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Technical Report TA User Project

Low cost Solar Concentrator

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Abbreviations

DER	Distributed Energy Resource
TA	Trans-national Access

Executive Summary

The test campaign has been run successfully at CRES during one week in September. The weather conditions were good except one afternoon. The CRES infrastructure was adequate for the purpose of the tests, allowing access to a roof well exposed to the direct sun and logistics support. Very kind attention has been given by the CRES staff to our people and has been pretty much appreciated. The tests allowed us to understand some effects on the specimen and to characterize the performance of the reflectors. The collected data are under detailed analysis before being presented to the European Space Agency, end of October.

Without testing, it would have been impossible to get such results and reach a deeper understanding of, namely, a gravity effect on the reflectors.

The design of the new concentrator will evolve to take the tests results into consideration.

1 General Information of the User Project

The “Low cost solar concentrator” project has been initiated by the European Space Agency to improve the cost and performance of solar generator of satellites (smart grid concept). The design has been extensively studied by analysis and is now protected by a patent. As testing under real conditions, in space, is nearly impossible at the present TRL (TRL 3), only ground testing is possible. The testing of a solar concentrator can be done in different ways: flasher with a calibrated space cell under AM0 (from space) or collimated solar flux under real sun (AM1,5). A facility enabling these tests has been chosen (CRES), allowing a good support. The direct real sun illumination configuration has been chosen as the collimation of the source is of the upmost importance for concentrator systems.

2 Research Motivation

Since the 70’s, various researches have been undertaken to concentrate the solar flux on solar panels.
The primary target is linked to the surface gain (and then cost) for the solar cells. The profitability needs a low cost concentrator. Moreover, lightweight and low constraints are necessary for spacecraft systems.
On this empirical basis, a quick analysis concludes to the interest of a high concentration ratio (higher gain in cell surface). This is the target followed by the first researches in the 70’s and 80’s.
But some difficulties appeared: high concentration led to difficulties in pointing and thermal design and finally made disappear most of the concepts of this period. Nowadays, other researches focalize on high concentration (400-500) on 3J cells, but only for ground applications. The cost of such cells justifies the use of high concentration ratio and high pointing accuracy. The advantage of low concentration is to maintain a low cost with very light constraints.

Only some space Fresnel concentrator still survive but with a moderate concentration ratio of $C < 10$.

In the 90’s, new concentrators with low concentration ratio appeared ($C < 2.5$), easily adapted to classical panels. Hughes has been the first to commercialize a spacecraft with such a technology (C_{power} ~1.5): in early 2000, The PanAmSat Galaxy XI was launched; its pair of 4-panel wings were the first flight of the Hughes 702 array, comprising thin film reflectors mounted either side of a conventional array. Nevertheless, a gradual loss of power appeared and deep investigations concluded that this was due to various causes: off-pointing, darkening and wrinkling of the reflective surfaces.

The increasing electrical power demand on-board telecommunication spacecraft leads the solar generator industry to develop new types of solar arrays. Progress in the field of high efficient photovoltaic cells give new insights for the solar power generation, but those new elements also bring new constraints from both technical and economical points of view.

2.1 Objectives

In 2000, a General Study has been ordered by ESA, in order to find out the state-of-the art in space solar generators and to identify enabling technologies and new concepts that may reach the achievement of new solar arrays able to satisfy the new power requirements. About 200 documents (papers, patents, datasheet, communications,...) have been compiled. The present WalOpt Manager, Mr J.P. Collette, was the Top Manager of this study and all its experience will be available for the proposed project. Space solar concentration is one of the main topics that were addressed. Two different trough concentrators and a linear Fresnel lens concentrator were compared to rigid arrays. Thermal and optical behaviours are included in the analysis.

In the proposed project, several technical aspects should be tested:

- Off-pointing with concentrators induces collection loss and illumination non uniformity, reducing the PV efficiency.

- Flatness of the concentrator is a major issue and more particularly as it is flexible for deployment purposes (unrolling process). A new design with an innovative material from the European industry will be tested, making it a technological breakthrough.

-Concentrator deployment increases the mission risk.

- Solar concentration increases the heat load on solar cells, while the conversion efficiency is significantly decreasing at warm temperatures.

The main objectives of the project are thus the following:

- Accurate Tracking of the real sun allowing measurements during a long duration up to thermal stability of the system
- Collimated solar flux to measure the efficiency of concentration (uniformity of cells illumination)

The size of the breadboard is approximately 0,5*0,5*0,3 m3.

Necessary means:

- Tracking system
- Clear atmosphere
- Pyranometer to monitor the solar irradiance
- Thermocouples and datalogger
- Alignment verification (autocollimator or other metrology means) before and after measurements in various positions (to take into account the gravity effect)

2.2 Scope

The tests concern alignment of reflectors in a collimated solar flux and measurement of illumination homogeneity on the solar cells plane, as well as potential defects in the reflector surfaces

3 State-of-the-Art/State-of-Technology

Using concentrator means using fewer cells to deliver the same power. Concentrator systems incorporate either mirrors, either Fresnel lenses. The idea of concentration on solar cells is not new. Numerous designs have been proposed and some of them have flown. Not to mention the huge R&D effort performed for ground applications.

From the Hughes incident, attention was paid to the contamination of the reflectors and more particularly to their operational temperature. A Multi-V design has been developed by the US and ourselves in Europe. The Multi-V design is made of a plurality of small tent-like reflectors disposed between rows of solar cells. These reflectors are automatically deployed when opening the solar panels. This concept, originally dedicated to space applications, found also use for ground applications.

Recently, in 2005, JAXA launched its small REIMEI scientific spacecraft, with two solar arrays equipped with a single lateral reflector.

Executed Tests and Experiments

3.1 Test Plan

The test under real sun illumination has been done the following way:

1. Deployment of the reflectors
2. Verification of angle with a mechanical gauge
3. Mounting of the solar panel in the box
4. Mounting and connection of the temperature sensors and solar cells to the datalogger
5. Verification of opening angle with a mechanical gauge
6. Verification of alignment reflectors ./. box openings
7. Mounting of the tracker
8. Alignment of the tracker (North with compass, horizontality with bubble, GPS for localisation, time)
9. (Mounting and alignment of the pyrheliometer).
10. Start recording
11. Mounting of the box & solar panel on the tracker platform

12. Verify alignment to the sun with a reference stylus
13. Starting tracker (time with internet clock)
14. Take 5 pictures under full sun (check with pyrheliometer)
15. Stop the tracker
16. Remove the cardboard (projection plane) and connect the N solar cells to the datalogger
17. Starting tracker (time with internet clock)
18. Measurement of the cells output
19. Create a misalignment of 2 arcdegree in azimuth
20. Place the cardboard
21. Verify alignment of tracker & Start tracker
22. Take 5 pictures under full sun (check with pyrheliometer)

3.2 Standards, Procedures, and Methodology

The methodology and procedures have been previously accepted by ESA. CRM is ISO 9001 and run the tests according to this norm

3.3 Test Set-up(s)

Description of the test set-up:

The solar panel BB will be placed in a closed box allowing only direct sun illumination on the reflectors. A black/whit cardboard will be placed at the normal solar cells place.

The set-up will be directed towards the sun with a tracker. Its payload capacity is 30 kg, even if the total weight of the assembly is higher.

A still camera will take pictures of the cardboard and will measure the non-uniformity of the illumination of the cell surface. This illumination will be quantified thanks to an image software made using matlab.

The camera will have to be calibrated to give quantitative measurement of the illumination variation.

3.4 Data Management and Processing

The data have been acquired via a data logger ref GL800, measuring tensions delivered by two thermocouples, and current coming from 5 Si solar cells (via 1 Ohm resistance xxx %).

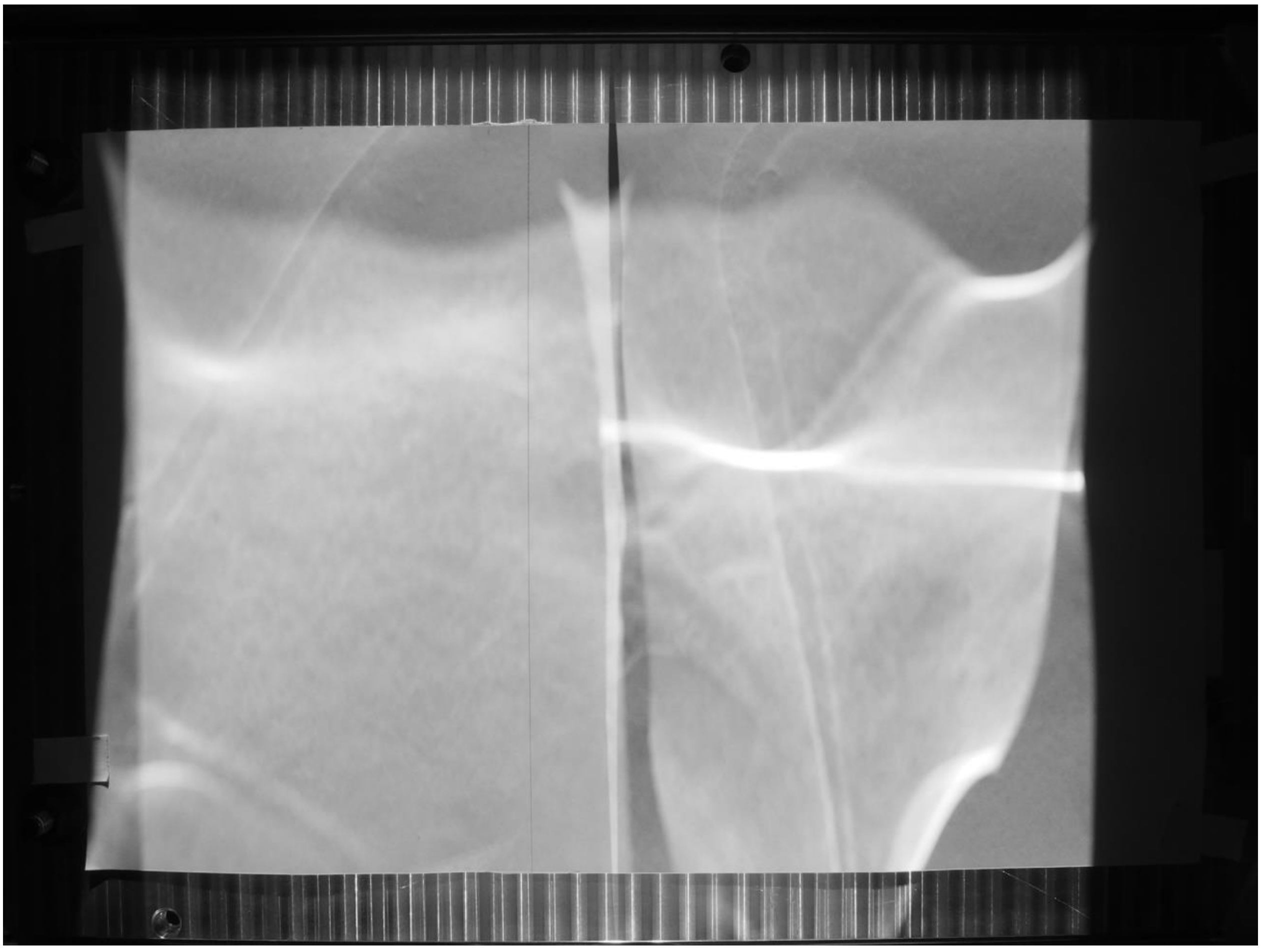
Illumination has been measured with a still camera (11808768 pixels, Olympus ref XZ-10) and image analysis will be performed with home S/W using Matlab.

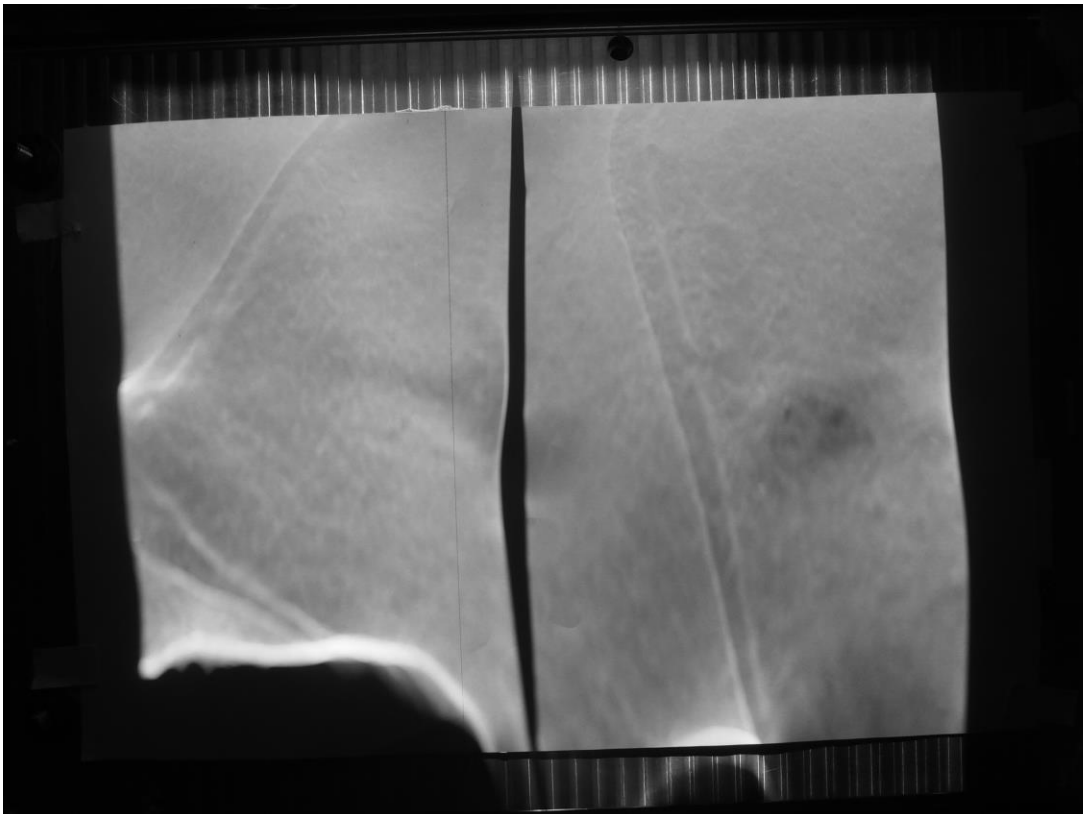
A tentative cross check has been made with a pyroheliometer available at CRES.

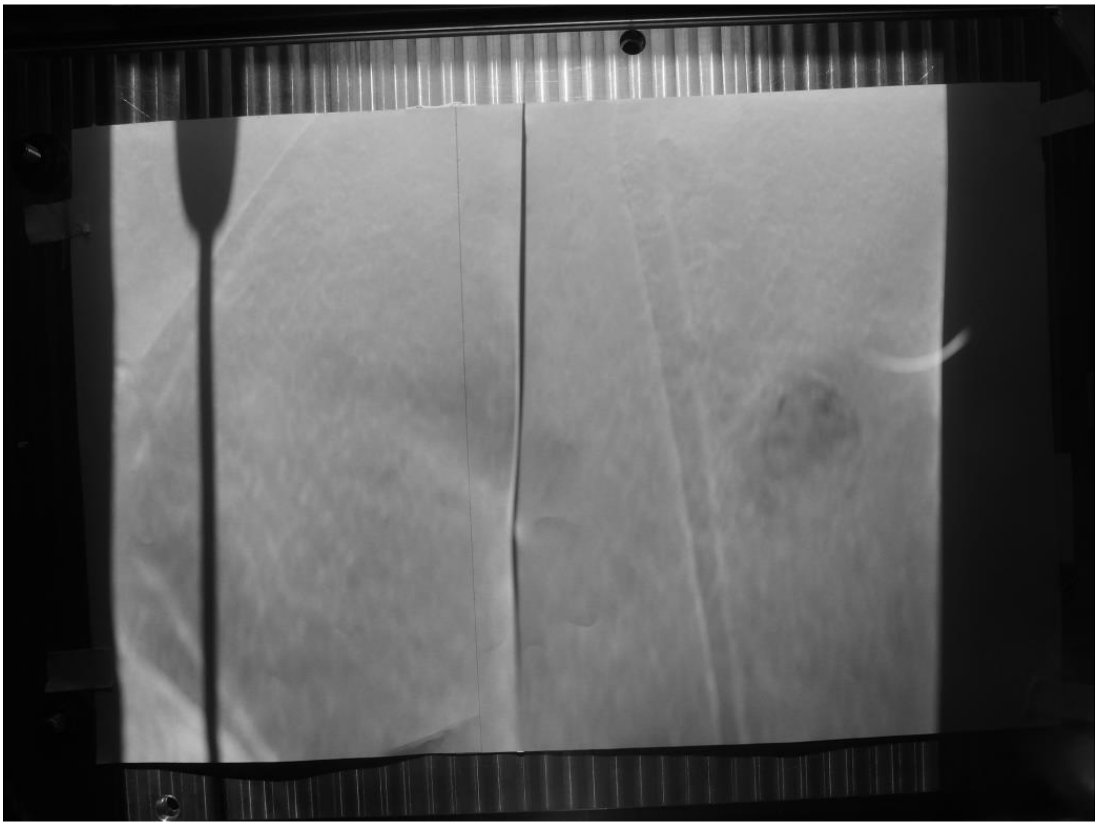
4 Results and Conclusions

The temperature is acceptable inside the box and is maximum 45 °C.

The inhomogeneity of the illumination is presented hereafter for various positions and configurations.







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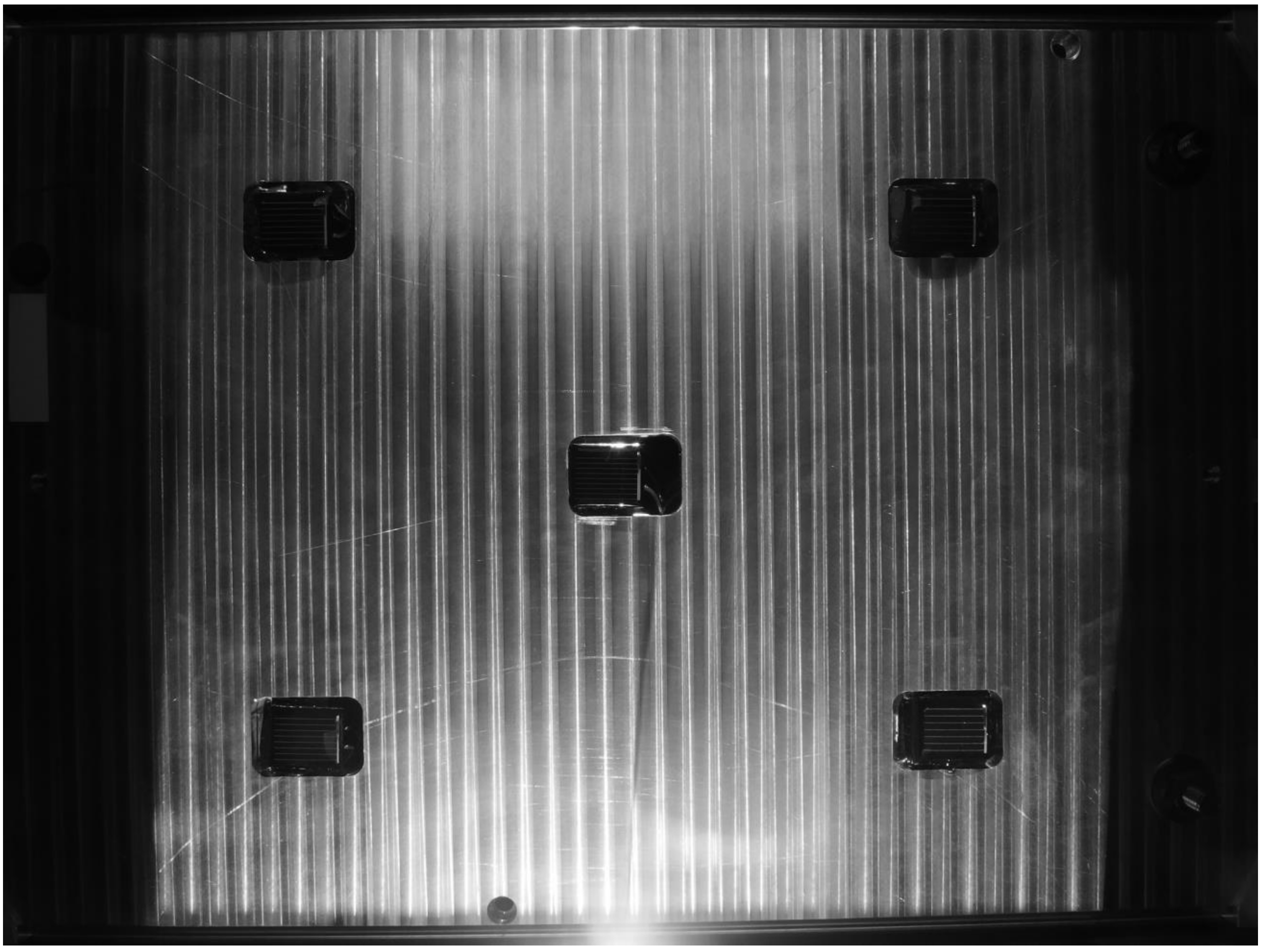

The effect of gravity should be taken into account when performing ground testing. In microgravity such effects will not exist and the results of illumination will therefore be better.

Defects on the reflectors were detected during the tests

The stability of the prototype was assessed and some design evolutions were identified (such as angle positioning system, motorisation, reflector hanging system, etc.)

5 Open Issues and Suggestions for Improvements

Some conclusions and perspective for follow-on program:

- The junction between the sheets has to be enhanced to prevent any over or under illumination
- The size/thickness of the available sheets has to be widened to limit the number of junctions and decrease radius of curvature
- Sensible effect of gravity on the thin film sheets. Action proposed: test under mirror vertical position with a normal light source (sun is only possible with a heliostat).
- Stopping of the deployment at the final angle is still to be designed

For the hosting Facility (CRES) it is suggested that the acquisition of a heliostat should be a plus.

Furthermore, its is also suggested to have a reference frame showing the axis of rotation of the Earth to facilitate installation of an equatorial tracker

6 Dissemination Planning

The final review will be hold at ESTEC premises October 25, 2018.

The main results of the testing and design will be presented at the next IAC Conference in Washington DC, in 2019 by J.P. Collette, N. Nutal and P. Hodgetts.

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