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COST STUDY OF SOLAR CELL SPACE POWER SYSTEMS

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SUMMARY

A study of historical costs for solar cell space power systems was made by a NASA ad hoc study group. The study covered thirteen missions that represented a broad cross-section of flight projects over the past decade. Fully burdened costs in terms of 1971 dollars are presented for the system and the solar array. The costs correlate reasonably well with array area and do not increase in proportion to array area. The trends for array costs support the contention that solar cell and module standardization would reduce costs.

INTRODUCTION

In 1971 a study was made of solar cell space power systems for NARA-OART. The study was performed by an NASA ad hoc group consisting of the author; Anthony T. Diamond, NASA-HQ; John Goldsmith, JPL; Charles M. MacKenzie, GSFC; Jimmy Miller, MSFC; and John Toma, LeRC. The study group looked at the solar power systems for thirteen missions that represented a broad cross-section of flight projects over the past decade. These covered a range in average output from less than 100 watts to 4 kw. They included body-mounted and oriented arrays, a variety of orbits and trajectories, and a variety of sponsors and contractors. Actual accrued costs or estimated costs to completion for projects in progress were obtained at a level considerably more detailed than presented in this paper. The detailed costs were reconstructed by the study group in as consistent a manner as possible to allow comparisons among projects. The costs were broken down into recurring and non-recurring costs for the solar array, battery, and power conditioning. Costs for orientation and development subsystems were not included. The study could not be made with the thoroughness or accuracy of an audit; often assumptions had to be made about burden rates and the breakdowns of costs to subsystem or to recurring and non-recurring categories. The costs are corrected to fully burdened values including overhead, G&A, and fee in terms of 1971 dollars.

RESULTS

It has been common to discuss power system costs in terms of dollar-per-kw, implying that costs correlate best with power. In this study correlations with maximum power and average system power were found to be poor. However, the costs correlate reasonably well with array area. Not surprisingly, considerable scatter remained in the data. Presumably the scatter was mainly due to factors such as differences in mission and schedule requirements, management philosophy, and troubles encountered in the course of the project. Nevertheless, enough of a pattern emerged to be able to make some general conclusions.

A word of caution should be expressed. For the purposes of discussing general trends, straight-line correlations between the logarithm of the cost and the logarithm of the area were fit by eye over the range of the data. Extrapolation made beyond the range of the data can not be justified.

The total cost of the power systems was compared on the basis of a total cost index defined as the non-recurring cost plus the recurring cost for two flight systems. The total cost index for the power system is shown in figure 2 as a function of the solar array area. (Not shown are two projects for which non-recurring costs were low because flight systems were similar to earlier ones.) This log-log plot shows a fair correlation between system costs and array area. The total costs rise more slowly than the area, about in proportion to the square root of the area. An order of magnitude increase in array area results in only a factor of 3 increase in cost, or a reduction of a factor of 3 in cost per unit area. At the 100 sq ft size the total cost index is about $5 M and at the 1000 sq ft size it is about $17 M, only a factor of 3 increase in cost for a factor of 10 increase in area.

The system non-recurring cost is shown in figure 2. There is considerable scatter here, but a rising trend with size is evident. The non-recurring cost about doubles for an order of magnitude increase in array size. For example, the non-recurring costs rises from about $2.5 M at 100 sq ft to about $5 M at 1000 sq ft. The system unit recurring cost (the cost of one complete flight system) also rises slower than the array area, as can be seen in figure 3. The straight line indicates a trend with the power or array area. At 100 sq ft the system unit recurring cost is about $1.2 M and at 1000 sq ft it is about $6 M.

Similar correlations were made for the solar array costs. Figure 4 shows the total cost index for the solar array rising with about the 0.7 power of area. The cost index is about $2.5 M at 100 sq ft and $12 M at 1000 sq ft. The solar array non-recurring costs (fig. 5)

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show considerable scatter. The straight line shown was fit to make this correlation consistent with the solar array cost index and unit recurring cost. Figure 6 shows the unit recurring cost for the solar array. Here again the cost does not rise in proportion to array area. The unit recurring cost is about $0.7 M at 100 sq ft and $4 M at 1000 sq ft.

All these trends indicate the costs do not rise in proportion to the size of the system. This is due in part to the relatively fixed nonrecurring costs. But the increase in recurring costs is also slow. For the array this trend suggests that there is significant cost reduction due to volume of production. This cost reduction would depend not only on the size of the array, but also on the number of arrays built. Figure 7 shows the solar array recurring cost per square foot plotted against the total area of flight arrays built for each project. Figure 7 shows a somewhat better correlation than figure 6. It also shows a stronger effect of area on cost reduction. The cost decreases from $10,000/sq ft for 100 sq ft to $4500/sq ft for 1000 sq ft to $3000/sq ft at 3000 sq ft. Figure 7 illustrates the gains in productivity as a team gains experience with repetitive operations. It strongly supports the opinion long-held in the solar array community that more standardization would reduce costs. Standardized cells or modules would allow the costs per square foot for the smaller programs to drop and approach the costs now possible only for the large programs.

CONCLUSIONS

This study of historical costs of solar cell power systems showed that cost per kw is not a useful parameter to characterize the system costs. System and array costs correlated reasonably well with array area. However, the costs did not rise as fast as array size. The trend for the array of reduced recurring cost per square foot as more array area is built for a project strongly supports the claim that solar cell and module standardization would reduce costs.

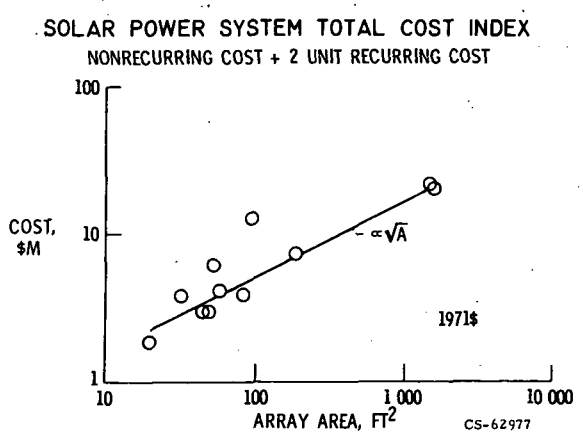

Fig. 1.

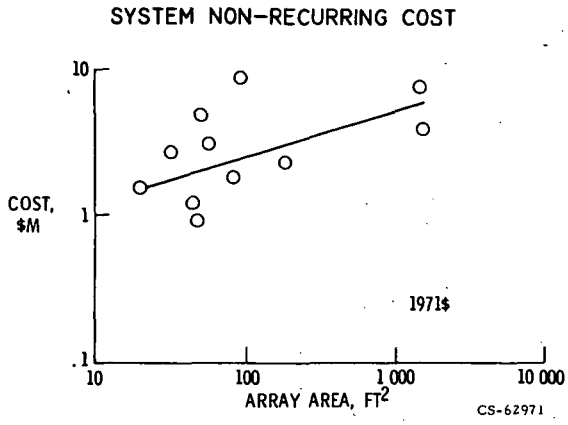

Fig. 2.

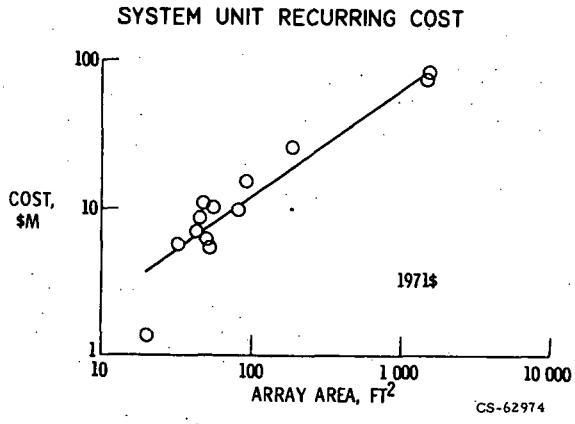

Fig. 3.

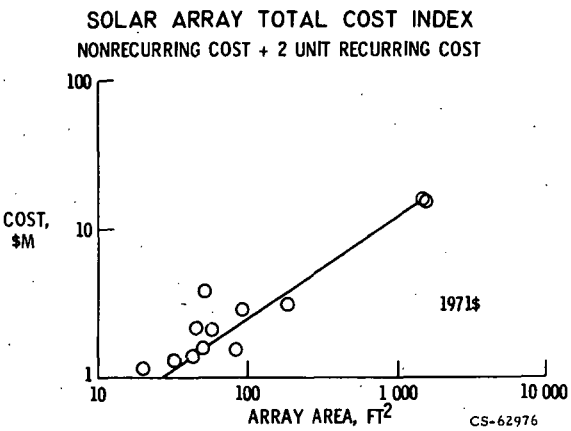

Fig. 4.

SOLAR ARRAY NON–RECURRING COST

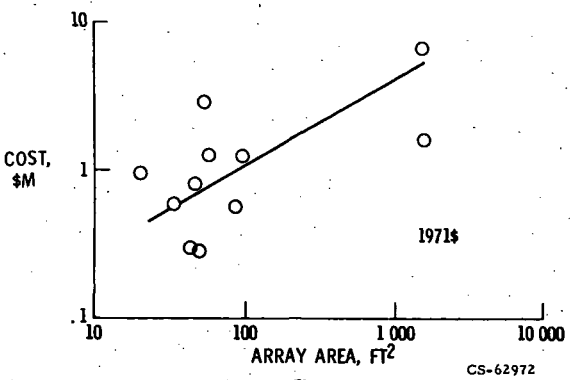

Fig. 5.

SOLAR ARRAY UNIT RECURRING COST

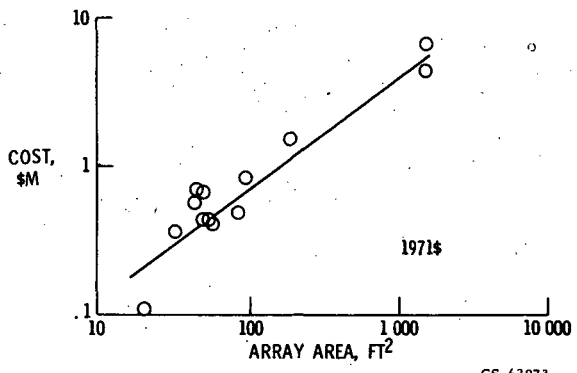

Fig. 6.

SOLAR ARRAY RECURRING COST PER SQUARE FOOT

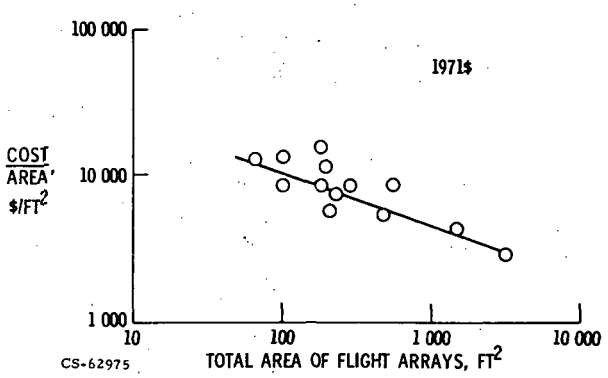

Fig. 7.