Statite: A Spacecraft That Does Not Orbit

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This paper describes a proposed new type of space vehicle, the statite—a spacecraft that does not orbit. The statite would use a solar sail propulsion system to maintain itself in a desired nonorbiting static equilibrium position adjacent to the Earth by balancing light pressure force against gravitational force. In most versions of the system, the statite would be offset from the polar axis toward the dark side of the Earth where it would be continuously viewable from either the northern or southern hemisphere. The statite would stay fixed at a point above the dark side while the Earth rotated beneath it. To a viewer on the Earth, the statite would revolve about the pole once every 24-h solar day. The typical distance of a statite from the center of the Earth would be 30–250 Earth radii. The round-trip radio delay time for 100 Earth radii is 4.2 s, making the statite more suitable for broadcast, data, FAX, and weather services than for two-way telephone conversations.

Nomenclature

A = light collecting area of solar sail
c = speed of light, 300 Mm/s
D = distance of statite from sun, $D^2 = (R + x)^2 + z^2$
F_c = centrifugal force on statite from motion around sun
F_e = force on statite from gravitational attraction of Earth
F_p = force on statite sail from light pressure
F_s = force on statite from gravitational attraction of sun
G = Newtonian gravitational constant, 6.67×10^{-11} $m^3/kg \cdot s^2$
L = sail lightness parameter, $\sigma = 1.5$ g/m^2 $\rightarrow L = 1.0$
M = mass of sun
m = mass of Earth
n = sail parameter ($n = 1$ Solar Photon Thrustor, $n = 2$ flat sail)
R = distance of Earth from sun, 1 a.u. = 150 Gm
r = distance of statite from Earth
S = solar light flux at Earth, 1.38 kW/m^2
T = orbital period of mass at distance r from Earth
t = instability time constant (equilibrium time scale)
u = mass of solar sail, σA
x = component of statite-Earth distance along Earth-sun line
z = component of statite-Earth distance normal to Earth-sun line
α = angle of sun-statite line off sun-Earth line
β = angle of statite direction from polar axis
γ = angle of statite light pressure force from Earth-sun normal
ϵ = angle of statite off Earth-sun line
θ = angle of flat solar sail to Earth-sun line
π = 3.1415926
σ = ratio of statite mass u to light reflecting area A
ϕ = angle of pole from terminator
ω = angular rotation rate of Earth around sun, 200 nrad/s

Introduction

IN order to reduce pressure on the equatorial geostationary orbit so as to relieve world tensions over this "limited natural resource," as well as to provide continuous space services to the polar regions of the Earth, a new type of spacecraft is proposed—a spacecraft that does not orbit the Earth. Since the spacecraft does not orbit the Earth, it is not a satellite of the Earth. The generic name of statite[1,2] has been coined for this new type of spacecraft because it remains essentially static or stationary in space with respect to the common center of mass of the combined system of the Earth and spacecraft. In contrast, a satellite is defined as "the lesser component of a two body system revolving, together with the primary, around a common center of mass."[3] This fundamental difference between a statite and a satellite is the basis for the patent application.[2]

As is shown in Fig. 1, the statite would use a solar sail light pressure propulsion system to maintain the statite and its payload in a desired nonorbiting fixed-equilibrium position above the northern or southern hemisphere of Earth by using light pressure force to exactly balance the Earth's gravitation force (more generally, the sum of the Earth's gravitational force, the sun's gravitational force, and the centrifugal force of the motion of the statite around the sun, which nearly, but not exactly, cancels out the sun's gravitational force).

Force Balance Analysis

The basic force diagram for the statite system is shown in Fig. 2. For simplicity, the light pressure propulsion system is shown as a flat solar sail. In practice, however, it is likely that an improved light pressure propulsion system, called the Solar Photon Thrustor,[4] would be used. In Fig. 2, the plane of the diagram is not normal to the plane of the ecliptic, but has been

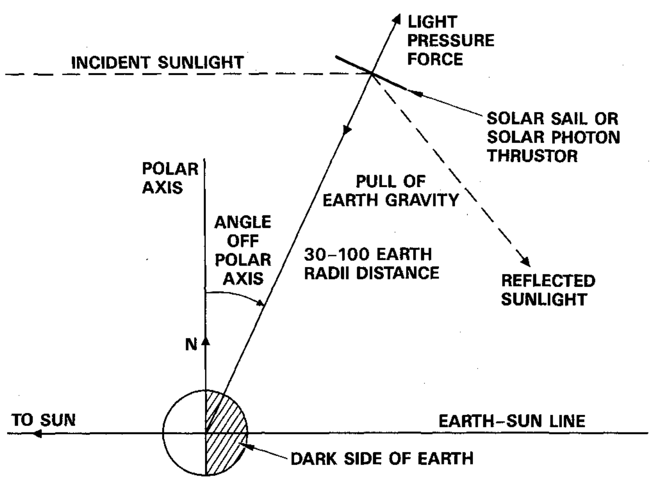

Fig. 1 Schematic diagram of statite concept.

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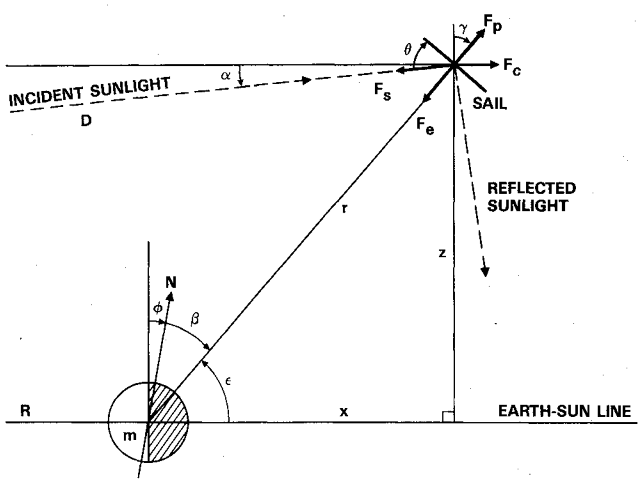

Fig. 2 Statite force diagram.

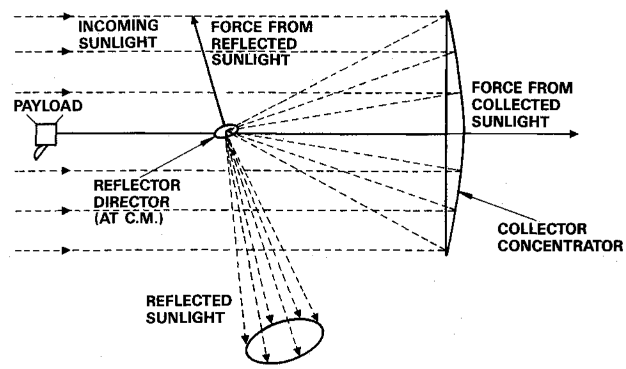

Fig. 3 Solar Photon Thrustor concept.

rotated about the Earth-sun line until it includes the rotation axis of Earth. In Fig. 2, the North Pole of the Earth is at an angle ϕ with respect to the terminator (the shadow line around the Earth), which is normal to the Earth-sun line. The angle ϕ is due to the tilt of the polar axis of the Earth with respect to the ecliptic and varies over ± 23.5 deg during the year.

The statite is placed at a distance r from the Earth and an angle β with respect to the polar axis, in this example, the North Pole. For simplicity, we have assumed in Fig. 2 that the statite is also in the plane of the diagram. In general, this will not be the case, as the statite can be anywhere over the dark side of the Earth and does not have to be exactly on the opposite side of the pole from the sun.

The sail on the statite is then oriented essentially tangent to the radial direction to the Earth. The light coming from the sun at the angle α strikes the reflective sail at the angle θ. The sunlight reflecting off the sail produces a light pressure force F_p. If the flat solar sail is highly reflecting (which is relatively easy to achieve in practice), then the direction of the light pressure force is essentially normal to the back of the sail and directed away from the Earth at the angle $\gamma = \theta - \alpha$. Since α is always less than 1 deg for all statite positions of interest in this paper, it will be assumed that $\gamma = \theta$. The magnitude of the light pressure force for a flat solar sail is given by the well-known relation[5]:

$$F_p = (2SAR^2/D^2c) \sin^2\gamma \tag{1}$$

The flux level at the statite has been modified by the ratio R^2/D^2 to account for the fact that the statite is at the distance D from the sun.

If a Solar Photon Thrustor,[4] shown schematically in Fig. 3, is used instead of a flat solar sail, the magnitude of the light pressure force is improved by a factor of $1/\sin\gamma$ over a flat solar sail since the light collecting area of the Solar Photon Thrustor is always facing the sun and does not change effective area with $\sin\gamma$ as does the flat solar sail[4]:

$$F_p = (2SAR^2/D^2c) \sin\gamma \tag{2}$$

Equations (1) and (2) can be combined into a single equation:

$$F_p = (2SAR^2/D^2c) \sin^n\gamma \tag{3}$$

where $n = 1$ for a Solar Photon Thrustor and $n = 2$ for flat solar sails.

The gravitational force of the Earth of mass m on a statite of mass u at the radial distance r is:

$$F_e = Gmu/r^2 = Gm\sigma A/r^2 \tag{4}$$

The gravitational force of the sun of mass M on the statite at the distance D is:

$$F_s = GMu/D^2 = GM\sigma A/D^2 \tag{5}$$

The centrifugal force of the motion of the statite around the sun at the angular rotational rate of the sun-Earth coordinate system ω is:

$$F_c = u\omega^2(R + x) = GM\sigma A(R + x)/R^3 \tag{6}$$

where the orbital equation for the Earth ($\omega^2 R = GM/R^2$) has been used because, in order to remain at some equilibrium position in the rotating sun-Earth coordinate system, the statite must provide propulsion to rotate around the sun at the same angular rate ω as the Earth, even though it may be at a different distance from the sun than the Earth.

In the operation of a statite, the combined gravitational force of the Earth, the gravitational force of the sun, and centrifugal force of the motion about the sun is to be exactly counterbalanced by the light pressure force so that the statite remains motionless in the rotating Earth-sun system. There are two sets of equations, one for the force components normal to the Earth-sun line (in the z direction):

$$F_p \cos\gamma = F_e \sin\epsilon + F_s \sin\alpha \tag{7}$$

and one for the force components in the direction of the Earth-sun line (in the x direction):

$$F_c + F_p \sin\gamma = F_e \cos\epsilon + F_s \cos\alpha \tag{8}$$

where the angles γ, ϵ, and α are shown in Fig. 2.

After some tedious algebra, Eqs. (7) and (8) can be rearranged into equations that give the sail mass-to-area ratio σ and thrust direction angle γ required for the statite to maintain itself at some equilibrium position in the rotating sun-Earth coordinate system. The equation for the mass-to-area parameter is:

$$\sigma = \frac{r^3 (2SR^2/D^2GMc) \sin^{n+1}\gamma}{x\{1 + (M/m)\ [(R + x)/x]\ (r^3/D^3)\ [1 - (D^3/R^3)]\}} \tag{9}$$

whereas the equation for the thrust angle is:

$$\tan\gamma = \frac{x\{1 + (M/m)[(R + x)/x](r^3/D^3)[1 - (D^3/R^3)]\}}{z[1 + (M/m)(r^3/D^3)]} \tag{10}$$

Equations (9) and (10) were programmed into a computer and solved for the thrust direction angle and the sail mass-to-area ratio at intervals spaced all over the x-z plane. This data array was then used to outline the allowed equilibrium operating regions and to produce contour plots of the sail mass-to-area ratio that would be needed by the sail in order to hover as a statite, at that position, in equilibrium with the rotating sun-Earth coordinate system.

Two contour plots were generated, Fig. 4 for the flat solar sail and Fig. 5 for the Solar Photon Thrustor. Figure 4 generally agrees in form with similar plots generated by McInnes et al.[6] in a recent preprint discussing flat solar sails in equilibrium in the rotating sun-Jupiter coordinate system.

By comparing Figs. 4 and 5, it can be seen that a Solar Photon Thrustor can hover closer to the Earth or closer to the terminator than a flat solar sail with the same mass-to-area ratio, or equivalently, a Solar Photon Thrustor can be 10 times heavier than a flat solar sail operating at the same position.

Note in Figs. 4 and 5 that there are two regions where it is possible for a solar sail to hover in equilibrium in the rotating sun-Earth coordinate system. One is the region over the dark side of the Earth, but inside a hemispherical shell that has a radius of 1.5 Gm (236 Earth radii). This radius is equal to the distance to the L-2 Lagrange point of the sun-Earth system. The other equilibrium region is over the sunlit portion of Earth outside a hemispherical shell that has a radius of 1.5 Gm (equal to the distance to the L-1 Lagrange point). McInnes et al.[6] have explored these equilibrium regions in detail both in the x-z plane (normal to the ecliptic) and the x-y (ecliptic) plane. They find that the contour patterns for the two orthogonal planes are almost identical. Thus, the volumetric equilibrium contours can be visualized quite accurately by imagining a rotation of the contours of Figs. 4 or 5 around the Earth-sun line.

Modes of Operation

Depending on the operational requirements, the statite system could be operated in a number of modes. These modes of operation include the fixed polar angle mode, variable position mode, and a mode involving "formation flying" with the Earth in a levitated solar orbit. All of these modes of operation would work equally well around any planet.

Fixed Polar Angle Mode

In the normal mode of operation, the statite would be kept as close to the Earth as possible, at a fixed angle from the polar rotation axis, in order to simplify the ground station antennas. The ground antenna dishes would be offset at a fixed angle from the axis of a polar mount, and the polar mount would be rotated by a clock drive once a day in order to track the statite during its rotation about the pole in the sky. The polar offset angle will have to be > 23.5 deg because the tilt of the rotation axis of the Earth takes each pole 23.5 deg to the sunward side of the Earth during one of the solstices and the statite has to stay over the dark side of the Earth if it is to remain in equilibrium at low altitudes.

As is shown in Fig. 6, the worst case for a statite serving the northern hemisphere comes at the summer solstice, when the rotation axis angle with respect to the terminator is $\phi = -23.5$ deg. In this case, the closest an ideal statite can come to the polar axis is 23.5 deg, and realistic statites will be at angles of 30–45 deg from the polar axis, or 45–60° lat.

As can be seen from Fig. 5, a Solar Photon Thrustor with a mass-to-area ratio of 5 g/m^2 can hover at 20 deg off the terminator (43.5 deg off the pole in the worst case) at a distance of 1.2 Gm (200 Earth radii), whereas high performance sails with a mass-to-area ratio of 0.5 g/m^2 or less can hover at a similar angle at an altitude of 300 Mm (50 Earth radii). Statites at these angles could serve the United States, Europe, Alaska, Canada, all of the USSR, Northern China, Argentina, Chile, New Zealand, Southern Australia, and, of course, the Arctic and Antarctic, which cannot use satellites on the equatorial geostationary orbit at all.

Variable Position Mode

Instead of keeping the statite at a constant angle from the polar axis and a constant distance from the center of the Earth, another mode of operation would be to keep the statite as close to the polar axis as possible. The statite would be put directly over the pole during that time of the year when the polar region being served is on the dark side of the Earth (around the winter solstice for the North Pole), so as to provide maximum service area. The altitude of the statite could be lowered at these favorable times to distances as close as 200 Mm (30 Earth radii) for Solar Photon Thrustors with mass-to-area ratios less than 0.5 g/m^2. During the summer, when the North Pole is in sunlight and there is an unfavorable sun angle, the statite would have to be moved off the polar axis position to a lower latitude.

This mode of operation would require more complicated ground station antennas capable of nodding once per year in addition to rotating around the pole once per day. In addition, service to the more equatorial areas would be interrupted during some times of the year. A variation on this mode of operation would be to allow the statite to drift higher in altitude at unfavorable sun angles in order to lower the gravitational force and allow the statite to be operated a few degrees closer to the zenith.

Formation Flying Mode

A very different mode of operation of the statite system is possible that would allow the statite to be placed directly over

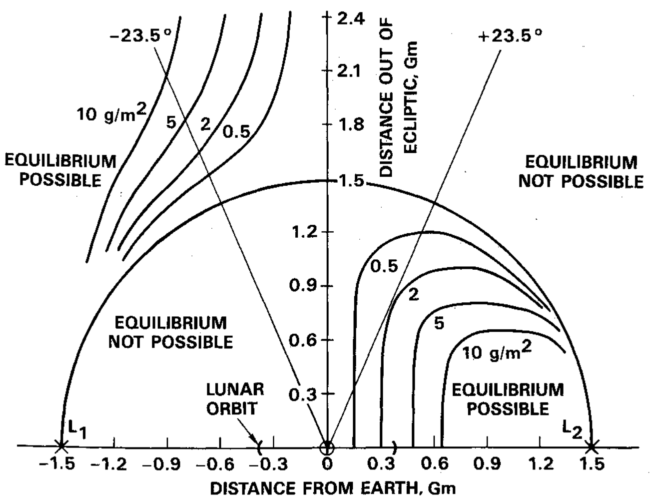

Fig. 4 Equilibrium contours for a flat solar sail.

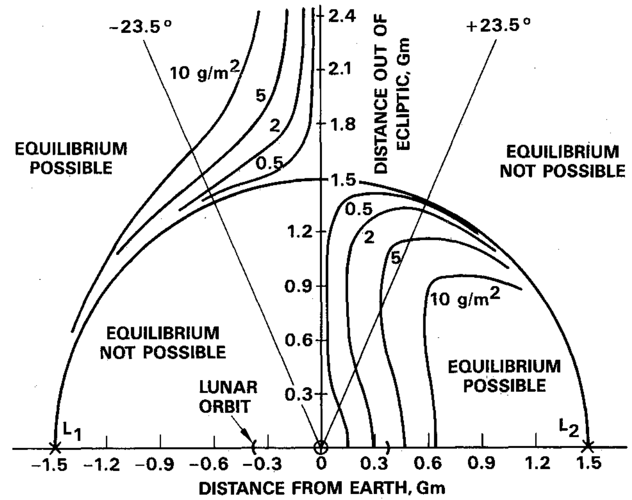

Fig. 5 Equilibrium contours for a Solar Photon Thrustor.

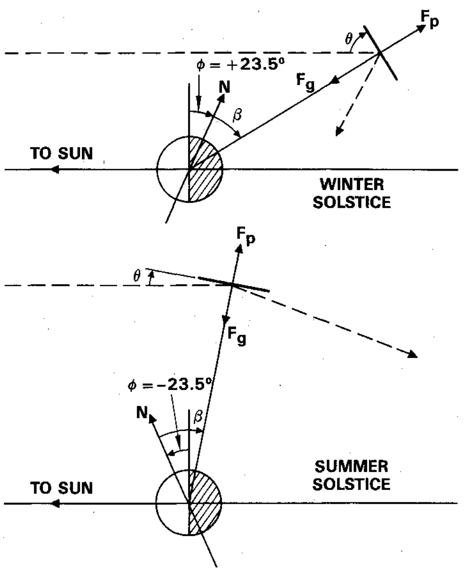

Fig. 6 Fixed polar angle operation of statite.

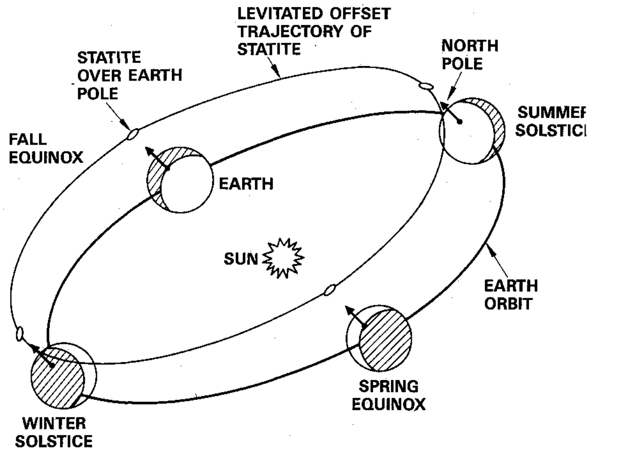

Fig. 7 Solar orbit dominated Earth statite.

the poles at all times of the year, even over the sunlit side, at the expense of a greater operating distance. The solar sail thrust would be controlled so that the statite traveled in a slightly elliptical orbit around the sun with a period equal to the Earth orbital period of one year. The light pressure would be used to levitate[1,2,7,8] the plane of the statite orbit above (or below) the ecliptic plane and to vary the radius of the orbit during the year so that the statite moved inside and outside the orbit of the Earth. This mode of operation is illustrated in Fig. 7, showing the statite above the North Pole at the equinoxes and the solstices.

In this mode of operation, the statite would be traveling from one of the equilibrium regions shown in Figs. 4 and 5 to the other equilibrium region and back again, passing over the terminator during the equinoxes. The altitude above the Earth would vary slightly from a little less than 1.5 Gm (<230 Earth radii) over the dark side of Earth to a little more than 1.5 Gm (>250 Earth radii) over the sunlit side. The actual dynamic trajectory through the narrow nonequilibrium region between the two equilibrium regions has not yet been calculated, and so it is not yet possible to estimate how accurately the spacecraft can stay aligned with the polar axis during those transition maneuvers.

A number of readers of the original version of this paper[1] have raised a concern that a statite could not maintain itself in an "orbit" that is constantly raised above the ecliptic plane. They seem to think orbital mechanics requires that the statite orbit crossover the ecliptic plane if the statite starts out above that plane. They forget that the statite has a powerful light pressure propulsion system that is constantly thrusting to keep the statite in its unnatural levitated "orbit" about the sun.

The amount of control exerted by a light pressure propulsion system on its trajectory around a light source like the sun is determined by the ratio of the light pressure force to the gravitational force, or its lightness L given by:

$$L = \frac{2SAR^2/D^2c}{GMu/D^2} = \frac{2SR^2}{\sigma GMc} \tag{11}$$

Notice that, since the light flux from the sun and the gravity force from the sun both fall off with the square of the distance D, the lightness is independent of the distance from the sun and is predominantly determined by the mass-to-area ratio of the light pressure propulsion system.

A lightness of unity means that the light pressure propulsion system can levitate itself against solar gravity. Spacecraft with a lightness of unity move in straight lines, as if the sun were not there. Spacecraft with a lightness greater than unity find themselves repelled by the sun. Only spacecraft with a lightness less than unity have to go into orbit about the sun to keep from falling in. These spacecraft move in the conic orbits with the sun at one focus that one expects, but even for those spacecraft, the constantly operating light pressure propulsion system reduces the effective mass of the sun from its normal value.

For a light pressure propulsion system to achieve a lightness of unity, it requires a mass-to-area ratio of

$$\sigma = 2SR^2/GMc = 1.5 \text{ g/m}^2 \tag{12}$$

The sail technology developed in 1976 at the Jet Propulsion Laboratory (JPL),[9,10] Pasadena, California, for the Halley Comet mission projected a mass-to-area ratio of 3.3 g/m^2. Thus, any reasonable design for a light pressure propulsion system, whether it be a flat solar sail or a Solar Photon Thrustor, should be close enough to a lightness of unity that it will have ample reserve propulsive capability to allow it to carry out the orbit levitation and orbit ellipticity maneuvers necessary to place a statite over either pole of the Earth at all times of the year using the levitated solar orbit formation flying mode.

Deployment and Operation

Since the operation of a statite would require the constant control of the thrust level and direction of the light pressure propulsion system in order to keep the statite on station, the deployment and operation of a statite would be significantly different from the deployment and operation of a satellite. Launching a satellite involves simply throwing it into space, where it floats in its orbit until it is commanded to move into a different orbit. In contrast, a statite must be kept under active control at all times or it will soon fall to the Earth.

The typical statite would have some sort of Earth services payload; a solar light pressure propulsion system such as a standard flat solar sail or the improved performance Solar Photon Thrustor[4]; a sensing system capable of determining the direction to the sun, the direction to a guide star off the ecliptic such as Canopus, and the direction and distance to the Earth; and a control system that uses the output of the sensing system to separately control the thrust level and direction of the light pressure propulsion system to keep the statite at the desired equilibrium position with respect to the center of the Earth.

By designing the solar sail system to have separate control of the parameters σ and γ, the statite can be moved in altitude by varying σ, and separately in latitude or longitude by a combination of varying the thrust angle γ and rotating the sail around the Earth-statite line. On a flat solar sail or heliogyro, the parameter σ can be varied without varying γ by changing the effective area of the sail. This can be done either by unfurling more or less sail, or by tilting panels or vanes in opposing pairs that decrease the effective area of the sail without applying torques to the structure. A Solar Photon Thrustor would achieve the same effect by movable panels on the small reflector-director mirror (see Fig. 3).

The sensing system to determine the distance to the Earth could be a passive one that measures the angular diameter of the Earth with a rotating infrared sensor or it could be an active one that picks up a radio timing signals from a cooperative station or stations on Earth and uses those signals to determine the direction, range, and range rate to the station(s).

One method of deploying the statite would be to launch it directly to the desired operating position, where the light pressure propulsion system would be deployed. Because of the high altitude, many days of time would be available for this maneuver before the statite would drop too far in the weak gravity field of Earth. Since the final velocity of the statite with respect to the center of the Earth during the operation of the system is essentially zero in most implementations, the direct placement maneuver would involve a simple "pop-up" type launch, with considerable savings in fuel over a launch into an orbit at that same altitude.

Alternatively, the statite could be launched into an Earth orbit that is high enough to let the propulsion system be deployed and the statite flown into position using the light pressure propulsion system. If a Solar Photon Thrustor were used, recent studies[11] have shown that it might be possible to launch the sail at Space Shuttle altitudes.

Once the statite is near its desired position and the light pressure propulsion system deployed, the sensing system would acquire the sun, Canopus, and Earth, determine the statite position with respect to the center of the Earth, then adjust the light pressure propulsion system force level and direction to bring the statite to the desired equilibrium position and maintain it there.

A typical distance of a statite from the center of the Earth will be 30–250 Earth radii, depending on the particular mode of operation chosen. The better the performance of the sail, the closer the equilibrium point will be to the surface of the Earth. The round-trip radio delay time for a distance of 100 Earth radii is 4.2 s, whereas for the closest practical distance of 30 Earth radii it is 1.3 s. These long communication delay times make the statite obviously more suitable for broadcast, data, FAX, and weather services than for interactive two-way telephone conversations.

Stability

It should be emphasized that a statite balanced in equilibrium by light pressure forces resisting gravitational and centrifugal forces is not stable. In the simple case of light pressure forces balancing just the gravitational force of the Earth, this is obvious. Because of the $1/r^2$ force law of the gravitational attraction, any small perturbation that brings the statite closer to Earth will increase the strength of the gravitational attraction, dragging the statite even closer. As a result of this inherent instability, the design of the statite control system must insure that the control mechanisms for both the sail area and the sail tilt angle have enough range ($\pm 20\%$ or more of the nominal value), speed (reaction time of one-tenth or less of the instability time constant), and redundancy, to hold the statite in position despite inevitable external perturbations, and internal performance degradations and point failures.

McInnes et al.[6] have shown, in general, that, for a flat solar sail in a corotating system of sun, sunlight, and planet, all of the statite equilibrium positions are unstable. They conclude, however, that "the instability is not problematic." They have calculated an equilibrium time scale, or instability time constant, for the situation. For a nominal sail mass-to-area ratio of 1.5 g/m^2 (a lightness of unity, which effectively eliminates the sun from the problem), the instability time constant reduces to

$$t = 2\pi\,(r^3/2Gm)^{1/2} = 0.707T \tag{13}$$

For a nominal distance of 600 Mm (about 100 Earth radii), the instability time constant is over a month. A time constant this long should allow more than adequate time for feedback control signals to maintain the statite at its equilibrium position.

McInnes et al.[6] have also examined the effect of perturbing gravitational and radiation-pressure-gradient torques on flat solar sails and were able to find torque free surfaces where the sail orientation would remain fixed in the corotating frame. Even away from this surface they found that perturbing torques on a flat sail could be compensated easily by generating an opposing torque through a simple shifting of the sail payload.

Perturbations

The reviewers have expressed concerns about perturbations induced by secondary physical effects acting on the structure of the sail and secondary gravitational forces acting on the mass of the sail. The secondary physical effects include time variations in solar luminosity, solar wind force, Poynting-Robertson drag, electrical charging, and degradation of the sail reflectivity and erosion of the effective sail area by sunlight, age, and interplanetary dust impacts. The sources of secondary gravitational effects include the higher order gravitational harmonics of the Earth and the masses of the Moon and other planets.

Most of secondary physical effects were examined during the extensive study of solar sails in 1976–1977 by JPL.[9,10] Force variations due to changes in solar luminosity, solar wind, Poynting-Robertson drag, and electrical charging are all well $< 1\%$ of the solar light pressure force and will cause no perturbations larger than the control range of the statite (assumed to be $\pm 20\%$ of the nominal value). Degradation of the sail performance by age, ultraviolet, and micrometeorite impact will eventually cause the control margin to be lost, but this time period will be measured in decades.

The planet causing the largest gravitational perturbation is Venus. Its mass is 0.815 that of Earth and it comes within 0.277 a.u. = 41.6 Gm distance at closest approach. Even at the extreme case of a statite far from Earth at a distance of 300 Earth radii = 1.9 Gm, the perturbation caused by the gravitational attraction of Venus is $< 2\times 10^{-3}$ or 0.2% of the Earth's gravitational attraction, and 2×10^{-5} or 0.002% of the sun's gravitational attraction and the centrifugal force due to motion about the sun, which are the dominating forces on the statite at these large distances from the Earth. Perturbations by the planets can essentially be ignored in statite design.

The harmonics of the Earth's gravitational potential, especially the second-order J_2 oblateness term, are well known to cause perturbations to ordinary satellites. The higher order terms even affect geostationary satellites out at 6.6 Earth radii, requiring them to carry modest amounts of propellant to compensate the perturbations in order for the satellites to stay on station. These higher order gravitational perturbations will cause less problem to statites for two reasons. First, the statites are further from Earth than most satellites. Second, the statites have a built-in propulsive capability that is much greater than that on any satellite since they must be able to continuously levitate their entire mass.

The higher gravitational harmonics of Earth not only fall off in magnitude with higher order, but they also are attenuated with distance by additional factors of $1/r$. For example, the second harmonic of the Earth J_2 has a comparative strength of 0.00108 and the gravitational force for this term falls off as $1/r^4$. In the extreme case of a statite hovering close to the Earth at 30 Earth radii, the gravitational force from the J_2 harmonic term is $0.001(1/30^2) = 1.2\times 10^{-5}$ or 0.0012% of the gravitational force due to the monopole term. Gravitational harmonics can be ignored in statite design.

The gravitational perturbations caused by the Moon is another matter. The altitude of the statites will be comparable to the distance to the Moon. One could imagine scenarios where poor placement of the statite could result in collision, or more likely capture, of the statite by the Moon. In practice, however, in order to serve most of a polar hemisphere of Earth, the statites would be placed above the polar regions of the Earth ($\pm$ 45–90° lat), while the Moon, in its essentially ecliptic orbit ($\pm$ 5 deg), will be above the equatorial regions of the Earth ($\pm$ 0–28.5° lat). The worst case for a northern hemisphere statite would be near full moon, around winter solstice, when operating at lunar distance (60 Earth radii), and at low latitude (45° N lat). The Moon, at maximum excursion from the ecliptic, could then be at 28.5° N lat. The resulting angular separation would be 16.5 deg, and the physical separation would be 17.4 Earth radii or 29% of the distance to the Earth. The mass of the Moon is 1/81 of the mass of the Earth, and so under this worst-case close approach, the gravitational force on the statite due to the Moon would rise to $(1/81)(1/0.29^2) = 15\%$ of the gravitational force due to the Earth. This is a significant perturbation, but it is completely predictable, has a month-long time constant, and is within the assumed control range of $\pm$ 20%. In addition, the perturbation will be much smaller in magnitude during other times of the year and will be even smaller for statites operating at other distances than 60 Earth radii and at the more desirable higher latitude ($\sim$ 60 deg) hovering positions.

Summary

A new type of spacecraft, called a statite, has been proposed. Unlike a satellite, the statite would not orbit the Earth. Instead of balancing out the gravitational pull of the Earth by using centrifugal force from orbital motion, the statite uses light pressure force from a solar sail.

A statite would be used for placing and maintaining a space services system so it is continuously viewable from either the northern or southern hemisphere of Earth. In most versions of the system, the statite would be offset from the rotation axis toward the dark side of the Earth. The statite would stay fixed at a point above the dark side, while the Earth rotated beneath it. From the viewpoint of an observer on the rotating Earth, the statite would revolve around the pole once every 24 h. Thus, ground stations for communication with these statites would need to have their antennas on a polar mount with a 24-h clock drive. A typical distance of a statite from the center of the Earth is 30–250 Earth radii. The better the performance of the sail, the closer the equilibrium point. The round-trip radio delay time for 100 Earth radii is 4.2 s.

Advantages of the statite concept are the following: it could provide continuous service to a region using a single spacecraft without requiring a slot on the already crowded equatorial geostationary orbit, and it could provide continuous coverage to regions of the Earth that are too close to the poles to use the existing equatorial geostationary orbit satellites. Disadvantages of the statite concept are the following: constant control would be required to maintain station, larger antennas would be needed because of the greater link distance, the round-trip link time is in seconds, and in most versions the ground station antenna must rotate once a day.

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