Electric
solar
wind
sail

ESAIL D51.2
Report of performed runs

Work Package: **WP 51**

Version: **Version 1.0**

Prepared by:	Finnish Meteorological Institute, Pekka Janhunen
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Coordinating person:	Pekka Janhunen, pekka.janhunen@fmi.fi

(List of participants:)

Participant no.	Participant organisation	Abbrev.	Country
1 (Coordinator)	Finnish Meteorological Institute	FMI	Finland

Table of Contents

1. Applicable documents

AD-1: Deliverable D51.1 “Dynamic simulator user guide”

AD-2: The Lua scripting language, http://www.lua.org

2. Introduction

Two branches of dynamic simulator, VESVISION-v2 and VESVISION-v3 were described in D51.1 [AD1]. Each simulator supports flexible running by providing the user with a programming language interface. In VESVISION-v2 the interface is in in C and in VESVISION-v3 it is in Lua [AD2]. The purpose of the present document is to briefly document the performed E-sail runs by describing the various C and Lua files written during the project.

3. VESVISION-v2

As described earlier [AD-1] the VESVISION-v2 code models the tether as a 1-D continuous string which has zero stiffness but finite elasticity and thermal expansion. The formulation also includes the relevant mass flow terms at the spacecraft end to allow simulation of tether reeling (changing the tether's length at some speed which is an arbitrary prescribed function of time). The tips of the tethers can contain Remote Units of given mass (modelled as point masses) and the tips can also be connected together by auxiliary tethers (with given mass per length and given elastic properties). There is also a possibility to add "extra" radial tethers with free ends pointing outward from the Remote Units. The extra tethers can also contain their own end masses.
The C files used are briefly listed and documented here.

3.1 tst3.c – Baseline stretched auxtether E-sail model. This is the file we use most often and where it is easy to study the effect of the numerous parametres affecting it, such as the number and length of tethers, their materials and linear mass densities, Remote Unit masses, auxtether linear mass density, auxtether elastic coefficient, tether rig spin rate etc.

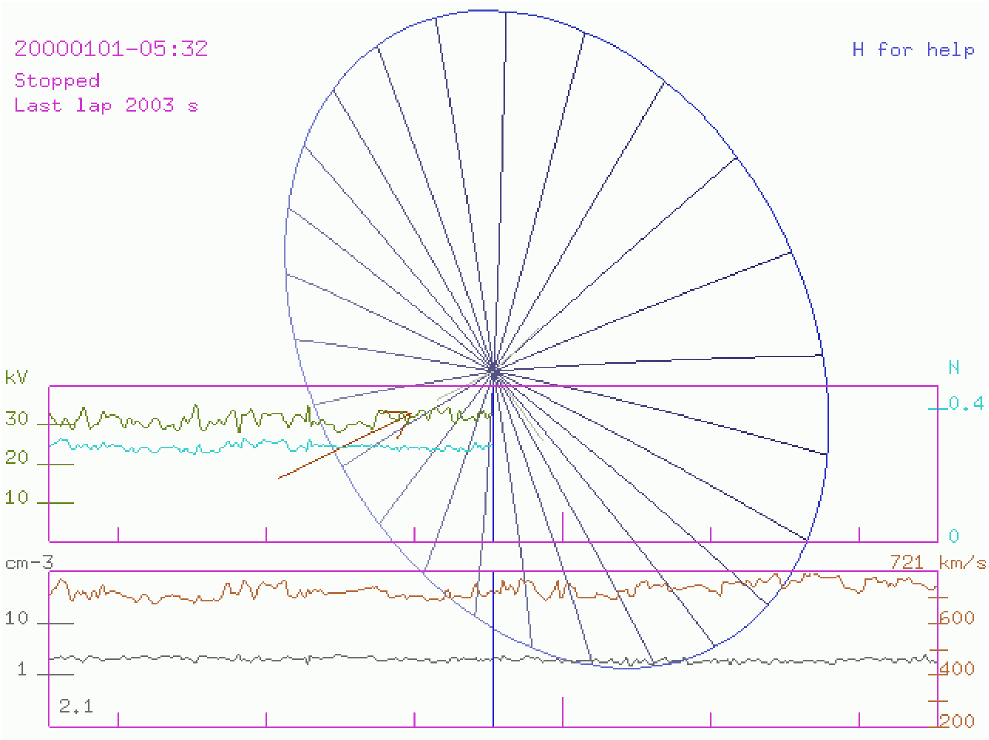

Figure 1: The tst3.c model

3.2 tst4.c – Version of auxtethered E-sail where the Remote Units are placed at the middle of the auxtethers, thus making the auxtether ring look saw-toothed or “edgy”. The model's dynamical properties are not much affected by the elastici coefficient of the auxtethers which is a benefit. On the other hand, in case of main tether breakage, it cannot be jettisoned unless the junction between the main tether and the two auxtethers also contains some active remote device which contains the jettisoning capability. The dynamical properties of the “edgy” model are not quite as good as the baseline stretched auxtether model.

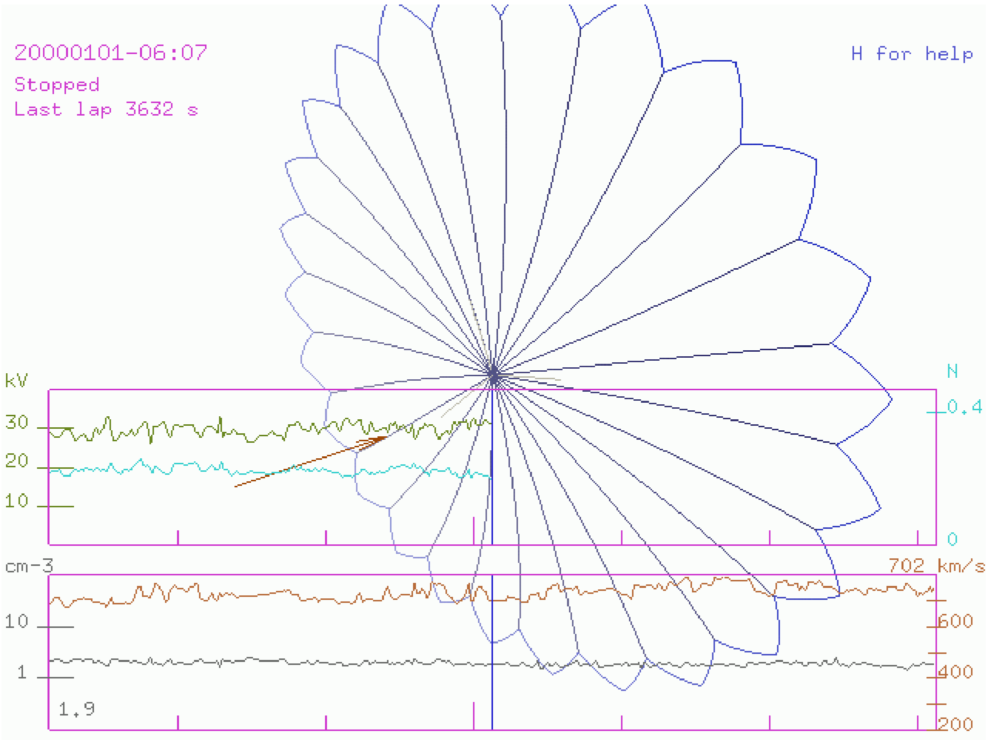

Figure 2: The tst4.c model

3.3 extratethers.c – Similar to stretched auxtether model, but with an extra metallic tether extending outward from each Remote Unit and ending up in another Remote Unit equipped with a small photonic blade for tether rig spin control. This is a recent attempt to improve the performance and scalability of the baseline auxtethered model by having a shorter auxtether ring (hence being more lightweight) and having more flexibility in selecting the number of tethers and tether length independently of each other without having to redesign the Remote Units. The extratethers model also has reliability benefits because although the inner Remote Units have moving parts (reels), they do not have to function after deployment, and while the outer Remote Units contain freely guided photonic blades which require continuous active attitude control, said control does not necessarily involve moving external parts and also Remote Units of the different tethers act as backups of each other so that no single point failures exist. On the downside, the system is somewhat more complex than the baseline because it has two different types of Remote Units and each main tether is deployed from two different reels, one in the main spacecraft and the other one in the inner Remote Unit.

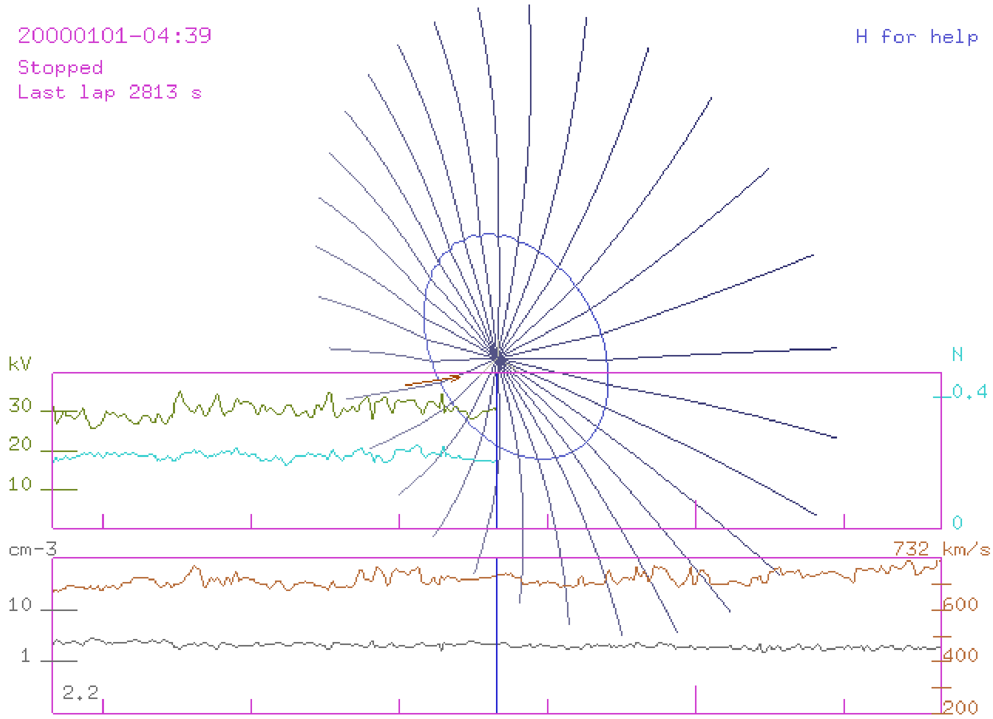

Figure 3: The extratethers.c model

3.4 solarfins.c – E-sail model without auxtethers where tether collision avoidance and tether rig spin control is done by sufficiently large actively controlled solar blades placed at the tip of each main tether. This model allows one to test if the solar blades of given size are sufficient for collision avoidance in the given solar wind flow. According to our numerical experiments, for 20 km tethers at 1 au one needs 16 m² blade for each tether, or 20 m² with some safety margin.

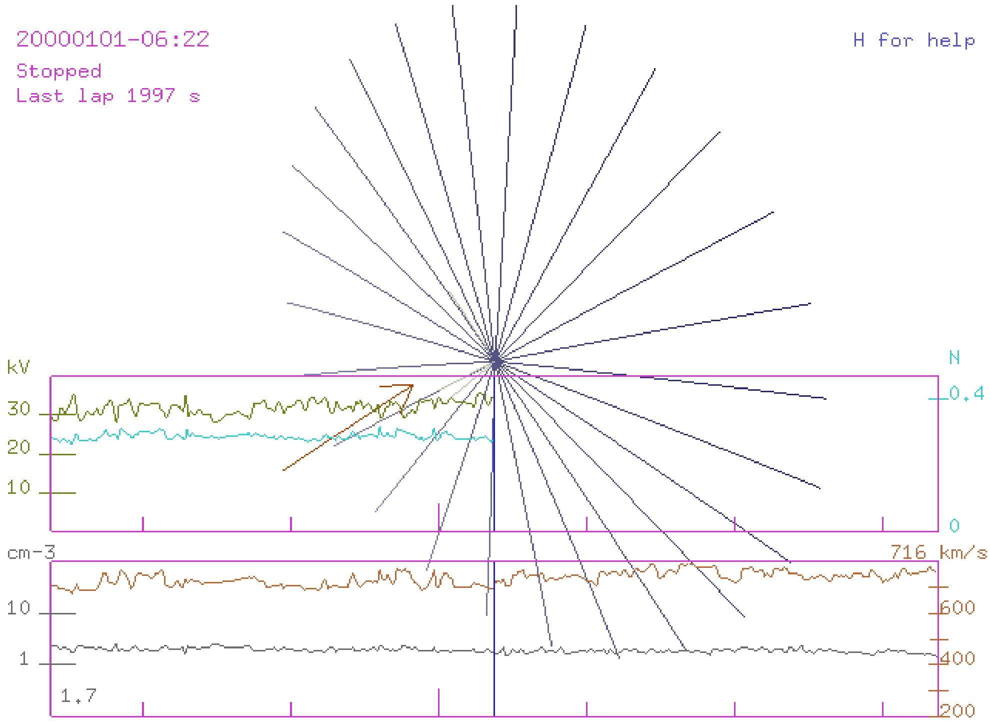

Figure 4: The solarfins.c model

3.5 rigidpiece.c – A model with a large (e.g., kilometre diameter) rigid ring where the tether reels are attached, with the hope that the configuration would be stable by the finite size of the rigid ring and the centrifugal force (in the similar way as helicopter blades do not collide with each other because of the finite size of the rotor centrepiece). However, according to experimentation with the model it seems that in the E-sail case this approach is not very fruitful: the rigid ring would have to be huge and/or the spin rate and tether tension would have to be larger than in the other models to stabilise the tether dynamics properly.

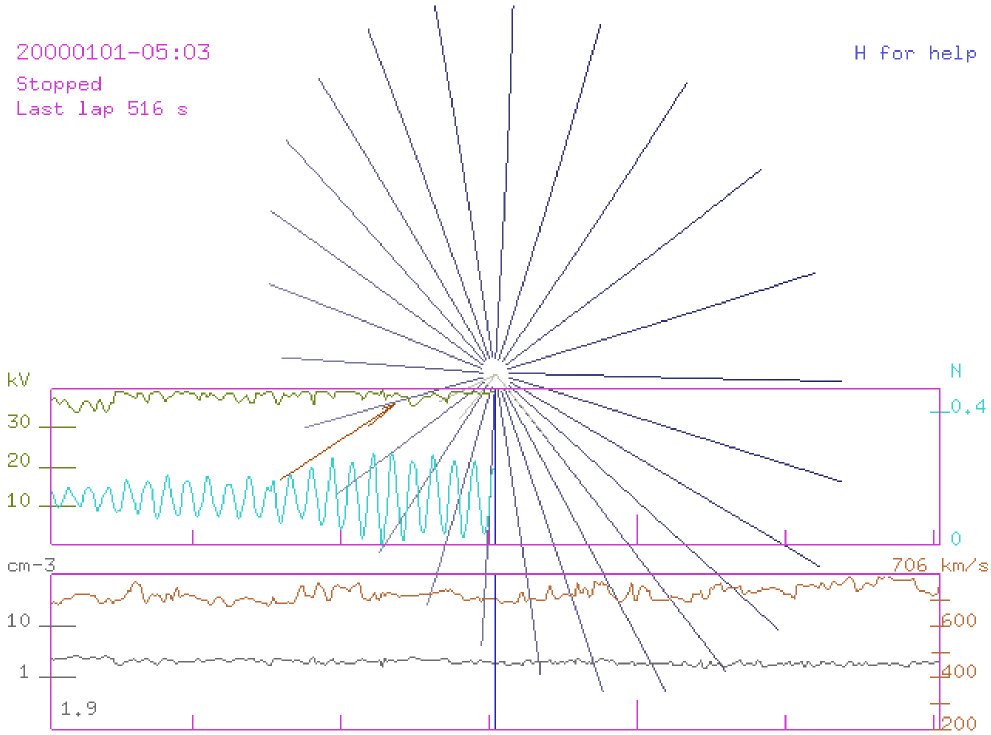

Figure 5: The rigidpiece.c model

3.6 deploy1.c – A model allowing to test the deployment phase of an auxtethered E-sail, with stretched or non-stretched auxtethers. The tether deployment is modelled by artificially stretching the main tethers by changing their rest length which is not completely correct because in reality the tethers should flow out from reels stored on the main spacecraft. In any case, we believe that essential parts of the dynamics are captured because the Remote Units are typically heavier than the tethers.

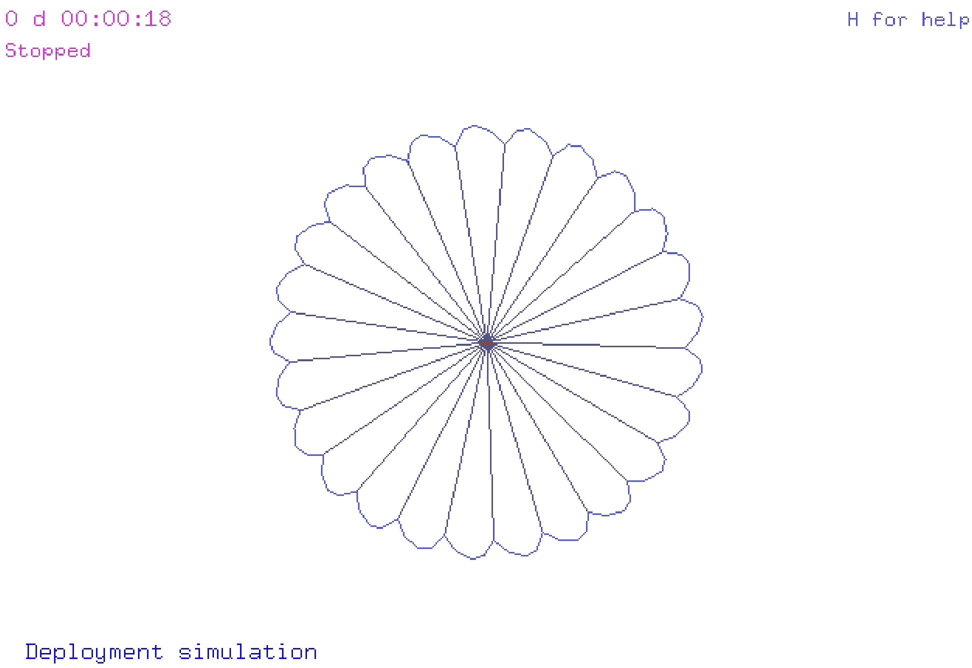

Figure 6: The deploy1.c model, with non-stretched auxtethers

4. VESVISION-v3

VESVISION-v3 is a quite general dynamical simulator which allows one to study the dynamics of an arbitrary collection of points masses and rigid bodies, connected by rather arbitrary interaction forces and external forces. The user defines the model by writing a Lua script [AD-2].

The written Lua script files are briefly listed and documented here.

4.1 auxtethers.lua – Baseline stretched auxtethers model, similar to tst3.c described in section 3 (Figure 1).

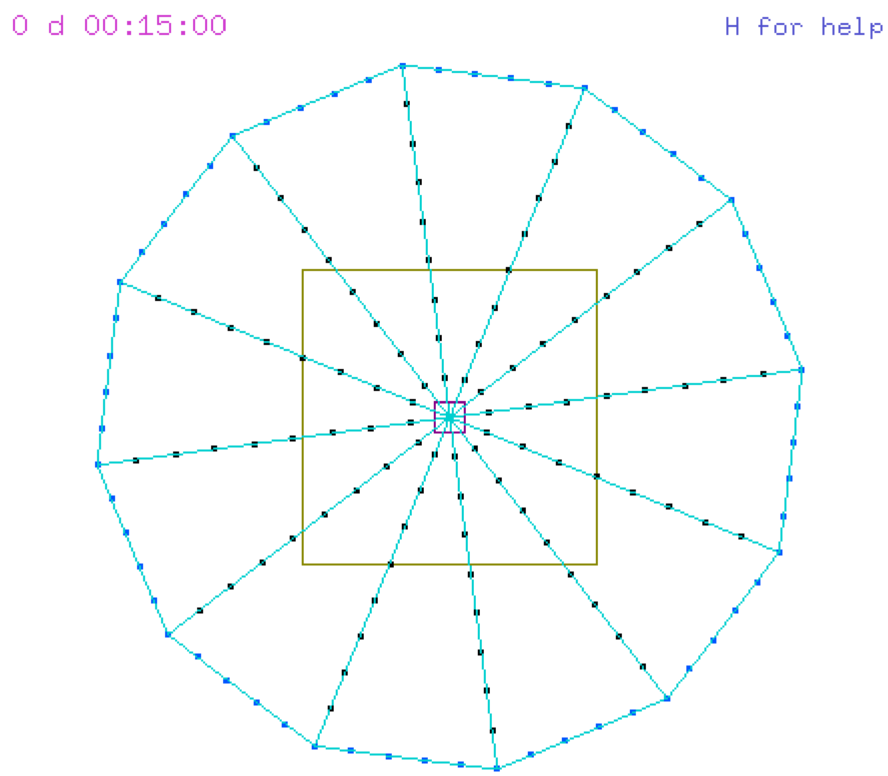

Figure 7: The auxtethers.lua model. The squares in this and other figures are for setting the scale; the largest square is 10 km across.

4.2 edgy.lua – Version with two redundant auxtether rings, each of them centrifugally stablised (non-stretched). This version (originally proposed by Emil Vinterhav in a project meeting) has the benefit over the normal non-stretched auxtether model that if a main tether breaks and the corresponding Remote Unit swings outward by the centrifugal force, the resulting mechanical shock when the tethers become taut is taken by the outer auxtether rather than the weaker main tethers. However, as the system is rather complex and its dynamics turned out not to be simple, it was not analysed further after the stretched auxtether variant was conceived.

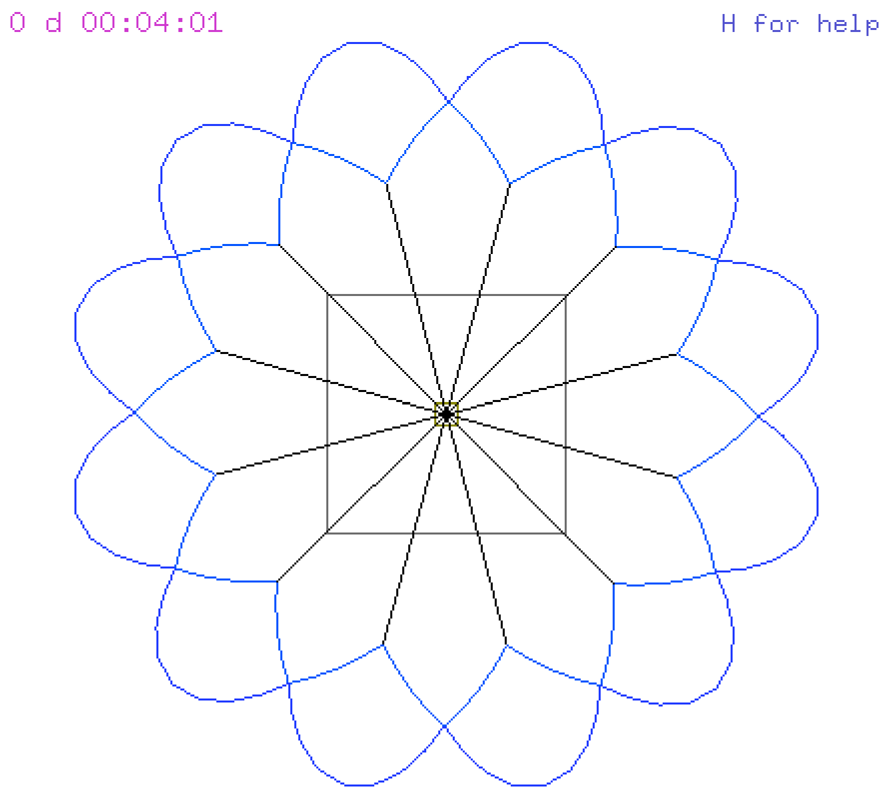

Figure 8: The edgy.lua model

4.3 Nearring.lua – A model where an auxtether ring is rather near the main spacecraft and where the main tethers (extratethers) are deployed from units located at the middle of the auxtethers. This is a bit similar to the extratethers.c model (Figure 3).

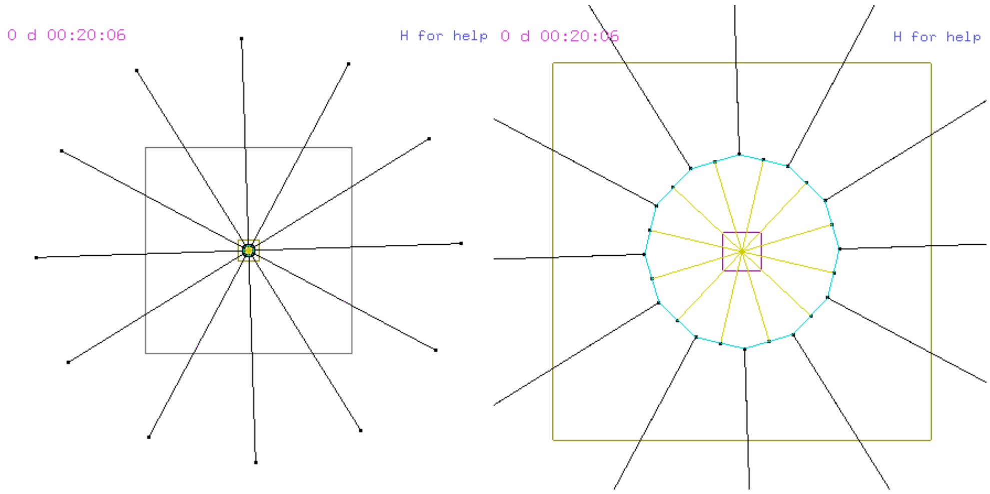

Figure 9: Left: the nearring.c model. Right: zoomed view.

5. Conclusions

Two numerical models, VESVISION-v2 and VESVISION-v3 have been created and are in active use for simulating the dynamical behaviour of E-sails and related systems. The functionality of the two versions is partly overlapping and partly complementary.

In this document we briefly listed and reviewed the various application programme files written in C and Lua for both models in the context of the ESAIL project.