

## ***Interactive comment on “Electric solar wind sail mass budget model” by P. Janhunen et al.***

**P. Janhunen et al.**

PEKKA.JANHUNEN@FMI.FI

Received and published: 9 October 2012

COMMENT 1: Obviously a parametric approach was used for the scaling of the spacecraft systems. It would be useful for the unfamiliar reader to state as much at the beginning of section 2. A reference to the e.g. SMAD (i.e. the Space Mission and Design Book from Larson & Wertz in whatever appropriate edition) would be helpful as well to justify that approach.

ANSWER 1: Thanks, we added to the beginning of 2nd section: "We now consider a parametric model for mass budgeting of E-sail missions of different sizes, see e.g. Larson and Wertz (1999) for the general approach."

COMMENT 2: Not all variables for mass or system fraction are explained and/or listed in tables 1,2 ... or the text which makes the formulae a bit harder to understand.

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Discussion Paper



ANSWER 2: Thank you for noting this. Indeed, some key information was missing from the paper. We now made the necessary amendments below equation (2) and at the end of subsection 2.7 (the power subsystem).

COMMENT 3: P433 L16 typo  $V_0=25, \text{kV}$

ANSWER 3: We do not find a typo in the source here and it latexes correctly (without the spurious comma) in our machine. It must be a problem on the journal side latex.

COMMENT 4: P434 L18 should not the equation be  $m_{vs} = \gamma_{vs} * P_{eg} / \text{efficiency}$  instead?

ANSWER 4: We are assuming that the electron gun efficiency is 100%. Gun designs exists where this is not a bad approximation because the number of electrons that hit the anode can be made negligible. Some power would be needed for heating the cathode if a hot cathode is used. However, as cathode heating power is low voltage it does not contribute to the mass of the high voltage source. We added the sentence "We assume 100 % gun efficiency and neglect the low voltage cathode heating power."

COMMENT 5: Why is the auxiliary tether considered to be rectangular Kapton and not e.g. Kevlar fibres? 12.7  $\mu\text{m}$  Kapton is a pretty rate commodity for manufacturing, handling and availability. Is there a specific technical reason for this e.g. the spooling mechanism of the reel? What would be the maximum length of an auxiliary tether?

ANSWER 5: To our knowledge, Kevlar is sensitive to UV degradation, at least if oxygen is present. Oxygen does not exist in the solar wind far from Earth orbit, so in principle Kevlar might still work with the E-sail, although its tolerance to UV in an oxygen-free environment should then be verified. But even in that case, one should probably protect the auxtether reels against sunlight during ground storage, launch and the before-deployment space travel where atmospheric or orbital oxygen has access to the device. Providing such protection would complicate the design of the Remote Units. Furthermore, in some missions we might want to fly through a near-Earth environment with

[Full Screen / Esc](#)[Printer-friendly Version](#)[Interactive Discussion](#)[Discussion Paper](#)

Interactive  
Comment

opened (although electrically inactive) E-sail tethers. In such a mission, the combination of UV and oxygen could not be avoided and thus the use of Kevlar would be problematic. Mainly for these reasons, and for the overall wish to stay conservative, we are, at least for the time being, baselining the E-sail concept with Kapton auxetethers.

Although 12.7  $\mu\text{m}$  is thinner than the most usual gauges, we were anyway able to buy it in bulk quantities at modest price. Even thinner Kapton (which would be more optimal for us) also exists as a standard product, but because it seems to be ITAR-restricted we did not consider it further. At 3 cm width, 12.7  $\mu\text{m}$  kapton is quite strong, actually almost impossible to break by hands. Even when 50% punched with holes for proper elasticity the kapton auxetether exceeds the maximum required 0.6 N pull strength by more than order of magnitude.

A tapelike auxetether is robust to reel which is one reason for preferring punched kapton tape (which is not to say that other types of tethers could not be reeled).

The maximum length of one auxetether (i.e. the distance between two Remote Units) is 1.25 km in the nominal full-scale 1 N device which uses 100 tethers, each of which 20 km long. Our Remote Unit auxetether reels are currently dimensioned to hold this length of auxetether. For this reason, we usually scale the number of main tethers and main tether length by the same factor so that the auxetether length stays the same.

COMMENT 6: Why a camera for every single tether instead of one single wide angle camera?

ANSWER 6: There is no specific reason to this, except that panoramic cameras might not be as easily available as COTS as moderate angle ones. We assume 12 cameras, regardless of the number of tethers.

COMMENT 7: Concerning the ACS (AOCS?) it is not stated if the whole spacecraft is spin or 3-axis stabilised and whether any reaction wheels are to be used. Spin stabilisation would make sense, however, this would have an implication on the payload

[Full Screen / Esc](#)[Printer-friendly Version](#)[Interactive Discussion](#)[Discussion Paper](#)

e.g. camera pointing etc. Can you discuss this a bit in more detail?

ANSWER 7: The spacecraft and its tether rig spin slowly. Some reaction wheels would typically be used (they are anyway common in other spacecraft as well), although it is not strictly mandatory. It is true that the fact that the platform spins slowly has some implications on especially imaging payload instruments.

We added the following sentence in the Introduction: "The main spacecraft and the tether rig spin slowly to keep the tethers taut, a typical spin period being some tens of minutes."

We also added the following paragraph at the end of the Introduction: "The fact that the E-sail spins slowly has some implications to the payload, especially to imaging science instruments requiring a combination of accurate pointing and lengthy exposure. Specific technical solutions such as despun platforms are available to mitigate or eliminate these potential issues. Analysing such matters is left outside the scope of this paper."

COMMENT 8: Despite the reference to SeppÄdnen et al. could you please include a short description of a Heytether for the completeness of the manuscript.

ANSWER 8: We added the following: "A Heytether consists of one parallel wire to which several (by default 3) loop wires are bonded to the base wire at regular, mutually interleaving intervals. In terms of micrometeoroid tolerance the four-wire Heytether is roughly equivalent to the criss-crossed four-wire Hoytether (Hoyt and Forward, 2000), but is easier to manufacture by our methods because only one base wire is needed."

COMMENT 9: It is usual to have margins (5,10,20%) also on sub-system level plus the overall 20% system margin. It is not clear if this was implemented in this approach.

ANSWER 9: Subsystem margins were not used. Our aim is to get a more or less conservative /estimate/ for the true mass of the system, rather than an upper bound which with some high certainty would not be exceeded. Based on our provided numbers a reader is anyway free to add his/her own margins if desired. If we would be design-

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Discussion Paper



ing a real mission, we would of course apply the margin policy used with the specific organisation who builds it.

The "Supplement" to this "Author Comment" contains a new typeset version of the paper where the corrections due to the referee comments are marked in red.

Please also note the supplement to this comment:

<http://www.geosci-instrum-method-data-syst-discuss.net/2/C206/2012/gid-2-C206-2012-supplement.pdf>

---

Interactive comment on Geosci. Instrum. Method. Data Syst. Discuss., 2, 429, 2012.

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Discussion Paper