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The Multi-Disciplinary Design Study

A Life Cycle Cost Algorithm

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The Multi-Disciplinary Design Study

A Life Cycle Cost Algorithm

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1 Introduction

The Multi-Disciplinary Design (MDD) Study investigates three aspects of manned Space Station design; total system cost over the life of the program, subsystem design parameters, and relationships between cost and design parameters. It is anticipated that complex spacecraft designs will be based on total system costs over the life of the program, especially for those spacecraft which are complex and have a long mission duration. An approach to evaluating system design for the complete Life Cycle Costs (LCC) is desirable so that total program costs may be assessed for any given design and provide a means to perform preliminary design trades on cost, risk, performance, and maintenance. This study develops a model which spans these different disciplines in effort to evaluate LCC sensitivities to different designs and critical parameters.

This report presents the methods and sample results for evaluating the Space Stations LCC with a Solar Dynamic Power Subsystem. Information on the prior years study during 1986 is provided in the following paragraph to provide a background for this report. Detailed information can be found in Ref 1.

2 Scope of the 1986 Study

The 1986 MDD study kicked-off an investigation of Space Station controls and structural design using LCC as a design criteria for evaluating different design configurations. Subsystem cost relationships were combined with engineering design and analysis techniques so that subsystem costs could be based on user defined parameters. The 1986 effort concluded with a multi-disciplinary computer program capable of estimating basic Space Station LCC. The Space Station dual keel configuration, Fig 1, was used for the basis of analyses and costing components.

The cost characteristics of the Space Station control system and structure from conceptual design through on-orbit operations were defined so that costs over the entire life cycle could be estimated. Space Station life cycle costs were categorized by the following characteristics.

- Non-recurring design
- Launch
- Expendables replenishment
- Part failure, replacement, and maintenance
- Ground support

- Software

The basic assumption for calculating the Space Station LCC is that identifiable costs characteristics can be related to engineering design variables. The LCC is sensitive to changes in the engineering design variables such that,

$$LCC = \frac{\partial(LCC)}{\partial \underline{C}} \underline{C}(\underline{\Theta}) \quad (1)$$

where,

$$\begin{aligned} \underline{C} &= \text{Vector of cost characteristics} \\ \underline{\Theta} &= \text{Vector of design variables} \end{aligned}$$

It should be noted that the LCC sensitivity to the cost characteristics in (1) are not explicitly known but the sensitivity to design parameters can be derived once the relationships between the design parameters and the cost characteristics have been defined.

Next, the Space Station subsystem design parameters were defined. Typical design parameters such as structural component types, weight, quantity as well as controls parameters such as numbers and types of sensors and actuators, flexible structure data, mass properties, and orbital parameters are input to the computer program. Engineering and programatic relationships are used to further define cost estimates beyond simple non-recurring cost estimates.

The final phase of the 1986 study combined the LCC and subsystem design parameter relationships in a single computer program called the Multi-Disciplinary Design Tool. At this point, the computer program became truly multi-disciplinary as structural, control subsystem, orbital dynamics and subsystem cost relationships are interrelated. The Multi-Disciplinary Design Tool (MDDT) performs design studies by evaluating different control system and structure designs for performance and LCC. Controller performance is evaluated and output with the cost data.

3 Scope of the 1987 Study

The 1987 Multi-Disciplinary Design Study is a continuation of the 1986 study. The 1987 task is directed at modeling and costing aspects of the Solar Dynamic Power Subsystem (SDPS). Cost sensitivity and design parameters were identified for SDPS and brought together in a fashion similar to the Space Station controls and

structural subsystems. Life cycle cost and performance algorithms for the SDPS system were incorporated into the MDDT computer program using the same cost characteristics defined in Ref 1. Impacts of the SDPS design on the Space Station LCC are also calculated in MDDT using common algorithms in subroutines. SDPS power output and combined SDPS and Space Station LCC are calculated and output for off-line evaluation.

The Space Station model considered for 1987 is the single transverse boom configuration, Fig 2. The MDDT computer program is not structural design unique so that reprogramming is not required to change the model. Rather, the data input file requires updating for parameters such as number of structural components, surface areas for drag calculations, etc. Mass properties and flexible structure information specific to the configuration can be either read from the IMAT data file or taken directly from the user specified input file.

Several "clean-up" tasks were included to make the program more user friendly and linearize some of the computations.

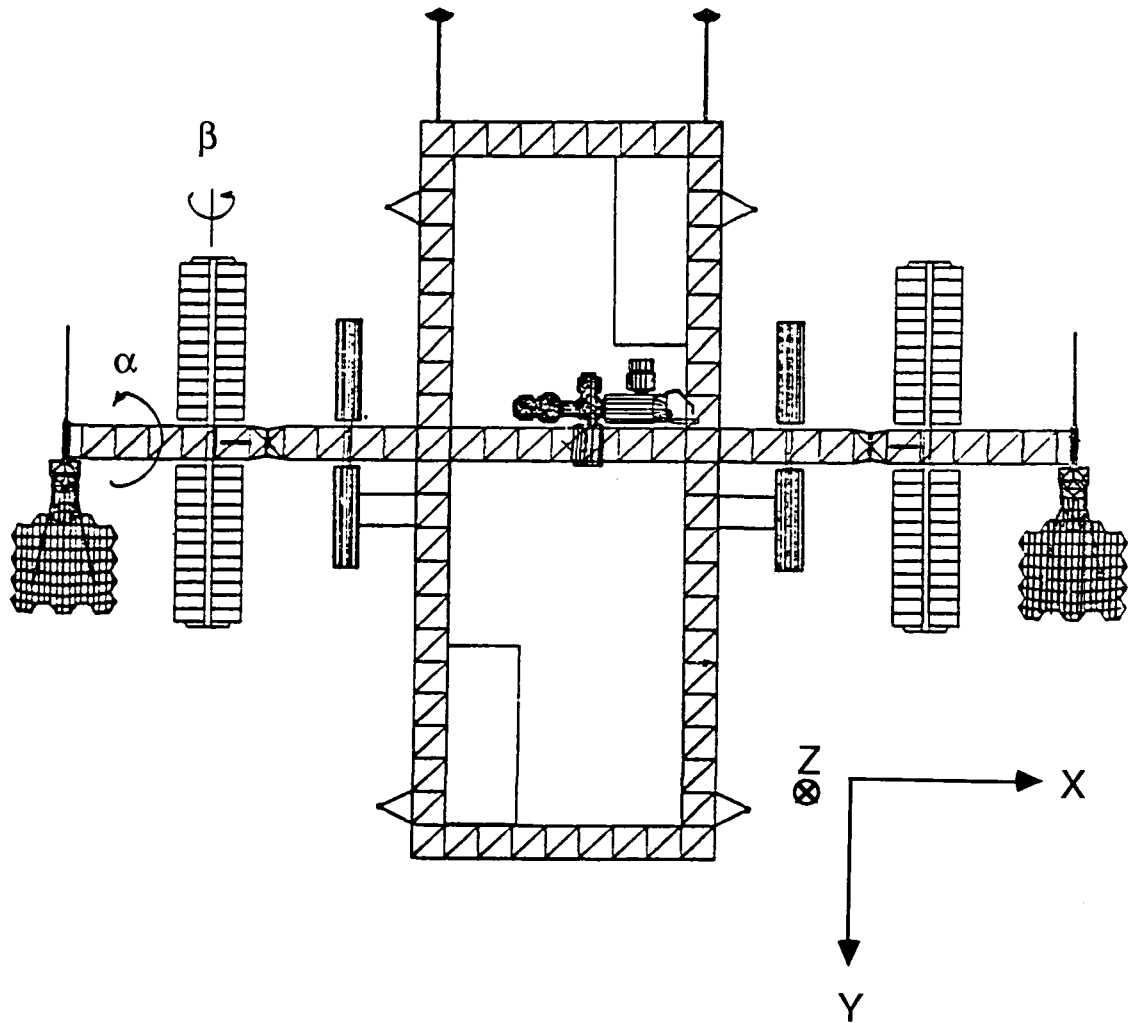


Figure 1: Space Station Dual Keel Configuration (1986)

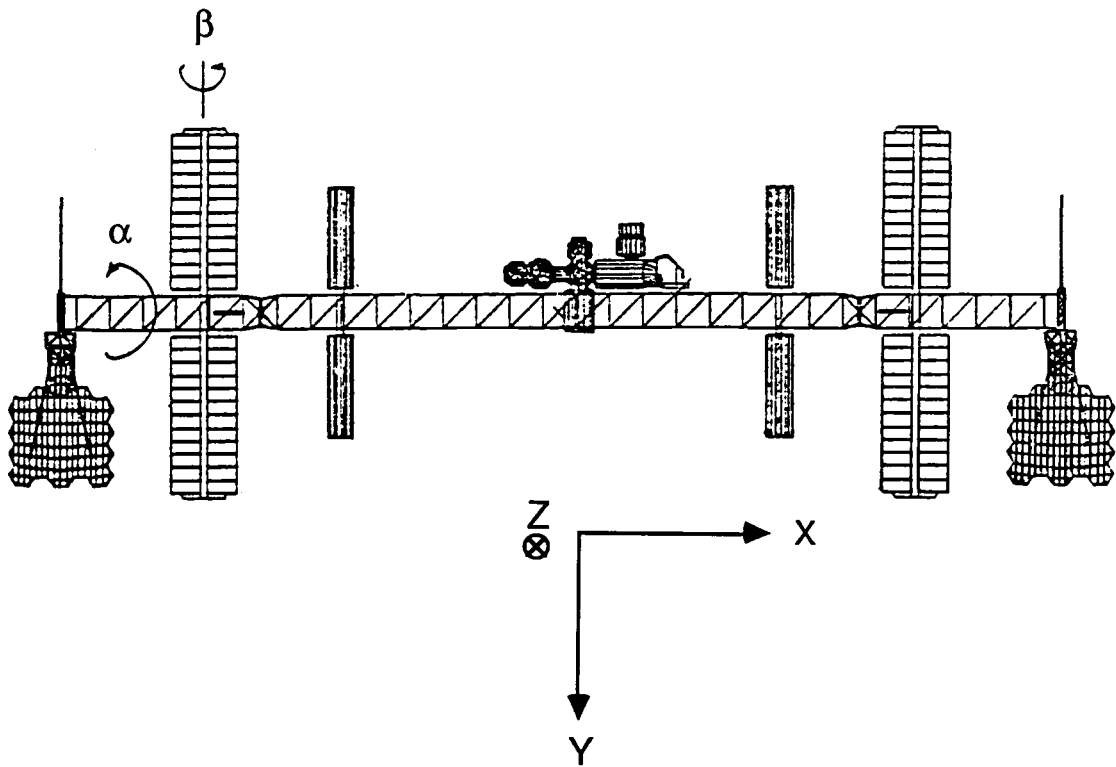


Figure 2: Space Station Transverse Boom Configuration (1987)

4 MDDT Program Flow and IMAT Interface

The MDDT computer program has been upgraded to include specific cost and performance related algorithms for SDPS. Fig 3 depicts the current subroutine calling sequence¹ for the main program. Fig 4 depicts the program architecture where the SDPS specific routines and calling sequence is shown in greater detail.

One of the study tasks for 1987 is to provide a capability in MDDT to access structural data files from Langley's Integrated Multi-Disciplinary Analysis Tool (IMAT). Early in the study, the decision was made to make the MDDT program interact with IMAT off-line, especially since MDDT needed only the structural and mass properties data anyway. As a result, the interface with IMAT is relatively simple. The burden is placed on the user to assure that the MDDT configuration such as number of components, exposed surface areas, etc, are consistent. Once a baseline model has been chosen, the same IMAT data can be reused as often as the user requires.

Fig 5 depicts the interfaces between MDDT which resides on a DEC Vax computer and the IMAT data which resides on the CDC Cyber computer. The objective of the interface design is to create a data file which can be accessed by MDDT, called **GEINPUT**. If the user needs to create a new version of **GEINPUT**, the user executes a command file called **GEDATA** which in turn executes a Fortran file, **IMAT_MDD**. **IMAT_MDD** prompts the user for information required for **GEINPUT**. Next, **GEDATA** grabs the user requested information from the IMAT data base on the Cyber and sends it back to the Vax in the formatted file, **GEINPUT**.

Note that the user needs to interface only with **GEDATA.COM** and, of course, MDDT. It is assumed that the user possesses the necessary Cyber account for accessing the IMAT data. During execution of **GEDATA**, the user will be requested to provide a Cyber account name and password.

¹See *MDDT User Manual, 1987* for a complete description and Fortran listing of the subroutines.

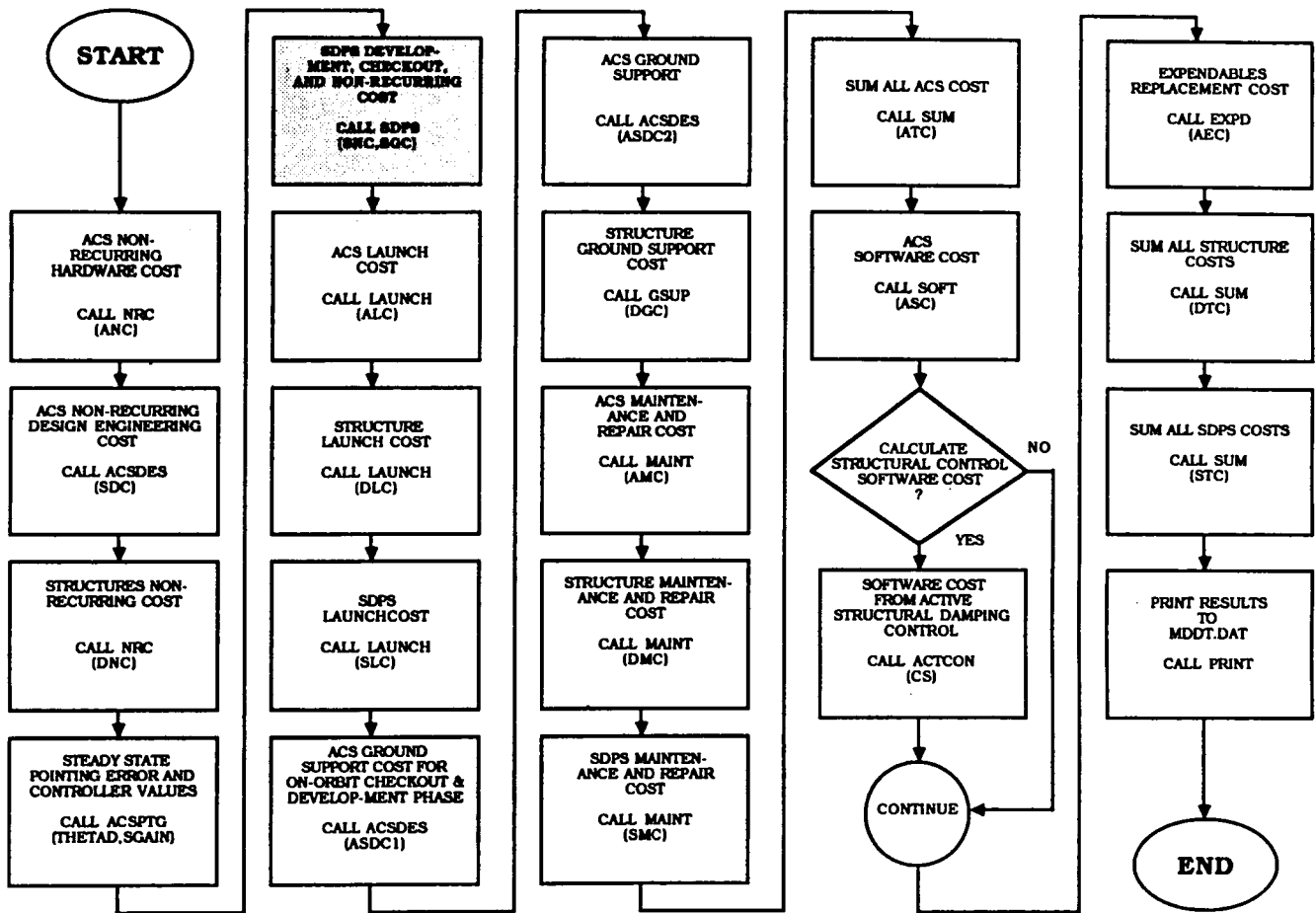


Figure 3: Multi-Disciplinary Design Tool Program Flow Diagram.

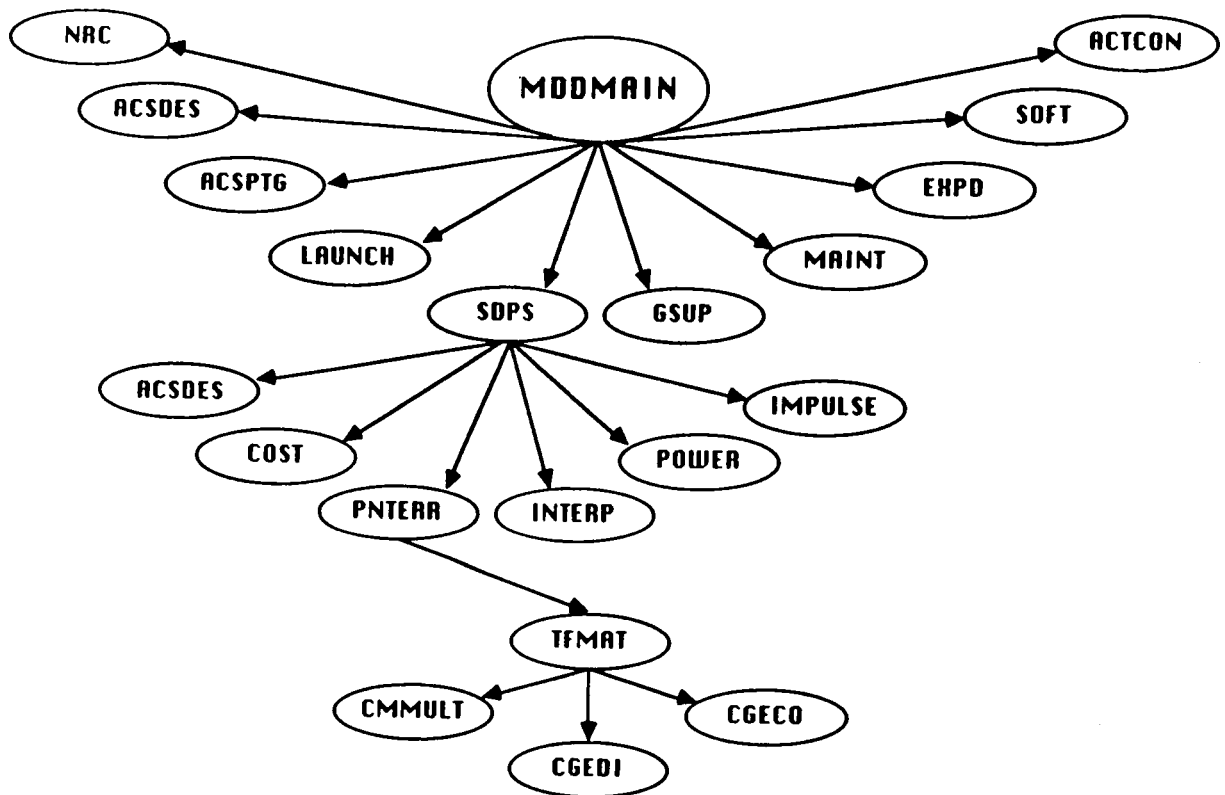


Figure 4: Multi-Disciplinary Design Tool Program Architecture with Solar Dynamic Power Subsystem Routines.

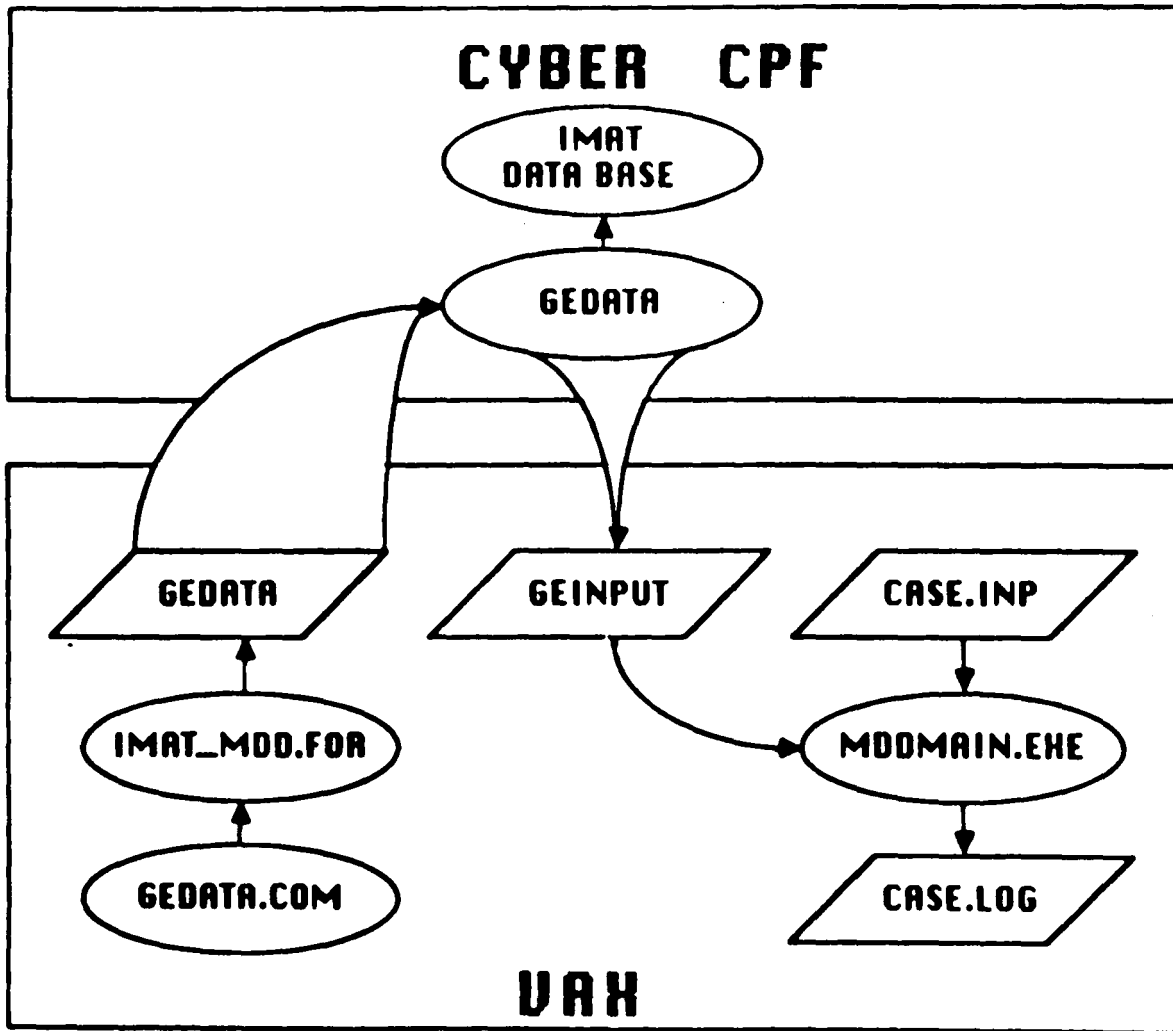


Figure 5: Multi-Disciplinary Design Tool and the Integrated Mult-Dsciplinary Analysis Tool Interface Flow Chart.

5 Solar Dynamic Power System LCC Model

A life cycle cost model of the Solar Dynamic Power System (SDPS) was developed for MDDT which relates the design variables to the cost characteristics. The purpose of the SDPS is to convert solar energy into electrical energy. The effectiveness of this system depends greatly on pointing accuracy of the solar reflector with respect to the sunline. Since the SDPS must be able to deliver a minimum of 37.5 kW of power regardless of design changes, power output is the SDPS design constraint for costing and cost optimization. The performance parameter which relates directly to power output is pointing error of the solar reflector. Design variables have been identified and their relationships to pointing error developed for the SDPS. The MDDT computer program computes, with a pointing performance measure, the non-recurring cost associated with various SDPS designs.

Pointing the SDPS is accomplished using two rotary joints (the α and β joints) which align the SDPS to the sun line. Errors in α and β joint positioning will therefore contribute to SDPS reflector pointing error. SDPS pointing will also be influenced by vibrations of the supporting structure. Because support structure rigidity relates to performance, it can also be traded against life-cycle cost.

SDPS power output is also influenced by the size of the reflector. Increased reflector area will result in a greater amount of solar energy captured but will increase the overall weight of the structure. Therefore, reflector area is also a design variable which relates directly to power output. The major design variables added to MDDT for the 1987 study are,

- α joint accuracy, $\Delta\theta_x$
- β joint accuracy, $\Delta\theta_y$
- Structural rigidity (eigenvalues and eigenvectors)
- Reflector size

Fig 6 illustrates the relationship between the design variables and the captured energy design constraint. The items in blocks are the intermediate parameters and mathematical models used to complete the relationship. These parameters and models are described in detail in the following paragraphs.

5.1 Solar Energy Distribution

The Solar Dynamic Power System reflector is an offset parabolic mirror which is designed to focus the solar energy onto the collector aperture, Fig 7. Because the reflector is not a perfect parabola, and due to mirror surface discontinuities

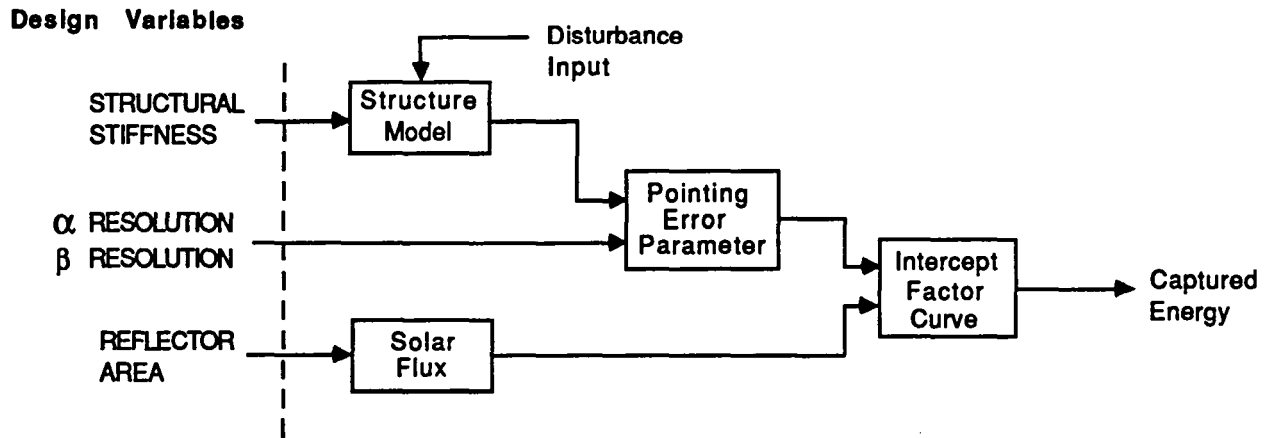


Figure 6: Design Variable to Energy Relationship.

and debris, the reflector will concentrate the solar energy over a region in space. It has been shown through the use of ray-tracing algorithms [1] that the actual energy flux will be a two-dimensional Gaussian distribution of standard deviation σ with a maximum flux density located at the center of the region, as shown in Fig 7. A collector aperture of finite size will no longer capture 100% of the energy contained in the distribution because of its gaussian shape. If the center of the distribution, which is the location of maximum energy density, is perfectly aligned with a collector aperture having diameter 3σ . Then, 99.7% of the reflected energy will be captured. Misalignment of the distribution peak (mean) with respect to the center of the aperture will result in a decreased amount of captured energy, Fig 8.

5.2 Pointing Error

SDPS reflector pointing inaccuracies result in reduced power available at the collector aperture. Dynamic and static pointing error sources are modeled. Total pointing error is expressed as one quantity called a quasi-static or time averaged. Both forms of pointing error are independently examined then combined into the total pointing error.

- **Static Pointing Error.** Static pointing error of the reflector is caused by inaccuracies in the gimbal drive pointing and gimbal alignment distortions. The gimbal drive pointing inaccuracies are the result of the digital nature of the stepper motors which drive the joints and rotate the reflector. The total gimbal errors of the α joint is represented by $\Delta \theta_x$ and that of the β joint by $\Delta \theta_y$, Fig 9.

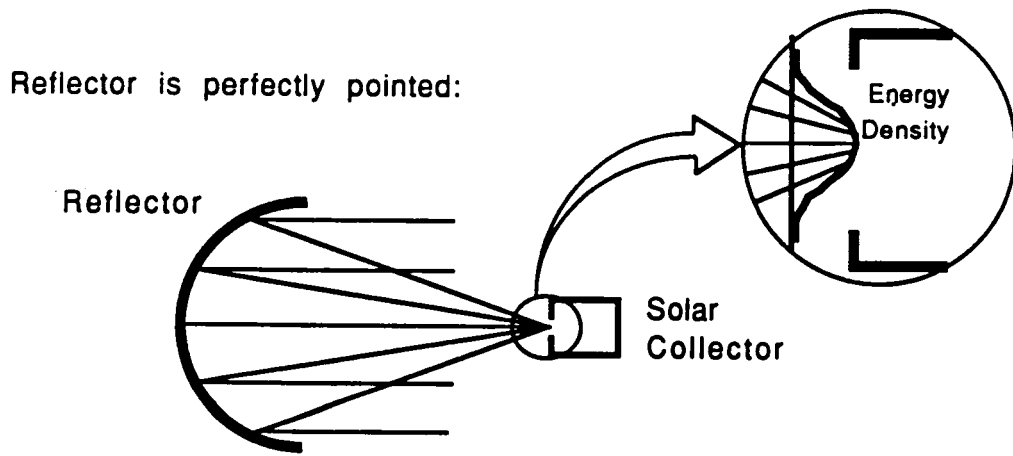


Figure 7: Reflected Energy Density.

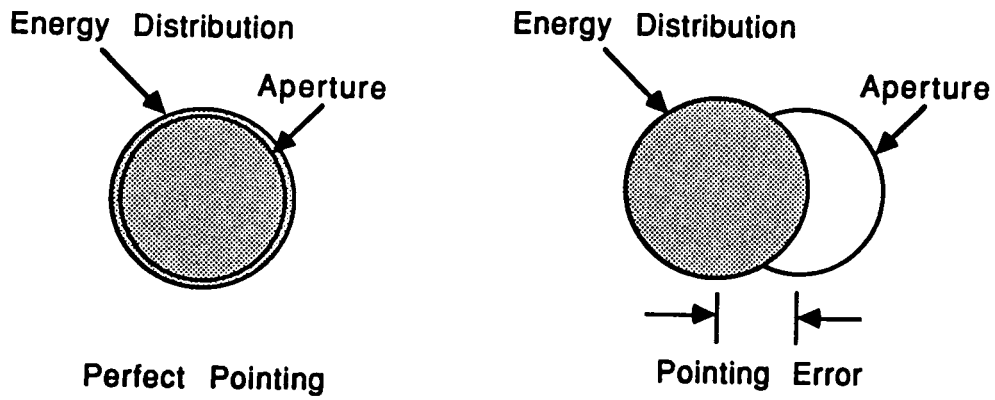


Figure 8: Solar Power Collector Efficiency.

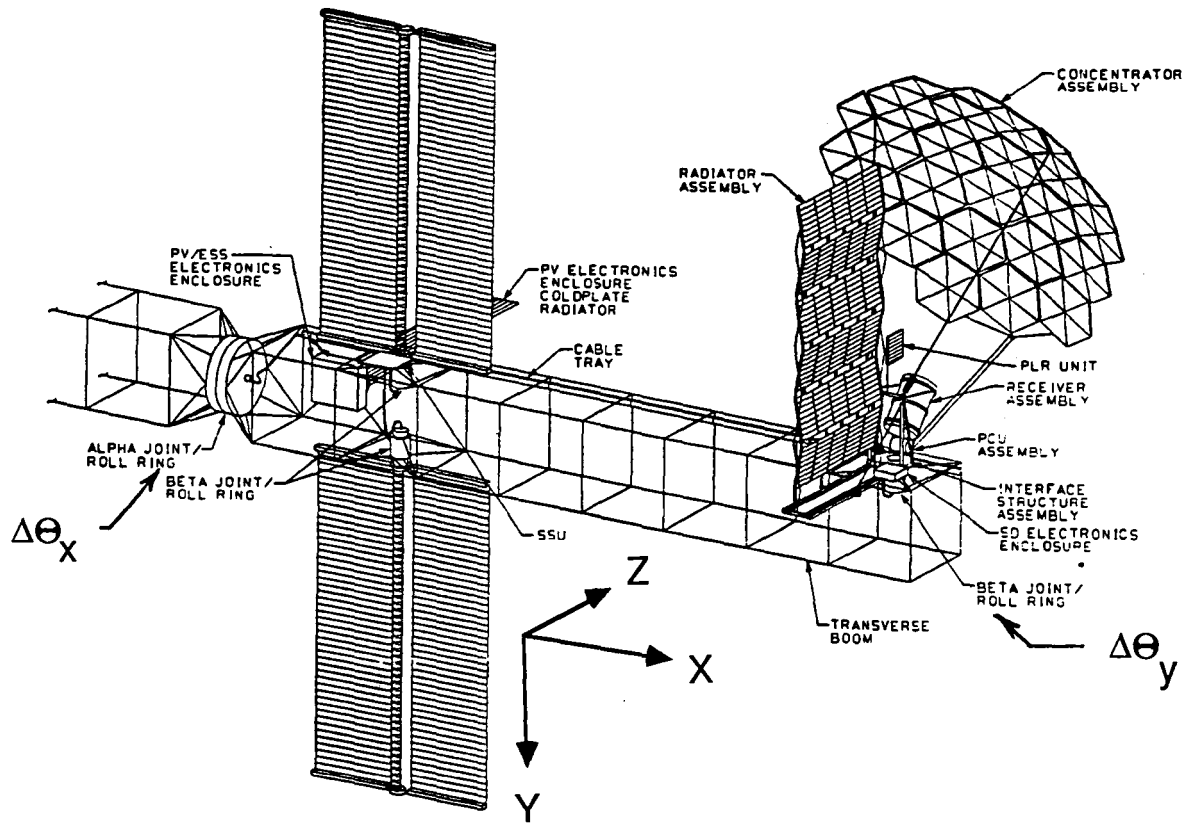


Figure 9: SDPS with α and β Gimbal Configuration.

- Dynamic Pointing Error.** Dynamic pointing error of the reflector results from vibrations of the SDPS support structure, and is a time-varying quantity as shown in Fig 10. It must be converted into a pseudo-static quantity so that it can be combined with static error to yield an equivalent constant pointing error measure. The root-sum-square (RSS) value of the vibratory response of the support structure at the location of the SDPS is chosen as the quasi-static measure of pointing error since it represents the effective constant value of delivered power over long periods of time. The following section derives the transfer function for pointing error sensitivity to input disturbances.

The static and dynamic pointing error are combined into one quantity, which is referred to as the total pointing error of the reflector. This quantity is the sum of the two sources for each axis,

$$\delta\theta_x = \Delta\theta_x + \bar{\theta}_x \quad (2)$$

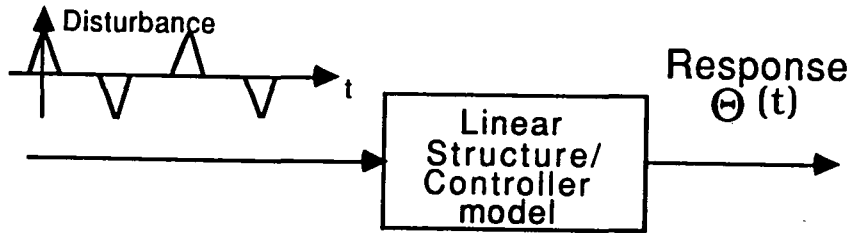


Figure 10: Linear Structure Model.

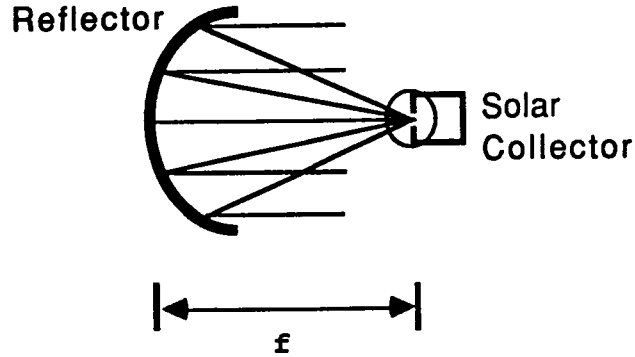


Figure 11: Solar Reflector and Collector Configuration.

$$\delta\theta_y = \Delta\theta_y + \bar{\theta}_y \quad (3)$$

where $\bar{\theta}_x^2$ and $\bar{\theta}_y^2$ are the effective values of the dynamic pointing error about the x and y axes and are defined in the next section. Note that the total pointing error is an angular quantity, and must be converted to a measure of distance. The total pointing error multiplied by the focal length of the reflector, f , becomes a measure of the distance from which the center of the energy distribution is displaced from the center of the aperture, Fig 11.

$$r_x = f \delta\theta_x \quad (4)$$

$$r_y = f \delta\theta_y \quad (5)$$

$$r_{total} = \sqrt{r_x^2 + r_y^2} \quad (6)$$

6 Dynamic Pointing Error

All of the dynamic pointing error is attributed to the response of the rigid body with the classical closed loop controller and to the flexibility of the space station structure. A model of the flexible space station with classical rigid body controller is created in MDDT in state space form. The open loop disturbance sensitivity transfer function is then created and evaluated for user specified disturbances. The current disturbance modeled in MDDT is that of an astronaut kick-off.

The linear, time-invariant state space model is defined by,

$$\dot{x}(t) = Ax(t) + Bu_{ctrl}(t) + B_{dist}T_{dist}(t) \quad (7)$$

$$u_{ctrl}(t) = Ky(t) \quad (8)$$

$$y(t) = Cx(t) \quad (9)$$

where,

A	=	system matrix
B	=	control input matrix
B_{dist}	=	disturbance input matrix
C	=	control observer matrix
K	=	gain matrix
u_{ctrl}	=	vector of control torques
T_{dist}	=	vector of disturbance torques
x	=	state vector
y	=	output (sensor) vector

and the state vector is defined by,

$$x = \begin{pmatrix} \dot{\phi} \\ \dot{\theta} \\ \dot{\psi} \\ \phi \\ \theta \\ \psi \\ \dot{q}_1 \\ q_1 \\ \dot{q}_2 \\ q_2 \\ \cdot \\ \cdot \\ \cdot \\ \dot{q}_n \\ q_n \end{pmatrix} \quad (10)$$

where,

- ϕ, θ, ψ = Euler angles, roll, pitch, yaw
- q_i = i th structural normal mode coordinates
- n = number of structural modes in model

Note that the linearized equations of motion for this system assume small angles of rotation so that the order of rotation can and is arbitrary. A straight forward derivation in the frequency domain of the disturbance sensitivity transfer function at the SDPS yields,

$$G(s) = \frac{\Omega_{x,y}(s)}{T_{dist}(s)} = C_{SDPS} \{sI - A - BKC\}^{-1} B_{dist} \quad (11)$$

$$= \begin{pmatrix} g_{11} & g_{12} & g_{13} \\ g_{21} & g_{22} & g_{23} \\ \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot \\ g_{61} & g_{62} & g_{63} \end{pmatrix} \quad (12)$$

where,

- $\Omega_{x,y,z}$ = Vector of x, y, z dynamic pointing errors and rates at the SDPS
- $T_{dist}(s)$ = Fourier transformation of the input disturbances vector
- B_{dist} = Disturbance input matrix
- C_{SDPS} = Observer matrix for the SDPS
- s = Laplace operator for complex radian frequency, $j\omega$

A disturbance with known frequency content will result in attitude and rate errors at the SPDS which can be computed using Eqn 11. As the system is assumed linear, the response at the SPDS is a linear combination of the inputs. A Fourier transformation of an input sequence can be used to evaluate the net response of all the harmonics given by the Fourier transform of the input.

The input disturbance is assumed to be a narrow square wave with the following characteristics which are input to MDDT by the user.

- 1 lb amplitude.
- 0.2 second pulse width.
- 26 second period.

MDDT computes the amplitude of the Fourier coefficients and the frequencies using an FFT algorithm for the the first 20 harmonics of the square wave shape. Fig 12 shows the ideal square wave disturbance and it's Fourier transformation.

MDDT then computes the Space Station response and the RMS value of the response using Eqn 11 evaluated at each harmonic frequency of the FFT disturbance. The total response at the SDPS due to all harmonics is approximated by RSSing the RMS response of all 20 Fourier series terms so that,

$$\bar{\theta}_x = \sqrt{\sum_{i=1}^p \left\{ \frac{1}{\sqrt{2}} [|g_{41}(j\omega_i)| |T_x(j\omega_i)| + |g_{42}(j\omega_i)| |T_y(j\omega_i)| + |g_{43}(j\omega_i)| |T_z(j\omega_i)|] \right\}^2} \quad (13)$$

and,

$$\bar{\theta}_y = \sqrt{\sum_{i=1}^p \left\{ \frac{1}{\sqrt{2}} [|g_{51}(j\omega_i)| |T_x(j\omega_i)| + |g_{52}(j\omega_i)| |T_y(j\omega_i)| + |g_{53}(j\omega_i)| |T_z(j\omega_i)|] \right\}^2} \quad (14)$$

where $p = 20$, the number of harmonic frequencies in the fast fouier transform, FFT. Note that the dynamic pointing error analysis does not include $\bar{\theta}_z$ as this error is about the sunline which does not degrade solar energy collection.

Table 1: Solar Dynamic Power System Energy Losses

Source	Power Loss (<i>kW</i>)
Reflector Losses	37.8
Receiver Losses	30.0
Thermal Energy Storage	122.1
Rejected Energy	137.9
Miscellaneous Losses	12.2

6.1 Efficiency: The Intercept Factor

Collector efficiency is related to total pointing error through a mathematical function called the Intercept Factor, Ref 2. This function relates pointing error to the fraction of reflected energy which is captured by the collector. Captured energy must meet or exceed a minimum energy threshold if the SDPS is to deliver its required power output of 37.5 *kW*, Ref 3. The minimum energy threshold for this analysis is 377.5 *kW* of solar energy. This minimum is based on power required to the Space Station and on SDPS losses which are itemized in Table 1.

The form of the intercept factor function is as shown in Fig 13². The intercept factor is essentially the fraction of total reflected solar energy that is captured by the collector, and is obtained by integrating the Gaussian flux distribution over the region of space that it has in common with the collector aperture. The intercept factor provides a means by which to test the SDPS design against the design constraint, which is the minimum allowable captured energy which will still provide for normal power cycle output of 37.5 *kW*.

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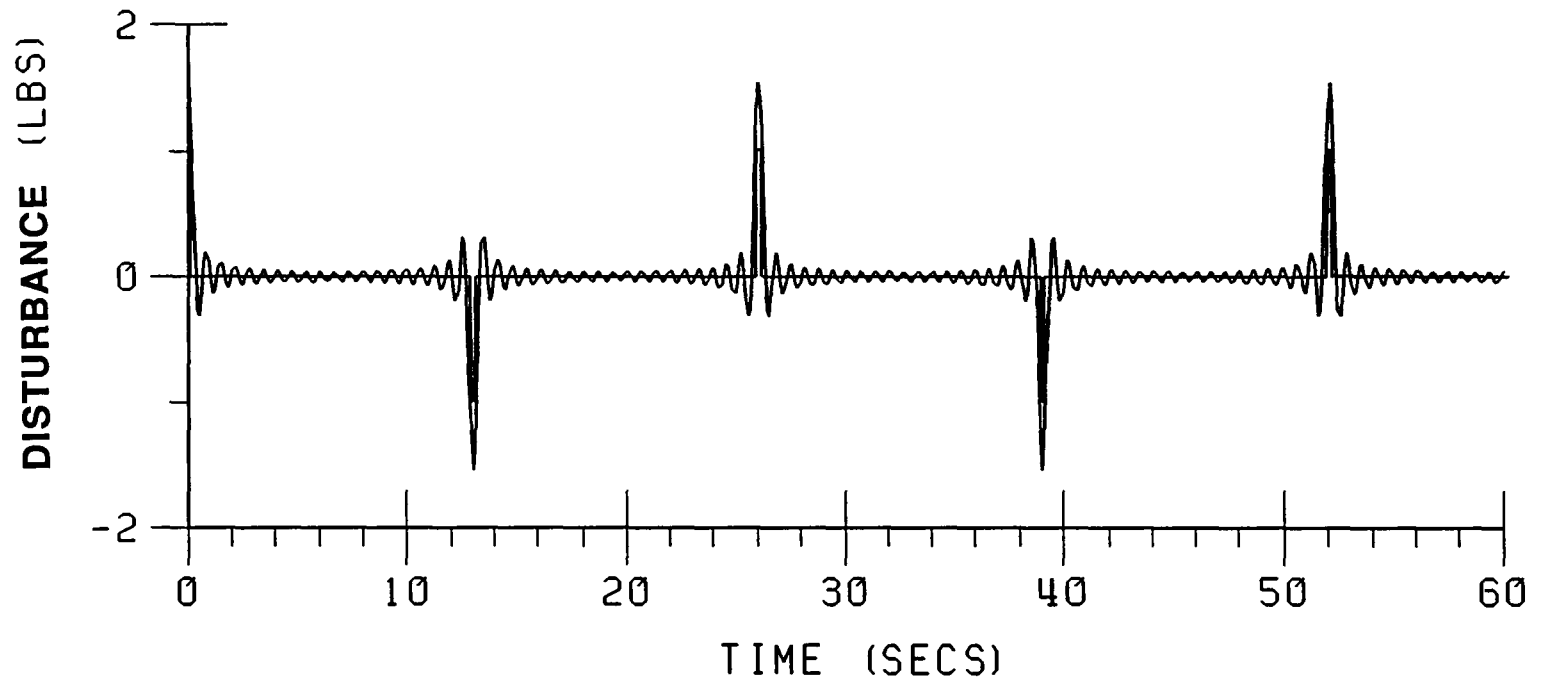
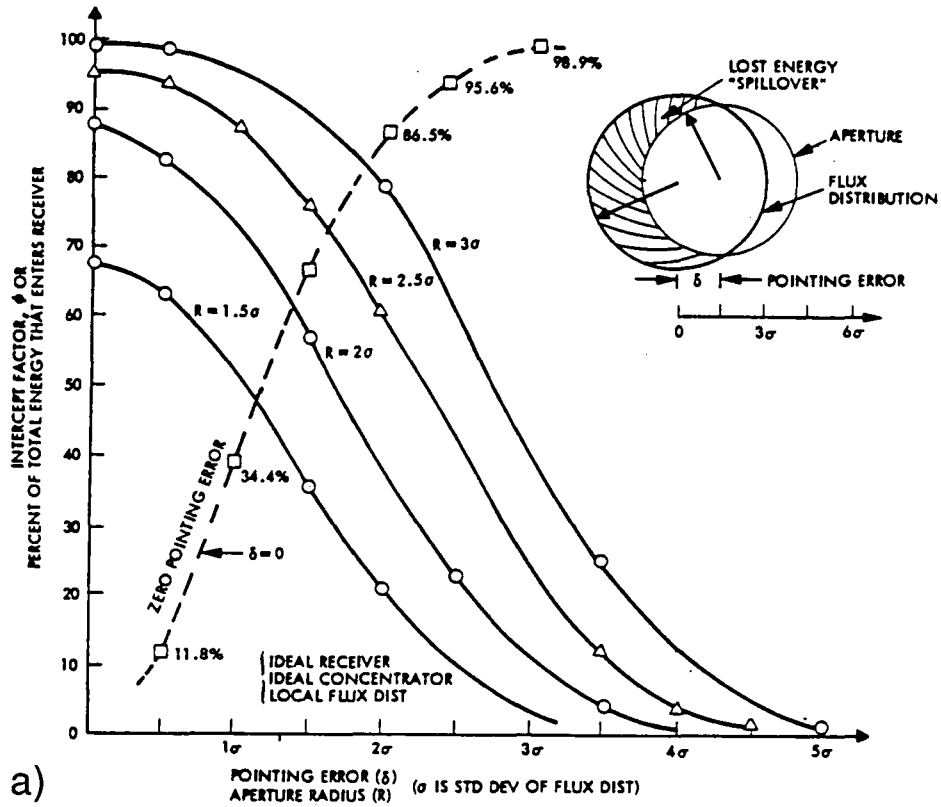
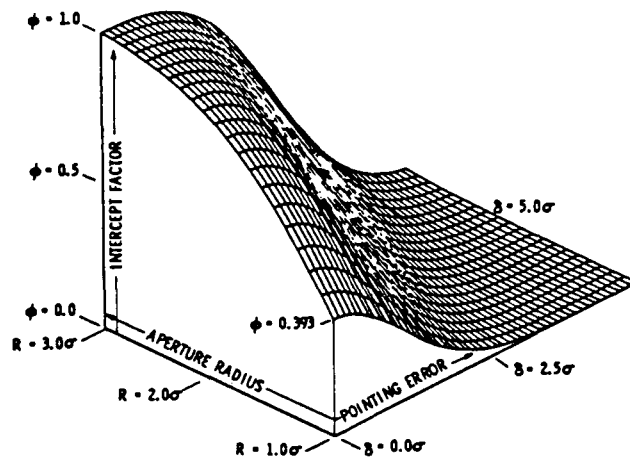


Figure 12: Square Wave Disturbance and FFT Approximation.



a)



b)

Figure 13: Intercept Factor Function.

Table 2: PRICE Model Subsystem Cost Data

Subsystem Design Parameter	Parameter Value	Cost (\$ millions)
High Cost Extreme:		
α pointing	0.01 deg	26.768
β pointing	0.01 deg	11.024
SDPS reflector area	345.00 m ²	192.819
Low Cost Extreme:		
α pointing	1.00 deg	11.043
β pointing	1.00 deg	4.428
SDPS reflector area	287.50 m ²	189.228

6.2 Cost Data

A range of non-recurring cost data associated with various SDPS designs was determined for the hardware subsystems. These subsystems include the solar dynamic power system and the α and β joint gimbals. The computer program Parametric Review of Information for Costing and Evaluation, PRICE, Ref 4 was used to determine high and low non-recurring cost extremes for the gimbals and the SDPS subsystems.

The PRICE program provides a standard and systematic means for estimating costs of the new hardware. The inputs to PRICE are assumed to be representative of the capability of subsystem to be costed. The PRICE inputs consist of parameters which have been estimated based on the top level subsystem design parameters, gimbal pointing accuracy and SDPS reflector area. From these top level design parameters, the PRICE inputs such as; weight, subsystem type (mechanical/electrical) reliability, design repetitiveness, and design and manufacturing complexity are estimated.

PRICE models for the α and β joints are new. The SDPS model was a modified version of an existing model which was created during a previous space station study, Ref 3. It was modified to include the reflector hardware. Changes in reflector size were related directly to SDPS weight in order to specify a range of SDPS reflector size and associated cost data. Likewise, changes in α and β joint accuracy were related to design and manufacturing complexity parameters to yield a range of gimbal cost data. Table 2 lists the ranges of PRICE generated cost data for each of the subsystems.

6.3 Solar Dynamic Power Subsystem Design Verification

The following are the basic steps which the MDDT program follows in the verification of a SDPS design:

1. Given the structural modal parameters, compute the response of the support structure at the location of the SDPS.
2. Compute the effective value of the dynamic pointing error.
3. Combine with the input static error and compute total pointing error.
4. Compute reflected solar energy based on reflector area.
5. Compute captured solar energy using Intercept Factor relationship.
6. Compare with design constraint of 377.5 kW.
7. Accept or reject design.

7 Solar Dynamic Power Subsystem Design Study

MDDT can easily be employed to perform preliminary design trades for α and β gimbal accuracy studies and solar reflector sizing. By keeping all parameters but the parameter of interest constant, and assuming that the effect of the variable parameter on all other parameters is second order and higher, a sensitivity study of LCC to the design variable of interest can be made. Other trades involving structural stiffness and damping can be made so that design requirements can be partitioned in an equitable and a cost effective manner.

The following paragraphs summarize the results of SDPS gimbal accuracy and reflector size study. The resulting LCC sensitivity includes effects such as assumed non-recurring costs, part reliability, mass, launch costs, and expendables due to the independent variable changes.

7.1 Gimbal Accuracy Optimization

Sensitivity of LCC to gimbal pointing accuracy can be achieved using MDDT. This analysis is based on the following Space Station configuration as an example.

- Single transverse boom structure configuration.
- The astronaut kickoff force depicted in Fig 12.

- Two structural resonances of equal mode size in Space Station x and y axes.
- Structural damping ratio of 0.01 (1.0% of critical).
- Constant solar reflector configuration (area, efficiency, mass).

Fig 14 is a graph of the incremental Space Station LCC, Δ LCC, as a function of varying α and β gimbal accuracy. Note that gimbal accuracies less than 0.1 *degrees* do not provide any significant increase in power output. This is because the baseline SDPS reflector and aperture design are capable of a maximum 336 *kW* with perfect pointing (i.e. the intercept factor is near 1.0) and gimbal pointing errors < 0.1 *degrees* is essentially perfect for this SDPS design. Likewise, it is interesting to note that a willingness to accept 5 *kW* less would result in a $> \$20$ *million* LCC savings.

7.2 Reflector Area Optimization

In similar fashion as the previous example, the effects of varying the SPDS reflector area can be assessed. This example assumes the same basic configuration as the gimbal accuracy study with the exception that the gimbal accuracy is held fixed at 1.0 *degrees* and the reflector area is varied. Fig 15 graphs the increased power and LCC due to increased reflector area.

A comparison of Figs 14 and 15 leads to the conclusion that the first \$20 *million* is better spent on increasing the reflector area instead of the more accurate gimbal design because the power increase is 58 *kW* for the larger reflector versus a 36 *kW* increase with the 0.3 *degree* gimbal design.

However, blindly increasing the reflector area in order to increase the SDPS power output can violate the assumption that the parameter variation has second order or higher effects on other design parameters held constant. The structural dynamic properties of the space station change with the reflector size. The dynamic properties should be recalculated when reflector area is increased greater than 20% in order to maintain the fidelity of the Space Station model.

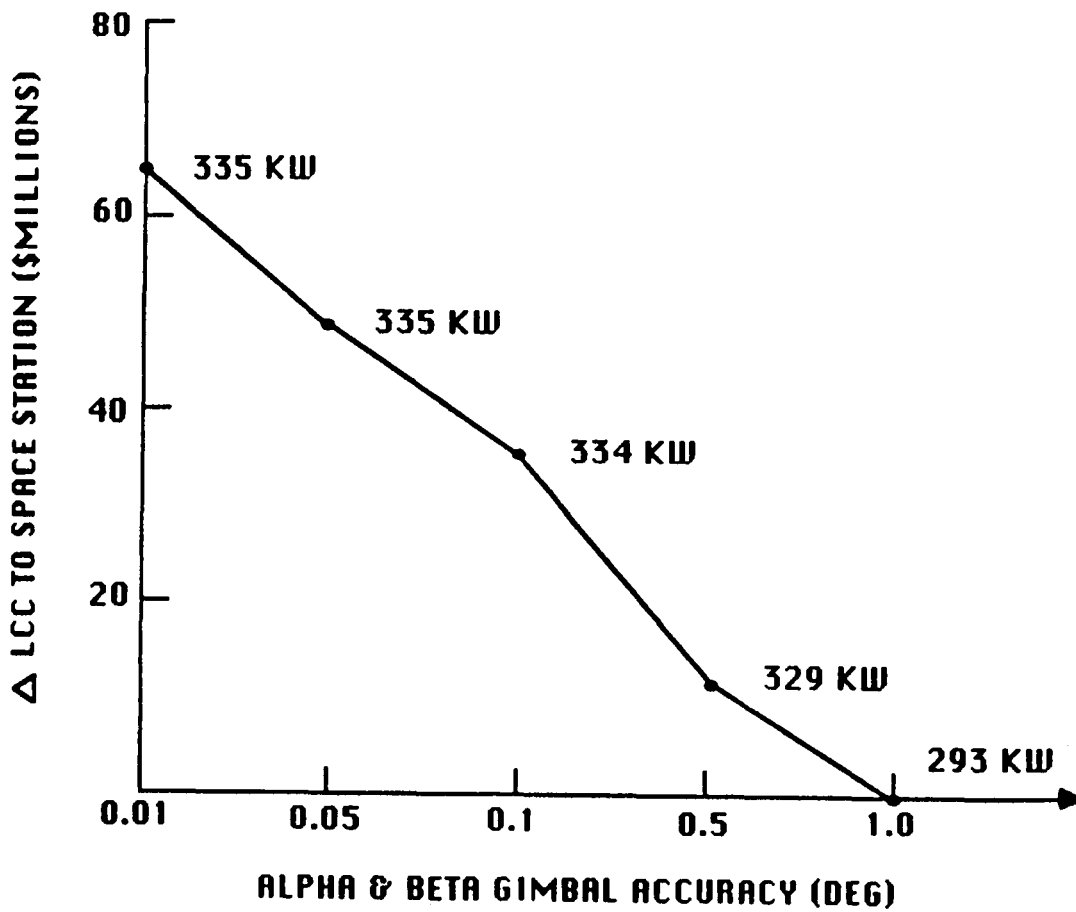


Figure 14: Gimbal Accuracy, SDPS Power Output, and LCC Analysis.

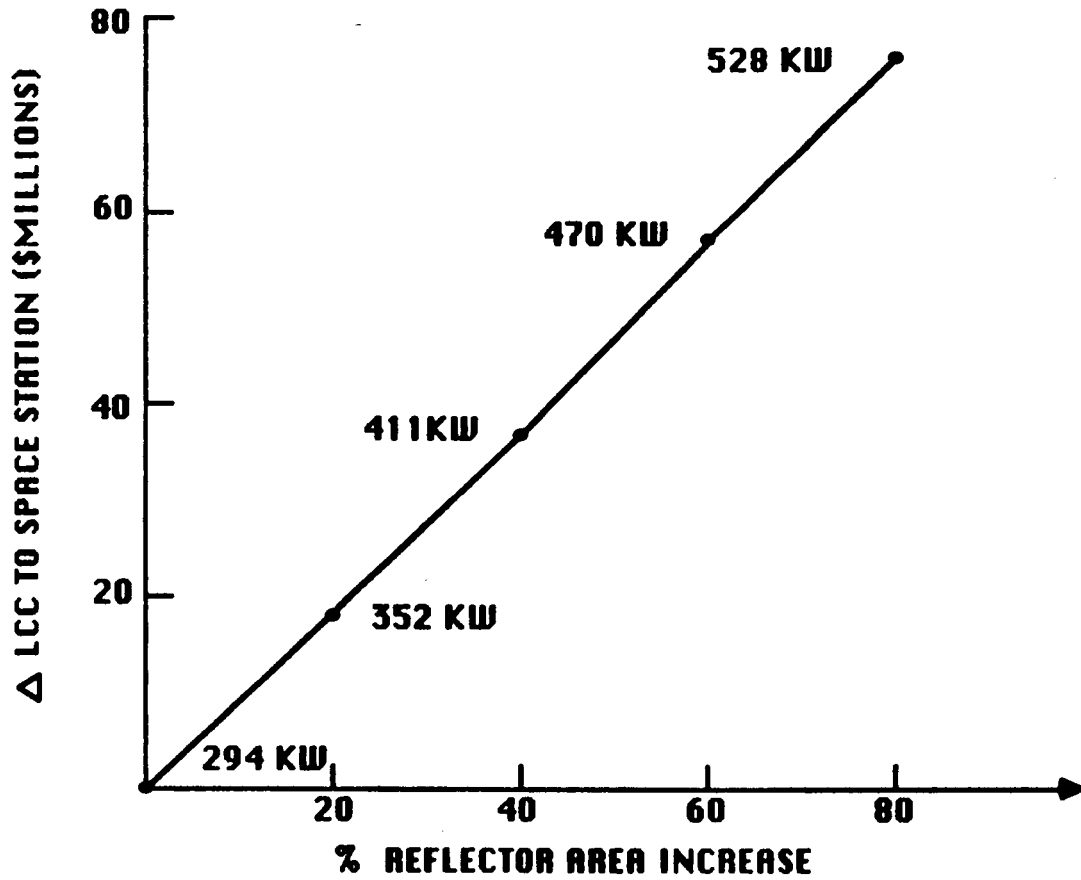


Figure 15: Reflector Area, SDPS Power Output, and LCC Analysis.

8 Summary

The Multi-Disciplinary Design Study has been completed with all objectives accomplished during 1986 and 1987. This report documents the approach and results of a Life Cycle Cost analysis of the Space Station Solar Dynamic Power Subsystem (SDPS) including gimbal pointing and power output performance. The MDDT computer program developed during the 1986 study has been modified to include the design, performance, and cost algorithms for the SDPS as described herein. As with the Space Station structural and controls subsystems, the LCC of the SDPS can be computed within the MDDT program as a function of the engineering design variables. Two simple examples of MDDT's capability to evaluate cost sensitivity and design based on LCC are included in the final section of this report.

MDDT has been designed to accept NASA's IMAT computer program data as input so that IMATs detailed structural and controls design capability can be assessed with expected system LCC as computed by MDDT. No changes to IMAT were required. Detailed knowledge of IMAT is not required to perform the LCC analyses as the interface with IMAT is non-interactive.

9 References

1. Harding, R.R., J.M. Duran, R.R. Kauffman, *The Multi-Disciplinary Design Study, A Life Cycle Cost Algorithm*, Contract NAS1-18032, CR-178192, May 1987.
2. Hughes, R. O., *Effects of Pointing Errors on Receiver Performance for Parabolic Dish Solar Concentrators*, Thirteenth Intersociety Energy Conversion Engineering Conference, San Diego CA. August, 1978.
3. *Space Station WP-04 Power System, Preliminary Analysis and Design Document DR-02*, Rocketdyne Division (RI/RD85-320), Canoga Park, CA, NAS 3-24666, 12/16/85.
4. *PRICE H (Hardware) Reference Manual*, RCA, 1985.



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16 Abstract <p>The Multi-Disciplinary Design Study has been completed with all objectives accomplished during 1986 and 1987. This report documents the approach and results of a Life Cycle Cost (LCC) analysis of the Space Station Solar Dynamic Power Subsystem (SDPS) including gimbal pointing and power output performance. The Multi-Discipline Design Tool (MDDT) computer program developed during the 1986 study has been modified to include the design, performance, and cost algorithms for the SDPS as described herein. As with the Space Station structural and controls subsystems, the LCC of the SDPS can be computed within the MDDT program as a function of the engineering design variables. Two simple examples of MDDT's capability to evaluate cost sensitivity and design based on LCC are included in the final section of this report.</p> <p>MDDT has been designed to accept NASA's IMAT computer program data as input so that IMAT's detailed structural and controls design capability can be assessed with expected system LCC as computed by MDDT. No changes to IMAT were required. Detailed knowledge of IMAT is not required to perform the LCC analyses as the interface with IMAT is non-interactive.</p>					
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