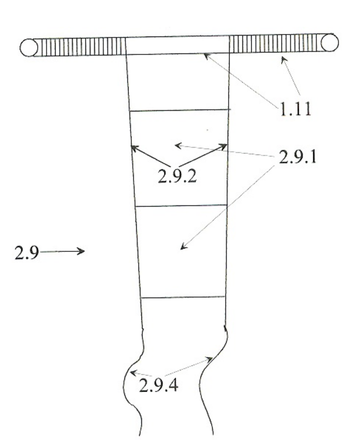
" Indeed, the packing and deployment problem has perhaps been the greatest impediment to practical solar sail utilisation."
Colin McInnes, Solar Sailing Technology, Dynamics and Mission Applications

Figure 1
Sail-Foil on it's roll



Instead of folding and packing a very large sail-, why not splitting it into many rows of sail foils, each smoothly furled onto it's own sail foil roll?
This would enable very large solar sails, avoiding the limitation of the sail size to the launchers carrying capacity.

It avoids the stressing and problematic folding and unfolding process too.
In addition mounting of the single sail foils on their rolls is easy. Just putting them into their brackets on the **Outer Ring** or outer edge of the sailcraft and connecting their end threads 2.9.4 to winches at a center location of the solar sail.

Figure 1 above shows a sail panel partly on it's roll. As the foil width of round sail sail panels shrinks when furled, the edge-threads 2.9.4 are protecting the sail foil during launch through lying on it and hold it firm. This along with the sparing furl and unfurl process should enable the usage of thinner – and lighter foils.

On self deploying spacecraft unfurling would be done with the winches and that only when it is needed (there are no masts, which have to uncoil while unfolding a stressed sail to enable steerage).

A further benefit of this roller-reefing possibility is, that the solar sail can furl again, reefing the sail before getting back to a near Earth location (like the ISS) with perturbing rest-atmospheric influence.
This enables returning solar sail carrier ships, delivering space materials for examination or utilization through humans, which are still under the protection of Earth's magnetic radiation shield.
Prerequisite therefore is, that the solar sail has a second means of propulsion – like ion thrusters or other low thrust devices.

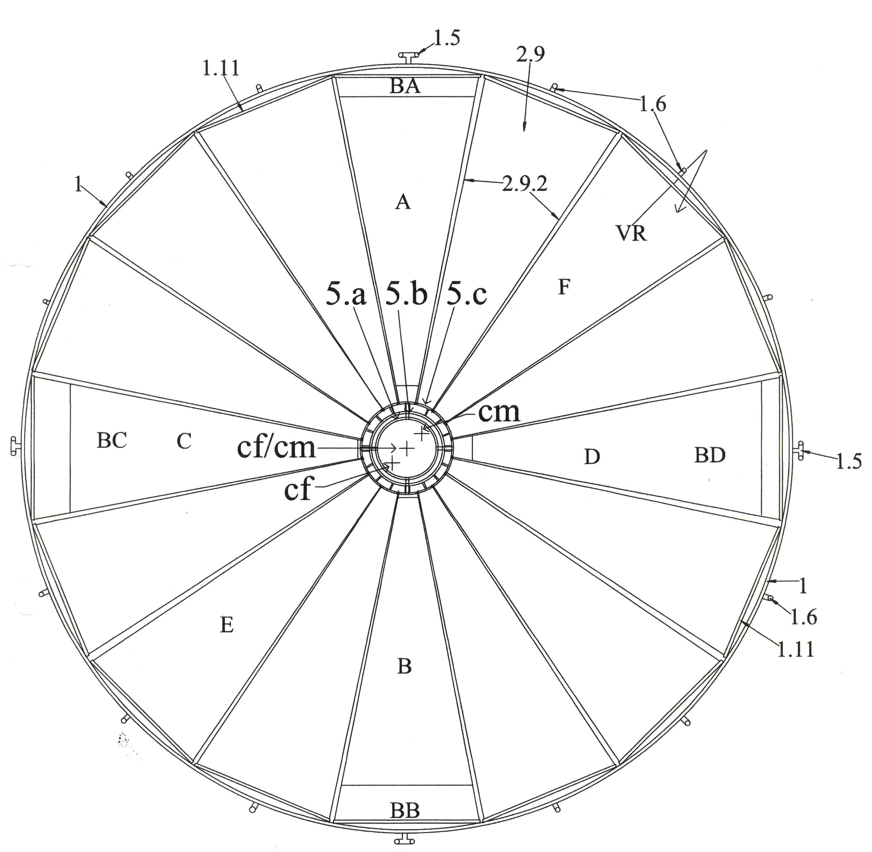
Fuelless Steering and Station-Keeping for Solar Sails with Roller Reefing devices

Figure 2 shows a **RingCraft** (a mainly flat spacecraft with a stiff, load bearing **Outer Ring** and low thrust thruster units on it's outer edge) as a large (square-mile sized) solar sail with an additional fuelless steering- and attitude control system (ACS).

The ACS is based on the "Roller Reefing"-Design. It uses winches located at the **Inner Ring Construction** and electric motors in the sail foil rolls which are plugged into brackets on the **Outer Ring** to furl and unfurl the sail foils. The **Inner Ring Construction** (carrying skeleton of several connected pipe rings) contains the central docking station, equipment and solar cell arrays, which provide ample power supply as well for the roller reefing system as also for the ion-thruster propulsion.

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´s this roller furling system adds two shifting processes for enhanced steering power into one single steering operation – (furling or unfurling the sail foil).

Figure 2 – RingCraft Solar Sail
with Roller-Reefing and Ballast-Foil-ACS



Above the **Outer Ring** skeleton (1) with low-thrust-thruster-units (1.5 and 1.6) and solar panel rolls (1.11) directly fixed into brackets on the **Outer Ring** pipe body.

The area inside of the **Outer Ring** is made up mainly of the sail panels with the docking station in the center. Besides the fuelless steering options it can also use it´s thruster units for steering but also as a secondary propulsion option.

Having a docking station (the Inner Ring 5.a), the **RingCraft** can also enhance the mass shift through moving the payload or daughter units with the help of move able docking brackets.
As well displacing the center of mass up towards Sun through placing the payload accordingly (if the craft carries a voluminous magazine docking station) is an option.
With that constellation the solar sail would drag it´s center of mass behind it, which could produce some kind of stabilization.

Further possibilities for fuelless attitude control are move-able control bars or vanes fixed to the outside of the **Outer Ring**. This versatility shows the helpfulness of a solar sail design with a stiff outer ring gossamer structure and central payload and docking station which has ample space and possibilities for spacecraft steering as well as for convenient payload mounting and docking and in addition carries ample solar arrays and equipment.
Masts and booms would not be needed for such a constellation.

Shifting and rolling ballast sail panel segments for steering purposes.

The ballast sail panel segments (here **BA, BC, BD** and **BE**) are thought to stand often furling and unfurling on and off their sail panel rolls. As they have to be clearly thicker and heavier as the regular extremely thin solar sail foil, they are well suited to serve as ballast mass for steering purposes.

In **Fig. 2** and as well in **Fig. 3** ballast sail panels for steering purposes are shown.

The ballast steering panels **BA** and **BD** in Figure 2 are rolled up to half of their unfurled area onto the sail panel rolls 1.11. That means the mass of the sail panels is shifted to the rolls of panels **BA** and **BD** and with it the sails center of mass - **cm** - as shown in the sails middle part is shifted into the same direction.

The center of solar radiation pressure force (here shown as **cf**) however is shifted into the opposite direction. As **BA** and **BD** are both rolled up halfway, in this case the **Outer Ring** of the sailcraft is turned upwards via direction **VR** shown on the sail panel F.

The pressure of the stronger radiation force (the opposite, fully unfurled panels have more sail area) pushes the sail down at the opposite Ring side of sail panel E. The longer the way between **cm** and **cf** the more steering inertia accrues per time unit.

By varying the length of the unrolled ballast panel segments it is even possible to shift the turning direction between the two segments which are actually used for steering according to their working ballast area.

Figure 3 - System Sail
of the Solar Sail Launch System – fully enhanced

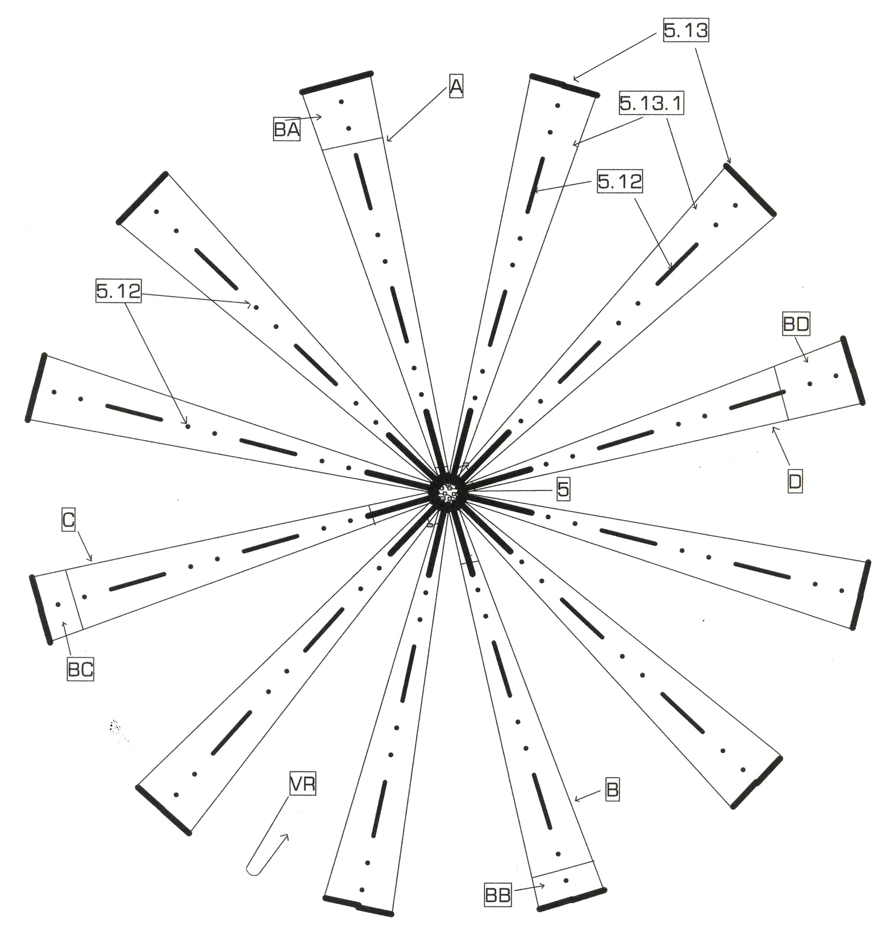


Fig. 3 shows the **System Sail** of the Solar Sail Launch System.
Unlike the larger **RingCraft** which has to be mounted in space, it is mounted on Earth. After launch the **System Sail** spreads out and sets sail without the need for further space construction tasks.

But still it carries a docking station with ample solar cell arrays for year long continuing operations, such as a observation or telecommunication purposes satellite or as a carrier for asteroid-landing operations.

In this case the ballast sail foil segments BC and BB are rolled up halfway onto their sail panel rolls 5.13 while the ballast sail segments BA and BD are fully unfurled. The stronger force lever of the fully unfurled sail foils A and D pushes the solar sail downwards at their side of the spacecraft's plane, while the sail foils C and B with their weaker forces (because they are only halfway unfurled) get tilted upwards, whereby "**VR**" is the center of the upwards tilt.

Underneath **Fig. 4** describes the design of a **System Sail** sail panel roll 5.13 on it´s bracket. The end of the bracket telescope segment 5.12 holds a turn motor 5.12.1 which can twist the steering sail foils into a propeller like shape and enables turning the sail around it´s pole.

The two roll motors 5.13.3 are the furling motors which work together with winches on the Inner Ring construction of the sail craft. The winches provide the driving forces to unfurl the sailfoils. The roll motors provide the driving force to unfurl the foils.

Fig. 5 pictures the origin of a bracket telescope segment at the inner ring construction.

Figure 4
sail foil roll of the **System Sail**

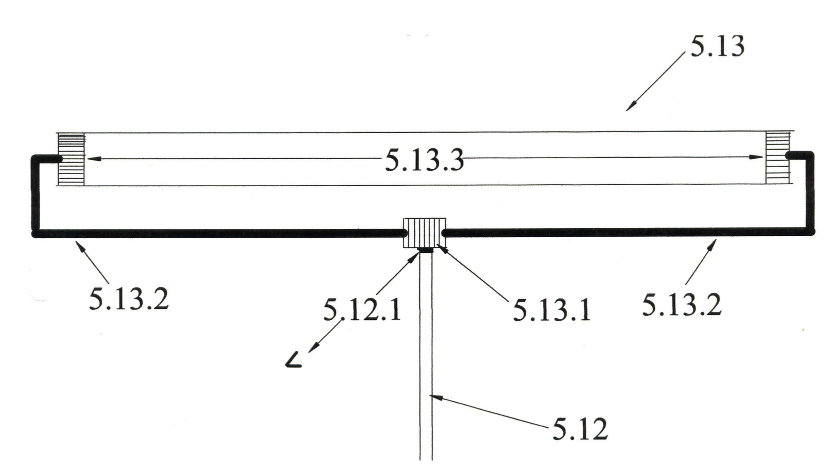
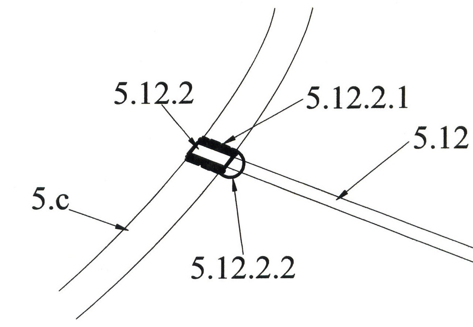


Figure 5 - telescoping mast
at the **Inner Ring** origin



Profiles and telescope-snap-in-mechanism of telescoping masts

Figure 6
some possible profiles of telescoping masts

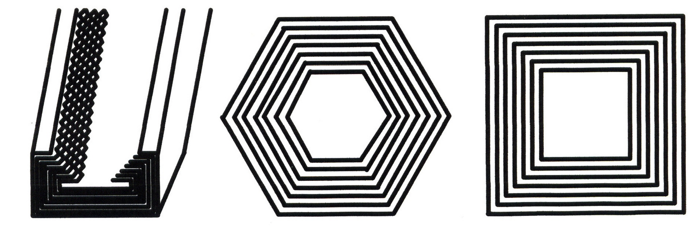
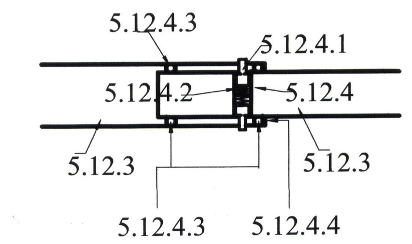


Figure 7 – Snap in Mechanism
of telescoping masts



In contrast to the **RingCraft** Solar Sail, the System Sail of the Launch System has rigid telescoping masts which are quite heavy compared to those of a square sail with uncoiling masts.

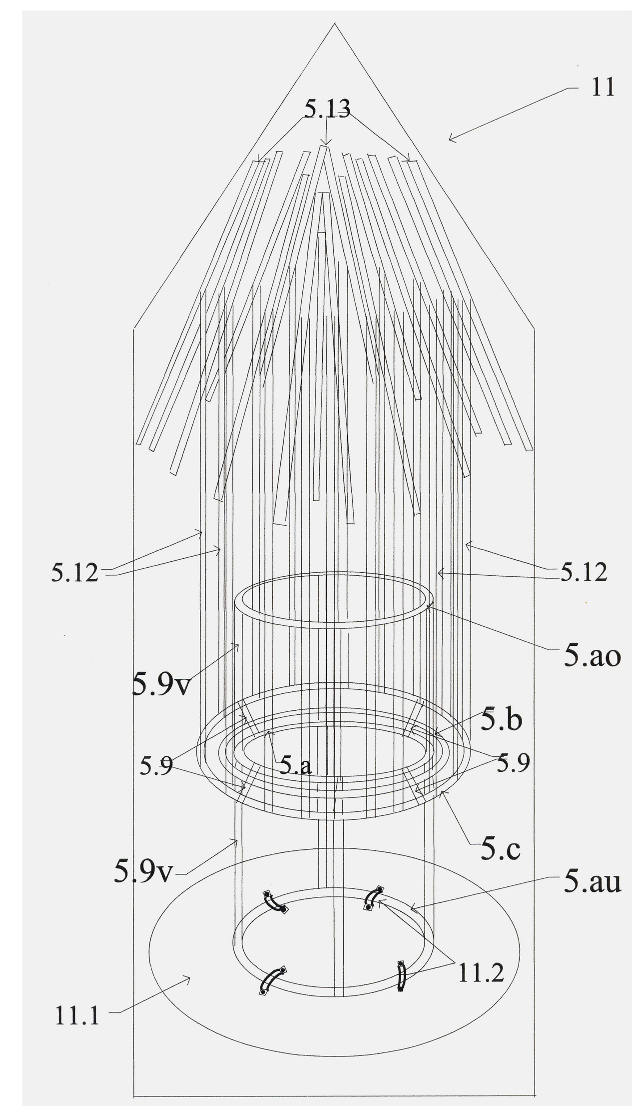
Figure 6 shows some of the possible profiles for those mast segments. The left profile would be dented to get driven by threaded electric motors.

The middle profile is the favorite one of the author, because it combines the uniform strength and material savings of a (roughly) round body with the impossibility to contort of a quadratic shape.

As those telescoping masts are segmented, all but the first outer segment are located inside a larger one when not already unplugged.

After pulling out of those masts to their full length through rotational forces, a snap in mechanism is needed, which holds the inner segment at the end of the outer one. This snap in mechanism, which works with snap in bolts 5.12.4.1 and spring sleeves, is shown in **Figure 7**.

Figure 8, Solar Sail Launch System
consisting of **System Launcher** and **System Sail**



The System Launcher
does not only launch the sail. It is part of the sails enlargement process and helps to spread out and enlarge the sails telescoping masts 5.12 shown on Fig´s 3, 8 and 9.

Outspreading of the sail foil brackets of the solar sail is done by opening up the launcher payload compartment in segments, each pulling one sail foil roll on their bracket sidewards. Enlargement of the solar sail happens through rotating the sail with the stationary rotation platform 11.1 which is mounted on the launcher.

The System Sail
uses the full area of the launcher payload compartment bottom to spread it´s stiff core frame of lightweight pipe rings which carry a good part of the spacecrafts equipment operation ready installed, such as solar cell arrays, thruster units with fuel, electronics, instruments and a central docking station. Such a base launch configuration is featured on the left drawing .

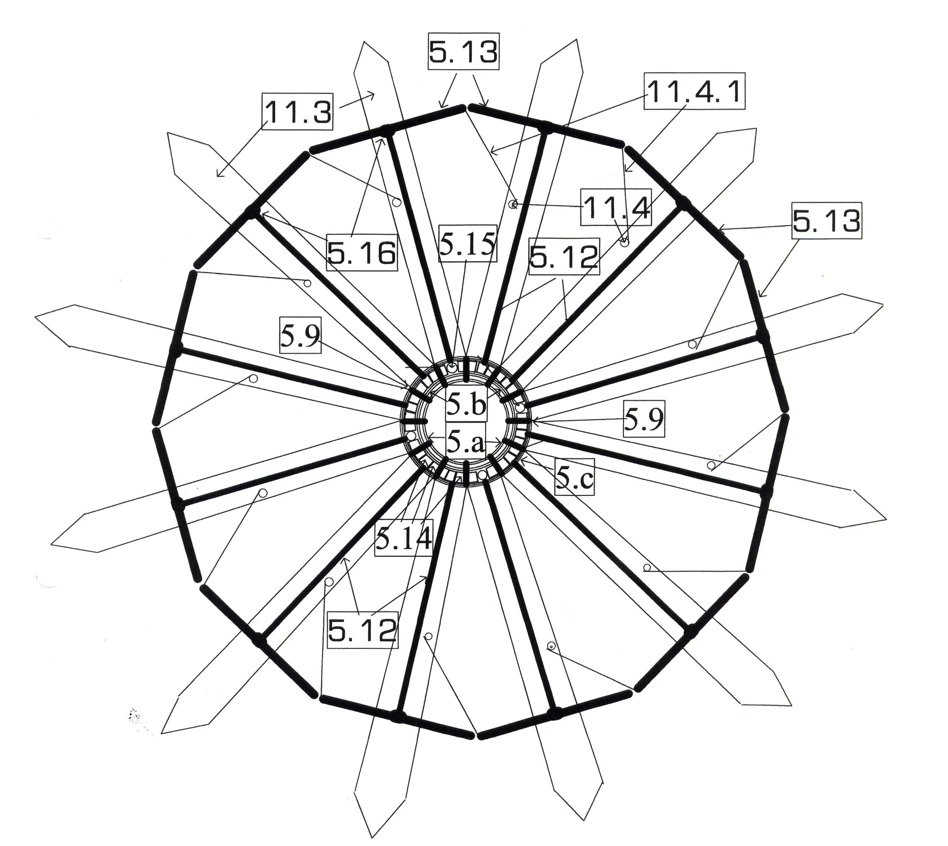
The docking station 5.9 has a quite large volume and would hold the daughter units (like landers or communication and observation) satellites already docked in at launch.

Between the rings 5.b and 5.c, around the middle of the docking station 5.9 is enough space to mount additional ion thruster units as additional means of propulsion.

The express way launch would use preferably a large launcher like the Ariane V to reach Earth escape velocity before separation happens. The long and painfully spiraling outwards of piggy back launched solar sails would be avoided.

The cheap way launch would use a smaller launcher, like a converted ICBM, to carry the load to NEO. After separation the sail craft uses it's thrusters, to get at least out of the influence of Earth atmospheric rests, while the sail foils are still furled onto their rolls.

Figure 9 – System Sail
outspread on opened up Launcher compartment, not yet enlarged



Phase one - Outspreading

The launcher tip opens up by spreading the tip segments sidewards, at the same time pulling the solar sail´s telescope brackets umbrella-like sidewards as well. Then the sail foil rolls get pulled into a position right-angled to their brackets with the help of winches, which are fixed to the launcher-tip segments. A fully outspread sail is featured with Fig. 3.

In Figure 9, the launcher tip segments 11.3 are already outspread, having pulled the solar sail telescoping masts 5.12 sidewards also. The winches 11.4 have already pulled the sail foil rolls into their 90 grade angle with the tilting threads 11.4.1. The threads depart through pulling and breaking away at their predetermined breaking point.

Phase two – Enlargement of the sailcrafts telescoping masts through rotation

The launcher's rotation platform 11.2 (see Fig. 8) starts to rotate and enhances the rotation rate smoothly until the centrifugal forces have pulled out all the telescope bracket segments to their full length. Each telescope segment of the telescope brackets have snap in mechanisms. When all segments have snapped in, the solar sail is enlarged to it´s full size. The rotation platform decelerates and eventually stops rotation.

Phase three – Separation and Sail Setting

The fasteners at the launcher´s rotation platform loosen, letting the solar sail free.

After separation the System Sailcraft may set sail through pulling each sail panel with winches off the roll towards the core ring construction or it could postpone the sail setting process and carry on using the thruster propulsion as needed.

Is the System Sail a solar-electric spacecraft or is it a solar sail?

Yes, it is a solar-electric spacecraft taking advantage of the possibility, to carry relative large solar-cell arrays (up to 12 square meters) and to power solar-electric thruster units.
Compared to a regular solar sail it needs to make good on the disadvantage of it's heavier mass with a main thruster propulsion.

On the other hand it is also a full fledged solar sail with a fuelless ACS for station keeping and attitude control, which enables yearlong service as an observation or communication satellite.
We could call it a **SEP-Sailcraf**t.

As a precursor of the “real” (space mounted or even better space fabricated) solar sails with square-miles-sized sailing area it could provide the needed experience in steering, projecting and handling such huge space carriers.
Simultaneously it could help building up space infra-structure, like satellite relay chains to freshen up the (with the square of distance) diminishing strength of the data signals.

Installing a satellite chain around the Sun at (for instance) 1/3 AU (where a lot more power for the solar cells and for the solar sail propulsion of the satellites is available) seems to be a good way to enhance the communication bandwidth considerably.

Even from locations behind the Sun would data delivery be possible through the satellites passing the data around their orbit to the next satellite, each freshening the signal up and delivering it from their nearest chain member back to Earth.

The System Sail as a carrier for asteroid mining operations

The Japanese Hayabusa space probe has shown, that landing on and restarting again of an Asteroid with a small, low thrust spacecraft is possible.
In 2005 Hayabusa did land two times at the asteroid Itokawa and is now in 2007 on it's way back to Earth.

The **System Sail** could carry the same or better ion propulsion as Hayabusa with it's better power supply.

While for Hayabusa reaching the asteroid, landing, restarting was clearly a success, it yet has to be shown, if sampling was successful also.
The operation team had no video/imaging data from the landing event and even was for a long time not sure if the craft has made it to the asteroid's ground.
Another weak point of the operation was the poor data connection.

As the System Sail of the Solar Sail Launch System features a magazine docking station, which could carry several docked in ion craft daughter units, like landers and observation crafts, it would be possible to deliver one or two lander to an asteroid with the Systems Carrier Sailcraft.

While at the asteroid, the carrier would provide bandwidth and serve as data relay for the landers and observation units.
After obtaining the asteroid material (for instance by soft-crashing into the asteroid and scooping or collecting material with robot arms) the landers would dock in again.

The carrier would than do the return-leg of the operation to Earth orbit again with ion-thruster propulsion, eventually combined with the solar sail options.

Other possible Usage and Missions for **System Sailcraft**

1. as a Space Tug, enhancing the orbits of older but working satellites. Winches mounted on the docking stations rings would hold the satellites with electromagnetic contacts,
2. as a delivery-spacecraft for smaller payloads,
3. as Sun observing satellites
4. as Asteroid finders, operating from a Near Sun orbit to detect even smaller Near Earth Asteroids inside Earth orbit through the reflection of Sun light.