NASA TM- 81418

NASA-TM-81418 19800009833

NASA Technical Memorandum 81418

ECONOMIC ANALYSIS OF THE DESIGN AND FABRICATION OF A SPACE QUALIFIED POWER SYSTEM

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January 1980

SUMMARY

An economic analysis was performed to determine the cost of the design and fabrication of a low earth orbit, 2 kW photovoltaic/battery, space qualified power system. A commercially available computer program called PRICE (Programmed Review of Information for Costing and Evaluation) was used to conduct the analysis. The paper discusses the sensitivity of the various cost factors to the assumptions used. Total cost of the power system was found to be $2.46 million with the Solar Array accounting for 70.5%. Using the assumption that the prototype becomes the flight system, 77.3% of the total cost is associated with manufacturing.

Results of this study will be used to establish whether the cost of space qualified hardware can be reduced by the incorporation of commercial design, fabrication and quality assurance methods.

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INTRODUCTION

Space power systems have historically been high cost items due to the quality components and level of technology necessary to meet the mission requirements. With the advent of the space shuttle, transportation costs will be greatly reduced, and, more importantly, the option of servicing spacecraft inflight becomes possible. The potential for orbital repairs or replacements may substantially reduce costs. That is, rather than designing a power system using the traditional space qualified approach, the cost of space hardware may be reduced by incorporating commercial design, fabrication, and quality assurance methods.

A study was recently completed for the NASA/Lewis Research Center to determine the cost of designing and fabricating a 2 kW photovoltaic space power system using a commercial approach (ref. 1). Since the purpose of that study was to enable a comparison between the cost of a "commercially" designed space power system and a "space qualified" system, it was necessary to determine the cost of the "design and fabrication" of a comparable "space qualified" (solar photovoltaic space power) system. A commercially available computer program called PRICE (Programmed Review of Information for Costing and Evaluation) was used for this cost analysis because of its applicability, simplicity, and accessibility.

This paper describes the application of PRICE to this cost analysis and discusses the sensitivity of cost to the assumptions which were used.

SPACE QUALIFIED SYSTEM CHARACTERISTICS

To enable a comparison between the space qualified system and the commercial power system, both systems were sized using the same mission characteristics as listed in table I. Five basic subsystems are derived from this table for use in the computer costing model. They are:

1. Solar arrays
2. Slip rings and solar array drive
3. Batteries
4. Switching regulator
5. Deployment mechanism

Weights and volumes of each subsystem are the primary inputs required by the costing model. Table II summarizes the input data of the subsystems. Data for these inputs was obtained from state-of-the-art space qualified components.

The conceptual design of the solar array is a two-wing system generating 5 kW of power (2 kW to the load, 2 kW to the batteries for storage, and 1 kW to compensate for losses throughout the system). Data from recent missions were revised for this specific power level and then used as inputs to the computer model.

Slip rings and a solar array drive were modeled to meet the mission criteria of a sun-oriented array. Data in table II represents the slip rings and solar array drive combined, as one unit.

Three 50 A-hr batteries are required to supply mission power during the time that the satellite is in the earth's shadow.

The switching regulator is a combination peak power tracker and battery charger. The input data was modeled directly after a commercially available switching regulator. The electronic assembly of the regulator is solid state and carries a high degree of redundancy.

An extendible, retractable deployment mechanism based on a lazy tong - coiled beam configuration was used.

COMPUTER COST MODEL

The program used to develop the cost data, PRICE, is a commercially available computer program capable of estimating the cost of virtually any type of mechanical and/or electrical system. The program utilizes empirical relationships to relate various system parameters to cost. The specific computer program used in this report is called PRICE 84 and represents the most recent refinement of the PRICE system (ref. 2).

Method of Operation

The space power system has been divided into its major subsystems and each is input separately to the model. The subsystems are characterized by variables such as weight, volume, and complexity factors. The cost of each subsystem is calculated and the program then integrates the subsystems into a total system to calculate the total system costs including integration.

It should be noted that no cost information is required as input data. The program, using internal empirical relationships, calculates costs from system description parameters provided in the input data. However, it will be shown later that certain input variables are more sensitive in costing the system than others.

Assumptions

Several assumptions have been made in this study which directly affect the output from the cost program. Perhaps the most significant is that only one prototype power system will be built and this unit will become the actual flight unit. This assumption was also made in the study of the cost of a commercially built system so that a direct comparison can be made. Other assumptions include:

Year of technology	1981
Year of economics	1981

1 year required to complete design work
1 year required to develop and test the prototype-flight model

Average levels of project management, documentation, special tooling, engineering change notices, etc.

Description of Input Variables

The program requires between 23-29 data inputs to describe each subsystem (ref. 2). The input data is classified into four separate categories as shown on the worksheet in figures 1 and 1(a). These categories are:

1. General
2. Mechanical/structural
3. Electronics
4. Development

A brief description of the input variables in each of these categories is provided as a reference. A more comprehensive discussion of these parameters is given in reference 2.

The General category consists of a set of input variables which are common to any type of subsystem. This includes such parameters as; the quantity of subsystems to be built, and the weight and volume of the subsystem. Other variables are the number of subsystems required for the system and the degree of integration of the subsystem with the next higher system. The optional general inputs are the year of technology, and the year dollars for the economics.

The mechanical/structural category contains almost any type item possible other than electronic componenets. Typical mechanical/structural items are mechanisms, motors, batteries, cables, hydraulics, optics, antennas, solar arrays, etc. Required mechanical/structural inputs are the structural weight, the degree of new or unique structure, and the mechanical/structural complexity factors. These complexities are basically manufacturing inputs; or, "How difficult is it to make?." An optional input is the degree of structural design repeats.

The electronics category includes items which contain electronic components such as tubes, discrete components, IC's (integrated circuits) hybrids, and LSI's (large scale integration). Typical electronic items are power supplies, receivers, transmitters, TV's, radar scopes, oscilloscopes, lasers, computers, etc. Mandatory inputs are the electronics density, the degree of new or unique electronics, and the electronics manufacturing complexity factor. An optional input includes the degree of electronic design repeat.

The development category contains variables needed to model the development procedure. Required inputs are the start date of the development (month, year), the date of the completion of the first prototype (month, year) and the date of the completion of development (month, year). Optional inputs include the engineering complexity ranking factor and the degree of tooling and testing equipment required for development. Here the engineering complexity factors refer to the people who are actually going to do the work and how experienced they are.

Sensitivity Analysis

As one may expect, certain input parameters are more sensitive than others in determining total system costs. For example, increasing the manufacturing complexity factor by 5 to 10% may double the cost while increasing the "quantity at the next higher assembly" will have little effect on unit costs. Knowledge of these sensitivities is helpful towards gaining a fuller understanding of the results.

Basically two sets of variables comprise the major cost drivers. They are:

1. Manufacturing complexity factors - electronic and mechanical/structural, to indicate the degree of difficulty.
2. Weight - total subsystem and subsystem structure, to determine the densities which affect dollars per pound.

Other variables also affect costs, but not to the same degree as the complexity factors and weights.

Complexity Factors

The manufacturing complexity factors for the electrical and mechanical/structural assemblies (MCPLXE and MCPLXS) are the largest cost drivers in the cost program. The sensitivity of these variables is illustrated by the exponential nature of the solar array cost versus MCPLXS curve shown in figure 2. Data from this figure indicates that increasing the complexity factor from 8 to 9 (a reasonable range for the solar array) will roughly double the solar array cost.

The complexity factors are also somewhat qualitative. A guideline from which to choose values for these factors can be found in reference 2. However, empirical experience can be substituted. Caution should be exercised when selecting these values because of their significant impact on total cost.

Weights

The total subsystem weight and the structural weight of the subsystem (WT and WS) rank second to the complexity factors in their affect on costs. A direct linear relationship exists between the total subsystem weight and subsystem costs as illustrated by the solar array cost versus weight in figure 3.

Year of Economics

The year of economics variable (YRECON) takes the economic situation into account by applying yearly inflation rates to the total cost. An example of the effect of YRECON on cost is shown in figure 4. In general, a deviation of ± 2 years will vary costs approximately 15%. Thus, when comparing separate systems, the year of economics should coincide as closely as possible to obtain realistic results.

Other Factors

Many other factors affect cost to a lesser degree than the complexity factors and weights. These variables include such items as the degree of new design/design repeat in the actual subsystem, subsystem volume, engineering complexity factor, year of technology, schedule, tooling, and test equipment required for development and production. An example of the small effect of each of these parameters on cost is shown in figure 5 of solar array costs versus production time.

Computer Model Output

The appendix shows standard PRICE 84 output sheets. The program cost portion of the output sheet displays the actual cost figures. The total subsystem cost is divided in several areas under the major headings of engineering and manufacturing. Note that each subheading has a zero cost figure for production. This is because the study is only considering the development costs of designing and fabricating one 2 kW space power system.

The final section of the output sheets shows a range for the total cost. All of the algorithms which are used in the computer program have been developed through regression analysis and therefore have inherent statistical error. When these "errors" are added up for all the algorithms used in the cost calculations, they produce a cost distribution around a mean value. The "From" and "To" costs in this section include the one sigma variation from that mean.

Entering a minimum amount of mandatory input data which causes the model to employ more algorithms in its calculations, will enlarge the cost range.

RESULTS

The purpose of this paper was to estimate the cost of designing and fabricating a 2 kW space qualified photovoltaic power system. The computer model used for the study, PRICE, calculated a total cost of $2.46 million. The output data from the computer program is listed in the appendix. A summary of the cost of each subsystem and the integration and testing is shown in table III.

The solar array is the major cost driver of the power system. This is typical of most photovoltaic power systems. The high cost of the solar array can be attributed to the extensive fabrication process required. Note, from the appendix under the solar array output sheet that the cost of manufacturing (fabrication) the prototype is $1472 thousand or 85% of the total solar array cost. Fabrication of a solar array is a complicated procedure requiring many process steps and quality assurance tests which tend to drive costs up drastically.

Looking again at the results in the appendix, note that the cost of manufacturing each subsystem is usually the major portion of the cost of each subsystem. This reflects the fact that the space power system was developed from a "mature" technology. The power system was assumed to have been designed and fabricated using existing levels of technology with no subsystems that require new technology development. This "mature" technology assumption in the model had the effect of lowering the development costs with respect to the manufacturing costs since little design effort was required.

The switching regulator was the only subsystem which was an exception to high manufacturing costs (see the appendix - switching regulator). Instead, the switching regulator had high development and design costs. The switching regulator output in the appendix shows that 78% of the regulator cost was devoted towards engineering (development and design). Although the switching regulator was designed from a mature technology, it is a highly redundant electronic assembly with thousands of components. High redundancy will lower manufacturing costs without affecting design costs greatly. From table IV, the high manufacturing costs with respect to the engineering costs again reflect that the space power system was developed using mature technology.

The major cost of the manufacturing section is the "Prototype" category comprising over 77% of the total cost. This category includes:

Prototype material and handling
Assembly and test labor costs
Overhead
Qualification test costs

The computer model only gives a cost figure for the total prototype category. It is not capable of dividing costs into material, handling, etc.

Another category in manufacturing is tool-test equipment. The cost in this category includes the normal standard special tools and testing equipment required for manufacturing.

In the engineering section, the design and project management categories comprise 74% of the total engineering cost. Costs in the design category includes:

Development and design engineering
Laboratory experimental work
Breadboarding and testing

The project management category includes the cost of:

Project management and control
Travel and living expenses
Reliability, maintainability, quality assurance
Computer operation costs
Preparation of in-house reports

As with any type of computer model, certain uncertainties in the results are inherent. The model computes a cost range of each output which bounds the uncertainties of the empirical relations used in the program. These cost ranges include a one sigma variation from the algorithms used in the program. The range for the power system studied was found to vary from \$2.195 million to \$2.765 million with the mean being \$2.46 million, the calculated cost. This represents a deviation of ±11%.

Leaving some of the optional input variables blank, or incomplete, will increase the uncertainty of the model. There are many input variables which are not mandatory, such as the year of economics or the degree of design repeat. The model will compute costs regardless of whether these operational variables are used but the uncertainty of the resulting costs will be increased. The model will then include these uncertainties in the cost range. However, the program cannot compute the uncertainties of incomplete required input varibles. Some variables cannot be given exact values and can only be estimated. These deviations are not included in the cost range since the program assumes them to be exact. It is estimated that these uncertainties add another ±5 to 10% to the cost range variation.

CONCLUDING REMARKS

A cost study of the design and fabrication of a 2 kW space qualified photovoltaic power system was conducted. The power system was modeled using PRICE 84, a commercially available computer costing program. An analysis of the results showed that the majority of the cost (70.5%) was devoted towards manufacturing the solar array. The cost of the total power system was computed at \$2.46 million.

The input parameters were varied to discover their cost sensitivities in relation to one another. The complexity factors and weights were found to be major cost drivers in the power system.

In engineering, where new design was needed, most of the cost was found to be with design and consequently, some additional drafting. If there were design repeats, the engineering costs logically would be low.

--- PRICE 84 ---
MECHANICAL ITEM

DATE 30-AUG-79   TIME 09:14 (790184)   FILENAME: IRSPS.DAT

SOLAR ARRAY

		UNIT WEIGHT	229.00	MODE	2
PROTOTYPE QUANTITY	2.0	UNIT VOLUME	9.75	QUANTITY/NHA	2

PROGRAM COST($ 1000)	DEVELOPMENT	PRODUCTION	TOTAL COST
ENGINEERING			
DRAFTING	9.	-	9.
DESIGN	24.	-	24.
SYSTEMS	1.	-	1.
PROJECT MGMT	105.	-	105.
DATA	24.	-	24.
SUBTOTAL(ENG)	163.	-	163.
MANUFACTURING			
PRODUCTION	-	-	-
PROTOTYPE	1472.	-	1472.
TOOL-TEST EQ	102.	-	102.
SUBTOTAL(MFG)	1574.	-	1574.
TOTAL COST	1736.	-	1736.

DESIGN FACTORS	MECHANICAL	PRODUCT DESCRIPTORS	
WEIGHT	229.000	ENGINEERING COMPLEXITY	0.500
DENSITY	23.487	PROTOTYPE SUPPORT	1.0
MFG. COMPLEXITY	8.500	PROTO SCHEDULE FACTOR	.250*
NEW DESIGN	0.068*	PLATFORM	2.0
DESIGN REPEAT	0.782	YEAR OF TECHNOLOGY	1981
EQUIPMENT CLASS	******	RELIABILITY FACTOR	1.0*
INTEGRATION LEVEL	0.3	MTBF(FIELD)	18568*

SCHEDULE	START		FIRST ITEM		FINISH	
DEVELOPMENT	JAN 81	(13)	JAN 82	(12)	JAN 83	(25)

SUPPLEMENTAL INFORMATION		TOOLING & PROCESS FACTORS	
YEAR OF ECONOMICS	1981	DEVELOPMENT TOOLING	1.0
ESCALATION	0.00		
DEV COST MULTIPLIER	1.00*		

COST RANGES	DEVELOPMENT	PRODUCTION	TOTAL COST
FROM	1559.	-	1559.
CENTER	1736.	-	1736.
TO	1916.	-	1916.

- - - PRICE 84 - - -
ELECTRONIC ITEM

DATE 30-AUG-79 TIME 09:16 (790184) FILENAME: IRSPS.DAT

SLIP RINGS AND SOLAR ARRAY DRIVE

PROTOTYPE QUANTITY	1.0	UNIT WEIGHT	15.00	MODE	1
		UNIT VOLUME	0.50	QUANTITY/NHA	1

PROGRAM COST($ 1000)	DEVELOPMENT	PRODUCTION	TOTAL COST
ENGINEERING			
DRAFTING	2.	-	2.
DESIGN	4.	-	4.
SYSTEMS	0.	-	0.
PROJECT MGMT	3.	-	3.
DATA	1.	-	1.
SUBTOTAL(ENG)	10.	-	10.
MANUFACTURING			
PRODUCTION	-	-	-
PROTOTYPE	29.	-	29.
TOOL-TEST EQ	2.	-	2.
SUBTOTAL(MFG)	31.	-	31.
TOTAL COST	42.	-	42.

DESIGN FACTORS	ELECTRONIC	MECHANICAL
WEIGHT	2.000*	13.000
DENSITY	40.000	26.000
MFG. COMPLEXITY	7.400	7.200
NEW DESIGN	0.024*	0.046*
DESIGN REPEAT	0.062*	0.499*
EQUIPMENT CLASS	******	******
INTEGRATION LEVEL	0.5	0.5

PRODUCT DESCRIPTORS	
ENGINEERING COMPLEXITY	0.400
PROTOTYPE SUPPORT	1.0
PROTO SCHEDULE FACTOR	.250*
ELECT VOL FRACTION	.100*
PLATFORM	2.0
YEAR OF TECHNOLOGY	1981
RELIABILITY FACTOR	1.0*
MTBF(FIELD)	174245*

SCHEDULE	START		FIRST ITEM		FINISH	
DEVELOPMENT	JAN 81	(13)	JAN 82	(12)	JAN 83	(25)

SUPPLEMENTAL INFORMATION	
YEAR OF ECONOMICS	1981
ESCALATION	0.00
DEV COST MULTIPLIER	1.00*

TOOLING & PROCESS FACTORS	
DEVELOPMENT TOOLING	1.0

COST RANGES	DEVELOPMENT	PRODUCTION	TOTAL COST
FROM	37.	-	37.
CENTER	42.	-	42.
TO	48.	-	48.

\- - - PRICE 84 - - -
MECHANICAL ITEM

DATE 30-AUG-79 TIME 09:18 (790184) FILENAME: IRSPS.DAT

BATTERIES

		UNIT WEIGHT	112.00	MODE	2
PROTOTYPE QUANTITY	3.0	UNIT VOLUME	1.12	QUANTITY/NHA	3

PROGRAM COST($ 1000)	DEVELOPMENT	PRODUCTION	TOTAL COST
ENGINEERING			
DRAFTING	0.	-	0.
DESIGN	0.	-	0.
SYSTEMS	0.	-	0.
PROJECT MGMT	22.	-	22.
DATA	8.	-	8.
SUBTOTAL(ENG)	30.	-	30.
MANUFACTURING			
PRODUCTION	-	-	-
PROTOTYPE	213.	-	213.
TOOL-TEST EQ	6.	-	6.
SUBTOTAL(MFG)	219.	-	219.
TOTAL COST	249.	-	249.

DESIGN FACTORS	MECHANICAL
WEIGHT	112.000
DENSITY	100.000
MFG. COMPLEXITY	6.250
NEW DESIGN	0.000
DESIGN REPEAT	0.451*
EQUIPMENT CLASS	******
INTEGRATION LEVEL	0.5

PRODUCT DESCRIPTORS	
ENGINEERING COMPLEXITY	0.200
PROTOTYPE SUPPORT	1.0
PROTO SCHEDULE FACTOR	.250*
PLATFORM	2.0
YEAR OF TECHNOLOGY	1981
RELIABILITY FACTOR	1.0*
MTBF(FIELD)	61559*

SCHEDULE	START		FIRST ITEM		FINISH	
DEVELOPMENT	JAN 81	(13)	JAN 82	(12)	JAN 83	(25)

SUPPLEMENTAL INFORMATION	
YEAR OF ECONOMICS	1981
ESCALATION	0.00
DEV COST MULTIPLIER	1.00*

TOOLING & PROCESS FACTORS	
DEVELOPMENT TOOLING	1.0

COST RANGES	DEVELOPMENT	PRODUCTION	TOTAL COST
FROM	217.	-	217.
CENTER	249.	-	249.
TO	296.	-	296.

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ELECTRONIC ITEM

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SWITCHING REGULATOR

PROTOTYPE QUANTITY	1.0	UNIT WEIGHT	24.00	MODE	
		UNIT VOLUME	0.40	QUANTITY/NHA	

PROGRAM COST($ 1000)	DEVELOPMENT	PRODUCTION	TOTAL COST
ENGINEERING			
DRAFTING	24.	-	24.
DESIGN	59.	-	59.
SYSTEMS	2.	-	2.
PROJECT MGMT	13.	-	13.
DATA	4.	-	4.
SUBTOTAL(ENG)	101.	-	101.
MANUFACTURING			
PRODUCTION	-	-	-
PROTOTYPE	26.	-	26.
TOOL-TEST EQ	3.	-	3.
SUBTOTAL(MFG)	28.	-	28.
TOTAL COST	130.	-	130.

DESIGN FACTORS	ELECTRONIC	MECHANICAL
WEIGHT	8.000*	16.000
DENSITY	36.000	40.000
MFG. COMPLEXITY	7.434	5.700
NEW DESIGN	0.500	0.200
DESIGN REPEAT	0.600	0.184*
EQUIPMENT CLASS	******	******
INTEGRATION LEVEL	0.5	0.5

PRODUCT DESCRIPTORS	
ENGINEERING COMPLEXITY	0.400
PROTOTYPE SUPPORT	1.0
PROTO SCHEDULE FACTOR	.250*
ELECT VOL FRACTION	.556*
PLATFORM	2.0
YEAR OF TECHNOLOGY	1981
RELIABILITY FACTOR	1.0*
MTBF(FIELD)	45395*

SCHEDULE	START		FIRST ITEM		FINISH	
DEVELOPMENT	JAN 81	(13)	JAN 82	(12)	JAN 83	(25)

SUPPLEMENTAL INFORMATION

YEAR OF ECONOMICS	1981
ESCALATION	0.00
DEV COST MULTIPLIER	1.00*

TOOLING & PROCESS FACTORS

DEVELOPMENT TOOLING	1.0

COST RANGES	DEVELOPMENT	PRODUCTION	TOTAL COST
FROM	114.	-	114.
CENTER	130.	-	130.
TO	153.	-	153.

--- PRICE 84 ---
MECHANICAL ITEM

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DEPLOYMENT MECHANISM

		UNIT WEIGHT	156.00	MODE	2
PROTOTYPE QUANTITY	2.0	UNIT VOLUME	4.00	QUANTITY/NHA	1

PROGRAM COST($ 1000)	DEVELOPMENT	PRODUCTION	TOTAL COST
ENGINEERING			
DRAFTING	4.	-	4.
DESIGN	9.	-	9.
SYSTEMS	0.	-	0.
PROJECT MGMT	13.	-	13.
DATA	4.	-	4.
SUBTOTAL(ENG)	30.	-	30.
MANUFACTURING			
PRODUCTION	-	-	-
PROTOTYPE	127.	-	127.
TOOL-TEST EQ	7.	-	7.
SUBTOTAL(MFG)	134.	-	134.
TOTAL COST	164.	-	164.

DESIGN FACTORS	MECHANICAL	PRODUCT DESCRIPTORS	
WEIGHT	156.000	ENGINEERING COMPLEXITY	0.400
DENSITY	39.000	PROTOTYPE SUPPORT	1.0
MFG. COMPLEXITY	6.000	PROTO SCHEDULE FACTOR	.250*
NEW DESIGN	0.059*	PLATFORM	2.0
DESIGN REPEAT	0.501*	YEAR OF TECHNOLOGY	1981
EQUIPMENT CLASS	******	RELIABILITY FACTOR	1.0*
INTEGRATION LEVEL	0.3	MTBF(FIELD)	63512*

SCHEDULE	START		FIRST ITEM		FINISH	
DEVELOPMENT	JAN 81	(13)	JAN 82	(12)	JAN 83	(25)

SUPPLEMENTAL INFORMATION		TOOLING & PROCESS FACTORS	
YEAR OF ECONOMICS	1981	DEVELOPMENT TOOLING	1.0
ESCALATION	0.00		
DEV COST MULTIPLIER	1.00*		

COST RANGES	DEVELOPMENT	PRODUCTION	TOTAL COST
FROM	143.	-	143.
CENTER	164.	-	164.
TO	194.	-	194.

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INTEGRATION AND TEST

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INTEGRATION AND TESTING

		INT WEIGHT	24.701*	MODE	5
PROTOTYPE QUANTITY	1	INT VOLUME	1.600*	QUANTITY/NHA	1

PROGRAM COST($ 1000)	DEVELOPMENT	PRODUCTION	TOTAL COST
ENGINEERING			
DRAFTING	16.	-	16.
DESIGN	57.	-	57.
SYSTEMS	10.	-	10.
PROJECT MGMT	12.	-	12.
DATA	4.	-	4.
SUBTOTAL(ENG)	99.	-	99.
MANUFACTURING			
PRODUCTION	-	-	-
PROTOTYPE	35.	-	35.
TOOL-TEST EQ	6.	-	6.
SUBTOTAL(MFG)	41.	-	41.
TOTAL COST	139.	-	139.

DESIGN FACTORS	ELECTRONIC	MECHANICAL
WEIGHT	0.696*	24.004*
DENSITY	35.000*	15.000*
MFG. COMPLEXITY	6.624*	7.070*
NEW DESIGN	0.100	0.100
DESIGN REPEAT	0.000	0.000
EQUIPMENT CLASS	*****	*****
INTEGRATION LEVEL	0.3	0.3

PRODUCT DESCRIPTORS	
ENGINEERING COMPLEXITY	1.200*
PROTOTYPE SUPPORT	1.0
PROTO SCHEDULE FACTOR	.250*
ELECT VOL FRACTION	.012
PLATFORM	2.0
YEAR OF TECHNOLOGY	1981
RELIABILITY FACTOR	1.0
MTBF(FIELD)	352616*

SCHEDULE	START		FIRST ITEM		FINISH	
DEVELOPMENT	JAN 81	(13)	JAN 82	(12)	JAN 83	(25)

SUPPLEMENTAL INFORMATION	
YEAR OF ECONOMICS	1981
ESCALATION	0.00
AMORTIZED UNIT COST	0.00*
DEV COST MULTIPLIER	1.00*
PROD COST MULTIPLIER	1.00*

TOOLING & PROCESS FACTORS	
DEVELOPMENT TOOLING	1.0*
PRODUCTION TOOLING	0.0

COST RANGES	DEVELOPMENT	PRODUCTION	TOTAL COST
FROM	125.	-	125.
CENTER	139.	-	139.
TO	159.	-	159.

--- PRICE 84 ---
INTEGRATION AND TEST

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INTEGRATION AND TESTING

TOTAL COST, WITH INTEGRATION COST

PROGRAM COST($ 1000)	DEVELOPMENT	PRODUCTION	TOTAL COST
ENGINEERING			
DRAFTING	55.	-	55.
DESIGN	152.	-	152.
SYSTEMS	13.	-	13.
PROJ MGMT	168.	-	168.
DATA	45.	-	45.
SUBTOTAL(ENG)	433.	-	433.
MANUFACTURING			
PRODUCTION	-	-	-
PROTOTYPE	1902.	-	1902.
TOOL-TEST EQ	125.	-	125.
PURCH ITEMS	0.	-	0.
SUBTOTAL(MFG)	2027.	-	2027.
TOTAL COST	2460.	-	2460.

COST RANGES	DEVELOPMENT	PRODUCTION	TOTAL COST
FROM	2195.	-	2195.
CENTER	2460.	-	2460.
TO	2765.	-	2765.

SYSTEM WT	536.00	SYSTEM WS	526.00
SYSTEM SERIES MTBF HRS.	3567.64	AV SYSTEM COST	0

REFERENCES

1. Burkholder, Joel H.: Economical Space Power Systems. (Solarex Corporation; NASA Contract NAS3-21353.) NASA CR-159696, 1979.
2. PRICE (Programmed Review of Information for Costing and Evaluation) Reference Manual. Radio Corporation of America, PRICE Systems, Camden, New Jersey, 1980.

TABLE I. - MISSION AND SYSTEM CHARACTERISTICS

I. Launch and orbital characteristics
- Shuttle launch
- Circular; low earth orbit - 200 nm
- Inclination - 28°
- Orbital period - 93 minutes
- Time in sun - 57 minutes minimum
- Time in eclipse - 36 minutes maximum

II. System electrical characteristics
- Power source - deployable/retractable solar array
- Power level - beginning of life (BOL) 2 kW elec. continuous to load
- Distribution voltage - 28 VDC unregulated
- Energy storage - batteries
- Battery - depth of discharge (DOD) 25%
- Electrical - mechanical system:
  - (1) 2 axis solar array drive
  - (2) slip rings

TABLE II. - SUMMARY OF INPUT DATA FOR COMPLETE COSTING MODEL

Subsystem	Total weight, lb	Volume, ft^3	Weight of electronics, lb	Power dissipated W
Solar array	457	19.5		
Slip rings and solar array drive	15	0.5	2	20
Batteries	336	3.35		
Switching regulator	24	0.4	8	100
Deployment mechanism	160	8		

TABLE III. - SUBSYSTEM COST SUMMARY

	Cost (Thousands of dollars)	% of total cost
Solar array	1736	70.5
Slip rings and solar array drive	42	1.7
Batteries	249	10.1
Switching regulator	130	5.3
Deployment mechanism	164	6.7
Integration and testing	139	5.7
Total	$2460	100%

Table IV shows the power system cost breakdown in terms of manufacturing and engineering.

TABLE IV. - POWER SYSTEM COSTS

- - - PRICE 84 - - -

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TOTAL COST, WITH INTEGRATION COST

PROGRAM COST ($ 1000)	DEVELOPMENT	PRODUCTION	TOTAL COST
ENGINEERING			
DRAFTING	55.	-	55.
DESIGN	152.	-	152.
SYSTEMS	13.	-	13.
PROJ MGMT	168.	-	168.
DATA	45.	-	45.
SUBTOTAL(ENG)	433.	-	433.
MANUFACTURING			
PRODUCTION	-	-	-
PROTOTYPE	1902.	-	1902.
TOOL-TEST EQ	125.	-	125.
PURCH ITEMS	0.	-	0.
SUBTOTAL(MFG)	2027.	-	2027.
TOTAL COST	2460.	-	2460.

COST RANGES	DEVELOPMENT	PRODUCTION	TOTAL COST
FROM	2195.	-	2195.
CENTER	2460.	-	2460.
TO	2765.	-	2765.

SYSTEM WT	536.00	SYSTEM WS	526.00
SYSTEM SERIES MTBF HRS.	8597.64	AV SYSTEM COST	0

PRICE Input Data Worksheet **Basic Modes**

File name:
Sheet ___ of ___

**PRICE 84 (This must be used only as the first line of the file.)

Title: Date:

General A	Production Quantity QTY	Prototypes PROTOS	Weight (lbs) WT	Volume (ft^3) VOL	MODE	
General B	Quantity/Next Higher Assembly QTYNHA	NHA Integration Factors Electronic INTEGE	Structural INTEGS	Specification Level PLTFM	Year of Economics YRECON	Year/Type of Technology YRTECH
Mechanical/ Structural	Structure Weight WS	Manufacturing Complexity MCPLXS	New Structure NEWST	Design Repeat DESRPS	Equipment Classification MECID	Mechanical Reliability MREL
Electronics	Electronics Weight/ft^3 WECF	Manufacturing Complexity MCPLXE	New Electronics NEWEL	Design Repeat DESRPE	Equipment Classification CMPID	Electronic Reliability EREL
Development	Development Start DSTART	1st Prototype Complete DFPRO	Development Complete DLPRO	Engineering Complexity ECMPLX	Tooling & Test Equip. DTLGTS	Prototype Activity PROSUP
Production	Production Start PSTART	First Article Delivery PFAD	Production Complete PEND	Cost-Process Factor CPF	Tooling & Test Equip. PTLGTS	Rate/Month Tooling RATOOL
Additional Data (Mode 10)	Electronic Volume Fraction USEVOL	Structural Weight/ft^3 WSCF	Target Cost TARCST			

Notes:

BASIC MODES
1 E/M ITEM
2 MECHANICAL ITEM
6 MODIFIED ITEM
10 DESIGN TO COST

GC 1613 2/79 Note: Inputs in shaded area are optional.

Figure 1.

PRICE Input Data Worksheet **Other Modes**

File name:
Sheet ___ of ___

**PRICE 84 (This must be used only as the first line of the file.)

Title: Date:

Purchased/GFE Item (Modes 3 & 4)

General A	Production Quantity QTY	Prototypes PROTOS	Weight (lbs) WT	Volume (ft^3) VOL	MODE	
General B	Quantity/Next Higher Assembly QTYNHA	NHA Integration Factors Electronic INTEGE	Structural INTEGS	Specification Level PLTFM	Year of Economics YRECON	Year/Type of Technology YRTECH
General C	Manufacturing Complexities Electronic MCPLXE	Structural MCPLXS	Equipment Classification Electronic CMPID	Structural MECID		
COST (Mode 3)	Purchased Unit COST	Cost Multipliers Development DMULT	Production PMULT	Escalation ESC		
SCHEDULE (Mode 3)	Development Start DSTART	1st Proto Complete DFPRO	Development Complete DLPRO	Production Start PSTART	Production Complete PEND	

Integration & Test (Mode 5 — must be the last box in the file.)

General A (I & T)	Production Quantity QTY	Prototypes PROTOS	New Electronics NEWEL	New Structure NEWST	MODE 5	
General B	Quantity/Next Higher Assembly QTYNHA	NHA Integration Factors Electronic INTEGE	Structural INTEGS	Specification Level PLTFM	Year of Economics YRECON	Year/Type of Technology YRTECH
Schedule	Development Start DSTART	1st Proto Complete DFPRO	Development Complete DLPRO	Production Start PSTART	Production Complete PEND	

Thru-put (Mode 8) CATEGORY CODES: FIELD SUPPORT—1 FIELD TEST—2 SOFTWARE—3 OTHER—4

General A (Thru-put)	Category Code CATGRY	Development Cost DCOST	Production Cost PCOST	Total Cost TCOST	MODE 8

Multiple Lot Production Adjustment (Mode 9 — must be preceded by a Mode 1 or Mode 2 input.)

General A (PROADJ)	Production Quantity QTY	Production Start PSTART	First Article Delivery PFAD	Production Complete PEND	MODE 9	Printout Control PRNT

GC 1613 2/79 Note: Inputs in shaded area are optional.

Figure 1. - Concluded.

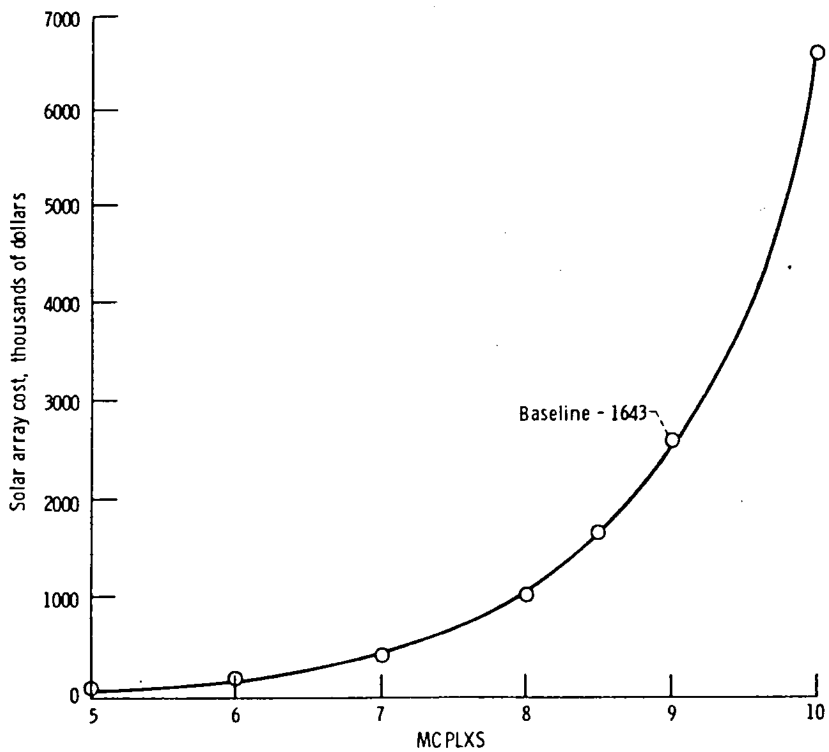

Figure 2. - Solar array cost versus MC PLXS (manufacturing complexity factor of structural items).

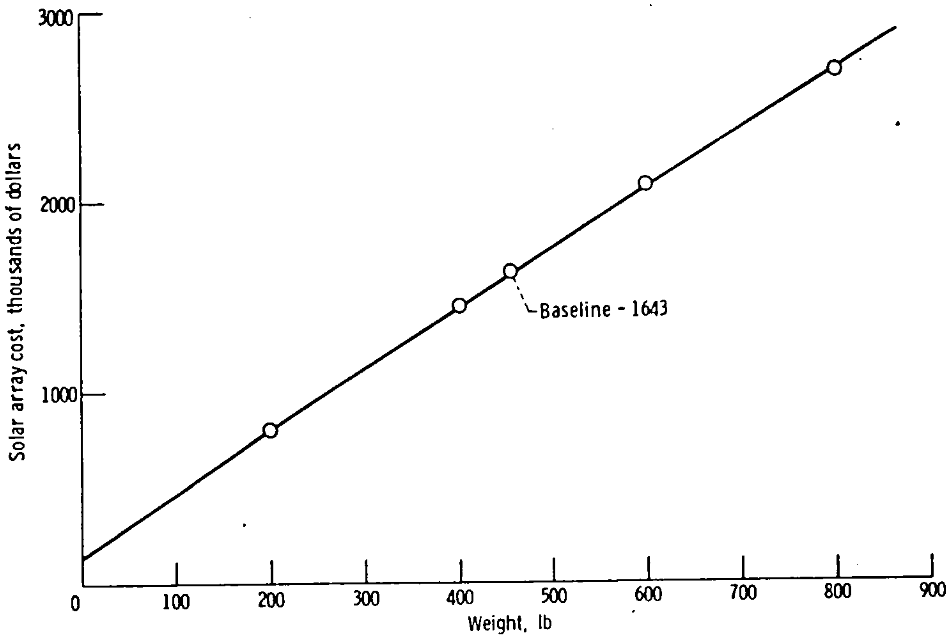

Figure 3. - Solar array cost versus weight.

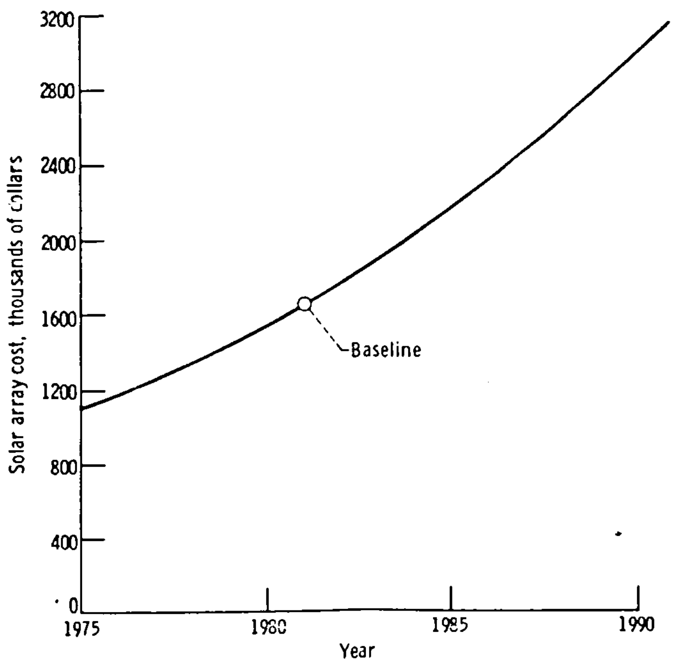

Figure 4. - Effect of year on solar array cost.

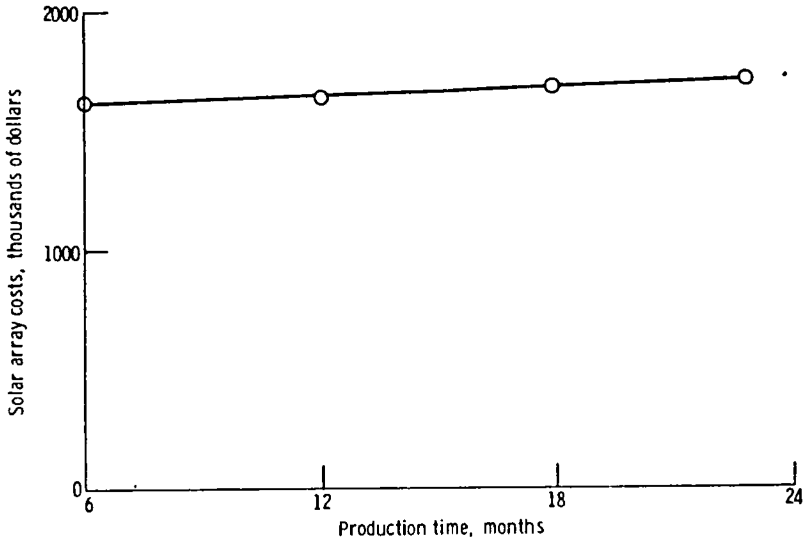

Figure 5. - Solar array costs versus production time.

1. Report No. NASA TM-81418	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle ECONOMIC ANALYSIS OF THE DESIGN AND FABRICATION OF A SPACE QUALIFIED POWER SYSTEM		5. Report Date January 1980
		6. Performing Organization Code
7. Author(s) Gregory Ruselowski		8. Performing Organization Report No. E-339
		10. Work Unit No.
9. Performing Organization Name and Address National Aeronautics and Space Administration Lewis Research Center Cleveland, Ohio 44135		11. Contract or Grant No.
		13. Type of Report and Period Covered Technical Memorandum
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

An economic analysis was performed to determine the cost of the design and fabrication of a low earth orbit, 2 kW photovoltaic/battery, space qualified power system. A commercially available computer program called PRICE (programmed review of information for costing and evaluation) was used to conduct the analysis. The paper discusses the sensitivity of the various cost factors to the assumptions used. Total cost of the power system was found to be $2.46 million with the solar array accounting for 70.5%. Using the assumption that the prototype becomes the flight system, 77.3% of the total cost is associated with manufacturing. Results of this study will be used to establish whether the cost of space qualified hardware can be reduced by the incorporation of commercial design, fabrication and quality assurance methods.

17. Key Words (Suggested by Author(s)) Space power; Solar photovoltaic; Energy storage; Computers; Cost		18. Distribution Statement Unclassified - unlimited STAR Category 20	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages	22. Price*

* For sale by the National Technical Information Service, Springfield, Virginia 22161

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