycle.

The modules were tested in accordance with the relevant specification. At the sub-module and uncovered module stages and again after covering, the assemblies were carefully examined at X20 magnification and performance tested in filtered 3000°K Tungsten light. The performance test on the completed modules was followed by twenty thermal cycles in vacuum between +80°C and -50°C, a random noise vibration test, repeat performance test and final inspection.

Before any modules were accepted for the flight satellites, samples from production were required to pass type approval tests, which included high temperature vacuum, humidity, cold storage, acceleration, vibration and extended thermal cycling between +80°C and -70°C. Subsequently, body and boom modules survived over 1000 cycles between these limits and 240 cycles between +80°C and -100°C without measurable loss of performance.

Production acceptance testing consisted of an adhesive tape pull-off test on every contact, a dimensional check, visual inspection at X20 magnification and a performance test under an R.A.E. filtered Xenon sun simulator.

During manufacture, a 1% sample of each week's production was subjected to quality assurance tests by the Inspection Authority (E.I.D.). These comprised dimensional check, visual examination, spectral response, performance measurement and a destructive soldered contact pull-off test.

To qualify for type approval, samples from the production line were required to pass electron bombardment and thermal cycling test (250 cycles -80°C to +80°C in vacuum) in addition to the quality assurance tests.

Fig. 6 (Ref. C-51-3) shows how the currents at various voltages degrade under 4 MEV electron bombardment. The current at 400 mV, which is near the working voltage of the cells, falls by about 7% after 10 electrons/cm^2, the flux estimated to be equivalent to the integrated electron flux encountered by the satellite over one year in orbit.

Systems Assembly and Testing

The final assembly stage was to mount the modules on the doors and booms of the satellite, interconnect them and measure the voltage/current characteristic of each panel in filtered 3000°K Tungsten light. This work was done by the main contractor, British Aircraft Corporation, Stevenage, using an illuminator designed by R.A.E. Fig. 8 shows typical characteristics of the load and battery panels as measured at 100 mW/cm and extrapolated to 140 mW/cm, the solar constant. The conversion efficiencies calculated from these curves, which agreed well with similar measurements made on the constituent modules, were 8.8% and 9.0% for load and battery panels respectively.

Pre-launch Testing

The solar arrays on the flight satellites were fully tested in natural sunlight at the launching site. Each body module was illuminated in turn (the others being covered) and its voltage current characteristic was traced on an XY plotter in a test circuit plugged into the turn-on connection. The intensity of the sunlight was monitored by a calibrated module mounted in the same place as the panel being tested. The measured curve was then extrapolated to sunlight above the atmosphere.

The boom panels were tested in pairs, in a similar fashion.

The techniques and equipment developed by R.A.E. for solar cell performance testing have been fully described elsewhere.

Panels are connected in parallel through protective silicon diodes. Boom and body modules weigh 78.0 and 39.7 gm respectively and in normal incidence sunlight each side will deliver about 1W into a matched load. Allowing for shadowing and degradation, it is estimated that after a year in orbit the solar cells will provide a mean power of not less than 5W with the satellite in any attitude relative to the sun. The solar cells are negative with respect to satellite frame to meet the requirements of the Birmingham experiment.

At all stages of manufacture cells and modules were subjected to close inspection and test. Individual cells and modules were illuminated by a 2 kW Xenon arc lamp and a final test of the solar array was carried out at the range by exposing one panel at a time to the sun and measuring its output characteristics.

The spin axis of the satellite is expected to precess slowly under the influence of magnetic and aerodynamic torques. To minimize the rate of precession, the axial component of magnetic moment was reduced to a low value by demagnetising the satellite in the R.A.E. magnetic facility. A small permanent magnet was fitted to cancel the residual axial component after the satellite had been demagnetised as much as possible.

The aim of the design was to keep the body solar cells and all other items, except the boom solar cells, between -15° and +60°.

Solar simulation tests were carried out on both satellite body and booms in the 2.5 μ vacuum chamber facility at the R.A.E. to compare measured temperatures with those obtained by computation. The shroud lining the chamber is cooled by liquid nitrogen and six carbon arc lamps are used to simulate the radiation input from the sun. Agreement to within 5°C between measured and calculated values was achieved.

Flight Details

Orientation:
Stablilzation: Spin
Unusual Phenomena:

Environmental Factors

Thermal Cycling of Panel (frequency, amplitude)
Radiation and Particle Environment
- Electron
- Proton
- Micrometer

Performance Details

I-V Characteristics as a Function of Time

V_{oc}	Vs.	Time
I_{sc}	"	"
Fill Factor	"	"
Maximum Power	"	"

Spacecraft Structure and Mechanisms

The spacecraft consists of a twelve sided body, mainly covered with solar cell panels, surmounted by a cone to which are attached the telemetry and R.S.R.S. aerials and the Meteorological Office experiment, as shown in Figs. 2 and 3 (Ref. C-51-1). Attached to the base of the body are four hinged booms carrying further solar cell panels, sensors for the Birmingham experiment and aerials for the Sheffield and Jodrell Bank experiments. The spacecraft is spin stabilized and weighs 197 pounds. During the launching phase the booms are tied down to the fourth stage motor of the Scout vehicle which is stabilized by spinning at 160 rev/min. before ignition.

The body structure consists of a central tube with four cruciform vanes of light-weight honeycomb material on which internal equipment is mounted. During the launching phase the base of the centre tube is attached to the Scout rocket separation system by an explosively operated clamp.

The body cells are mounted on aluminium honeycomb in modules of 48 connected in a series-parallel matrix with 6 cells in parallel and 8 in series. The boom modules are similar except that they are double sides with cells on both sides of the boom. The load array consists of 14 panels, each comprising 5 modules in series, mounted on two opposite booms and alternate sides of the body. When the tie-down cord is cut by explosively operated guillotine mechanisms the booms deploy outwards under the influence of centrifugal force. To prevent them from deploying too rapidly and damaging the spacecraft, damper mechanisms are used. These consist of a drum mounted on a fixed spindle with a 25 to 1 step up gear train driving an escapement mechanism. Two of these dampers are mounted on opposite booms as shown in Fig. 2 (Ref. C-51-1) and the deployment of the booms is restrained by a terylene cord which is wound round the damper drums. This cord passes through ferrules in the boom structure and through a spring loaded tensioner mechanism which allows the booms to move together by bevel gears at their pivots. The de-spin sequence is as follows. At 90 sec after third stage separation, i.e. about 60 sec after fourth stage burn-out, yo-yo weights are released and the vehicle spin rate is reduced from 160 to 90 rev/min. The tie-down cord is cut 30 sec later and the booms move away from the motor, unlocking the damper drums, the Birmingham sensors swing outwards on their hinges and the booms deploy at a controlled speed. The rotational speed of the damper drums is governed by the escapement mechanism, and an equal amount of cord is unwound from each drum if both dampers operate correctly. Both dampers, however, contain sufficient cord to allow the booms to erect fully even if one damper fails to operate. The system was also designed to operate satisfactorily in the event of failure of the yo-yo de-spin system.

When the booms have deployed fully, they are locked in position at 65° to the spin axis by detents. Due to the increase in moment of inertia about the spin axis as the booms deploy, the spin rate decreases from 90 to 30 rev/min. Separation from the fourth stage motor occurs after boom deployment is complete at about 4 min after yo-yo release. The Sheffield and Jodrell Bank experiment aerials are released soon after boom deployment commences by the movement apart of retaining fingers attached to adjacent boom tubes.

Alternative designs of damper mechanism were considered during the development stages but any form of damper at the hinge was rejected on account of excessive bending loads being applied to the boom structural members. The de-spin and boom deployment systems were extensively tested at B.A.C. using development and prototype satellites and as a result a number of improvements were made to increase the reliability of the systems. These included a modification of the drum locking mechanism and the replacement of nylon cord by stronger terylene cord.

U.K. 3, now named Ariel 3, is the third satellite to be launched in a co-operative Anglo-American space research program. Unlike the first two in the series, which were designed and built in the U.S.A. to carry British built experiments, the U.K. 3 spacecraft was designed, built and tested in the United Kingdom. It was launched by a Scout rocket from the U.S. Western Test Range at 9 a.m. local time (4 p.m. GMT) on 5th May 1967. A circular orbit at an inclination of 80° and altitude of 550 km had been specified for the mission; the actual orbit achieved had an inclination of 80.2°, an apogee of 606 km and a perigee of 498 km.

Fig. 1 (Ref. C-51-1) shows the organization of the project. The U.S. National Aeronautics and Space Administration (NASA) was responsible for providing the Scout launching vehicle, the satellite separation system, range facilities and the use of the Satellite Tracking and Data Analysis Network (STADAN) of ground stations. In the U.K. the Ministry of Technology Space Department at the Royal Aircraft Establishment acted as the research, development and design authority with responsibility for management of the satellite project on behalf of the Science Research Council. The main contractors were the

British Aircraft Corporation (B.A.C.) who were responsible for manufacturing the spacecraft, ground check-out and handling equipment and the General Electric Company (G.E.C.) who made the satellite electronic equipment apart from that for the five experiments, which are described in the next section, and the solar aspect sensors. Other contractors are shown on Fig. 1. (Ref. C-51-1)

The Science Research Council, through the Space Research Management Unit, was responsible for the overall management of the program, the coordination of experiments, and the reduction and analysis of the data.

REFERENCES

C-51-1 - A. P. MacLaren - Design and Development of The Ariel III Satellite, Royal Aircraft Establishment Technical Report 67250 (AD 832873)

C-51-2 - R. B. Bent - Attitude Determinations of The Ariel III Satellite, (A68-31925)

C-51-3 - F. C. Treble, R. C. Cook, P. G. Garratt, The Ariel III Power System, Royal Aircraft Establishment TR68052 (paper presented at a Joint IERE/IEE Symposium of "The Ariel 3 Satellite" held in London on 13 Oct. 1967.)

C-51-4 - E. C. Semple - Solar Simulation Tests on the U.K. 3 Spacecraft, Royal Aircraft Establishment TR68014, (AD840618)

C-51-5 - F. C. Treble - Development of The Solar Cell System for The U.K. 3 Satellite (A67-22179)

C-51-6 - E. A. R. Anstey, P. E. Townsend, Thermal Vacuum and Solar Simulation Tests on The D2 Model of the U.K. 3 Satellite, RAE TR67259 (AD833459)

C-51-7 - F. C. Treble, R. C. Cook, P. G. Garratt, The Ariel III Power System (A68-25149)

C-51-8 - P. G. Garratt, E. A. Pomroy, Characteristics Affecting the Operation of the U.K. 3 Satellite Battery, RAE TR65172, (AD478910)

C-51-9 - C. V. Savage - The Earth's Radiation Environment and Its Possible Effects on the U.K. 3 Satellite, RAE TR65272

C-51-10 - Anonymous, Attitude Determination of The Ariel III Satellite, (N68-84120)

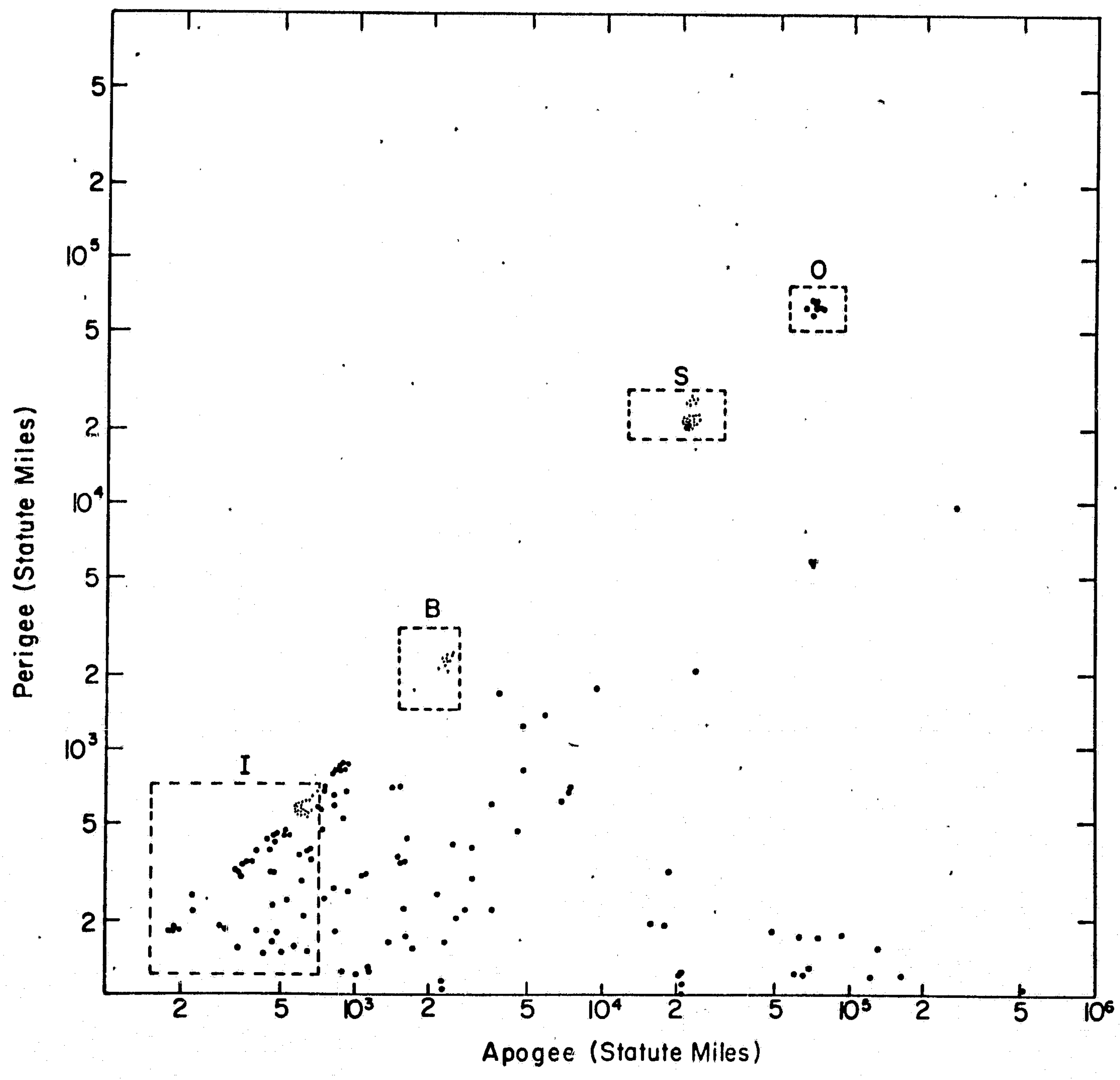

Fig. 1. Perigee vs. Apogee for Class # 1 Flights

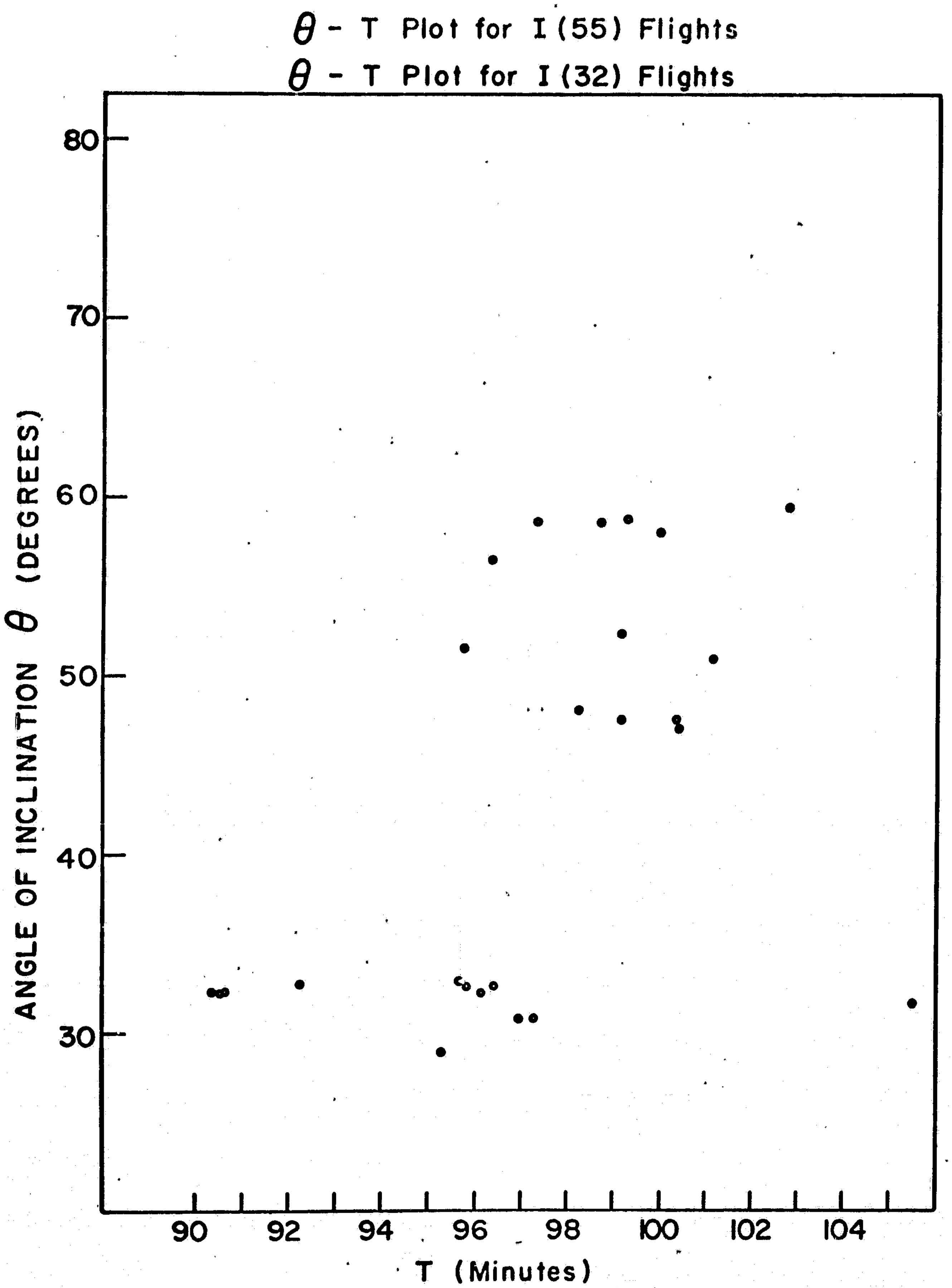

Fig. 2. Angle of Inclination vs. Period for I(55) and I(32) Flights

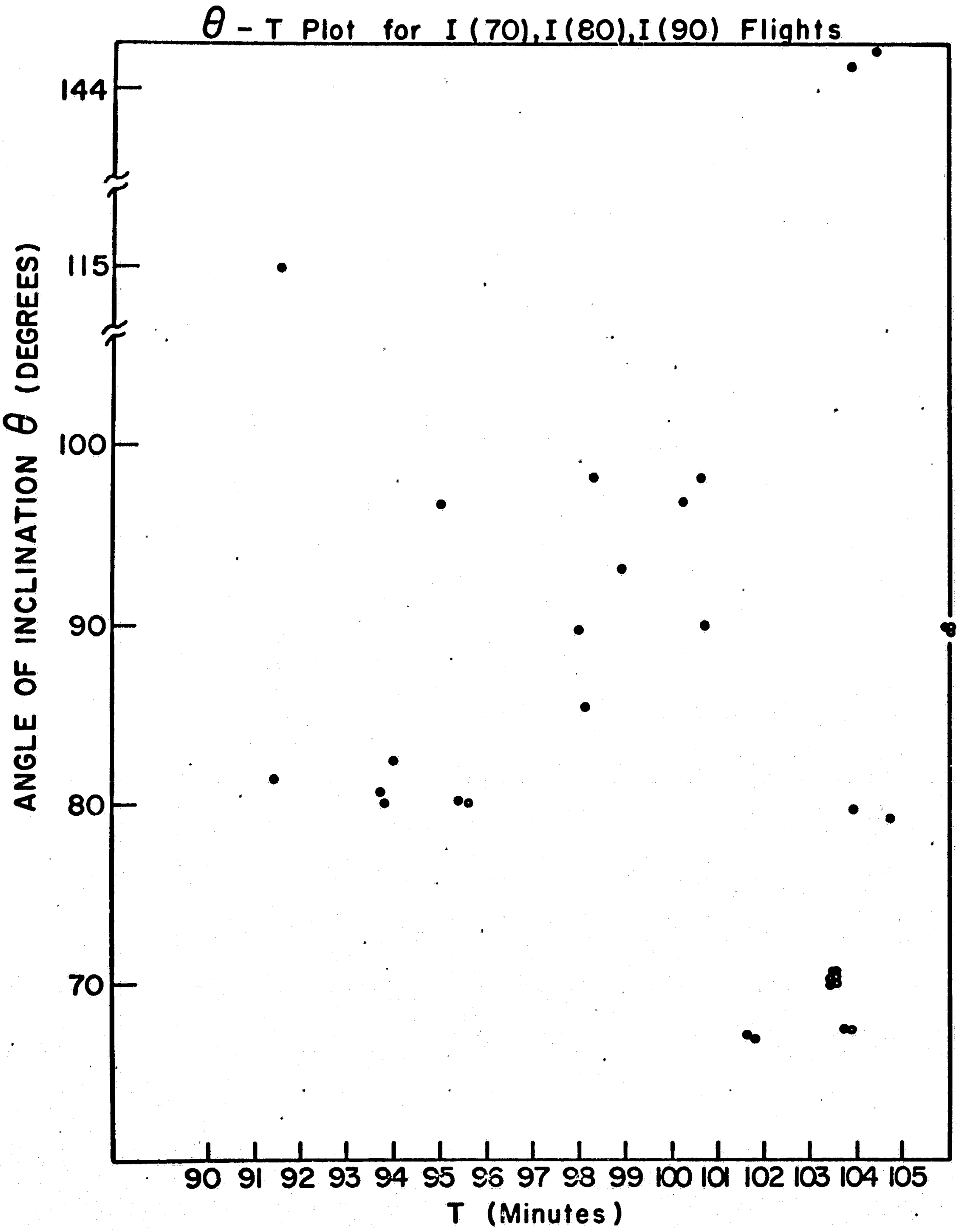

Fig. 3. Angle of Inclination vs. Period for I(70), I(80) and I(90) Flights

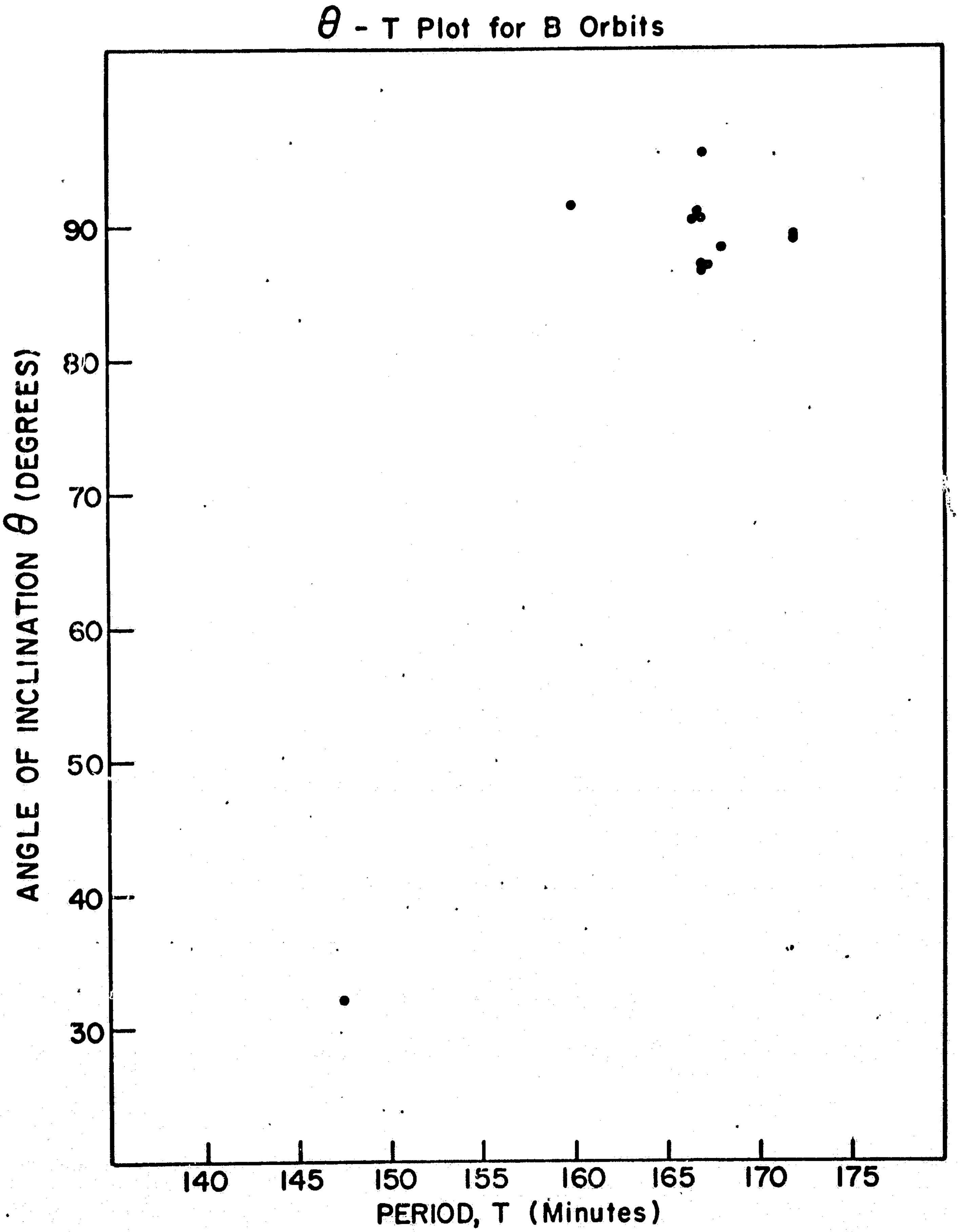

Fig. 4. Angle of Inclination vs. Period for B Flights

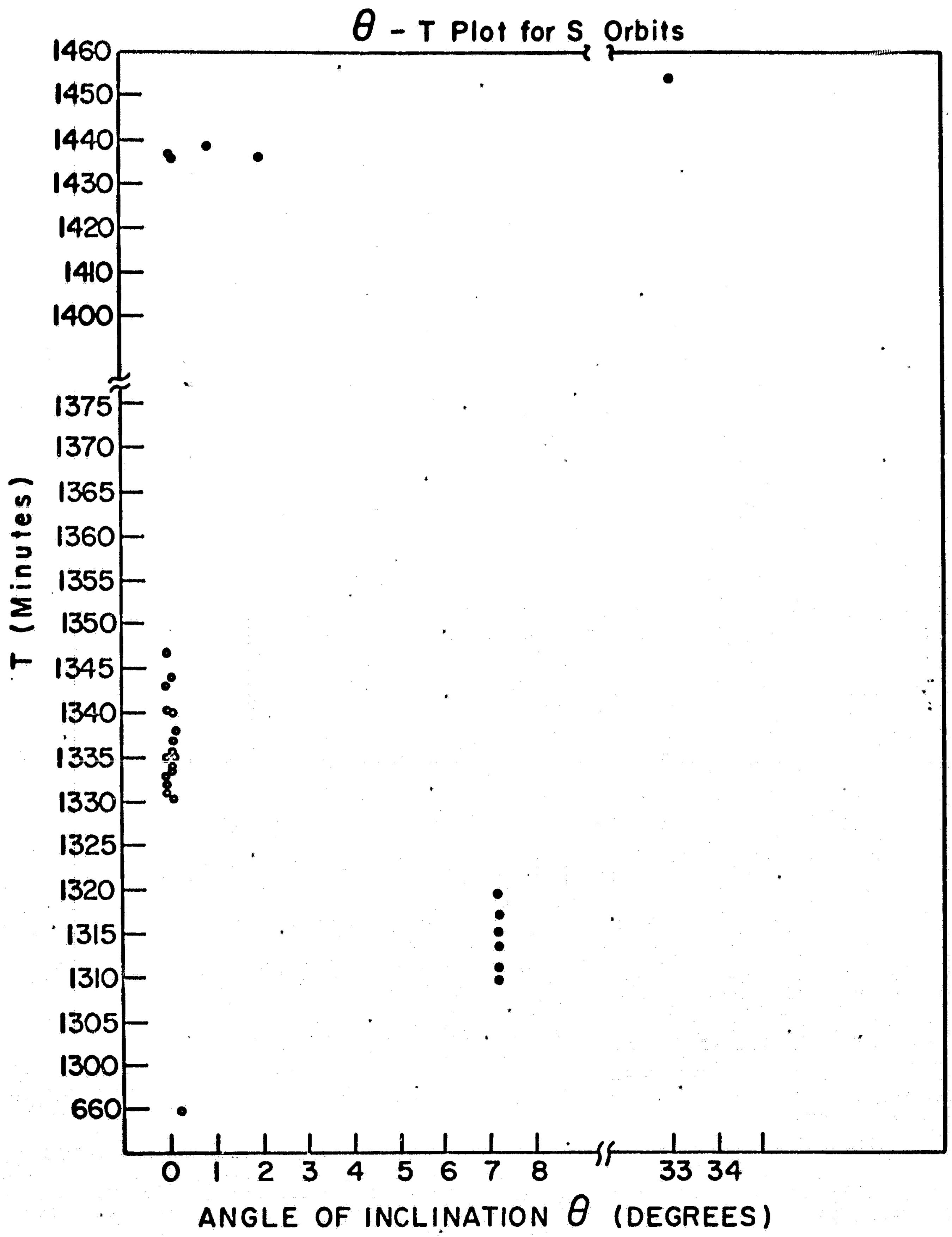

Fig. 5. Angle of Inclination vs. Period for S Flights

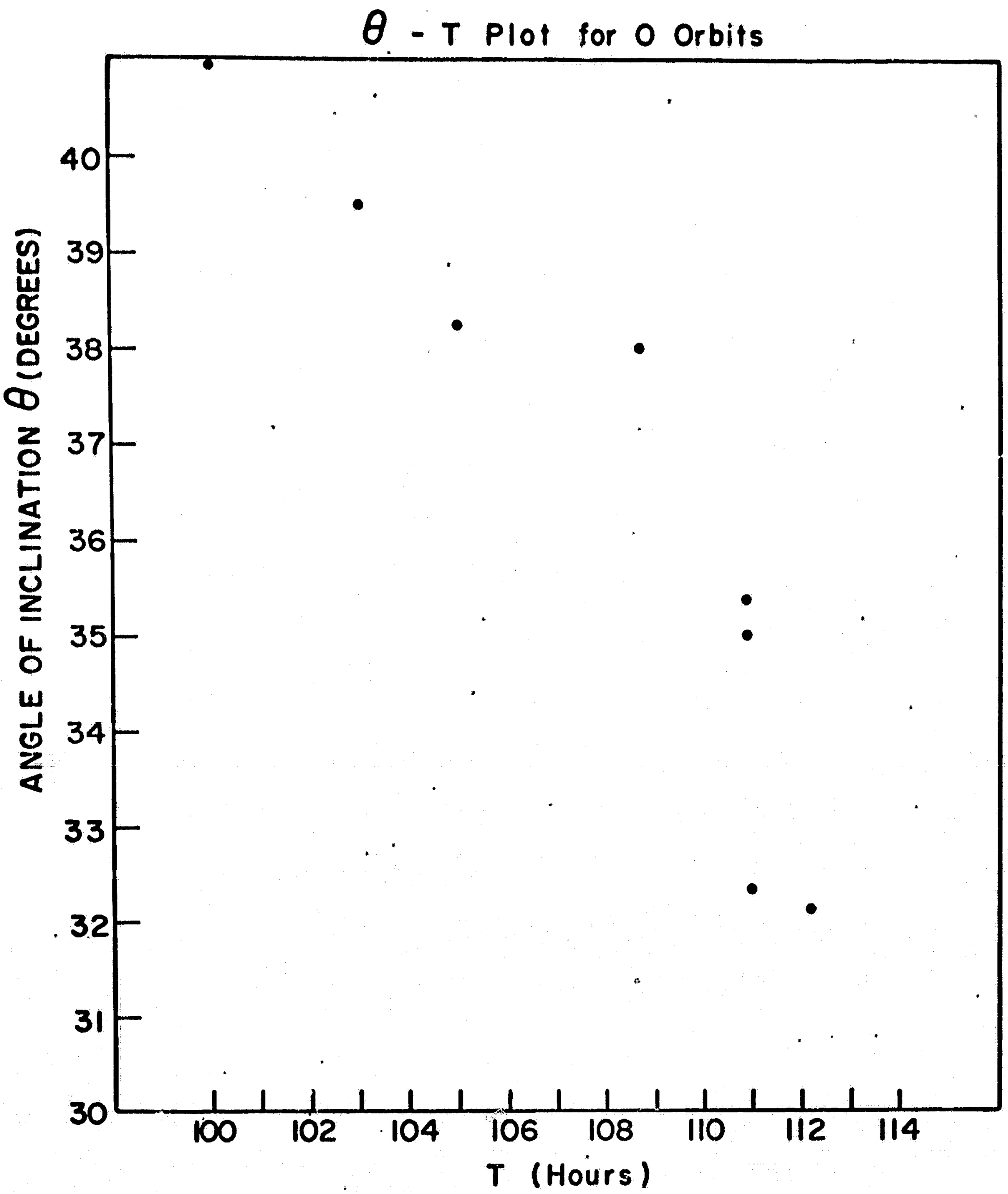

Fig. 6. Angle of Inclination vs. Period for O Flights

TABLE I

LOG OF 1958-68 SPACE PROJECTS - CLASS # 1

NAME	INT'L. DESIG.	PROJ. DIR.	DATE	SITE	PERIGEE*	APOGEE
EXPLORER 1	1958 A1	USA	1/31/58	ETR	224	1584
VANGUARD 1	1958 B2	USN	3/17/58	ETR	405	2462
EXPLORER 4	1958 E1	ARPA	7/26/58	ETR	163	1372
PIONEER 4	1959 N1	NASA	3/3/59	ETR	.9871AU	1.142AU
EXPLORER 7	1959 I1	NASA	10/13/59	ETR	346	676
DISCOVERER 8	1959 Λ1	USAF	11/20/59	WTR	120	1032
TIROS 1	1960 B2	NASA	4/1/60	ETR	430	468
TRANSIT 1B	1960 Γ2	ARPA	4/13/60	ETR	232	463
TRANSIT 2A	1960 H1	USN	6/22/60	ETR	389	665
SOLRAD 1	1960 H2	USN	6/22/60	ETR	382	657
PIONEER 5	1960 A1	NASA	3/11/60	ETR	.8061AU	.995AU
TIROS 2	1960 Π1	NASA	11/23/60	ETR	387	452
DISCOVERER 18	1960 Σ1	USAF	12/7/60	WTR	143	426
SAMOS 2	1961 A1	USAF	1/31/61	WTR	300	350
DISCOVERER 20	1961 E1	USAF	2/17/61	WTR	177	486
DISCOVERER 21	1961 Z1	USAF	2/18/61	WTR	149	659
DISCOVERER 23	1961 Λ1	USAF	4/8/61	WTR	126	882
EXPLORER 11	1961 N1	NASA	4/27/61	ETR	304	1113
TRANSIT 4A	1961 O1	USN	6/29/61	ETR	534	623
INJUN 1/ SOLRAD 3	1961 O2	USN	6/29/61	ETR	534	634
DISCOVERER 26	1961 Π1	USAF	7/7/61	WTR	146	503
TIROS 3	1961 P1	NASA	7/12/61	ETR	461	506
MIDAS 3	1961 Σ1	USAF	7/12/61	WTR	2130	2130
EXPLORER 12	1961 T1	NASA	8/15/61	ETR	182	48,000
DISCOVERER 30	1961 Ω1	USAF	9/12/61	WTR	154	345
MIDAS 4	1961 AΔ1	USAF	10/21/61	WTR	2058	2324
TRANSIT 4B	1961 AH 1	USN	11/15/61	ETR	582	700
TRAAC	1961 AH 2	USN	11/15/61	ETR	562	720
RANGER 3	1962 A1	NASA	1/26/62	ETR	.9839AU	1.163AU
TIROS 4	1962 B1	NASA	2/8/62	ETR	441	525
OSO 1	1962 Z1	NASA	3/7/62	ETR	344	370
NONE	1962 K1	USAF	4/9/62	WTR	1731	2116
ARIEL 1	1962 O1	NASA/UK	4/26/62	ETR	242	754

*Indicates miles except where noted.

TABLE I (Cont'd.)

Log of 1958-68 Space Projects - Class # 1

Name	Int'l. Desig.	Proj. Dir.	Date	Site	Perigee	Apogee
NONE	1962 Σ1	USAF	5/15/62	WTR	180	401
TIROS 5	1962 AA1	NASA	6/19/62	ETR	367	604
TELSTAR 1	1962 AE 1	AT&T	7/10/62	ETR	593	3505
MARINER 2	1962 AP 1	NASA	8/26/62	ETR	.7046AU	1.229AU
TIROS 6	1962 AΨ1	NASA	9/18/62	ETR	423	444
EXPLORER 14	1962 BΓ1	NASA	10/2/62	ETR	174	61,190
RANGER 5	1962 BH1	NASA	10/18/62	ETR	.9490AU	1.052AU
EXPLORER 15	1962 BΛ1	NASA	10/27/62	ETR	194	10,760
ANNA 1B	1962 BM1	USN	10/31/62	ETR	670	728
INJUN 3	1962 BT2	USAF/USN	12/12/62	WTR	153	1729
RELAY 1	1962 BT1	NASA	12/13/62	ETR	819	4612
EXPLORER 16	1962 BX1	NASA	12/16/62	WI	466	733
EXPLORER 17	1963 9A	NASA	4/2/63	ETR	158	568
TELSTAR 2	1963 13A	AT&T	5/7/63	ETR	604	6713
NONE	1963 14A	USAF	5/9/63	WTR	2249	2290
ERS 5	1963 14B	USAF	5/9/63	WTR	2241	2297
ERS 6	1963 14C	USAF	5/9/63	WTR	2238	2282
NONE	1963 22A	USN	6/15/63	WTR	463	528
TIROS 7	1963 24A	NASA	6/19/63	ETR	385	401
HITCH-HIKER 1	1963 25B	USAF	6/26/63	WTR	201	2571
GEOPHYSICAL RESEARCH SATELLITE	1963 26A	USAF	6/28/63	WI	267	808
ERS 9	1963 30B	USAF	7/18/63	WTR	2276	2319
SYNCOM 2	1963 31A	NASA	7/26/63	ETR	22,062	22,750
NONE	1963 38C	USAF/USN	9/28/63	WTR	667	705
VELA 1	1963 39A	USAF	10/16/63	ETR	63,441	70,631
VELA 2	1963 39C	USAF	10/16/63	ETR	62,806	72,974
EXPLORER 18	1963 46A	NASA	11/26/63	ETR	119	122,522
ATLAS-CENTAUR 2	1963 47A	NASA	11/27/63	ETR	303	1093
EXPLORER 19	1963 53A	NASA	12/19/63	WTR	366	1487
TIROS 8	1963 54A	NASA	12/21/63	ETR	430	474
GGSE 1	1964 1B	USN/USA	1/11/64	WTR	560	585
SECOR 1	1964 1C	USN/USA	1/11/64	WTR	563	582
SOLRAD 7A	1964 1D	USN/USA	1/11/64	WTR	563	582
RELAY 2	1964 3A	NASA	1/21/64	ETR	1298	4606

TABLE I (Cont'd.)

Log of 1958-68 Space Projects - Class # 1

Name	Int'l. Desig.	Proj. Dir.	Date	Site	Perigee	Apogee
ECHO 2	1964 4A	NASA	1/25/64	WTR	642	816
SATURN SA-5	1964 5A	NASA	1/19/64	ETR	164	471
ARIEL 2	1964 15A	NASA/UK	3/27/64	WI	180	843
VELA 3	1964 40A	USAF	7/17/64	ETR	63,369	65,024
VELA 4	1964 40B	USAF	7/17/64	ETR	58,766	69,482
ERS 13	1964 40C	USAF	7/17/64	ETR	120	64,886
NONE	1964 45B	USAF	8/14/64	WTR	163	2332
SYNCOM 3	1964 47A	NASA	8/19/64	ETR	22,164	22,312
NONE	1964 48A	USAF	8/21/64	WTR	217	226
EXPLORER 20	1964 51A	NASA	8/25/64	WTR	541	634
OGO 1	1964 54A	NASA	9/4/64	ETR	175	92,827
EXPLORER 21	1964 60A	NASA	10/3/64	ETR	122	59,253
EXPLORER 22	1964 64A	NASA	10/9/64	WTR	549	669
MARINER 3	1964 73A	NASA	11/5/64	ETR	.6150AU	.8155AU
EXPLORER 23	1964 74A	NASA	11/6/64	WI	288	609
EXPLORER 24	1964 76A	NASA	11/21/64	WTR	344	1551
EXPLORER 25	1964 76B	NASA	11/21/64	WTR	345	1547
MARINER 4	1964 77A	NASA	11/28/64	ETR	1.1089AU	1.5730AU
NONE	1964 83C	USAF/USN	12/12/64	WTR	639	672
EXPLORER 26	1964 86A	NASA	12/21/64	ETR	190	16,280
TIROS 9	1965 4A	NASA	1/22/65	ETR	435	1602
OSO 2	1965 7A	NASA	2/3/65	ETR	343	393
LES 1	1965 8C	USAF	2/11/65	ETR	1726	1744
PEGASUS 1	1965 9A	NASA	2/16/65	ETR	308	462
GGSE 2	1965 16B	USAF/USN/ USA	3/9/65	WTR	562	583
GGSE 3	1965 16C	"	3/9/65	WTR	562	583
SOLRAD 7B	1965 16D	"	3/9/65	WTR	562	583
SECOR 3	1965 16E	"	3/9/65	WTR	562	583
OSCAR 3	1965 16F	USAF/USN/ USA	3/9/65	WTR	565	585
SURCAL	1965 16G	"	3/9/65	WTR	564	585
SURCAL	1965 16H	"	3/9/65	WTR	563	586
SECOR 2	1965 17B	USN/USA	3/11/65	WTR	206	624
SNAPSHOT	1965 27A	USAF/USA	4/3/65	WTR	805	826
SECOR 4	1965 27B	USAF/USA	4/3/65	WTR	797	816

TABLE I (Cont'd.)

Log of 1958-68 Space Projects - Class # 1

Name	Int'l. Desig.	Proj. Dir.	Date	Site	Perigee	Apogee
EARLY BIRD	1965 28A	CSC	4/6/65	ETR	21,748	22,733
EXPLORER 27	1965 32A	NASA	4/29/65	WI	584	819
LES 2	1965 34B	USAF	5/6/65	ETR	1757	9384
PEGASUS 2	1965 39A	NASA	5/25/65	ETR	314	466
EXPLORER 28	1965 42A	NASA	5/29/65	ETR	121	163,831
VELA 5	1965 58A	USAF	7/20/65	ETR	66,476	72,234
VELA 6	1965 58B	USAF	7/20/65	ETR	63,217	75,561
ERS 17	1965 58C	USAF	7/20/65	ETR	129	69,723
PEGASUS 3	1965 60A	NASA	7/30/65	ETR	323	336
SECOR 5	1965 63A	USA	8/10/65	WI	702	1503
ATLAS-CENTAUR 6	1965 64A	NASA	8/11/65	ETR	105	509,829
SURCAL	1965 65B	USN	8/13/65	WTR	680	738
SURCAL	1965 65C	USN	8/13/65	WTR	680	738
SURCAL	1965 65E	USN	8/13/65	WTR	680	738
NONE	1965 65F	USN	8/13/65	WTR	680	738
SURCAL	1965 65H	USN	8/13/65	WTR	680	738
SURCAL	1965 65L	USN	8/13/65	WTR	680	738
OV1 2	1965 78A	USAF	10/5/65	WTR	256	2146
OGO 2	1965 81A	NASA	10/14/65	WTR	260	941
OV2 1/LCS2	1965 82A	USAF	10/15/65	ETR	439	492
EXPLORER 29	1965 89A	NASA	11/6/65	ETR	693	1414
EXPLORER 30	1965 93A	USN/NASA	11/18/65	WI	440	548
EXPLORER 31	1965 98B	NASA	11/28/65	WTR	314	1850
PIONEER 6	1965 105A	NASA	12/16/65	ETR	0.814AU	0.985AU
OV2 3	1965 108A	USAF	12/21/65	ETR	110	20,903
LES 4	1965 108B	USAF	12/21/65	ETR	124	20,890
OSCAR 4	1965 108C	USAF	12/21/65	ETR	101	20,847
LES 3	1965 108D	USAF	12/21/65	ETR	121	20,477
ESSA 1	1966 8A	ESSA	2/3/66	ETR	432	521
ESSA 2	1966 16A	ESSA	2/28/66	ETR	843	885
OV1 4	1966 25A	USAF	3/30/66	WTR	550	630
OV1 5	1966 25B	USAF	3/30/66	WTR	613	659
OV3 1	1966 34A	USAF	4/22/66	WTR	220	3568
NIMBUS 2	1966 40A	NASA	5/15/66	WTR	684	734
EXPLORER 32	1966 44A	NASA	5/25/66	ETR	173	1629
OGO 3	1966 49A	NASA	6/6/66	ETR	170	75,769

Table I (Cont'd.)

Log of 1958-68 Space Projects - Class # 1

Name	Int'l. Desig.	Proj. Dir.	Date	Site	Perigee	Apogee
SECOR 6	1966 51B	USAF/USA	6/9/66	WTR	104	2266
ERS 16	1966 51C	USAF/USA	6/9/66	WTR	112	2251
OV3 4	1966 52A	USAF	6/10/66	WI	399	2939
GGTS 1	1966 53A	USAF	6/16/66	ETR	20,913	21,051
IDCSP 1	1966 53B	USAF	6/16/66	ETR	20,923	21,053
IDCSP 2	1966 53C	USAF	6/16/66	ETR	20,927	21,066
IDCSP 3	1966 53D	USAF	6/16/66	ETR	20,936	21,088
IDCSP 4	1966 53E	USAF	6/16/66	ETR	20,935	21,194
IDCSP 5	1966 53F	USAF	6/16/66	ETR	20,949	21,258
IDCSP 6	1966 53G	USAF	6/16/66	ETR	20,936	21,139
IDCSP 7	1966 53H	USAF	6/16/66	ETR	20,948	21,350
PAGEOS	1966 56A	NASA	6/23/66	WTR	2607	2662
EXPLORER 33	1966 58A	NASA	7/1/66	ETR	9880	270,560
OV1 8	1966 63A	USAF	7/13/66	WTR	612	635
OV3 3	1966 70A	USAF	8/4/66	WTR	220	2780
PIONEER 7	1966 75A	NASA	8/17/66	ETR	1.010AU	1.125AU
SECOR 7	1966 77B	USAF/USA	8/19/66	WTR	2287	2299
ERS 15	1966 77C	USAF/USA	8/19/66	WTR	2280	2300
ESSA 3	1966 87A	ESSA	10/2/66	WTR	860	923
SECOR 8	1966 89B	USAF	10/5/66	WTR	2287	2304
INTELSAT 2A	1966 96A	CSC	10/26/66	ETR	2088	23,014
OV4 3	1966 99A	USAF	11/3/66	ETR	187	188
OV4 1R	1966 99B	USAF	11/3/66	ETR	181	181
OV4 1T	1966 99D	USAF	11/3/66	ETR	181	190
LUNAR ORBITER 2	1966 100A	NASA	11/6/66	ETR	129	1147
ATS 1	1966 110A	NASA	12/6/66	ETR	22,277	22,920
OV1 9	1966 111A	USAF	12/11/66	WTR	297	3004
OV1 10	1966 111B	USAF	12/11/66	WTR	403	479
PACIFIC 1	1967 1A	CSC	1/11/66	ETR	22,244	22,257
IDCSP 8	1967 3A	USAF	1/18/67	ETR	20,835	21,038
IDCSP 9	1967 3B	USAF	1/18/67	ETR	20,854	21,031
IDCSP 10	1967 3C	USAF	1/18/67	ETR	20,867	21,036
IDCSP 11	1967 3D	USAF	1/18/67	ETR	20,875	21,063
IDCSP 12	1967 3E	USAF	1/18/67	ETR	20,901	21,089
IDCSP 13	1967 3F	USAF	1/18/67	ETR	20,923	21,128
IDCSP 14	1967 3G	USAF	1/18/67	ETR	20,932	21,192
IDCSP 15	1967 3H	USAF	1/18/67	ETR	20,935	21,275

TABLE I (Cont'd.)

Log of 1958-68 Space Projects - Class # 1

Name	Int'l. Desig.	Proj. Dir.	Date	Site	Perigee	Apogee
ESSA 4	1967 6A	ESSA	1/26/67	WTR	822	894
LUNAR ORBITER 3	1967 8A	NASA	2/4/67	ETR	124	1150
OSO 3	1967 20A	NASA	3/8/67	ETR	336	354
ATLANTIC 2	1967 26A	CSC	3/22/67	ETR	22,246	22,254
ATS 2	1967 31A	NASA	4/5/67	ETR	115	6947
ESSA 5	1967 36A	ESSA	4/20/67	WTR	840	883
VELA 7	1967 40A	USAF	4/28/67	ETR	67,804	69,991
VELA 8	1967 40B	USAF	4/28/67	ETR	67,238	71,674
ERS 18	1967 40C	USAF	4/28/67	ETR	5357	69,316
OV5 3	1967 40D	USAF	4/28/67	ETR	5357	69,316
OV5 1	1967 40E	USAF	4/28/67	ETR	5357	69,316
LUNAR ORBITER 4	1967 41A	NASA	5/4/67	ETR	1681	3750
ARIEL 3*	1967 42A	UK	5/5/67	WTR	306	373
EXPLORER 34	1967 51A	NASA	5/24/67	WTR	154	131,187
SURCAL	1967 53B	USAF/USN	5/31/67	WTR	570	582
GGSE 4	1967 53C	USAF/USN	5/31/67	WTR	569	577
GGSE 5	1967 53D	USAF/USN	5/31/67	WTR	570	575
SURCAL	1967 53F	USAF/USN	5/31/67	WTR	569	575
SURCAL	1967 53J	USAF/USN	5/31/67	WTR	569	577
MARINER 5	1967 60A	NASA	6/14/67	ETR		
SECOR 9	1967 65A	USA/USN	6/29/67	WTR	2362	2451
AURORA 1	1967 65B	USA/USN	6/29/67	WTR	2370	2458
IDCSP 16	1967 66B	USAF	7/1/67	ETR	20,509	20,846
IDCSP 17	1967 66C	USAF	7/1/67	ETR	20,542	20,857
IDCSP 18	1967 66D	USAF	7/1/67	ETR	20,582	20,866
DATS 1	1967 66E	USAF	7/1/67	ETR	20,620	20,875
DODGE	1967 66F	USAF	7/1/67	ETR	20,661	20,884
LES 5	1967 66G	USAF	7/1/67	ETR	20,692	20,894
EXPLORER 35	1967 70A	NASA	7/19/67	ETR	500	4600
OGO 4	1967 73A	NASA	7/28/67	WTR	256	564
LUNAR ORBITER 5	1967 75A	NASA	8/1/67	ETR	122	3738
PACIFIC 2	1967 94A	CSC	9/27/67	ETR	22,220	22,245
OSO 4	1967 100A	NASA	10/18/67	ETR	334	354

*Exception made here because ARIEL 3 is a well documented flight.

TABLE I (Cont'd.)

Log of 1958-68 Space Projects - Class # 1

Name	Int'l. Desig.	Proj. Dir.	Date	Site	Perigee	Apogee
ATS 3	1967 111A	NASA	11/5/67	ETR	22,228	22,254
ESSA 6	1967 114A	ESSA	11/10/67	WTR	876	925
OV3 6	1967 120A	USAF	12/4/67	WTR	252	271
PIONEER 8	1967 123A	NASA	12/13/67	ETR	1.0AU	1.1AU
TTS 1	1967 123B	NASA	12/13/67	ETR	182	300
EXPLORER 36	1968 02A	NASA	1/11/68	WTR	635	926

TABLE II

"INSIDE ORBITS" (I) - 760 MILES

	FLIGHT NAME	INT'L. DESIG.	PROJ. DIR.	PERIGEE (MILES)	APOGEE (MILES)	PERIOD (T) (MINUTES)	INCLINATION (θ) (DEGREES)
1.	PEGASUS 3	1965 60A	NASA	323	336	95.3	28.9
2.	PEGASUS 1	1965 9A	NASA	308	462	97.0	31.7
3.	PEGASUS 2	1965 39A	NASA	314	466	97.3	31.7
4.	TRANSIT 4B	1961 AH1	USN	582	700	105.6	32.4
5.	TRAAC	1961 AH2	USN	562	720	105.6	32.4
6.	OSO 1	1962 Z1	NASA	344	370	96.2	32.8
7.	OV4 3	1966 99A	USAF	188	187	90.6	32.8
8.	OV4 1R	1966 99B	USAF	181	181	90.4	32.8
9.	OV4 1T	1966 99D	USAF	181	190	90.7	32.8
10.	OSO 2	1965 7A	NASA	343	393	96.5	32.9
11.	OSO 3	1967 20A	NASA	336	354	95.9	32.9
12.	TTS 1	1967 123B	NASA	182	300	92.3	32.9
13.	OSO 4	1967 100A	NASA	334	354	95.7	32.9
14.	TIROS 3	1961 P1	NASA	461	506	100.4	47.8
15.	TIROS 4	1962 B1	NASA	441	525	100.4	48.3
16.	TIROS 1	1960 B2	NASA	430	468	99.2	48.3
17.	TIROS 2	1960 II-1	NASA	387	452	98.3	48.5
18.	ANNA 1B	1962 BM1	USN	670	728	107.8	50.1
19.	EXPLORER 7	1959 I-1	NASA	346	676	101.2	50.3
20.	TRANSIT 1B	1960 Γ2	ARPA	232	463	95.8	51.3
21.	EXPLORER 23	1964 74A	NASA	288	610	99.2	51.9
22.	EXPLORER 16	1962 BX1	NASA	466	733	104.3	52.0
23.	ARIEL 1	1962 O1	NASA/UK	242	754	100.9	53.9
24.	EXPLORER 17	1963 9A	NASA	158	568	96.4	57.6
25.	TIROS 5	1962 AA1	NASA	367	604	100.5	58.1
26.	TIROS 6	1962 AΨ1	NASA	423	444	98.7	58.2
27.	TIROS 7	1963 24A	NASA	385	401	97.4	58.2
28.	TIROS 8	1963 54A	NASA	430	473	99.3	58.5
29.	EXPLORER 30	1965 93A	USN/NASA	440	548	102.8	59.7
30.	TRANSIT 2A	1960 H1	USN	389	665	101.7	66.7
31.	SOLRAD 1	1960 H2	USN	382	657	101.6	66.8
32.	TRANSIT 4A	1961 O1	USN	534	623	103.7	67.0
33.	INJUN 1/ SOLRAD 3	1961 O2	USN	534	634	103.8	67.0
34.	SOLRAD 7A	1964 1D	USN/USA	563	578	103.5	69.9

Table II (Con't.)

"Inside Orbits" (I) - 760 Miles

	Flight Name	Int'l. Desig.	Proj. Dir.	Perigee (Miles)	Apogee (Miles)	Period (T) (Minutes)	Inclination (θ) (Degrees)
35.	SECOR 1	1964 1C	USN/USA	563	578	103.5	69.9
36.	GGSE 1	1964 1B	USN/USA	560	585	103.5	70.0
37.	SURCAL	1967 53B	USAF/USN	570	582	103.5	70.0
38.	SURCAL	1967 53F	USAF/USN	569	575	103.4	69.9
39.	GGSE 4	1967 53C	USAF/USN	569	577	103.4	70.0
40.	GGSE 5	1967 53D	USAF/USN	570	575	103.4	70.0
41.	SURCAL	1967 53J	USAF/USN	569	577	103.4	70.0
42.	GGSE 2	1965 16B	USN/USA/ USAF	562	583	103.5	70.1
43.	GGSE 3	1965 16C	USN/USA/ USAF	562	583	103.5	70.1
44.	SOLRAD 7B	1965 16D	USN/USA/ USAF	562	583	103.4	70.1
45.	SECOR 3	1965 16E	USN/USA/ USAF	562	583	103.5	70.1
46.	OSCAR 3	1965 16F	USN/USA/ USAF	565	585	103.5	70.1
47.	SURCAL	1965 16G	USN/USA/ USAF	564	585	103.5	70.1
48.	SURCAL	1965 16H	USN/USA/ USAF	563	586	103.5	70.1
49.	EXPLORER 22	1965 64A	NASA	549	669	104.7	79.7
50.	EXPLORER 20	1964 51A	NASA	540	634	103.9	79.9
51.	ARIEL 3	1967 42A	UK	306	373	95.6	80.2
52.	DISCOVERER 20	1961 E1	USAF	177	486	95.4	80.4
53.	DISCOVERER 21	1961 Z1	USAF	149	659	93.8	80.4
54.	DISCOVERER 18	1960 Σ1	USAF	143	426	93.8	80.8
55.	DISCOVERER 36	1961 AK1	USAF	148	280	91.5	81.2
56.	NONE	1962 Σ1	USAF	180	401	94.0	82.5
57.	OGO 4	1967 73A	NASA	256	564	98.1	86.0
58.	NONE	1963 38C	USN	667	705	107.4	89.9

Table II (Con't.)

"Inside Orbits" (I) - 760 Miles

	Flight Name	Int'l. Desig.	Proj. Dir.	Perigee (Miles)	Apogee (Miles)	Period (T) (Minutes)	Inclination (θ) (Degrees)
59.	SECOR 2	1965 17B	USA	206	624	98.0	89.9
60.	NONE	1964 83C	USAF/USN	639	672	106.3	90.0
61.	NONE	1964 83D	USAF/USN	639	672	106.3	90.0
62.	SURCAL	1965 65B	USN	680	738	108.1	90.0
63.	SURCAL	1965 65C	USN	680	738	108.1	90.0
64.	SURCAL	1965 65E	USN	680	738	108.1	90.0
65.	SURCAL	1965 65F	USN	680	738	108.1	90.0
66.	SURCAL	1965 65H	USN	680	738	108.1	90.0
67.	SURCAL	1965 65L	USN	680	738	108.1	90.0
68.	NONE	1963 22A	USAF/USN	463	528	100.7	90.0
69.	OV1-10	1966 111B	USAF	403	479	98.9	93.5
70.	SAMOS 2	1961 A1	USAF	300	350	95.0	97.0
71.	ESSA 1	1966 8A	ESSA	432	521	100.2	97.9
72.	NIMBUS 2	1966 40A	NASA	684	734	108.1	100.3
73.	OV1-12	1967 72D	USAF	342	344	95.6	101.6
74.	OV1-86	1967 72A	USAF	303	390	95.5	101.7
75.	NONE	1964 48A	USAF	217	226	91.6	115.0
76.	OV1 4	1966 25A	USAF	550	630	103.9	144.5
77.	OV1 5	1966 25B	USAF	613	659	104.4	144.7

TABLE III

"FIRST BELT" ORBITS (B) 1500 - 2500 MILES

	DESIGNATION		P MILES	A MILES	T MIN.	θ°
1.	1961 Σ1 Midas 3	USAF	2130	2130	160	91.1
2.	1961 AΔ1 Midas 4	USAF	2058	2324	166	95.9
3.	1963 14A None	USAF	2249	2290	166.6	87.4
4.	1963 14B ERS 5	USAF	2241	2297	166.5	87.4
5.	1963 14C ERS 6	USAF	2238	2282	166.5	87.3
6.	1963 30B ERS 9	USAF	2276	2319	167.9	88.4
7.	1965 8C LES 1	USAF	1726	1744	147.7	32.2
8.	1966 77B Secor 7	USAF/USA	2287	2299	167.6	90.1
9.	1966 77C ERS 15	USAF/USA	2280	2300	167.5	90.1
10.	1966 89B Secor 8	USAF	2287	2304	167.6	90.2
11.	1967 65A Secor 9	USA/USN	2362	2451	172.1	89.8
12.	1967 65B Aurora 1	USA/USN	2370	2458	172.1	89.8

TABLE IV

GEOSTATIONARY ORBITS (S)

	DESIGNATION		P MILES	A MILES	T MIN.	θ°
1.	1963 31A Syncom 2	NASA	22,062	22,750	1454	33.1
2.	1964 47A Syncom 3	NASA	22,164	22,312	1436.2	0.1
3.	1965 28A Early Bird	CSC	21,748	22,733	1436.4	0.1
4.	1966 53A GGTS 1	USAF	20,913	21,051	1334.2	0.1
5.	1966 53B IDCSP 1	USAF	20,923	21,053	1334.7	0.1
6.	1966 53C IDCSP 2	USAF	20,927	21,066	1335.3	0.1
7.	1966 53D IDCSP 3	USAF	20,936	21,088	1336.6	0.1
8.	1966 53E IDCSP 4	USAF	20,935	21,194	1340.8	0.0
9.	1966 53F IDCSP 5	USAF	20,949	21,258	1344.0	0.1
10.	1966 53G IDCSP 6	USAF	20,936	21,139	1338.6	0.2
11.	1966 53H IDCSP 7	USAF	20,948	21,350	1347.6	0.0
12.	1966 110A ATS 1	NASA	22,277	22,920	660	0.2
13.	1967 3A IDCSP 8	USAF	20,835	21,038	1330	0.1
14.	1967 3B IDCSP 9	USAF	20,854	21,031	1331	0.0
15.	1967 3C IDCSP 10	USAF	20,867	21,036	1332	0.0
16.	1967 3D IDCSP 11	USAF	20,875	21,063	1333	0.0
17.	1967 3E IDCSP 12	USAF	20,901	21,089	1335	0.0
18.	1967 3F IDCSP 13	USAF	20,923	21,128	1337	0.1
19.	1967 3G IDCSP 14	USAF	20,932	21,192	1340	0.1
20.	1967 3H IDCSP 15	USAF	20,935	21,275	1343	0.0
21.	1967 26A Atlantic 2	CSC	22,246	22,254	1436.1	2.0
22.	1967 66B IDCSP 16	USAF	20,509	20,846	1309.8	7.2
23.	1967 66C IDCSP 17	USAF	20,542	20,857	1311.6	7.2
24.	1967 66D IDCSP 18	USAF	20,582	20,866	1313.5	7.2
25.	1967 66E DATS 1	USAF	20,620	20,875	1315	7.2
26.	1967 66F DODGE	USN	20,661	20,884	1317	7.2
27.	1967 66G LES 5	USAF	20,692	20,894	1319	7.2
28.	1967 94A Pacific 2	CSC	22,220	22,245	1439.5	0.9

TABLE V

DEEP ORBITS (O) 60,000 - 70,000 MILES

	DESIGNATION		P MILES	A MILES	T MIN.	θ°
1.	1963 39A Vela 1	USAF	63,441	70,031	105	38.3
2.	1963 39C Vela 2	USAF	62,806	72,974	108.7	38.0
3.	1964 40A Vela 3	USAF	63,369	65,024	100.3	39.5
4.	1964 40B Vela 4	USAF	58,766	69,482	100.1	40.9
5.	1965 58A Vela 5	USAF	66,476	72,234	110.9	35.2
6.	1966 58B Vela 6	USAF	63,217	75,561	110.9	35.0
7.	1967 40A Vela 7	USAF	67,804	69,991	111.0	32.2
8.	1967 40B Vela 8	USAF	67,238	71,674	112.2	32.1

TABLE VI

SPECIFIC FLIGHTS TO BE STUDIED - SELECTION CRITERIA

	FLIGHT NAME	INT'L. DESIG.	PROJ. DIR.	ARRAY VOLTAGE	ARRAY CURRENT	ARRAY TEMP.	NOTES	NO SOLAR ARRAY
1.	PEGASUS 3	1965 60A	NASA	X	X	X	1	
2.	PEGASUS 1	1965 9A	NASA	X	X	X	1	
3.	PEGASUS 2	1965 39A	NASA	X	X	X	1	
4.	TRANSIT 4B	1961 AH1	USN				2	
5.	TRAAC	1961 AH2	USN				2	
6.	OSO 1	1962 Z1	NASA	X	X	X	3	
7.	OV4 3	1966 99A	USAF				4	X
8.	OV4 1R	1966 99B	USAF				5	X
9.	OV4 1T	1966 99D	USAF				5	X
10.	OSO 2	1965 7A	NASA	X	X	X	3	
11.	OSO 3	1967 20A	NASA	X	X	X	3	
12.	TTS 1	1967 123B	NASA	X		X	6	
13.	OSO 4	1967 100A	NASA	X	X	X	3	
14.	TIROS 3	1961 P1	NASA	X		X	7	
15.	TIROS 4	1962 B1	NASA	X		X	7	
16.	TIROS 1	1960 B2	NASA	X		X	7	
17.	TIROS 2	1960 II-1	NASA	X		X	7	
18.	ANNA 1B	1962 BM1	USN				2	
19.	EXPLORER 7	1959 I-1	NASA				8	
20.	TRANSIT 1B	1960 Γ2	ARPA				2	
21.	EXPLORER 23	1964 74A	NASA				2	
22.	EXPLORER 16	1962 BX1	NASA				8	

Table VI (Cont'd.)

Specific Flights to be Studied - Selection Criteria

	Flight Name	Int'l. Desig.	Proj. Dir.	Array Voltage	Array Current	Array Temp.	Notes	No Solar Array
23.	ARIEL 1	1962 O1	NASA/UK				9	
24.	EXPLORER 17	1963 9A	NASA				10	X
25.	TIROS 5	1962 AA1	NASA	X		X	7	
26.	TIROS 6	1962 AΨ1	NASA	X		X	7	
27.	TIROS 7	1963 24A	NASA	X		X	7	
28.	TIROS 8	1963 54A	NASA	X		X	7	
29.	EXPLORER 30	1965 93A	USN/NASA			X	11	
30.	TRANSIT 2A	1960 H1	USN				2	
31.	SOLRAD 1	1960 H2	USN			X	11	
32.	TRANSIT 4A	1961 O1	USN				2	
33.	INJUN 1/ SOLRAD 3	1961 O2	USN			X	11	
34.	SOLRAD 7A	1964 1D	USN/USA			X	11	
35.	SECOR 1	1964 1C	USN/USA			X	12	
36.	GGSE 1	1964 1B	USN/USA			X	11	
37.	SURCAL	1967 53B	USAF/USN			X	11	
38.	SURCAL	1967 53F	USAF/USN			X	11	
39.	GGSE 4	1967 53C	USAF/USN			X	11	
40.	GGSE 5	1967 53D	USAF/USN			X	11	
41.	SURCAL	1967 53J	USAF/USN			X	11	
42.	GGSE 2	1965 16B	USN/USA/ USAF			X	11	

Table VI (Cont'd.)

Specific Flights to be Studied - Selection Criteria

	Flight Name	Int'l. Desig.	Proj. Dir.	Array Voltage	Array Current	Array Temp.	Notes	No Solar Array
43.	GGSE 3	1965 16C	USN/USA/ USAF			X	11	
44.	SOLRAD 7B	1965 16D	USN/USA/ USAF			X	11	
45.	SECOR 3	1965 16E	USN/USA/ USAF			X	12	
46.	OSCAR 3	1965 16F	USN/USA/ USAF			X	13	
47.	SURCAL	1965 16G	USN/USA/ USAF			X	11	
48.	SURCAL	1965 16H	USN/USA/ USAF			X	11	
49.	EXPLORER 22	1965 64A	NASA				2	
50.	EXPLORER 20	1964 51A	NASA				8	
51.	ARIEL 3	1967 42A	UK				14	
52.	DISCOVERER 20	1961 E1	USAF				15	X
53.	DISCOVERER 21	1961 Z1	USAF				15	X
54.	DISCOVERER 18	1960 Σ1	USAF				15	X
55.	DISCOVERER 36	1961 AK1	USAF				15	X
56.	NONE	1962 Σ1	USAF				16	
57.	OGO 4	1967 73A	NASA	X	X	X	17	
58.	NONE	1963 38C	USN				2	

Table VI (Cont'd.)

Specific Flights to be Studied - Selection Criteria

	Flight Name	Int'l. Desig.	Proj. Dir.	Array Voltage	Array Current	Array Temp.	Notes	No Solar Array
59.	SECOR 2	1965 17B	USA			X	12	
60.	NONE	1964 83C	USAF/USN				2	
61.	NONE	1964 83D	USAF/USN				2	
62.	SURCAL	1965 65B	USN			X	11	
63.	SURCAL	1965 65C	USN			X	11	
64.	SURCAL	1965 65E	USN			X	11	
65.	SURCAL	1965 65F	USN			X	11	
66.	SURCAL	1965 65H	USN			X	11	
67.	SURCAL	1965 65L	USN			X	11	
68.	NONE	1963 22A	USAF/USN				2	
69.	OV1-10	1966 111B	USAF	X		X	18	X
70.	SAMOS 2	1961 A1	USAF				15	X
71.	ESSA 1	1966 8A	ESSA	X		X	7	
72.	NIMBUS 2	1966 40A	NASA	X	X	X	19	
73.	OV1-12	1967 72D	USAF	X		X	18	
74.	OV1-86	1967 72A	USAF	X		X	18	
75.	NONE	1964 48A	USAF				16	
76.	OV1-4	1966 25A	USAF	X		X	18	
77.	OV1-5	1966 25B	USAF	X		X	18	

Notes to Table VI.

1. The Pegasus series, flights 1, 2, and 3, do have sufficient data telemetered back to establish a performance analysis. These vehicles were manufactured by Fairchild-Hiller. Information can be obtained from:

   Mr. Richard Julius
   S & J Industries
   6009 Farrington Avenue
   Alexandria, Virginia 22304

   Mr. James Mott
   Fairchild-Hiller Corporation
   Fairchild Drive
   Germantown, Maryland

2. These are APL flights for which the data cannot be located. Information can be obtained from:

   Mr. Wade Radford
   Mr. W. E. Allen
   Applied Physics Laboratory
   The Johns Hopkins University
   8621 Georgia Avenue
   Silver Spring, Maryland 20910

3. The OSO series of satellites do have sufficient data telemetered back to make a performance analysis of the solar arrays. Information can be obtained from:

   Mr. Hal Manzenti
   Mr. Bruce Thompson
   Ball Brothers Research Corporation
   Boulder, Colorado 80302

   Mr. John Thole
   Goddard Space Flight Center
   Greenbelt, Maryland

4. OV4 did not have any solar array. Information can be obtained from:

Mr. Robert Demoret
Martin Company
Denver, Colorado

5. OV4 1R and OV4 1T did not have solar arrays. Information can be obtained from:

Mr. J. I. Barker
Avionics Laboratory
Wright-Patterson Air Force Base, Ohio

6. TTS 1 had data telemetered back, but the scatter was too large to observe performance degradation, therefore, this vehicle is not being studied. Information can be obtained from:

Mr. Frank Kelly
Office M2/1145
TRW Systems Group
One Space Park
Redondo Beach, California 90278

7. The Tiros series of vehicles had no current data telemetered back regarding the condition of the solar array. Information can be obtained from:

Mr. Robert Rados
Goddard Space Flight Center
Greenbelt, Maryland

Mr. Abe Schnapf
Astro Electronics Division
Radio Corporation of America
Heightstown, New Jersey

8. Explorer flight 16 monitored battery voltage only. Explorer flights number 7 and 20 are two flights for which the availability of flight data is not yet known. Information can be obtained from:

Mr. Frank Martin
Mr. Herman Lagow (Explorer 7)
Mr. E. D. Nelson (Explorer 20)
Goddard Space Flight Center
Greenbelt, Maryland

Mr. Earl Hastings, Jr. (Explorer 16)
Mr. Walter E. Ellis (Explorer 16)
Langley Research Center
Hampton, Virginia

9. There was no flight data telemetered back regarding the solar array on this vehicle. Information can be obtained from:

Mr. Luther Slifer
GSFC
Greenbelt, Maryland

10. Explorer 17 has no solar array. Information can be obtained from:

Mr. Frank Martin
GSFC
Greenbelt, Maryland

11. These vehicles did not have any current data or array voltage telemetered back. They had the array temperature and battery voltage telemetered back. Information can be obtained from:

Mr. Peter Wilhelm
Mr. Joseph Yuen
NRL
Washington, D. C.

12. Secor 1, 2, and 3 had only the battery voltage and solar array temperature data telemetered back. Information can be obtained from:

Mr. George Sharman
Cubic Corporation
9233 Balboa Avenue
San Diego, California

Mr. E. Cyran
U. S. Army Map Service
6500 Brooks Lane
Washington, D. C. 20315

13. Oscar 3 is a satellite built by the American Radio Relay Link. This vehicle was built by a group of amateur radio operators, and had the battery voltage and temperature, but no solar array current data telemetered back. Information can be obtained from:

Mr. William Dunkerly
American Radio Relay Link
Millington, Connecticut

14. This vehicle has extensive data published on it. But it was built in the United Kingdom, and the degree of difficulty of acquiring data is anticipated to be too great to include it in the study. Information can be obtained through the people listed in Table VIII.

15. Discoverer flights number 18, 20, 21, and 36 and Samos 2 did not have solar arrays. Information can be obtained from:

Mr. L. Chidester
Box 504
Building 154, Dept. 6225
Lockheed Missile and Spacecraft Company
Sunnyvale, California

16. For vehicles None 1962 Sigma 1 and None 1964 48A, no data could be found at SAMSO. The suggestion was made to search Lockheed for the data required. Information at SAMSO was obtained through:

Major General L. I. Wilson, Jr.
SAMSO
LO OAR
Air Force Unit Post Office
Los Angeles, California 90045

17. OGO 4 has sufficient flight data available for a performance analysis of the solar arrays. Information can be obtained from:

Mr. Robert Beltz
Office M2/2170
TRW Systems Group
One Space Park
Redondo Beach, California 90278

18. The OV1 series does not have any direct measurement of solar array current, but the battery current is monitored. By knowing the load current, the solar array current can be calculated. Information can be obtained from:

Major James McSherry
Lt. Col. Robert S. Slizeski
SAMSO
LO OAR
Air Force Unit Post Office
Los Angeles, California 90045

Mr. Bruce Ziligitt
Department 506-10
General Dynamics Corporation
Convair Division
P. O. Box 1128
San Diego, California 92112

19. Nimbus 2 has sufficient data telemetered back regarding the solar array for a performance analysis and extensive documentation is available on the vehicle itself. Information can be obtained from:

Mr. C. McKenzie
Goddard Space Flight Center
Greenbelt, Maryland

Mr. K. F. Martin
Mr. K. L. Hansen
Missile and Space Division
Valley Forge Space Technology Center
General Electric
P. O. Box 8555
Philadelphia, Pennsylvania 19101

TABLE VII.

Citations Obtained From
Computer Literature Searches

Search Control Number	Number of Documents Cited	Number of Documents Ordered	Number of Documents Received*
NASA # 7140(1)	930	219	210
DDC # 000803(1)	94	40	32
NASA # 7400(2)	41	26	26
DDC # 002510(2)	67	19	18

(1) Broad Coverage Searches

(2) Specific Searches

* As of March 7, 1969

TABLE VIII.

Specific Flights with Individual Contact

Flight Name	International Designation	Sponsoring Agency	Individual Contact	Contact Affiliation
Anna 1B	1962 BM1	USN	R. E. Fischell J. H. Martin W. E. Radford W. E. Allen	APL
			J. H. Martin J. S. Teener E. L. Ralph	Heliotek
Ariel 1	1962 01	NASA/UK	L. Slifer	GSFC
Ariel 3	1967 42A	UK	R. B. Bent	S. R. C. Radio & Space Research Station Slough, England
			F. C. Trebel R. C. Cook P. G. Garratt	Royal Aircraft Establishment
Discoverer 18	1960 Σ1	USAF	L. Chidester	Lockheed
Discoverer 20	1961 E1	USAF	L. Chidester	Lockheed
Discoverer 21	1961 Z1	USAF	L. Chidester	Lockheed
Discoverer 36	1961 AK1	USAF	L. Chidester	Lockheed
ESSA	1966 8A	ESSA	A. Schnapf R. Rados	RCA GSFC
Explorer 7	1959 I-1	NASA	J. Boehm Herman Lagow	MSFC MSFC
Explorer 16	1962 BX1	NASA	F. Martin Earl Hastings Walter Ellis	GSFC
Explorer 17	1963 9A	NASA	F. Martin	GSFC
Explorer 20	1964 51A	NASA	E. D. Nelson	GSFC
Explorer 22	1965 64A	NASA	W. Allen	APL
Explorer 23	1964 74A	NASA	F. Martin	GSFC
Explorer 30	1965 93A	USN/NASA	F. Martin	GSFC

TABLE VIII. (Cont'd.)

Specific Flights with Individual Contact

Flight Name	International Designation	Sponsoring Agency	Individual Contact	Contact Affiliation
GGSE 1	1964 1B	USN/USA	P. Wilhelm	NRL
GGSE 2	1965 16B	USN/USA/USAF	J. Yuen	NRL
GGSE 3	1965 16C	USN/USA/USAF	"	"
GGSE 4	1967 53C	USAF/USN	"	"
GGSE 5	1967 53D	USAF/USN	"	"
Nimbus 2	1966 40A	NASA	K. F. Merten	G.E.
			K. L. Hansen	
			W. J. Schlotter	
			H. Press	GSFC
			C. McKenzie	
None	1963 38C	USN	R. F. Fischell	APL
None	1964 83C	USAF/USN	J. H. Martin	
			W. E. Radford	
			W. E. Allen	
None	1962 Σ1	USAF		
None	1963 22A	USAF/USN	R. F. Fischell	APL
None	1964 48A	USAF		
None	1964 83D	USAF/USN	R. F. Fischell	APL
OGO 4	1967 73A	NASA	H. Montgomery	GSFC
			F. B. Shaffer	
			J. Callaghan	
			G. J. Gleghorn	TRW
			A. Krausy	
			R. L. Robinson	
			R. B. Beltz	
			H. G. Mesch	
			A. C. Lee	
Oscar 3	1965 16F	USN/USA/USAF	W. Dunkerly	ARRL

TABLE VIII. (Cont'd.)

Specific Flights with Individual Contact

Flight Name	International Designation	Sponsoring Agency	Individual Contact	Contact Affiliation
OSO 1	1962 Z1	NASA	J. Thole	GSFC
OSO 2	1965 7A	NASA	W. Gallagher	"
OSO 3	1967 20A	NASA	W. Downs	Ball Bros. Corp.
OSO 4	1967 100A	NASA	H. Manzenti	"
			B. Thompson	"
OV4 3	1966 99A	USAF	R. Dermoret	Martin Company
OV4 1R	1966 99B	USAF	J. I. Barker	WPAFB
OV4 1T	1966 99D	USAF	J. I. Barker	WPAFB
OV1 4	1966 25A	USAF	L. Otten	General Dynamics
OV1 5	1966 25B	USAF	B. Zillgitt	"
OV1 10	1966 111B	USAF	J. McSherry	SAMSO
OV1 12	1967 72D	USAF	R. Slizeski	"
OV1 86	1967 72A	USAF	"	"
Pegasus 1	1965 9A	NASA	J. Mott	Fairchild-Hiller
			G. Graff	Fairchild-Hiller
Pegasus 2	1965 39A	NASA	R. Julius	S & J Industries
Pegasus 3	1965 60A	NASA	"	"
Samos 2	1961 A1	USAF	F. Ackerman	Lockheed
			L. Chidester	Lockheed
Secor 1	1964 1C	USN/USA	G. Sharman	Cubic Corp.
Secor 2	1965 17B	USA	E. Cyran	U.S.A. Map Service
Secor 3	1965 16E	USAF/USN/USA	"	"
Solrad 1	1960 H2	USN	P. Wilhelm	NRL
Injun/ Solrad 3	1961 02	USN	G. Peiper	NASA
Solrad 7A	1964 1D	USN/USA	P. Wilhelm	NRL
Solrad 7B	1965 16D	USAF/USN/USA	J. Yuen	NRL
Surcal	1965 16G	USAF/USN/USA	"	"
Surcal	1965 16H	USAF/USN/USA	"	"
Surcal	1965 65B	USN	P. Wilhelm	NRL
Surcal	1965 65C	USN	"	"
Surcal	1965 65E	USN	"	"

TABLE VIII. (Cont'd.)

Specific Flights with Individual Contact

Flight Name	International Designation	Sponsoring Agency	Individual Contact	Contact Affiliation
Surcal	1965 65F	USN	P. Wilhelm	NRL
Surcal	1965 65H	USN	"	"
Surcal	1965 65L	USN	"	"
Surcal	1967 53B	USAF/USN	"	"
Surcal	1967 53F	USAF/USN	"	"
Surcal	1967 53J	USAF/USN	"	"
Tiros 1	1960 B2	NASA	R. Rados	GSFC
Tiros 2	1960 II-1	NASA	W. G. Stroud	
Tiros 3	1961 P1	NASA	E. Cortright	
Tiros 4	1962 B1	NASA	J. Maskasky	
Tiros 5	1962 AA1	NASA	A. Schnapf	RCA
Tiros 6	1962 AΨ1	NASA	R. Scott	RCA
Tiros 7	1963 24A	NASA	"	"
Tiros 8	1963 54A	NASA	"	"
Tiros 10	1965 51A	NASA	"	"
TRAAC	1961 AH2	USN	R. E. Fischell	APL
			W. Allen	"
Transit 1B	1960 Γ2	ARPA	R. E. Fischell	APL
Transit 2B	1960 H1	USN	W. C. Scott	APL
Transit 4A	1961 01	USN	W. Allen	"
Transit 4B	1961 AH1	USN	"	"
TTS 1	1967 123B	NASA	P. Burr	GSFC
			R. Kelly	TRW

TABLE IX.

Specific Flights with Solar Cell Vendor

Solar Cell Vendor	Flight Name	International Designation
Heliotek	OSO 2	1965 7A
	OSO 3	1967 20A
	OSO 4	1967 100A
	Tiros 10	1965 51A
	Transit 4B	1961 AH1
Hoffman Electronics	Explorer 7	1959 I-1
	Explorer 20	1964 51A
	Explorer 22	1965 64A
	OSO 1	1962 Z1
	OGO 4	1967 73A
	TRAAC	1961 AH2
	Transit 4A	1961 01
International Rectifier	Tiros 1	1960 B2
	Tiros 2	1960 II-1
	Tiros 3	1961 P1
	Tiros 4	1962 B1
	Tiros 5	1962 AA1
	Tiros 6	1962 AΨ1
	Tiros 7	1963 24A
	Tiros 8	1963 54A
	Nimbus 2	1966 40A
Texas Instrument	TTS-1	1967 123B

TABLE X.

Form C-01

DATA AVAILABILITY CODE - PHASE I

CARA Flight Number ________________

Flight Name & International Designation ____________________

E	SC	SP	P	T	M
M	W	W	PC	M	C
T	F	F	PV	R	I
R	M	M	IV	T	M
O	T	T	SCC	E	F
	R	R	OCV		A
	P	P	FF		D
	O	O	MPP		
			TS		

DIRECTIONS:

1. See Master Chart (Form C-02) for Letter Identification
2. Circle Letter When Information is Available
3. Write "A" Under Letter When Either the Document Containing Information is in CARA Office or When Person Holding Information is Known.

TABLE XI.

Form C-02

MASTER CHART: DICTIONARY FOR FORM C-01

E (Environmental)

- M (Mechanical)
- T (Thermal)
- R (Radiation)
- O (Orbit Description)

SC (Procurement Specifications for Cells)

- W (Weight)
- F (Fabrication)
- D (Mounting and Deployment)
- M (Mechanical)
- T (Thermal)
- R (Radiation)
- P (Power)
- O (Operation Schematic Details)

SP (Procurement Specifications for Panels

- W (Weight)
- F (Fabrication)
- D (Mounting and Deployment)
- M (Mechanical)
- T (Thermal)
- R (Radiation)
- P (Power)
- O (Operation Schematic Details)

P (Performance)

- PC (Panel Control)
- PV (Panel Voltage)
- IV (Current vs. Voltage)
- SCC (Short Circuit Current)
- OCV (Open Circuit Voltage)
- FF (Fill Factor)
- MPP (Maximum Power Point)
- TS (Telemetry Specifications)

T (Tests for Acceptance)

- M (Mechanical)
- R (Radiation)
- T (Thermal)
- E (Efficiency)

M (Materials and Manufacturing)

- C (Cell Construction Details)
- MT (Cell Materials)
- I (Interconnections)
- M (Cell Mounting)
- F (Frame Construction and Materials)
- A (Attachment of Panel)
- D (Deployment)

TABLE XII.

Form C-03

OUTLINE FOR RECORDING PERTINENT DATA

CARA Flight Number

Satellite Name — International Designation

Sponsoring Agency

Prime Contractor — Contract Number

Solar Cell Manufacturer — Contract Number

Orbit Data

Launch Data:
Site:
Vehicle:

Perigee: θ:
Apogee: T:

Solar Cell Data

Type:
Dimension:
Resistivity:
Efficiency:
Spectral Response:

Base Material

Type:
Thickness:
Purity:
Method of Preparation:

TABLE XII. (Cont'd.)

Dopant

- Type
- Diffusion Depth
- Concentration

Cover Slide

- Material
- Thickness
- Transmission
- Vendor

Cover Slide Adhesive

- Name & Vendor
- Thickness
- Transmission
- Preparation
- Application
- Cure

Cover Slide Coating

- Type
- Thickness
- Transmission & Spectral Response
- Application Technique

Front Surface Conductor

- Type
- Material
- Resistivity
- Thickness
- Application Technique

"Finger" Conductors

- Type
- Material
- Resistivity
- Thickness
- Dimensions
- Application Technique

Solder Contact

- Material
- Thickness
- Resistivity
- Application Technique

TABLE XII. (Cont'd.)

<u>Solar Cell Module</u>

Dimensions
Number of Cells
Type of Overlays
Description of Exposed Area

<u>Interconnections</u>

Wiring Diagram
Material
Processing Technique

<u>Panel</u>

Size
Deployment Technique
Location of Spacecraft
Module Interconnection Details

<u>Preflight Test Details</u>

Mechanical
Performance
V_{oc}
I_{sc}
Vacuum-thermal
Illumination

<u>Flight Details</u>

Orientation
Stabilization
Unusual Phenomena

<u>Environmental Factors</u>

Thermal Cycling of Panel (frequency, amplitude)
Radiation and Particle Environment
  Electron
  Proton
  Micrometer

<u>Performance Details</u>

I-V Characteristics as a Function of Time
V_{oc} Vs. Time
I_{sc} " "
Fill Factor " "
Maximum Power " "

TABLE XIII.

Form A of Proposed Data Collection Process to Accompany Satellite Flights

VEHICLE INFORMATION

Directions: This form is to be completed by the Prime Contractor. Wherever possible, the requested information should be expanded and given in as great a detail as possible. Any pertinent reports or published articles should be referenced. If it is possible, the location of extensive printed data requested should be identified on this form.

1. Satellite Name:

2. International Designation:

3. Sponsoring Agency:

   a. Name & Address of Project Manager:

4. a. Prime Contractor:

   b. Name & Address of Project Manager:

   c. Contract Award Number:

   d. Name & Address of Negotiating Officer: (corporate and individual managers)

5. Name, Address, & Contract Award Numbers of Appropriate Subcontractors:

   a. Power Sub-system:

   b. Solar Array:

TABLE XIII. (Cont'd.)

c. Solar Cell:

d. Other:

6. Orbit Data:

	Planned	Actual
a. Launch Date:		
b. Launch Site:		
c. Launch Vehicle:		
d. Perigee:		
e. Apogee:		
f. θ (angle of inclination):		
g. T (period):		

7. Vehicle Specifications: (brief narratives, if required)

a. Operating Environment: (including thermal cycling of components with frequency and amplitude, and radiation and particle environment)

b. Power Requirements:

c. Expected Life:

d. Operating Characteristics:

e. Stabilization:

TABLE XIII. (Cont'd.)

8. Power Sub-System Specifications

   a. Operating Characteristics:

   b. Dimensions & Location of Components on Vehicle:

   c. Location of Sub-system Schematics & Drawings:

9. Solar Array Performance Details

   a. I-V Characteristics as a Function of Time:

   b. V_{oc} Vs. Time

   c. I_{sc} Vs. Time

   d. Fill Factor Vs. Time

   e. Maximum Power Vs. Time

   f. Telemetered Data: (e.g., solar array temperature, voltage, and current -- including calibration techniques)

   g. Look Angle of Solar Array Vs. Time Including Effects of Component Shadows & Earth's Albedo:

   h. Ground Testing Procedures & Significant Data:

   i. Flight Testing Procedures & Significant Data:

   j. Description of Techniques to Correlated Flight Data Sampling with Vehicle Altitude & Flight Time:

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TABLE XIV.

Form B of Proposed Data Collection Process to Accompany Satellite Flights

SOLAR CELL MODULE DATA

Directions: This form is to be completed by the solar cell module manufacturer. Wherever possible, the requested information should be expanded and given in as great a detail as possible. Any pertinent reports or published articles should be referenced. If it is possible, the location of extensive printed data requested should be identified on this form.

1. Satellite Name:

2. International Designation:

3. Name, Address, & Contract Award Number of Customer:

4. a. Name & Address of Contractor:

   b. Names & Addresses of Project Manager & Key Personnel:

5. Solar Panel

   a. Location on Spacecraft:

   b. Deployment Technique:

   c. Dimensions & Weight:

   d. Number & Arrangement of Modules:

   e. Module Interconnection & Wiring Details:

TABLE XIV. (Cont'd.)

7. Interconnections

   a. Wiring Diagram:

   b. Materials Used:
      (include descriptions of)

   c. Processing Technique:

8. Cover Slide

   a. Name & Address
      of Manufacturer:

   b. Material:

   c. Dimensions:

   d. Transmission
      Characteristics:

   e. Description of Coatings
      & Application Techniques:

9. Adhesives Used for Solar Cell to
   Substrate & Cover Slide to Solar Cell

   a. Names & Addresses
      of Vendors:

   b. Application Techniques:

   c. Transmission
      Characteristics:

   d. Thickness:

   e. Preparation:

   f. Cure:

TABLE XIV. (Cont'd.)

10. Module Substrate

    a. Construction Details:

    b. Materials Used:

11. Preflight Test Details

    a. Mechanical:

    b. Vacuum - thermal:

    c. Illumination:

    d. Electrical Performance: I-V curve, V_{oc}, I_{sc}

TABLE XV.

Form C of Proposed Data Collection Process to Accompany Satellite Flights

SOLAR CELL DATA

Directions: This form is to be completed by the solar cell manufacturer. Wherever possible, the requested information should be expanded and given in as great a detail as possible. Any pertinent reports or published articles should be referenced.

1. Satellite Name:

2. International Designation:

3. Name, Address, & Contract Award Number of Customer: (purchaser of solar cells)

4. Solar Cell Design Specifications: (These data should include all of the solar cell specifications supplied by the customer to the solar cell manufacturer.)

5. Solar Cell Data

   a. Type: (e.g., N/P, P/N, thin film, etc.)

   b. Dimension (area): (e.g., 1 x 2 cm, 2 x 6 cm, etc.)

   c. Resistivity: (e.g., 1 ohm nominal, 10 ohm nominal, etc.)

TABLE XV. (Cont'd.)

d. Efficiency:
(e.g., 10%, specify conditions of measurement)

e. Spectral Response:
(specify peak, cutoffs & conditions of measurement)

6. Base Material

a. Type:
(e.g., Si.)

b. Thickness:
(e.g., 0.015 $\pm$ 0.002 inch, etc.)

c. Purity:
(specify concentrations of impurities of base material as purchased)

d. Method of Preparation:
(This should be a brief narrative describing the preparation, materials and quantities used, growing techniques, including operating conditions of equipment (temperature, time, pressure, seed crystal, and speed of rotation and elevation, etc.), methods of testing, handling procedures, and any other relevant information.)

7. Manufacturing Technique for the Rest of the Solar Cell:
(This should be a brief narrative describing the

TABLE XV. (Cont'd.)

procedures used in making the solar cell. It should include descriptions of materials, techniques operating conditions, and equipment used in all steps of the process. If possible, a standard procedure should be generated, and referenced in this space, with specific deviations listed on this form.)

8. Dopant

   a. Type:
      (e.g., Boron, etc.)

   b. Diffusion Depth:
      (e.g., 10 microns, etc.)

   c. Concentration:
      (specify concentration by depth, if possible)

   d. Application Technique:
      (e.g., gas carried specifying carrier gas, etc.)
      (Note: A procedure should be referenced for the various possible techniques in this step, with specific differences from that referenced procedure mentioned here.)

9. Back Surface Conductor

   a. Type:
      (e.g., solder on vapor deposited base specifying types of materials used, etc.)

TABLE XV. (Cont'd.)

b. Dimensions (area):
(e.g., edges free, covering specified percentage of area, etc.)

c. Thickness:
(e.g., specify thickness for initial layer and after application of solder)

d. Application Technique:
(same as 8.d. Note)

10. End Conductors

a. Type:
(e.g., edge, wrap around, etc.)

b. Material:
(specify materials used for initial and secondary layers)

c. Thickness:
(same as 9.d.)

d. Area Dimensions:
(e.g., 2 cm x 0.025 inch, etc.)

e. Application Technique:
(same as 8.d. Note)

11. Front Surface Conductors

a. Dimensions:
(specify dimensions for each and separation from each other)

TABLE XV. (Cont'd.)

b. Material:
(specify initial and secondary layers of materials)

c. Thickness:
(same as 9.d.)

d. Application Technique:
(specify if different than 10.e.)

12. Antireflecting Coating

a. Type:
(e.g., SiO)

b. Thickness:
(specify thickness and monitoring criteria)

c. Application Technique:
(same as 8.d. Note)