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A NEW ARCHITECTURE FOR ELECTRICITY GENERATION ONBOARD TELECOMMUNICATIONS SATELLITES

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Replacing traditional PV solar arrays on telecommunications satellites by thermoacoustic engines brings to unacceptable over mass and therefore over cost of the satellites. In this paper, we show that redesigning a complete satellite around thermoacoustic engines paves the way for such energy onboard together with lower global mass and much lower costs.

Introduction. The onboard energy of telecommunications satellites has increased over years, culminating around 20 kW DC power today. However, costs also have increased for GaAs multi-junctions high efficiency cells, so that, on recurring satellites, the solar generator price can reach up to 20% of the satellite one. Finding a path to decreasing such a cost therefore is quite an interesting subject. However, the race today more seems to be in ever more efficient with ever more junctions photovoltaic cells, so that the competitiveness equation for the prime contractors which make satellites and sell them at world level always remains the same with no player able to make any real breakthrough compared to the others. It clearly is the objective of this paper to show the way we could create such havoc in the field and which would oblige most players to radically change their way of thinking their satellites architectures.

Indeed, like we experienced it in aeronautics, changing the onboard energy paradigm cannot consist only in changing the ad hoc devices on a standard product and then cross the fingers waiting for its working. Such type of trials were made with electric planes and showed to be no-ways. On the contrary, those who built new concepts of planes around a new type of energy generation (e.g. fuel cells) succeeded. This is what we intend to show in this paper: there is a potential for rupture through a radical change in the energy generation onboard spacecrafts. For this, we propose converting sun energy into heat and heat into electricity with the help of a thermoacoustic engine. We shall describe the potential problems we shall encounter and shall propose some “to be completed solutions. But this is how incremental R&T works: we solve the problems pace to pace, knowing in advance that the realization is globally possible. Of course, current spacecrafts are optimized for the technologies they use, so there is no surprise that changing as an important subsystem as the energy generation will imply a brand new architecture which will need to be also optimized.

1. Possible alternatives to photovoltaic cells. Our purpose is to generate electricity from the sun. There are not so many ways to do so. The most straightforward possibility against photovoltaic generation is the one of thermal machines. In such a case, thermal energy is given by the sun and therefore the thermal machine must not be a one with internal combustion. In such a case, the best suited machine could or should be the Stirling engine which theoretical efficiency is given by the celebrated Carnot formula

$$\eta = 1 - \frac{T_{\mathrm{c}}}{T_{\mathrm{h}}}$$

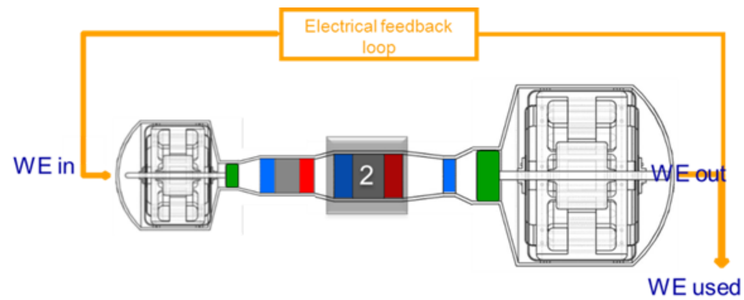

Fig. 1. Hekyom thermoacoustic principle.

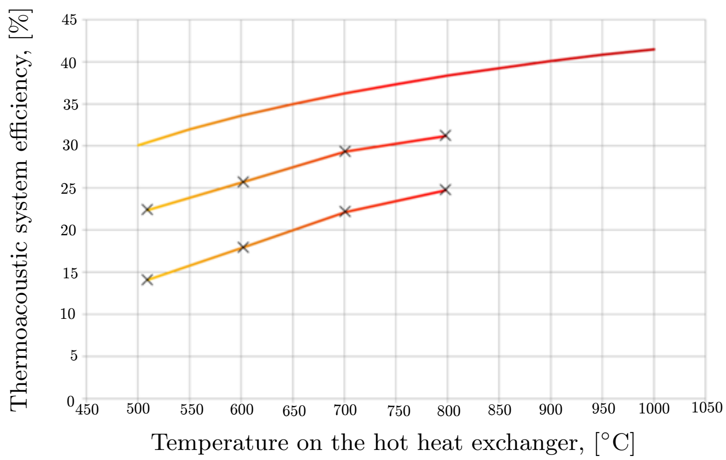

Fig. 2. Expected efficiency (ratio "net electrical power/thermal input") of the Hekyom engine.

where T_c is the cold temperature of the engine and T_h is the hot one. However, traditional Stirling engines, that they be of α, β or γ type, all have mechanical moving parts and satellite makers do not like mechanical moving parts onboard. This is the reason why our choice has gone to thermoacoustic engines which are kind of Stirling engines. Roughly speaking, such engines are Stirling like but this is a sound wave which plays the role of the piston, so that there almost are no moving parts in them as we shall see.

There also is another reason why we choose thermal engines as a potential replacement to photovoltaic cells. Indeed, the latter use only a part of the spectrum of sun. Multi-junctions cells only deal with superposing different photosensitive layers which are transparent to the other wave lengths they are sensitive to. Theoretically, there seems to be no limitation to stacking such layers, but we know by experience, that the cost dramatically increases with the number of layers. On the other hand, increasing the efficiency of a thermoacoustic engine, which naturally deals with the whole spectrum, whereas it already has an excellent one as we shall see, does not seem so costly.

2. Choice of the thermoacoustic engine. In its tradeoffs, Airbus Group Innovations has paid particular attention to the Hekyom solution which is shown in the figure 1.

Let us quickly explain the working principle. The linear alternator on the left generates a primary sound which is thermally amplified and feeds the linear alternator on the right which creates electricity. A portion of the electricity is injected again in the system for further functioning.

Hekyom and Airbus Group Innovations have cooperated on the making of a 1-stage 250 We demonstrator which allows expecting, in the end, a global efficiency sun to electricity of 40% as shown on the figure 2.

The bottom curve represents what we experimentally got. The middle curve represents what we would have got if we had had 90% efficiency linear alternators. The top curve represents what we would have got with a 2-stage engine.

Please notice that the expected global efficiency is as good as the one of todays best available GaAs cells.

3. The problem. Several traditional satellites architectures have been studied. They basically consist in replacing the PV arrays by parabolic concentrators.

The results however were disappointing: the global mass was such that the cost reduction got from the use of a thermoacoustic engine was not worth, the over cost being due to the global over mass of the system. More precisely, given the price per kilogram in orbit, that is 20 k\$/kg, the launch cost increase overshot the savings due to the thermoacoustic engine, for reaching about the same cost in total as a standard solution.

But let us comment some side questions. For a 20 k\$/kg, the cost of a TAG in a traditional architecture is about the same as the one of a traditional solar generator. However, space launchers are on the brink to enter a revolution. Such launchers as Falcon of Space X, for example, already propose a 10 k\$/kg for launches. With such figures, TAGs become competitive. Moreover, competition for launch costs is far from being over and we can expect dramatic upcoming decrease, so that TAGs will become even more interesting. In addition, the range of use of TAGs is much larger than the one of traditional solar arrays. We could even imagine some standard TAGs which would be used as off-the-shelf oversized low cost devices for plenty of space applications. In clear, this means that even if the savings on a given spacecraft in development is not there, it implies great savings for the whole ESA-led community of space. What will not be spent on solar arrays in the future thanks to TAGs can be used for some other new programs, as, for example, more near sun research satellites, leading Europe being the leader in sun physics.

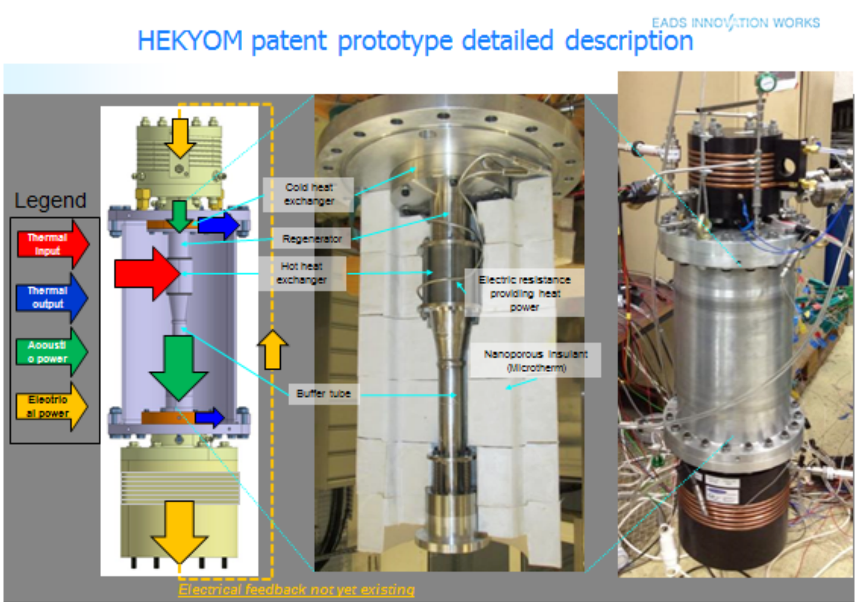

Fig. 3. Hekyom demonstrator.

4. The mass problem. Let us turn to the mass problem. For the sake of simplicity, we shall speak of a telecommunications satellite, but it remains valid for all applications. The problem splits into two parts: the weight of the thermoacoustic engine itself and the one of its environment (concentrators and their deployment).

4.1. The engine. Let us begin with the engine. The figure 3 shows the demonstrator developed by Hekyom under Airbus Group Innovations order.

A first way to decrease the mass is to add a third stage, so that the input alternator will inject weaker power and therefore will be much lighter. A second way consists in designing a new type, much lighter of a linear output alternator. We are on track!

With such a potential solution, we expect to divide the mass of the engine by a factor of 2. Please be aware that this applies for all ranges of powers.

4.2. The sun capture structure. Now, we have to deal with the sun capture and concentration so that the engine can work. Traditional struts Mecano is not adapted because it is too heavy. In order to avoid such mass penalty, we think inflatable structures will better fit our needs. Moreover, the reader should be aware that on a traditional telecommunications satellite, the solar arrays need to follow the sun and then need to rotate a full turn per day, involving the use of an engine. Finally, since the energy source turns, there must be a rotating transmission of the current into the satellite. This therefore implies the use of a device called

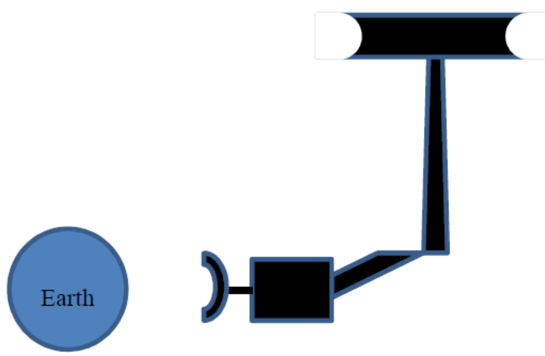

Fig. 4. Possible architecture.

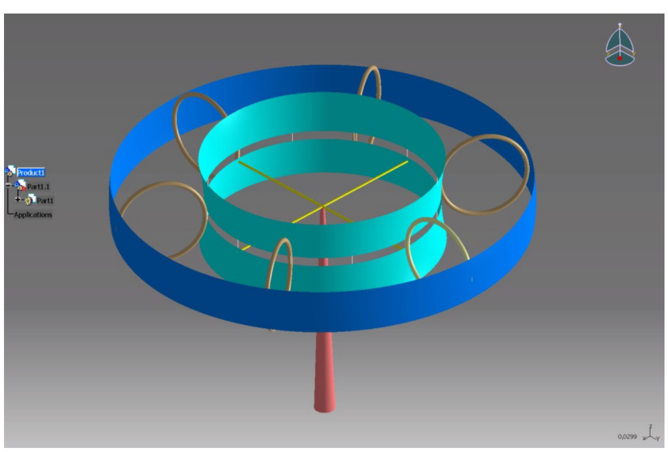

Fig. 5. Detailed view of the toroid.

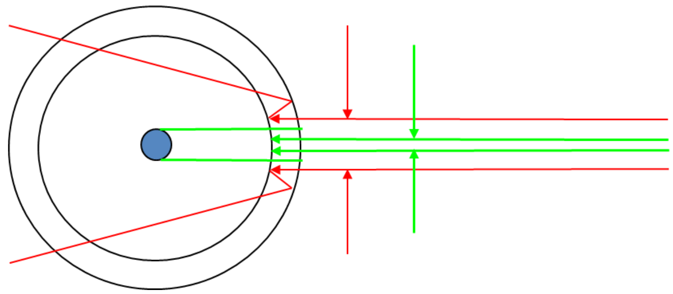

Fig. 6. Light collector.

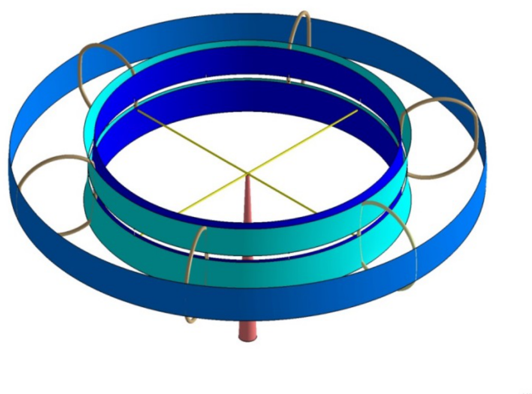

Fig. 7. System with a tertiary mirror.

"Solar Array Drive Mechanism" (SADM) which can pose problems of reliability and which costs a lot.

Before commenting on, let us first give a picture of our concept.

As can be seen on the figure 4, the mirror is a toroid. An alternative view of it is given on the figure 5.

The main problem is displayed on the figure 6. Indeed, only the green part of light is useful for concentration which implies potentially a too big structure.

The question is: how much light are we going to be able to concentrate, since the entire diameter is not efficient? Roughly speaking, for a given efficient surface of the concentrator, we have the choice of the diameter of the torus. Since an infinite diameter torus would give 100% efficiency, we shall choose the greatest possible diameter and the efficiency will of course depend on that diameter. Moreover, we can imagine alternative solutions like the one displayed on the figure 7.

Since everything will be made of thin inflatable fabric, it is expected to be very light. Dealing with sunlight for heat creation only, allows not to be too binding for the geometry. Just please also remark that such a solution allows functioning without any rotating engine to follow the sun daily and no SADM! Of course, alternative architectures still are under study.

5. Making of the device. The making of the device is through inflation and polymerization of fabric under UVs. Typically, the mast is inflatable and could be, say, unfolded through inflation the same way as a fishing rod is. The typical mass for such a mast is about 1 kg/m.

Then the torus is inflated with tricks allowing having parts of it with a parabolic surface with the right characteristics and other parts which will disappear under UVs once the parabolic shapes will have hardened. Typically, after inflation

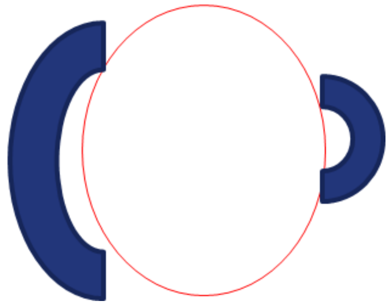

Fig. 8. Device inflation.

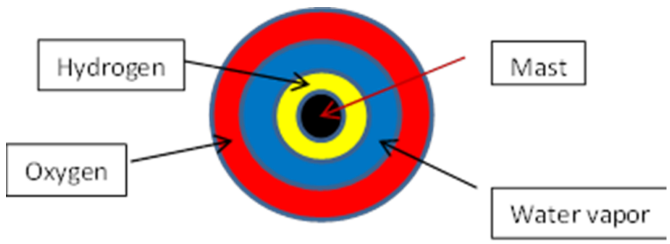

Fig. 9. System with a tertiary mirror.

and therefore deployment, the blue parts in the figure 8 will polymerize whereas the red ones will "melt" under UVs.

6. Remaining problems. We have no room to describe in detail in this paper all the remaining problems. They are in fact not numerous, but there is a major one which is the interface between light and heat in the neighborhood of the thermoacoustic engine. The targeted heat is about 1000°C so that we have to deal with what we call the solarization of the engine which is a difficult problem. But we think we are able to deal with it. Basically, we are going to build a solar oven and transfer heat to the engine through hot heat pipes (1000°C or more).

7. Synergy with the system. Finally, the mast is best suited for being the support of the radiator for the cold source. There, we propose to take the opportunity to use it in the same time as a radiator, as a tank for fluids and replacing the traditional battery on board by an H_2/O_2 fuel cell. It looks like on the figure 9.

We suggest using pretty big tanks, with small pressure inside so that even water will remain under gas form and that the radiating surface is big enough to ensure an interesting cold temperature (less than 50°C).

Then we suggest coupling this radiator which we need whatever happens, with the telecommunications payload since what mainly limits the integration density of communications payloads is the Joule effect. In the end, since fuel cells ultimately will have a global energy density about 10 times the one of batteries (Airbus internal study), the global mass will be much lighter than the one of a traditional satellite.

8. Conclusion. As a conclusion we draw the fact that combining:

1 – a thermoacoustic engine

2 – with an inflatable structure for sun concentration

3 – the structure being polymerized under UVs for long life time (about 18 years)

4 – coupled with a fuel cell which tank is used as the cold source

5 – together with low cost launches

will be a dramatic breakthrough in the upcoming years for electricity generation onboard spacecrafts in general allowing much greater available powers, more reliable power subsystems and in the end much cheaper devices. The fact is that the European Space Agency follows us since we were awarded a contract together with SSTL, Airbus Group Innovations, Hekyom and Fotec to detail such an architecture and prove its industrial mean term feasibility.

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