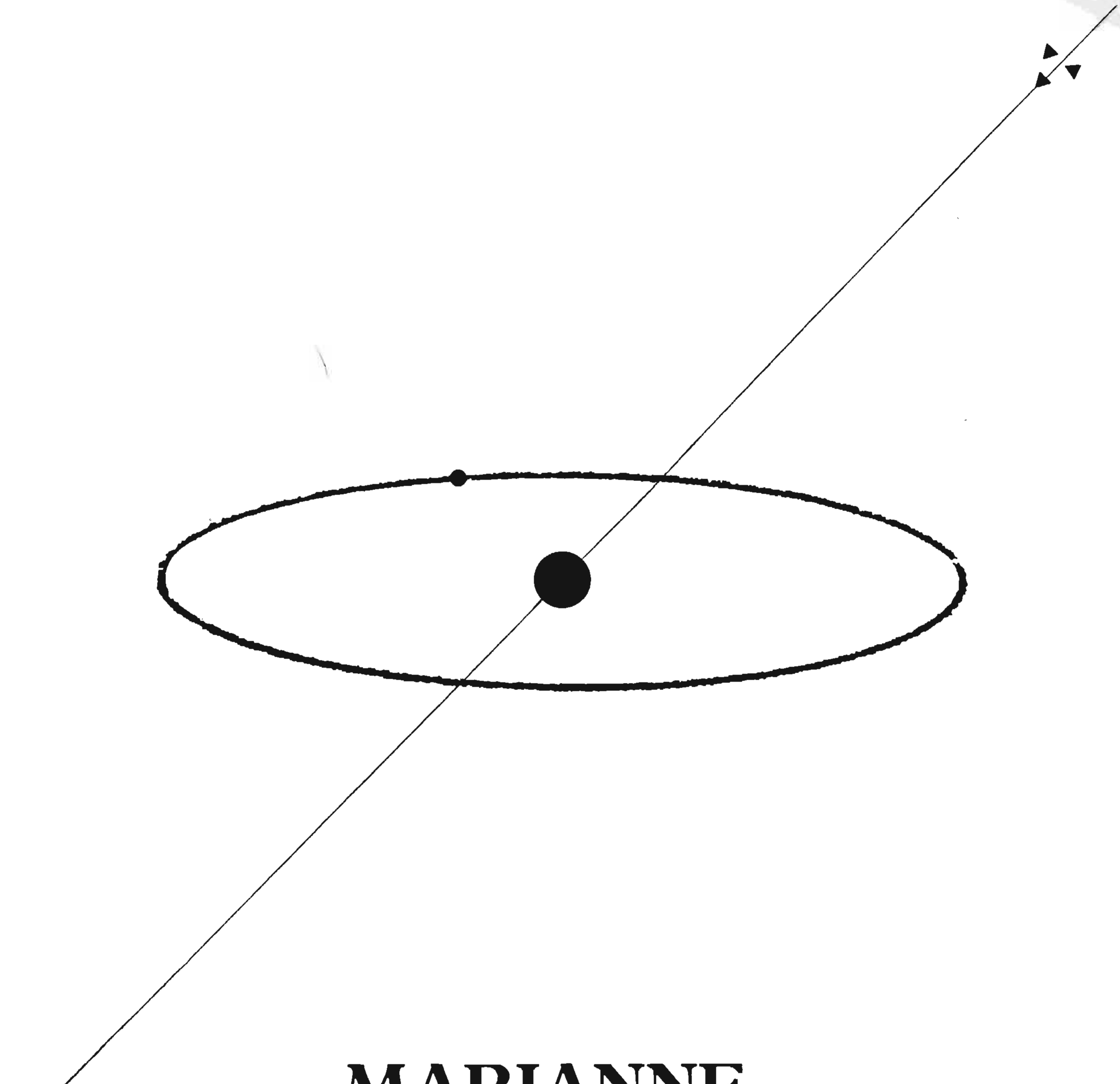


MARIANNE

for

AN EIFFEL TOWER IN SPACE

Competition, Sept., 1986

We propose to install in space - at the Lagrange Point - a constellation of 3 satellites all to reflect the light of the Sun to the nightside of the Earth.

We propose that each satellite reflects the Sun by a different color and that the 3 colors shall be: Blue, White, Red.

We propose that this lasting occurrence in space shall be named MARIANNE.

MARIANNE will enable the inhabitants of Earth to observe a reflection of the Sun during any time of the night.

The 3 satellites will together form a visualization of the anti — solar point so as to mark for all observers from the Earth, where the Sun will appear in half a year.

The satellites will remain at a distance from the Earth that will correspond to the very size of the Sun.
At this distance the star of our solar system and Earth will appear to be of exact same size.
Consequently, the reflected light from anyone of the satellites will transfer the image of the whole solar disc to the entire nightside of our globe.

MARIANNE will appear to man as the first constellation of stars made by man himself.
She will as well become the only image on the sky that will manifest an ever changing configuration to be perceived by man in a sensuous manner.

The 3 satellites will move imperceptibly but constantly change positions in relation to each other.
These perpetual motions will be displayed to man in front of the stars of the Zodiac.
Stars that themselves seem to travel due to the rotation of the Earth around the Sun.

Although MARIANNE will appear to man as a perpetual changing constellation of 3 stars in Blue, White and Red, - she will in fact travel in space at the one and the same time as a new planet in our solar system and as a new Moon to Earth.

The exact position of each of the 3 reflecting satellites will be determined by the masses in our solar system and the pressure of sunlight itself.

The satellites will travel around the Lagrange Point by different routes and at different speeds.
All orbits will describe Lissajou movements in 3 dimensions but with different amplitudes.

The equilibrium of the forces of gravity, the pressure of photons and the masses and dimensions of the satellites will establish new points of balance in our solar system.

MARIANNE will picture the physical and sensuous presence of these points of balance in our Universe.

Eric Andersen, artist
Niels Lund, astrophysicist
Kurt Cleff, architect

CONTENTS

Enclosures:

1. Model of satellite.

2. Disk for Commodore Amiga Personal Computer with the following graphics:
   a) The Lissajou pattern described for a period of 7.5 years. 2,6 mill. times real time.
   b) The relative movements of the 3 satellites of MARIANNE, including the effect of the shadow of the Earth. 1 mill. times real time.
   c) MARIANNE seen on a stellar background, illustrating the relative brightness.

3. Enlargement of figure 1.

Orbit concept and visibility.

We propose to place three reflecting satellites in orbits around the Lagrange Point over the night side of the Earth (fig. 1).
From this position the satellites will always be visible simultaneously from any place on the dark side of Earth, - except during short periods, where one of the satellites will be eclipsed by the Earth.
The satellites will differ in color, and they will travel according to Lissajou movements around the libration point to picture different triangles in space.
The brightness of the satellites will be as second magnitude stars (as the bright stars in Ursa Major).
Thus, they will be easily visible with the naked eye, even from the big cities on Earth (fig. 2).
The orbits will never deviate more than two degrees from the anti-solar point.
Through the year the satellites will therefore wander among the well known constellations of the Zodiac, always showing where the Sun will be in half a years time.
The point around which the satellites move will not be at the exact distance (1,5 mill. km) calculated by Lagrange 200 years ago.
The solar radiation pressure will influence the orbits and the satellites will be located closer to Earth at a distance of about 1,4 mill. km.

The ever changing configuration of MARIANNE in space.

The oscillations of a satellite around the libration point exhibit Lissajou patterns (fig. 3).
These patterns emerge due to the fact that the oscillation periods are different perpendicular and parallel to the ecliptic plane.
The two periods are approximately 183 days and 177 days.
The triangle as it will be defined by the three satellites of MARIANNE, each moving at different phases in their individual Lissajou patterns, will continually change and never repeat.
We have enclosed to our proposal a computer animation, which illustrates the patterns generated by the three satellites.

Satellite concept.

There are three boundary conditions for our concept:

a) Three satellites are required to achieve the impression of a changing figure in space.
b) Each satellite should appear bright enough to be easily visible with the naked eye.
c) The three satellites should be light enough to fit into a single ARIANE-4 launcher, - preferably even a shared launch.

The last condition constrains the mass of each satellite to approximately 400 kg.
The mirror of each satellite must at any time be oriented so as to keep the image of the Sun centered at the nightside of the Earth.
As the satellites move in their orbits, the mirror orientation must continually be adjusted but the movements are very slow, since the orbital periods are about 180 days.
The pointing requirements, 0.05 degrees, should not form a problem.
Therefore we are sure that the forces required for the attitude control can be obtained by solar radiation pressure, by shifting the center of gravity of the satellite with respect to the mirror or by the use of suitable moving panels.
Likewise we must use the solar radiation pressure for orbit control and stabilization. Halo orbits around the Lagrange Point are mildly unstable, and require control forces corresponding to velocity changes of the order 1 m/s per month for stabilization. For our satellites this can be achieved by adjusting the size of the mirrors by a few percent up or down.
The mirror itself is basically a thin (20 microns) foil of aluminized plastic. The type of plastic must be chosen for durability in the space radiation environments.
The reflecting layer of aluminium may have to be overcoated with another material in order to achieve the desired colors of the reflected light (Blue, White, Red), and probably also to achieve an acceptable surface temperature.
The mirror must be kept flat to an accuracy of 0.05 degrees. This, we believe, can be achieved by putting the foil under a slight tension.
The solar radiation pressure will not introduce much flexure in the mirror as the total force acting on the entire surface is only about 0.01 N.
The attitude system will use the Sun as one reference point but will also need a star tracker system, since the Earth itself will not be visible from the position of the satellites due to the intense glare from the Sun.

Calculation of the required size of the satellites.

We want the satellites to be visible across the entire night side of the Earth. Therefore the visual magnitude of the satellites should at least equal that of a second magnitude star.
The objects will shine by reflected sunlight, and we note, that the Sun shines 10^{11} times brighter than a star of the second magnitude. It follows that the satellites must reflect back to the Earth an amount of light 10^{-11} the amount of sunlight striking the dayside of the Earth. Thus, a minimum area 10^{-11} times the cross-sectional area of Earth is required, or about 1250 m^2. This minimal area only suffices if all of the sunlight striking this area is redirected to the dark side of the Earth, and nothing is wasted shining into empty space.
It is a fact that the Lagrange Point, L2, lies as far behind the Earth, measured in Earth radii, as the Earth itself lies from the Sun, measured in solar radii. Therefore, from the L2 distance, a simple, plane mirror will do the job of imaging the solar disc on the Earth. From this position it is possible to achieve the required brightness with a mirror of the minimum size.
It may appear curious that the above argument about the required minimum size of the object is independent of the distance from the reflecting object to the Earth. Certainly, many satellites have been sighted with the naked eye although they were a lot smaller than 40 metres in diameter (corresponding to 1250 m^2 area). However these satellites did not illuminate the entire Earth - satellites in more conventional orbits can only be seen from limited regions and only during brief intervals. Also, we must emphasize, that few satellites shine as bright as second magnitude stars.

Satellite mechanical design.

Each satellite consists of a main body with all the required subsystems and three long booms carrying the reflecting sail (fig. 4).
The satellite body is in the shape of a flat cylinder, 2 m in diameter and 0.5 metres high. On the end facing the Sun and the Earth is mounted the solar panels and the telemetry antenna.
Each of the three booms are 30.5 metres long, and they carry between them the reflecting sail, which is an equilateral triangle with a sidelength of 54 metres. The sail has a circular cut-out in the center to allow the satellite body an unobstructed view of the Sun and Earth.
The sail can be displaced by about 0.5 metres in any direction by adjusting the tension in control ropes. This adjustment possibility is essential for the use of the pressure of the sunlight for the satellite attitude control. The exposed area of the sail must also be adjustable by a few percent to allow orbit stabilization control.
The sail is an aluminized plastic foil. The foil can be very light as the forces acting on it are extremely small. A foil thickness of 20 microns is sufficient and thus the weight of the sail itself is only about 25 kg. Even allowing for some reinforcements at the edges and corners the sail should weigh less than 50 kg.

During launch the sail is folded and stowed in a ring shaped compartment on the satellite circumference.
The booms are the most critical part of the design. We have assumed the use of so-called "collapsible tube masts" presently under development for the European Space Technology Center (ESA-ESTEC). These masts are very thin walled metal tubes, which may be "flattened" and rolled into a compact coil during launch. We estimate the mass of each boom to be about 50 kg including its deployment mechanism.
In the launch configuration the three satellites are mounted on top of each other in a compact stack (fig. 5). This permits the launch vehicle to be shared with a commercial satellite.

The launch.

Assuming a shared launch with a telecommunication satellite the three MARIANNE satellites will initially be placed in a "geostationary transfer orbit" with an apogee of 36000 km and a perigee of 200 km. At this stage the three satellites will still fly as a single unit. This unit will then have to be boosted into a transfer orbit reaching the Lagrange Point. In order to conserve mass, a low velocity transfer lasting about 100 days, is recommended.
After arrival to the Lagrange distance about 1,42 million km. from the Earth the three satellites will be separated and inserted into their final orbits. For this an additional velocity change is required. Only after the final orbit insertion will the booms and reflecting sails be deployed.
It is important for the final visual impression of MARIANNE that the three satellites will always be relatively close together in the sky. However considerations of the dimensions of the shadow of the Earth precludes the choice of very small orbits around the libration point.
We have found that with an oscillation amplitude of ± 2 degrees both in the Ecliptic plane and perpendicular to this plane, the Earth shadow is insignificant for more than 95% of the orbit time.
It is also a requirement that the satellites move with very different phases in their Lissajou patterns around the libration point. Only then is it possible to realize the impression of a continuously changing shape in space.
We do not have at our disposal the necessary computer programs to suggest the optimal procedure for the final orbit insertion step, but we note, that both ESA and NASA have, in the past, studied this type of satellite orbits, so we are confident that the necessary expertise is available.
We may also mention, that a satellite was successfully placed in an orbit around the L1 Lagrange Point (between the Earth and the Sun) by NASA in 1978 and was kept there for four years until it was re-directed for a comet rendez-vous mission.

Operations.

The MARIANNE satellites will need to be controlled from the ground - probably on a daily basis. The primary purpose of the ground control is to monitor and adjust the satellite attitudes and orbital parameters.
As mentioned before, the required forces to correct the attitude and maintain the orbit can be derived from the pressure of the sunlight on the large reflector sails.
The magnitude of this pressure is small, about 0.01 N, but even a few percent changes in this force (obtained by adjusting the position and exposed area of the sail) suffices to obtain accellerations of the order 1 m/s per month which is about the required size.
Since we want to achieve very long satellite lifetimes we do not want to use gas-jets or other systems relying on consumables for orbit and attitude control.
The successful exploitation of the force of sunlight for attitude and orbit control would be an important technological development resulting from the MARIANNE project.

Costs.

If the project is to be realized on a purely commercial basis the costs would probably lie between 100 and 200 million ECU.
We suppose, however, that it may well be possible to find industrial firms in Europe which would be willing to contribute to the project by supplying some of the required hardware at a nominal cost.
The launch costs may be negotiated, because MARIANNE could fly "piggy-back" on a commercial launch - allowing the commercial customer a large degree of freedom as to the launch schedule.
The operation costs may be taken up by ESA or CNES (or other national agencies) if some scientific instrumentation were included in the MARIANNE satellites. (For suggested areas of research, see below).

Feasibility.

From a technical point of view this project is challenging, but not out of reach. In our opinion the technical points which needs further study are the following:

1) The availability and properties of the collapsible tube masts or alternative approaches to the sail suspension.
2) The choice of material and surface treatment of the colored reflecting sails.
3) The choice of electronic and mechanical components for achieving functional lifetimes in excess of 10 years.
4) The mass budget at launch, with particular emphasis on the rocket motors needed for reaching the Lagrange distance and halo orbit insertion.

Scientific uses.

Satellites at the Lagrange Points have important scientific potentials. This is testified by several studies of such missions already performed both by ESA and NASA.
Although the MARIANNE satellites will be designed primarily for their artistic and symbolic effect it should well be possible to carry limited scientific packages typically having masses of 20 kg and requiring only a small amount of power and telemetry.
There are two areas of research where such a possibility could be of great importance.
The first area is the study of the solar wind and its interactions with the magnetosphere of the Earth. The "CLUSTER" mission, presently under study by ESA, is precisely aiming at this problem, and MARIANNE would offer new possibilities for coordinated observations of the plasma-phenomena at different points in the space surrounding the Earth.
The second area is the study of the "Cosmic Gamma-Ray Bursts", incidentally the research field of one of the proposers of MARIANNE.
Here MARIANNE would offer unique possibilities for coordinated observations with optical telescopes from the Earth and gamma ray telescopes in space. The problem for this research is that gamma-ray bursts are rare phenomena, - only one event per week can be expected if the observations cover the half-sky away from the Sun. Therefore long lasting satellites are required, and also satellites from which the radio signals, giving the alert and the approximate position of the burst, can be received directly at the Earth based astronomical observatory trying to catch the "burster" in the act.

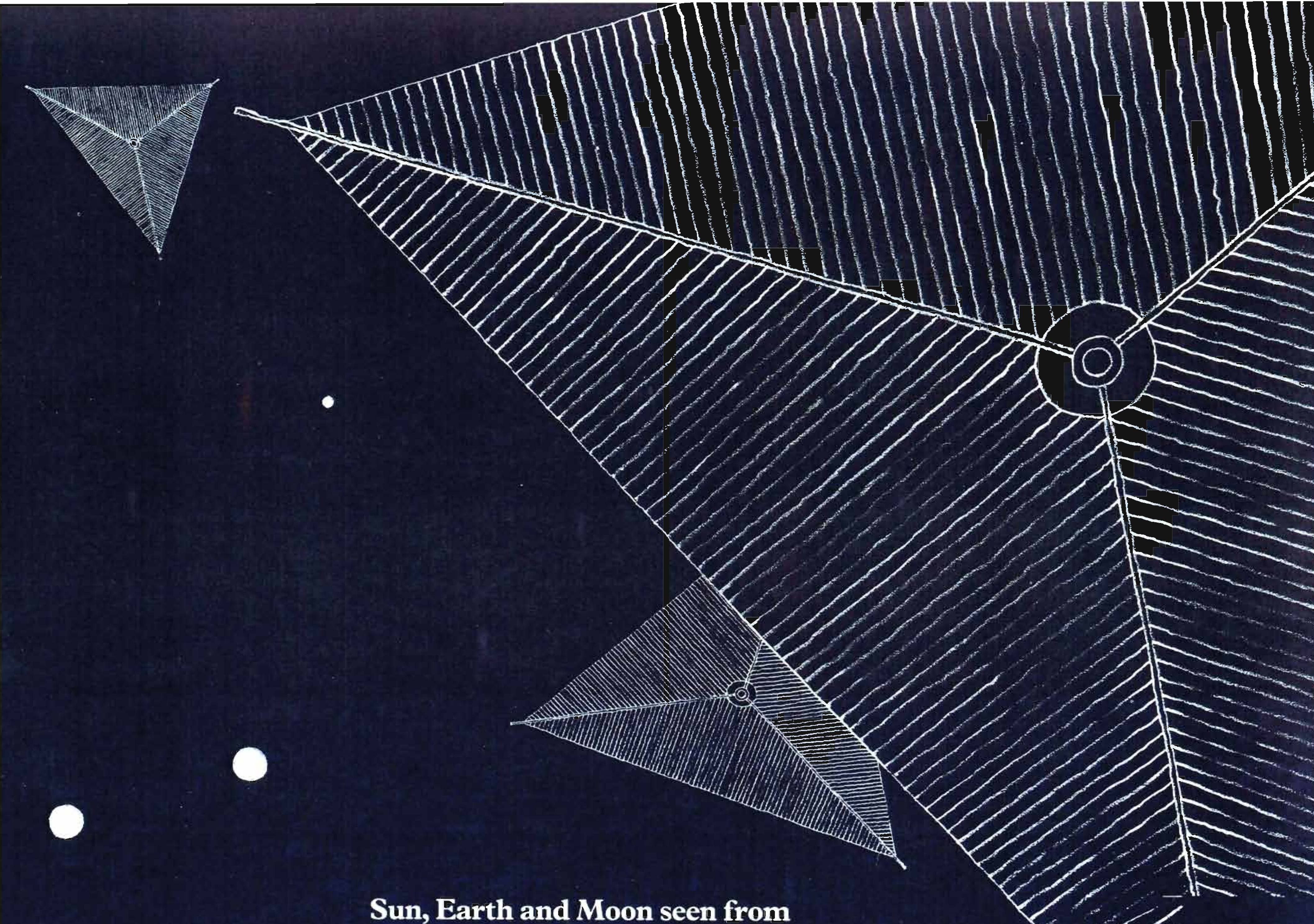
Didactic uses.

The visible presence of the MARIANNE satellites ever moving and at the same time always remaining in the center of the night sky, will undoubtedly be a great inspiration for teachers and pupils all over the world.
It will establish a departure point for many discussions of the interplay between gravity, the centrifugal force and the pressure of sunlight.
The beautiful properties of the Lissajou curves traced by the satellites in their movements around the libration point can also be used in the study of periodic and nearly periodic systems.
The sharpness and accuracy with which the position of the satellites can be determined, even with the naked eye, against the background stars, allows interesting teaching experiments, such as determining the distance to the satellites by observing their parallax movement during the night due to the rotation of the Earth. (This method was originally used by Tycho Brahe in his attempts to measure the distance to comets).
Another possibility is for an observer to determine his own geographic latitude on the Earth by comparing his observations of MARIANNE with the predicted positions from an ephemeris.

To travel light.

Today, the Eiffel Tower no longer symbolizes the triumphing railway technology that was its basis.
Today, the question is not of transforming mass to energy, and we have left behind the subjugation of the world, the optimistic penetration into the remotest corners of a domesticated and colonized earth.
MARIANNE is made possible by contemporary technology, but MARIANNE is not a victorious colonizer of space.
MARIANNE dances in the sky as an example that powers can be played with instead of conquered.
Photons, the very substance of light, is one power that keeps MARIANNE in position between immense celestial bodies: space travel has discovered energy transformations that are beyond our taming. The sun of our solar system beats its tremendously powerful light on the slight structures of MARIANNE, while MARIANNE, playfully balancing this power, shows us the mirror image of our sun, exact in the smallest detail.
MARIANNE plays with powers greater than ours, and moves imperceptibly in larger movements than any railroad dream, sending its great message from sun to earth.
MARIANNE shows us that movement does not have to have a fixed direction, nor a premeditated goal: that what seems to be movement may be motionlessness: and that fixed points may be moving fast and wide.
The light from the sun is mirrored to us in MARIANNE's own time. Resembling stars, moons, and planets while playing with the immense powers of mass, MARIANNE - itself fragile and almost weightless - stays dancing, balancing in a point of no departure.
With MARIANNE we no longer contemplate the colonization, domestication, and transformation of our universe. We realize that what matters is to find the balancing points. That we do not communicate in spite of the powers of our great world, but by simply moving with them, playing with them, letting them be.
MARIANNE therefore shows us that we have come a long way to understanding that leaving home is staying at home: that we have only imagined endings and points of departure. And that what matters when we play with the greatest powers is - to travel light.

September 1986
Anne Knudsen

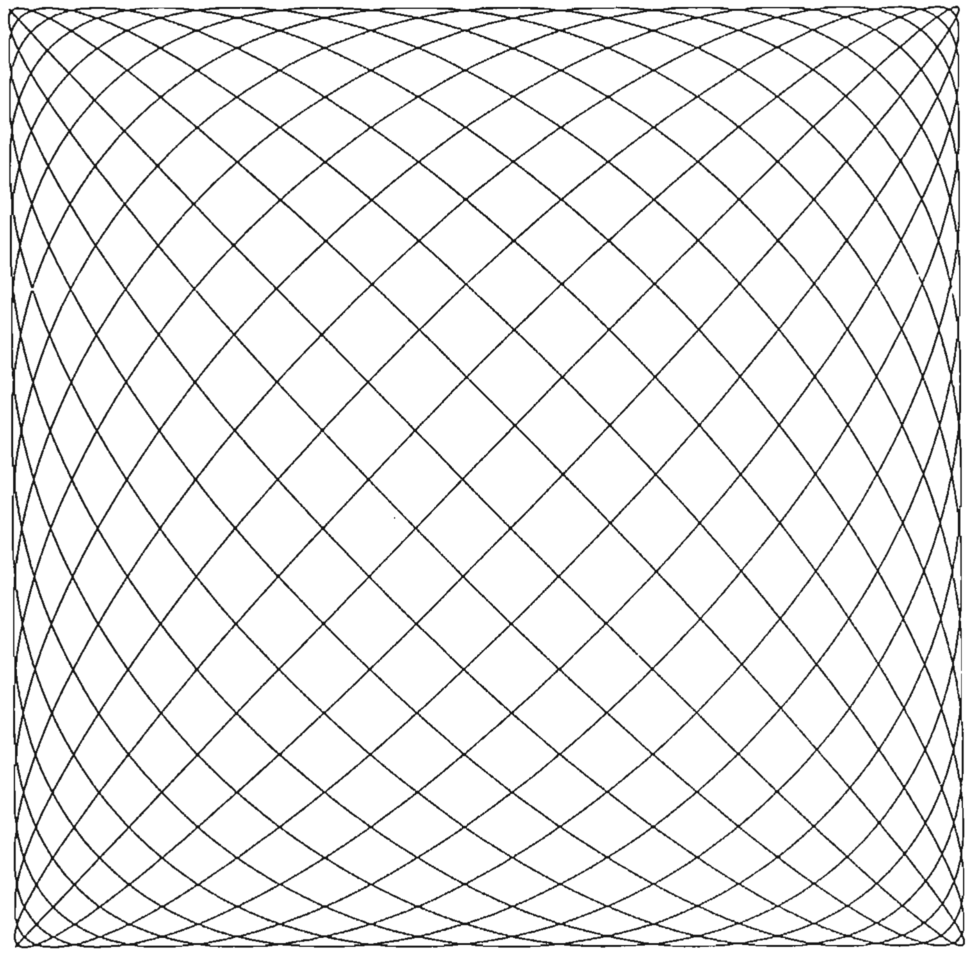


Sun, Earth and Moon seen from
the Lagrange Point.

Figure 1.

MARIANNE appearing between Taurus and the Pleiades.

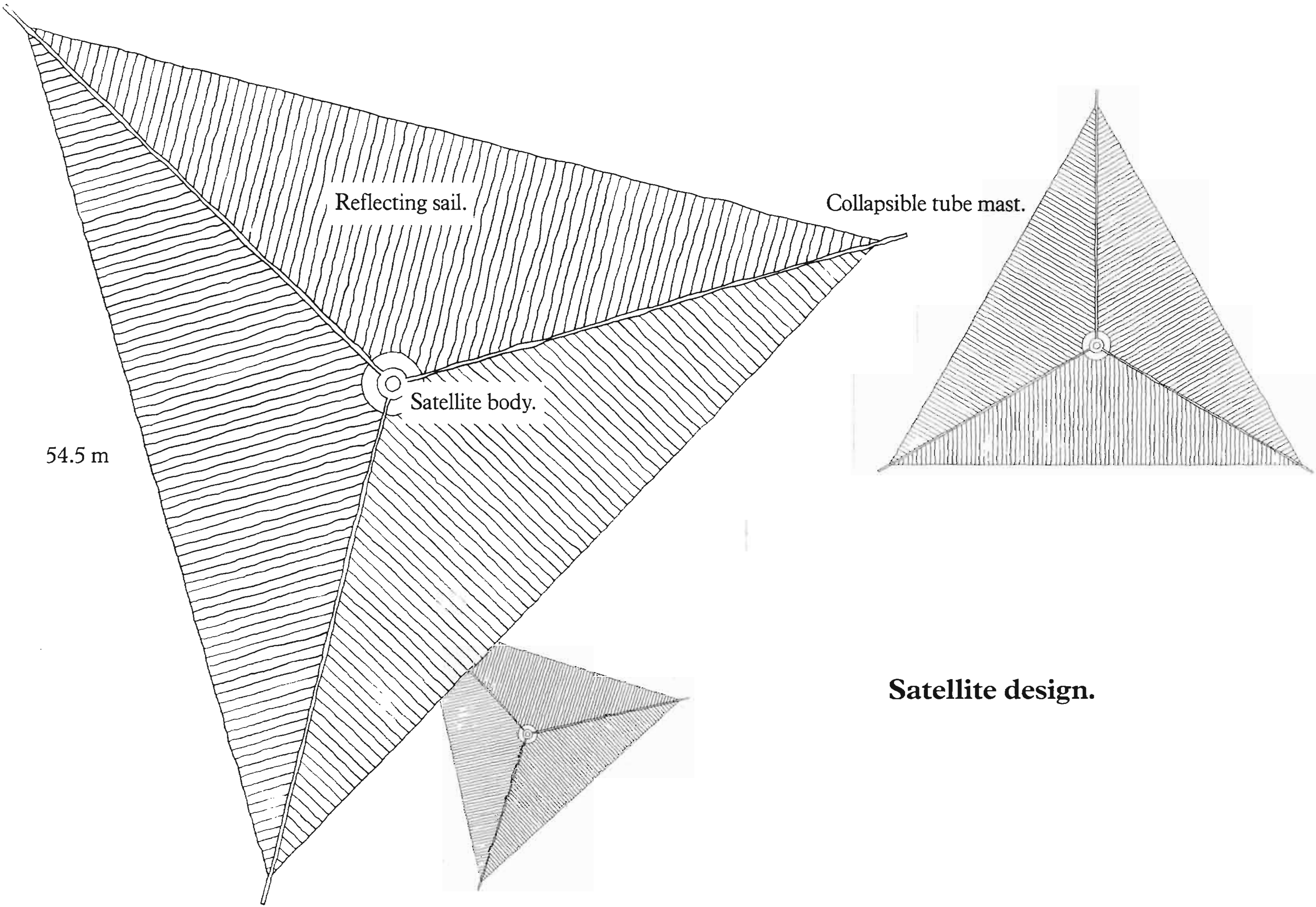
Figure 2.



Lissajou movements.

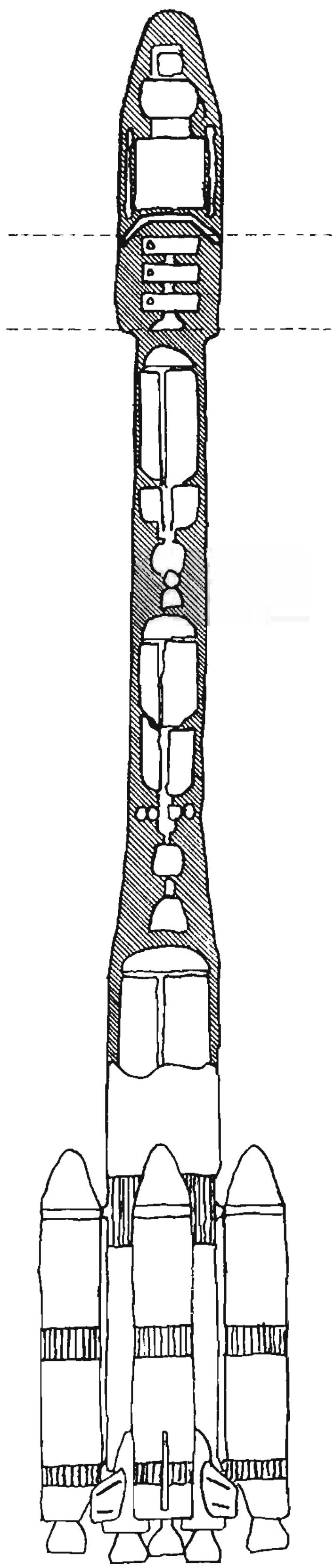
The period is 183.5 days perpendicular to the ecliptic and 177.6 days parallel to the ecliptic.
The entire trace of the figure corresponds to about 7.5 years.

Figure 3.



Satellite design.

Figure 4.



The 3 satellites of MARIANNE before launch.