N91-71219

THE MOON BASE POWER SATELLITE: A PRELIMINARY ANALYSIS

B. R. Sperber, M. I. T., Dept. of Aeronautics and Astronautics

In a recent study on space colonization[1] a nuclear power plant was used to power an electromagnetic mass launcher and a moon base. The base-lined specific mass of the nuclear power plant was 45 kg $(kw)^{-1}$. There is probably no alternative to using a nuclear power plant for the first mass launcher.

However, an economically viable space colonization system is probably a fast-growing one, with power requirements on the order of those put out by power satellites. These requirements are taken to be .75 to 2 Gw_e approximately 10 years after establishment of the moon base. A power satellite might be actively stationed at Lagrange point L-1, transmitting microwave power to the lunar surface for subsequent mass launchers. A procedure for estimation of power satellite system mass as a function of microwave transmission wavelength has been developed.

The acquisition cost of a power satellite with receiving array may be described by the equation

$$K = \gamma\ (T_A A_T + T_M P \eta_T^{-1} \eta_R^{-1} + C P \eta_G^{-1} \eta_T^{-1} \eta_R^{-1} + \beta R A_R)$$

where

γ = lift cost to satellite site per unit mass material

β = rectenna site/satellite site lift cost ratio

A_T = microwave transmitting array area

A_R = microwave receiving array area

P = system power output to load at rectenna

T_A = mass per unit area of microwave transmitting antenna

T_M = specific mass of microwave generation equipment

C = specific mass of solar to D.C. electric conversion system

R = mass per unit area of rectenna

η_G = D.C. to microwave generation efficiency

η_T = geometric beam transmission efficiency

η_R = microwave to D.C. conversion (rectenna) efficiency

THE MOON BASE POWER SATELLITE: A PRELIMINARY ANALYSIS

B. R. Sperber

Factoring out lift cost γ leaves an equation for the power satellite system's location-referred mass $M = K\gamma^{-1}$. This simply means that the portion of the system mass on the lunar surface is multiplied by the factor of increased transportation cost to the lunar surface with respect to L-1. This number will be taken to be $\beta = 3/2$ here.

With the substitution $\alpha = T_A A_T + \beta R A_R$, M may be written as a function of λ, the microwave transmission wavelength:

$$M = \alpha(\lambda) + T_M(\eta_G(\lambda))P\eta_T^{-1}\eta_R(\lambda)^{-1} + CP\eta_G(\lambda)^{-1}\eta_T^{-1}\eta_R(\lambda)^{-1}.$$

$T_M(\eta_G)$, $\eta_G(\lambda)$ and $\eta_R(\lambda)$ are shown on Figures 1-3. α can be minimized by using the antenna relation

$A_R A_T = \pi^2 k^{-2}\lambda^2 H^2 \eta_T^2$, where k is a dimensionless constant.

The antenna relation says that for a given configuration and λ, $A_R A_T$ is constant. This allows α to be written as

$\alpha = T_A(A_R A_T)A_R^{-1} + \beta R A_R$. Differentiating w.r.t. A_R,

$d\alpha/dA_R = -T_A(A_R A_T)A_R^{-2} + \beta R$. Rearranging terms at the minimum

yields $A_T = \beta A_R R T_A^{-1}$. Plugging this result into the antenna relation

yields $A_R = \pi k^{-1}\lambda H\eta_T(\beta^{-1} R^{-1} T_A)^{1/2}$. Furthermore,

$\alpha = 2\beta R A_R = 2\pi k^{-1}\lambda H\eta_T\beta^{1/2}R^{1/2}T_A^{1/2}$.

For a constant amplitude transmitting aperture illumination with $H = 6.4 \times 107$ m and $\eta_T = .8$, k was found to be $1.93 \simeq 2$. It is likely that only a fraction of the rectenna area would be installed to begin with, so that no matter how tight the antenna pattern, most of the power is wasted anyway. The constant amplitude illumination was chosen because it is likely to be the easiest to build.

Shown on Figure 4 are $T = T_M P\eta_R^{-1}\eta_T^{-1}$ and two cases of solar-electric conversion mass fraction $c = CP_G^{-1}\eta_T^{-1}R^{-1}$ as functions of λ for P = 2Gw. The difference in the two cases of c is that for a typical photovoltaic satellite design C = 1.5 kg $(kw)^{-1}$(Ref.2) whereas for a thermal conversion design

$C = 4.6$ kg (kw)$^{-1}$. (Ref. 3).

On Figures 5 and 6 M is plotted for the cases of photovoltaic and thermal solar-electric moon base power satellites, respectively, for different values of R, assuming $T_A = 4.3$ kgm^{-2}. Each curve is a factor of 4 in R different from adjacent curves and also represents satellite mass alone for the curve above it.

Since the fits to Figs. 1-3 are crude, the results in Figs. 4-6 are purely demonstrative, especially at shorter wavelengths. However, carrying out such plots allows an appropriate microwave wavelength to be selected in a rational manner. The selected wavelength will vary according to the criterion used, i.e., is M or the satellite mass minimized?

Thanks to Prof. R. Miller, W. C. Brown and an unnamed host of proof readers for their help.

References:

(1) Report of the NASA-Ames/ASEE/Stanford 1975 Faculty Summer Study of Space Colonization. (To be published.)

(2) Nathan, A., Space-Based Solar Power Conversion and Delivery Systems (Study) - Engineering Analysis, NAS 8-31308, Grumman Aircraft Corp. No NSS-P-001, Aug. 6, 1975.

(3) Woodcock, G. R. and Gregory, D. L., AIAA Paper 75-640, p.8.

(4) Brown, W. C., IEEE [MTT-21], 12, p. 759.

(5) Brown, W. C., Private communication.

THE MOON BASE POWER SATELLITE: A PRELIMINARY ANALYSIS

Sperber, B. R.

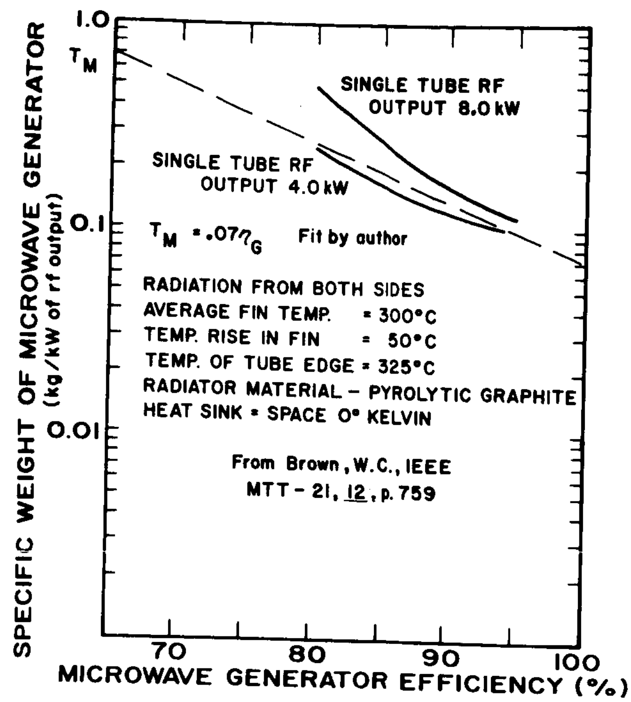

FIGURE 1.

FIGURE 2.

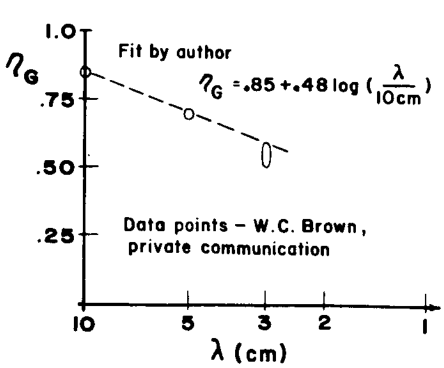

FIGURE 3.

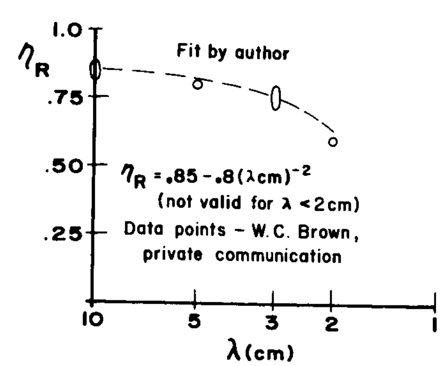

FIGURE 4.

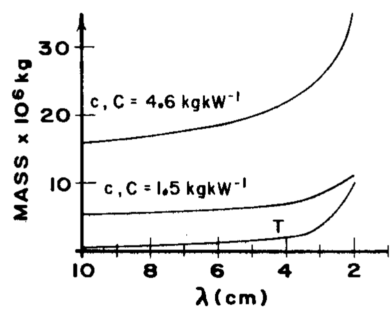

FIGURE 5.

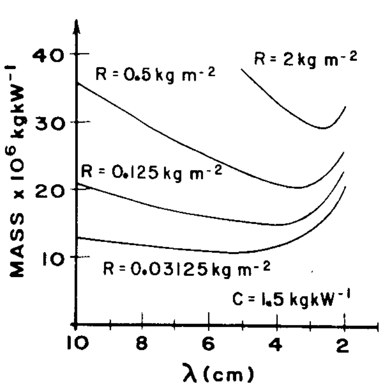

FIGURE 6.