SOLAR SAILING AND SOLAR POWER GENERATION BY "ROLLER REEFING"

Frank Ellinghaus, for ISSS 2010

Identifying Roller Reefing as enabling technology that combines solar sailing and space based solar power generation with high precision attitude control and fuelless station keeping.

A DESIGN PAPER OF A DIRECT LAUNCHABLE DEMONSTRATOR

SOLAR SAIL POWER STATION (SSPS)

Abstract

Roller Reefing is an enabling technology that combines solar sailing and space based solar power generation with fuelless high precision attitude control and station keeping.

It allows the on orbit construction of very large solar spacecraft, as well as the direct launch of smaller solar sail power stations (SSPS) with relative large solar cell arrays.

This paper presents the design of a direct-launch-able solar sail spacecraft that could be used as a space-based solar power station and proposes a way to operate it as a movable spacecraft in a geostationary orbit (GEO).

It is based on the Solar-Sail-Launch-System (patented in Germany and UK, patent application pending in the US). A modified System-Sail spacecraft of the Launch-System will be used as a space based solar power station and might serve as a demonstrator for larger units.

Introduction

In 2009 PG & E, a large california power utility struck a deal with Solaren Corp. which would allow Solaren to deliver beamed energy from space to the companies facilities for a fixed price.

The deal shows, that an economic base exists for space based solar power stations and energy beamed from space to Earth.

This design paper proposes a
mobile demonstrator **Solar Sail Power Station (SSPS)**
based on „Roller-Reefing“ solar sailing technology.

Challenges

Besides technical challenges, financing is a major hurdle to space solar power (SSP) ambitions. Huge - kilometer-sized constructions, assembled in space would be a multi billion dollar adventure.

To convince investors, a demonstrator spacecraft has to show, that the technology is viable.

Since Solaren has announced the power supply by 2016, a demonstrator craft, which costs "only" multi millions of dollars is needed very fast.

Chances

For several years of service, a space based solar power station in GEO, which does not use solar sailing technology, would need tons of fuel delivered to GEO. To deliver this fuel even more fuel is needed. A SSPS with fuelless attitude control and station keeping could avoid this.

This could become a chance for the construction of a space based solar power station which is also a solar sail spacecraft.

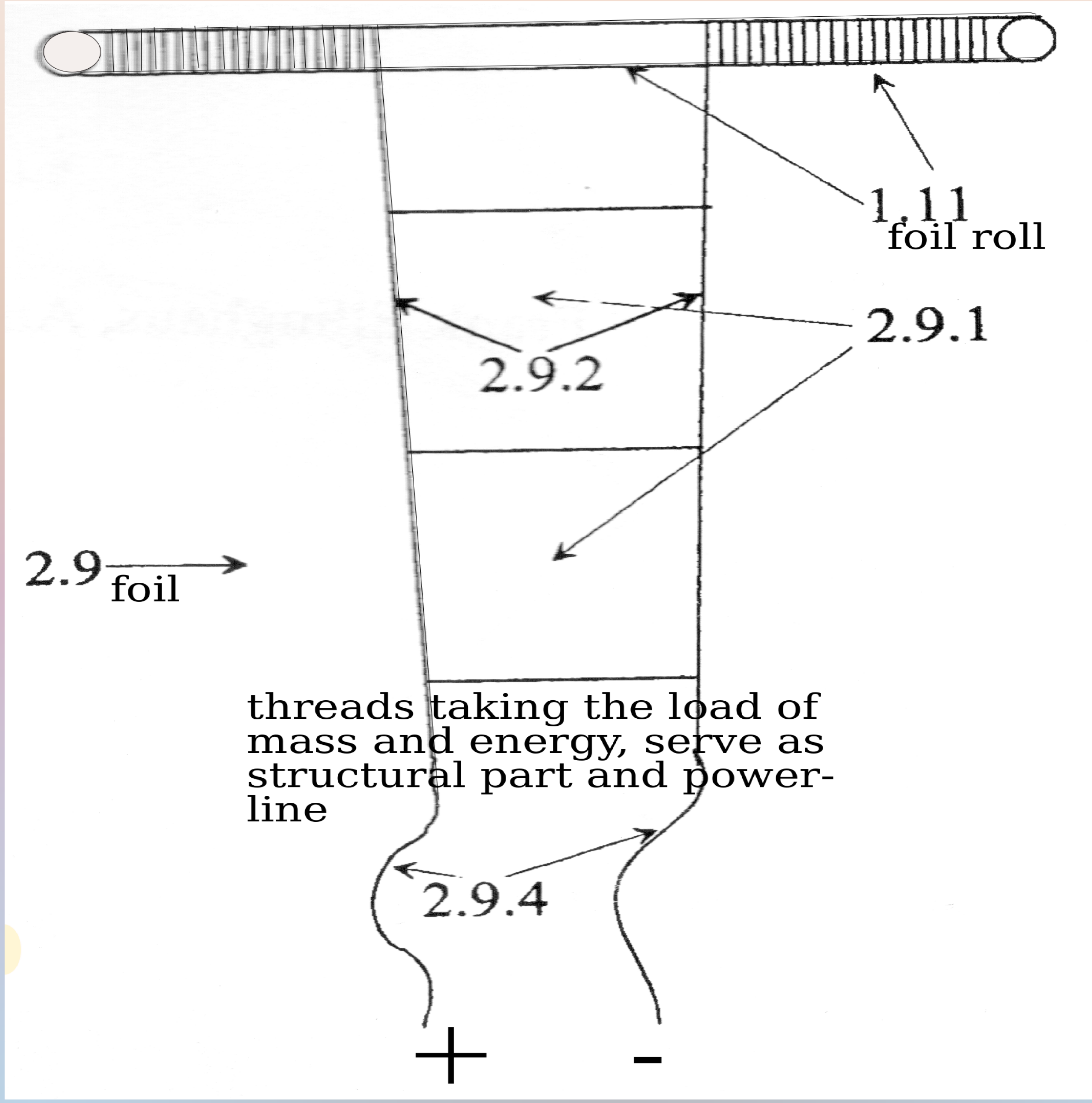
While solar sailing already lost out to solar-electric propulsion because for the mission(s) in question reaching the destination with the proven thruster technology was assumed to be faster and cheaper.

In the following design, the craft does not need to reach GEO with the help of solar sailing technology. Solar sailing would just be used for fuelless station keeping and fuelless high precision attitude control. - Something, solar sailing could do best of all known space propulsion technologies.

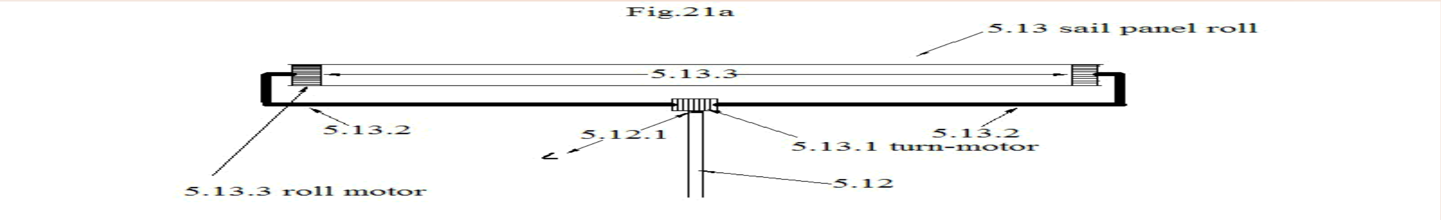
Advancements in thin film solar-cell technology

- make it possible, to furl and unfurl flexible, rollable solar cell arrays onto and off rolls
- this allows to launch SSPS, which are considerably lighter than the massive solar power stations, designed with rigid solar cell arrays or complicated mirror arrangements in mind.
- Roller-Reefing is the natural choice to launch, transport and use this new thin film pv-technology.

Roller-Reefing foil on foil roll



Foil roll on roll holder with motors



The two roll-motors mounted on the sides of the roll, pull the foils towards the spacecraft rim when reefing. On the central structure of the craft winches would be mounted, which pull towards the spacecraft center for setting sail/solar cell arrays.
Having winches or roll motors slightly pulling, while the counterpart is blocked, would allow to keep the foils straight and avoid wrinkles.

The central turn motor is attached to the pole of the mast of a direct launchable SSPS or fixed to an Outer Ring of a large space constructed SSPS and allows to turn the unfurled sail foil similar to a windmill-wing. Doing that with some or all of the foils would allow to turn the craft around it's plane-center or to stop or reverse unwanted rotation/spin.

Roller-Reefing allows to use the same attitude control technology for smaller Earth launched (demonstrator spacecraft) as well as for very large space constructed units.

Solar-Sail-Launch-System features

The **Solar-Sail-Launch-System** consists of a System Launcher and the System-Sail spacecraft.

The **System-Launcher** features

- a payload compartment which opens up longitudinal like a flower
- a rotation platform
- several winches

The **System-Sail** spacecraft features

- a central docking and payload station consisting of several connected pipe rings
- several daughter units already docked in the sailcraft's docking station
- around the middle of the docking station two rings forming a plane which can be used to attach spacecraft equipment and gear (thrusters, tanks, solar-cell-arrays, etc) on both sides (above and under the spacecraft).
- Hybrid propulsion – solar sail and solar-electric thrusters
- tiltable telescopic masts
- foil-rolls attached to the outer ends of the telescopic masts

Solar-Sail-Launch-System drawing

<u>Reference Design for Ariane V ™ ECA</u>

The SSPS-demonstrator is a mothership with several daughter units, at least two of them would be used as transmission units, one of them with laser- and one of them with microwave technology.

The mothership would serve as the energy collection unit.

Solar Foil area = 3120 sqm

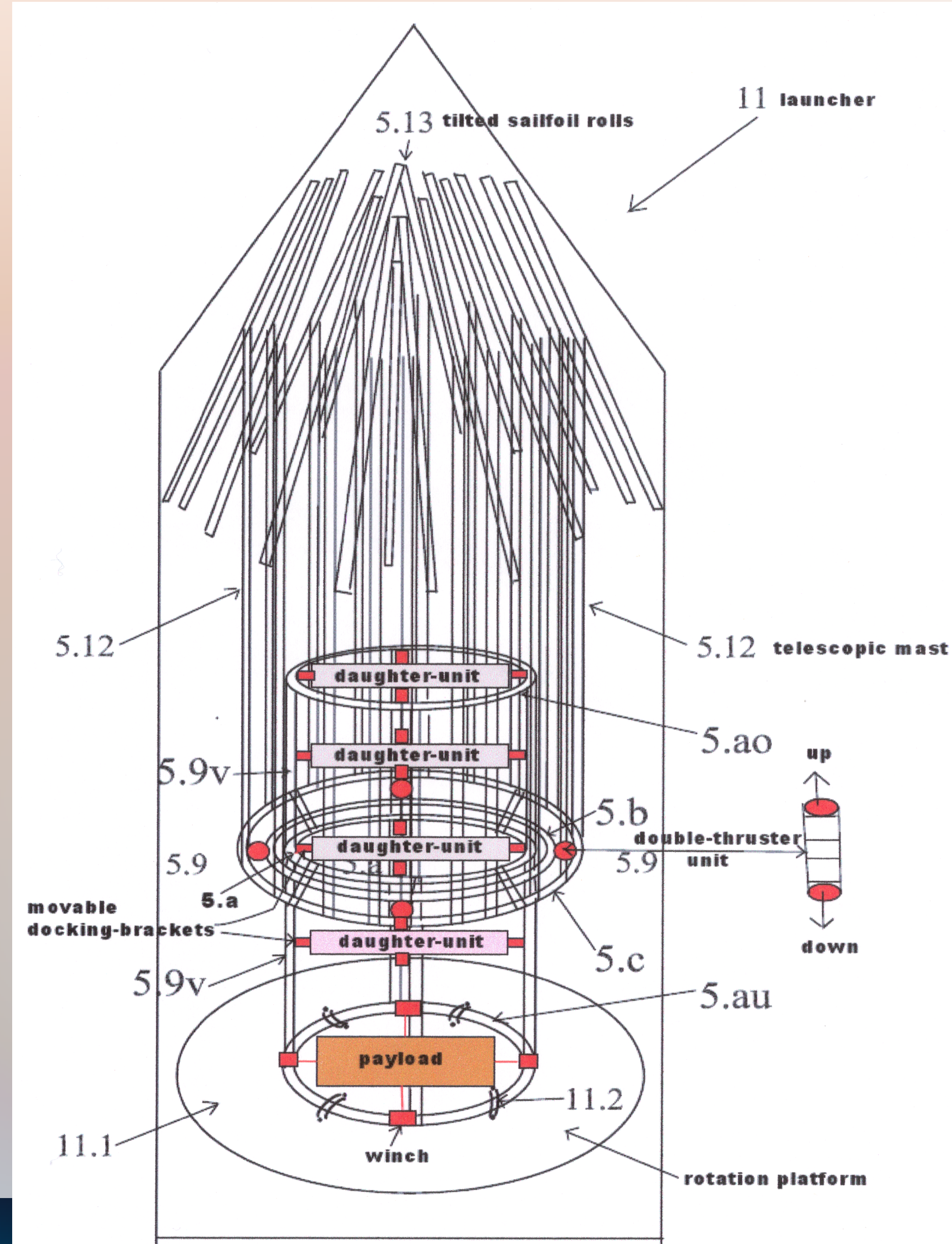
(more than the solar cell-arrays carried by the ISS).

The foil area is scaleable by enhancing the number of mast-segments.

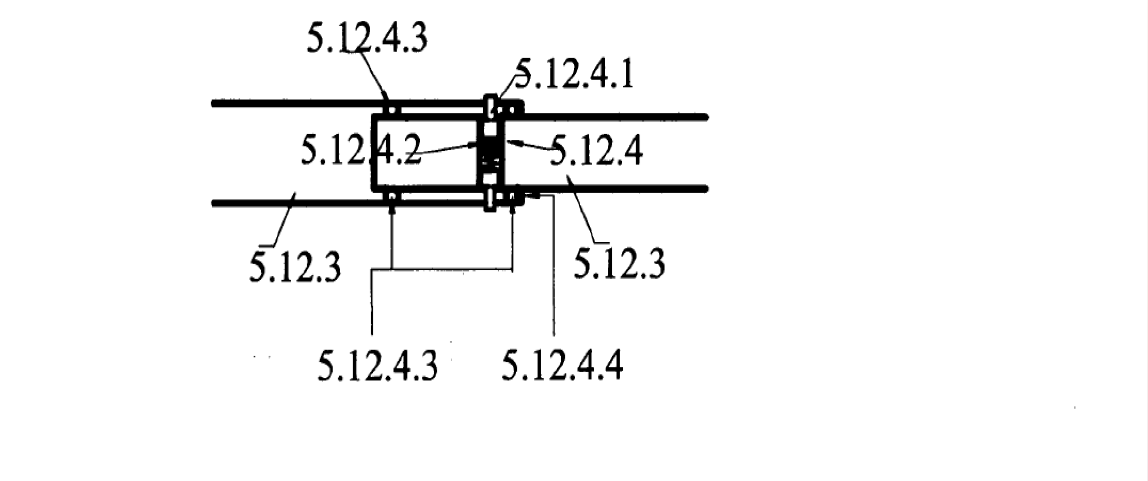
12 seven segment masts, each about 70 m long,
with solar foils of about 260 sqm each.

Volume of docking-station = 28 cbm

area of additional gear- and equipment plane = 12,4 sqm
x 2 (above and under the plane = 24,8 sqm)



Lock in mechanism for mast segments



Just a spring driven pin locks the mast segments in their elongated positions. Ball bearings would enable sliding of the segments.

This locking mechanism keeps the telescopic mast stiff and in it's full length. Along with the rigid masts and rolls, the mechanism makes it possible to operate the spacecraft without having to spin it.

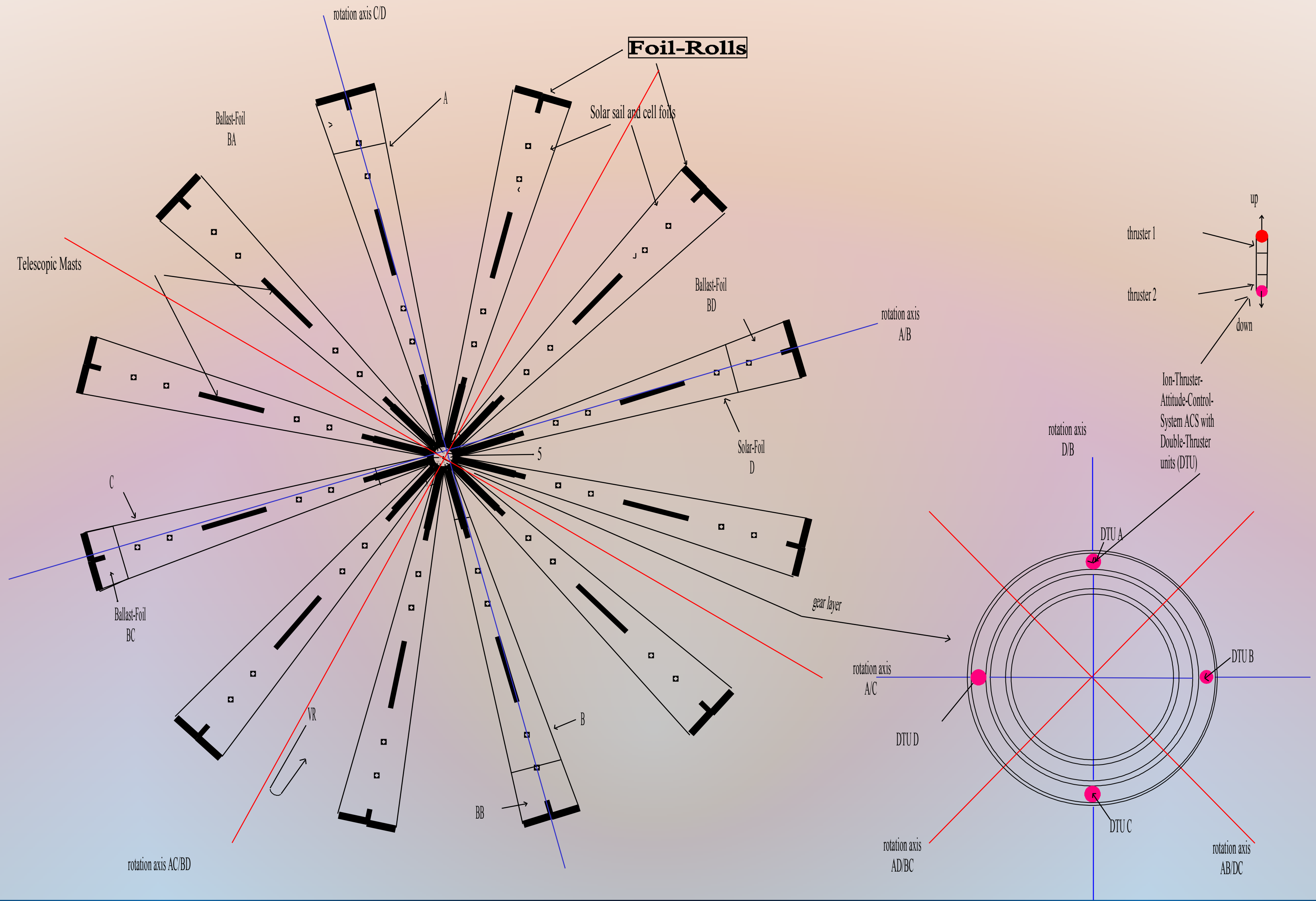
Attitude Control System, Station-Keeping and propulsion

The System-Sail power station would feature several possibilities to manipulate attitude and movement:

a) Roller-Reefing by furling and unfurling of steering foils (fuelless center of mass/center of radiation pressure movement)
b) Using the ion thrusters for propulsion and attitude control with double thruster unit (DTU) configuration
c) Fuelless mass displacement through moving the daughter units with movable docking brackets
d) Fuelless mass displacement through moving payload inside the docking station with winches
e) tilting the sail foil rolls around the poles of the masts to generate or avoid rotation about the power stations plane center.

The additional solar-electric thruster-propulsion allows low cost LEO-launch.

Deployed SSPS with Hybrid ACS



Attitude Control by Roller-Reefing

The **drawing on slide 13** shows set sail foils on 12 extended telescopic masts of the System-Sail spacecraft.

Four of those foils are serving as steering foils and feature **ballast foils** on their ends toward the sailcraft's rim. **Only this ballast foils would be furled and unfurled for attitude control.**

They would be designed to take on the heavy stresses of often furling and unfurling and would serve as ballast (sliding)-mass too, while the delicate solar-sail and cell-foils would just be moved, not rolled. Therefore the ballast parts are made of heavier and stronger materials than the regular foils.

Unfurling and furling the sail ballast panels (here ballast panels BA, BC, BD and BE) steers the sail craft through shifting the center of mass and at the same time shifting the center of light pressure into the opposite direction. In contrast to a pure mass shifting ACS this roller reefing and unfurling system adds two shifting processes for enhanced steering power into one single steering operation – (furling or unfurling the sail or ballast foil).

In this example the ballast panel BC is only half way unfurled while the ballast panel BD is fully unfurled, which reduces the C-foils sailing area and shifts the center of solar radiation pressure towards panel D on the opposite rim oft the craft while the center of mass is shifted toward panel C since the mass of the whole foil is shifted toward the C-foil-roll at the outer end.

As the driving forces on the spacecraft are pretty small but consistent, Roller-Reefing promises to be a high precision attitude control and station keeping system.

Attitude Control by Double Thruster Units (DTU)

The **drawing on slide 13** shows also a magnified view of the equipment and gear plane layer around the central docking station with four double thruster units. Above the magnified gear plane, a magnified double thruster unit is shown.

Such units feature two thrusters mounted opposite to each other in one jet tube. **This allows to slow down, stop or even reverse each move or turn** originated by thruster force **by switching to the opposite thruster(s).**

As each DTU has a partner unit placed on a diagonal line on the other side of the spacecraft center, having one thruster thrusting upwards and one of the opposite double thruster unit thrusting downwards, will result in the spacecrafts turn around a common rotation axle between these DTU's.

In this example with only 4 DTU's we have only 4 rotation axles.
Two between two DTUs and two between two combined pairs of DTUs. If all downward- or upward-thrusters are fired together, the spacecraft plane will be pushed upwards or downwards.

Daughter Units

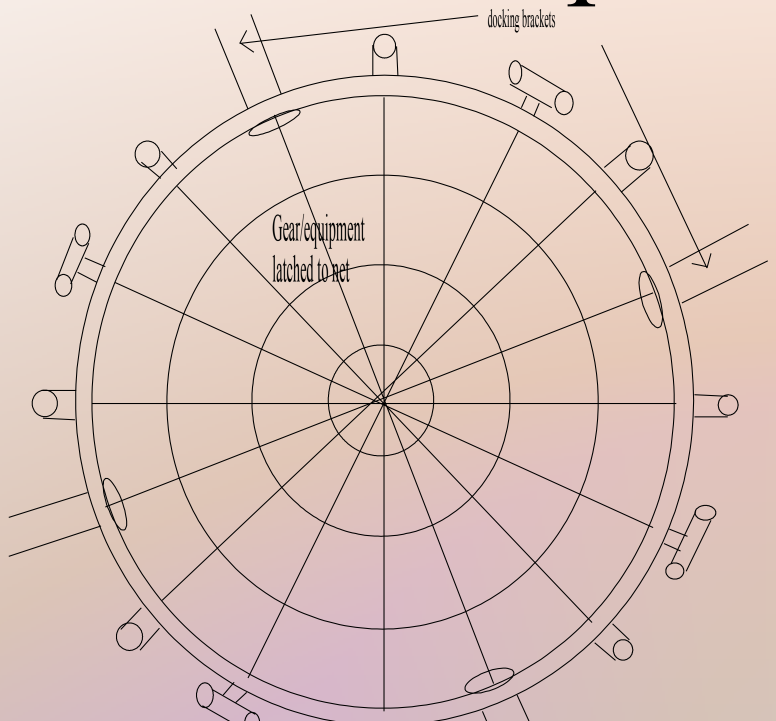
Daughter-units of the SSPS-mothership would serve as transmitting parts of the power station. They are independent spacecraft, but also connected with power cables to the System-Sail spacecraft and transfer the electric power by pointing and transmitting the energy towards Earth.

To investigate both beaming possibilities, at least two beaming units, one equipped with laser- one with microwave technology would be carried inside the docking station.
The power cables prevent conversion losses and are just the simplest way to do a demonstrator mission.

Further daughter units (at least two, one for the mothership and one for the working beaming unit) can and should be carried with the mission for observation and tele-communication.
This enables visual tele-operation by photo and video data and a thorough analysis to develop the needed knowledge and strategies to steer and operate larger SSPS also.

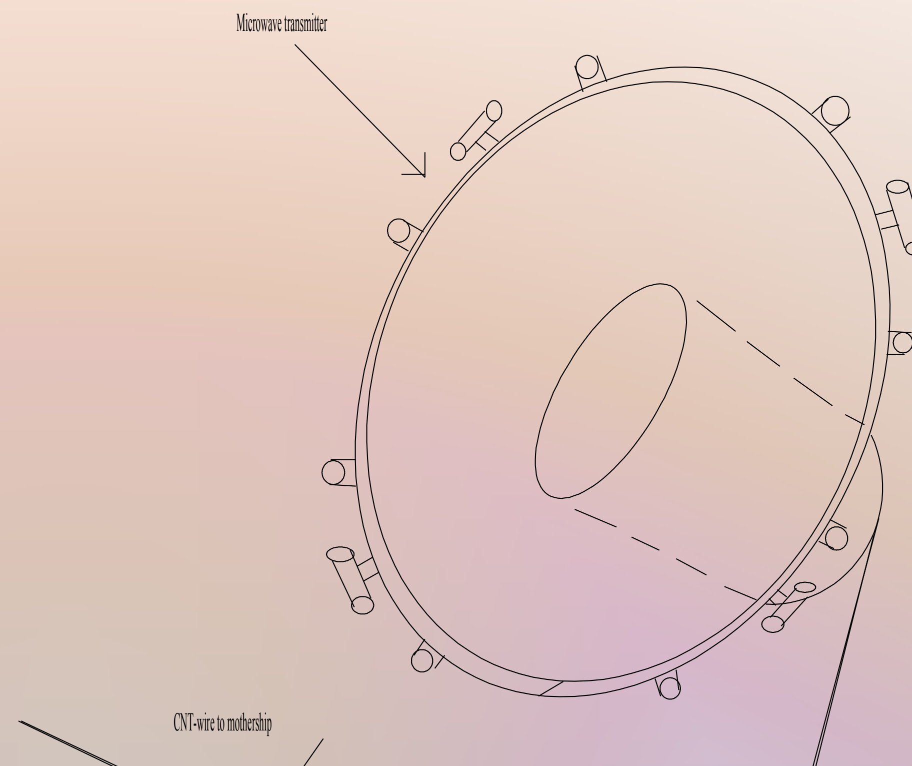
Most daughter units feature an Outer Ring with DTU solar-electric propulsion. This thruster rings are serving also as handles for the movable docking brackets of the mother unit's docking station.

2 example-daughter units



Standard daughter unit with DTU-propulsion on a thruster-ring and about 6 sqm (3 sqm above and under the spacecraft plane) gear- and equipment net inside the ring.

The unit is held from outside with docking-brackets in the docking-station of the mothership.



„free flying“ microwave transmission-daughter-unit (about 3 sqm) with DTU-propulsion and power cable connected to the mothership.

PROPOSED QUASI STATIONARY GEO-ORBIT

As space based solar power stations with their large solar cell arrays have to point constantly towards Sun, they will always produce thrust. Thrust which may be used to accelerate or decelerate the orbital speed of the spacecraft around Earth in a controlled manner instead of pushing the sailcraft along with other mainly gravitational forces out of geostationary orbit.

The idea of this proposal is, to change once a day from solar sail acceleration mode to deceleration mode and once a day the other way around.

The acceleration and deceleration modes would have to cancel each other out. The SSPS would need to stay around a GEO slot where it is allowed to move once a day fore- and once a day backwards above Earth's surface.

The sailcraft could not stay above one spot on Earth all the time but it would stay above the same point on Earth the same time of each day.

Proposed video monitoring for attitude control

Personally I think that it is better to get rid of flywheel- or spin-based attitude control for solar power stations, which have constantly to change their attitude.

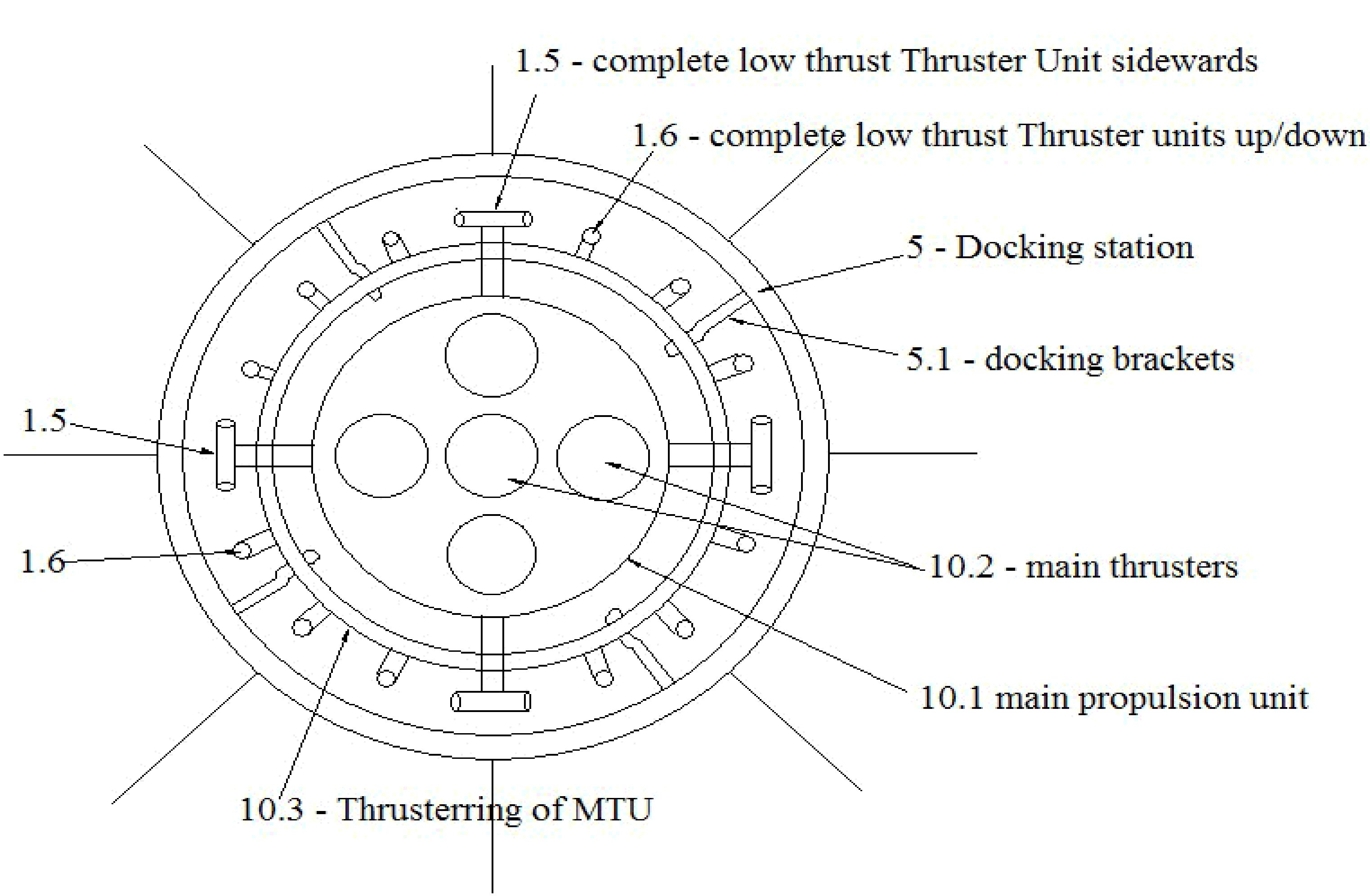
Instead video-data from cameras mounted on the spacecraft should be placed onto a monitor grid and constantly observed in relation to the position of fixed stars in the vicinity.

Once the positions of those stars on the monitor-grid change, the available actor devices (Roller-Reefing, thrusters, mass movement), would steer fuzzy-logic-style against not wished directional movements.

A Solar power station in GEO should have enough energy to provide the needed kind of bandwidth to transfer fulltime video coverage to Earth. This wealth of bandwidth could get the film- and gaming industrie into the boat as developers and sponsors of space operations to develop a virtual reality remote steering environment.

Mobile dockingable thruster unit (MTU) docked in docking station

Fig. 16 Mobile dockingable Thruster Unit (MTU)



Usage of mobile MTUs

MTUs, as shown on **slide 20** have thrusters on an Outer Ring to dock into and out of the docking station of a mothership. They have also one or a cluster of (stronger) thrusters located inside the ring and are thought to drive the mothership when the thruster unit is docked.

They could dock out when the fuel is depleted, letting room for refueling through another MTU which just docks in again. Fuel service motherships, stuffed with several MTUs, would allow to refuel a mothership or solar power station „on the fly“ through providing new dockingable thruster units .

When the demonstrator-SSPS has done it's duty for the first GEO-orbit mission, he gives way for the larger space constructed solar power station and just starts with such a delivered MTU to find new challenges, like to discover solar sail specific orbits, approaching an asteroid (by taking in mining- and prospector daughter units) or serving as a relay-spacecraft for the yet to build space video internet chain.

Conclusion

Roller Reefing can provide a commercial base to space based solar power production by substantially reducing launch mass, construction time in space and fuel consumption while also delivering high precision steering, attitude control and **fuelless** station keeping.

The presented design of a Solar Sail Power Station (SSPS) could serve as a demonstrator mission for larger space mounted power stations and power satellites. It uses Roller-Reefing and allows to deploy solar cell arrays in one single launch, which are larger than the ISS-arrays mounted in years of prolonged construction works.

Both technologies, solar sailing and space based solar power generation could profit of each other by their combination.