

## ANALYSIS OF THE INFLUENCE OF ALUMINUM BAFFLE IN THE HEAT FLUX FROM INFRARED LAMP ARRAY.

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*Abstract: This paper deals with a method to obtain a uniform heat flux on a surface. The work is composed of a numerical method, which was refined by an experimental test. The test was carried out in a 1 x 1 m thermal vacuum chamber using a setup of four tungsten filament lamps, radiometers, power supplies, controllers and aluminum baffles. These radiometers are made by aluminum in cylinder format with a copper black sensor, which they are isolated from the main bodies. The lamp behavior was previously known by another test, which the main goal was to quantify the intensity lamp radiation on a given surface. Based in the results obtained, it was made a numerical method to simulate the heat flux from two or more lamps. Using extrapolation and theoretic behavior obtained from the lamp manufacturer, a numerical method to obtain uniformity heat fluxes on a larger surface was developed. Only in the borders, the uniformity values were different from the average. To increase the uniformity and refine the method, an experimental test was fulfilled to verify the influence of the aluminum baffles (reflect surfaces). The final result was the qualification of a model to simulate the behavior of the heat flux from many lamps. The same setup is hoped to be used in a Thermal Balance Test of CBERS-2B Satellite, to simulate the space conditions that this satellite will be suffer. This test will be necessary to qualify the satellite to flight.*

**Keywords:** tungsten filament lamp, aluminum baffles, space simulation, radiometers.

### 1. Introduction

The basic aim of Space Simulation (SS) is to qualify the satellite, or a given spacecraft device so that these may operate reliably in space. The simulation techniques differ from one another basically according to the experimental arrangement used in the imposition of the heat source and the space background. The main techniques are: Solar Simulation (the use of a simulator equipped with Xenon lamps), as described by Nuss (1987); Tungsten Filament Lamps (TFL), which operate in the near infrared range (Messidoro et al., 1983); Heating Plates (Cardoso and Garcia, 1989); Skin Heaters (Ramos et al., 1988); A combination of techniques, as presented by Braig et al., (1988). The skin heater and heating plate techniques are applied in the far infrared radiation spectrum, which is out of the solar spectrum range, to which a given satellite is exposed to during its orbital life. The use of solar simulation is the most adequate because of the closeness of the solar spectrum; however, the high cost of a simulator is not viable in the light of the present Brazilian economic situation. For this reason, Tungsten Filament Lamp (TFL) simulation, where the high tungsten filament temperature (2500 K) produces a spectrum closer to that the solar spectrum (Messidoro et al., 1983), has become an attractive alternative. In order to develop this space simulation technique, which uses tungsten filament lamps as a source of thermal radiation, thermal-vacuum test group of the Integration and Testing Laboratory (LIT) has projected and manufactured an experimental apparatus, which consists of a some radiometer, aluminum baffles and an array of four Tungsten Filament Lamps (model 500T3/CL) from the Research Inc. The behavior of the lamp is known through an experiment in LIT (Santos e Garcia, 2005) in which was that the greater the height of the lamp in relation the area, the more uniform behavior, as well as the lesser the power of the lamp. Using the numerical results of this experiment, it was found a setup to get a heat flux uniform. It was observed that the edges of the simulated area presented an inferior value of flux to central parts. In order to increase the value of the flux in the deficient region, the idea was to use reflecting surfaces, called baffles. The energy radiated by lamps, which did not arrive at the area in study, is reflected for itself. The objective of this work is to show the importance of these baffles to get a uniform flow in a determined area. The apparatus uses aluminum plates as baffles, radiometers, four lamps with support and power

suppliers. Preliminary tests were carried out at Laboratory atmospheric pressure conditions. The principal results were obtained in a high vacuum environment ( $\cong 10^{-7}$  Torr) in a 1x1 m thermal vacuum chamber. In order to guarantee that the thermal loads emanated only from the lamp, the chamber was kept at a temperature of  $-180^{\circ}\text{C}$ . Several tests were carried out altering the wattage of the lamps. In order to measure the temperature data from each radiometer, the LIT data acquisition system, which handles 500 measuring channels with acquisition at 30 seconds intervals, was used. From this information the heat fluxes are calculated and presented in the form of graphs. From the results obtained, it was possible to analyze the influence of baffles in the rise of the flux in the borders, as in the remaining of the area reached for the radiation. The next step of this study would be to simulate new setup with the lamps in order to confirm the results obtained in this experiment. With this, we would have conditions to create a model of simulation for any requirement, as much of area as of heat flow.

## 2. Experimental apparatus

In order to analyze the influences of the baffles in the heat flux in a determined area, it was used an apparatus described below (Fig. 1):

- Four aluminum plates with black paint in external surface and covered internally with aluminum leaf, in order to increase the reflector effect of this surface, and settled in order to form a box without upper and downer surfaces.
- Fifty radiometers constituted of a copper plate (sensors) with black paint in external surface and a thermocouple in internal surface. These sensors are fixed in the aluminum body through small supports of Teflon with rip. To isolate the internal part of the radiometer body an isolating blanket (Multilayer Insulation – MLI) was glued in the inferior part.
- The lamp had been fixed in a steel support that is only supported in the box of baffles for possible changes. The symmetry of setup helped in the making of these supports.



Figure 1: Experimental apparatus.

### 2.1. The radiometer arrangement

The radiometer arrangement (Fig. 2) is constituted of 50 units, having been each one formed by four parts: aluminum body, isolating parts, sensor and thermocouple (Fig. 2 – top/left). The aluminum body (Fig. 2 – top/center), is a cylinder with holes to put the Teflon isolate parts, fix radiometer on a plate, to make vacuum inside and to facilitate the passage of the electrical wires and thermocouple. The sensor is thermal radiation isolated from the inferior body base by MLI (which is adhered in this base). The sensor is a circular copper plate ( $\varnothing$  35 mm, thickness = 0,6mm), black paint on the superior face (space qualified paint, model PU1 MAP with 50  $\mu\text{m}$  thickness,  $\epsilon=0.865$  and  $\alpha=0.898$ ). On the sensor opposite side, to make measurements, a thermocouple was installed on each one (Fig. 2 – center part). These radiometers were thermally isolated from the aluminium body by three Teflon points, which were fixed in the aluminium body (Fig. 2 – right top). The radiometers were produced in LIT/INPE, which has specialized tools to fabricate MLI, machines, to measurement of thermo-optical properties and to perform contamination analysis. This laboratory has painting facilities, too.

The main steps in the radiometer production process are the following (Fig. 2 – middle and top parts): a) manufacturing of the copper circular plates (radiometer sensors); b) black painting on sensors (carried out at the LIT Painting Laboratory, which guarantees the same conditions and characteristics as satellite surfaces); c) production of MLI; d) manufacturing of aluminum body with Teflon isolating putting; e) MLI adhering; f) attachment of the thermocouples to the back sensor (the same technique is employed when satellites are tested in Space Simulation); g) precision assembly of the

sensors in the Teflon cylinder isolations (precision bonding of the sensor to the Teflon isolating because they have to have a minimum contact between them, consequently minimizing heat losses).

After preparing all 50 radiometers (as described above), the setup preparation was fulfilled. The radiometers were placed over a plate protected by an adhered kapton film (size 1x1m).

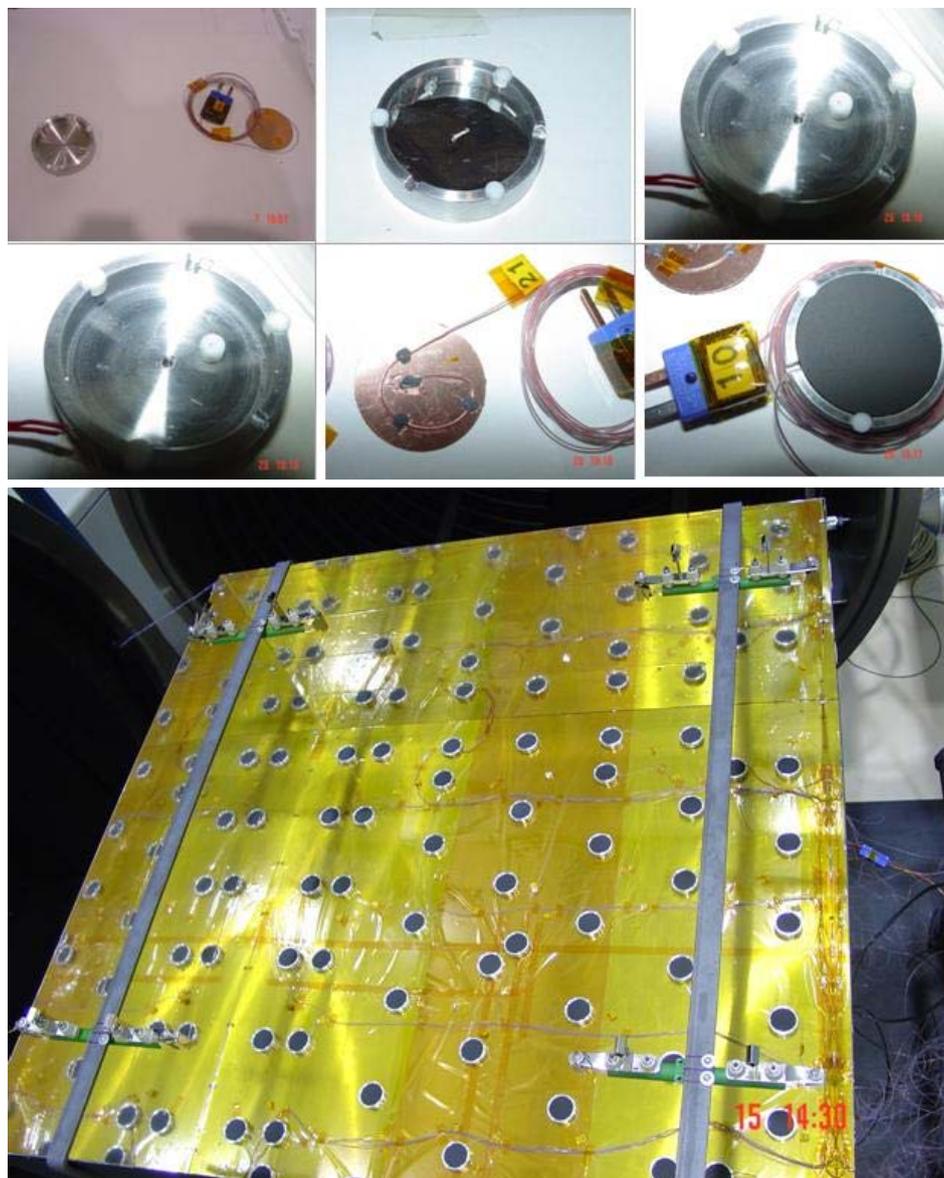


Figure 2: Bottom: view of the setup: radiometers, base plate, lamps and support. Top and middle: phases of the radiometer manufacturing process.

## 2.2. Tungsten filament lamp

In order to establish an exact position for the lamp and reflector (5236.5 golded reflector) set in relation the radiometer plate, a mechanical device for positioning the lamp was devised (Fig. 3). This device is made up of: a vertical circular rod with an articulation joint soldered to the center of one of the extremities of the aluminium plate; and a articulated arm with two (2) degrees of freedom (x and y), composed of circular rods, spheres and articulation joints. The third degree of freedom of the device (z) is performed by the attachment of the arm to the articulation joint of the vertical rod. In this way it was possible to vary and guarantee the position of the lamp. Figure 4 shows the positioning of the lamp in relation to the radiometer.

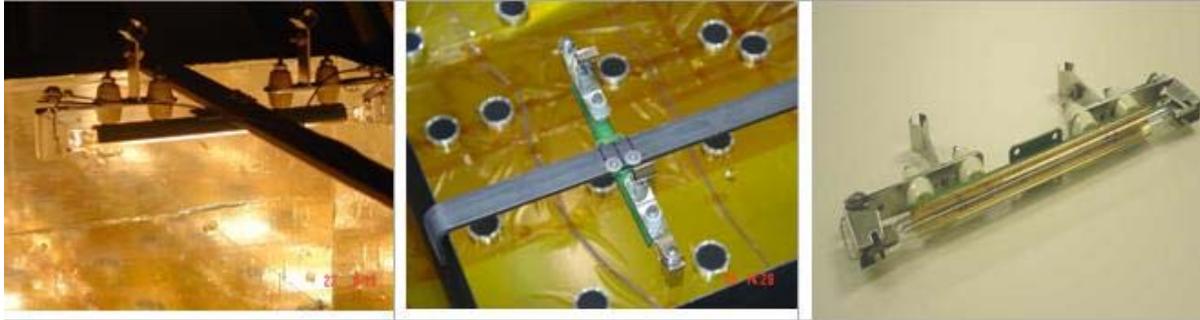


Figure 3: Lamp arrangement device.

Specification of the lamp used in the apparatus and experimental test is as follows (Simulate IR Serie, 1998):

|   |   |
|---|---|
| Type                                    | 500T3/CL Research Inc, Tungsten Filament Wire, T3 Quartz Lamp |
| Overall Length                          | 224(mm)- 8.81 (inches)  |
| Lighted Length                          | 127(mm) 5 (inches)  |
| Rated Voltage                           | 120 V   |
| Current at Rated Voltage                | 4.17Amps  |
| Total Power Dissipated at Rated Voltage | 500W  |
| Average Life                            | 5000 hours  |
| Color Temperature                       | 2500 K  |
| Possible Corona Region in Dry Air       | None  |
| Brightness                              | Bright White  |
| Usual Size, Inches (mm)                 | 0.375 or Dia. Tube(9.525)                                     |
| Usual Range of Peak Energy Wavelength   | 0.89 to 1.5 Microns   |
| Radiation                               | 72 to 86%   |
| Relative Response to Heat-up            | Seconds   |
| Relative Response to Cool-down          | Seconds   |
| Mechanical Shock                        | Good  |
| Thermal Shock                           | Excellent   |

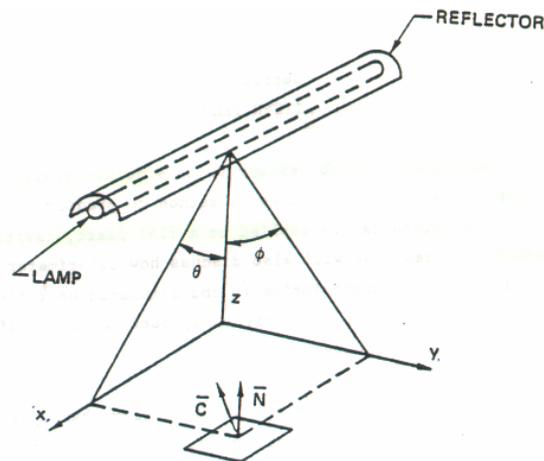


Figure 4: Positioning of the lamp.

### 3. Experimental test

In order to analyze how the baffles influences the heat flux from an array of lamps as a source of thermal radiation in terms of uniformity some experimental tests were carried out using the 1x1m LIT thermal vacuum chamber. The apparatus was fixed, not needing to be modified during the some carried through experiments. The unique necessary changes are the tension and the chain that the sources (one for each lamp) yield to the lamps. It is considered that all electric energy is absorbed by lamps, in order to be able to calculate the value of the power of lamp through the values of measured chain and tension in the proper source.

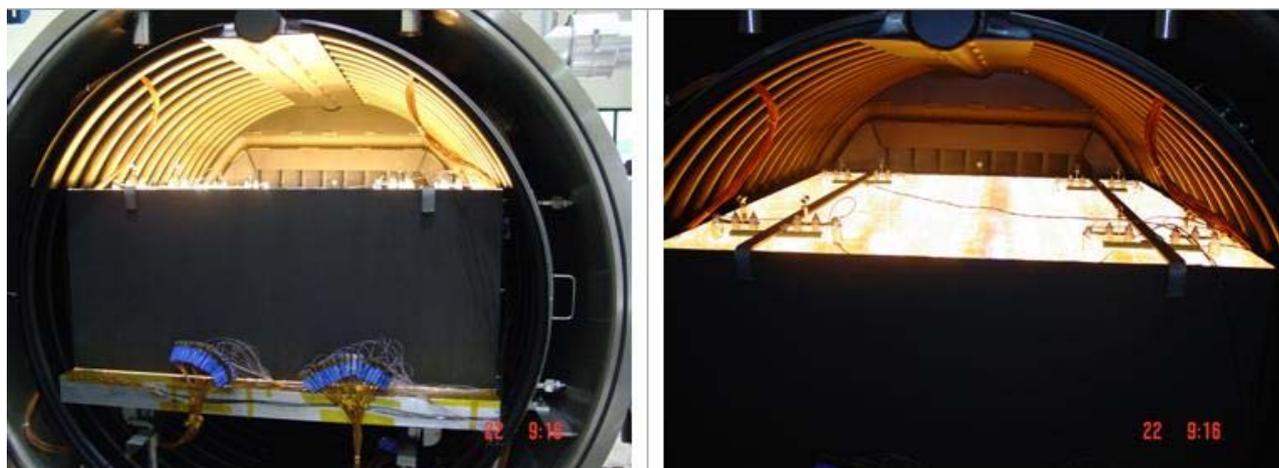


Figure 5: Experimental arrangement.

During tests, the thermal vacuum chamber was kept at high vacuum ( $\cong 10^{-7}$  Torr), and to guarantee that the thermal loads originated only from the lamps the chamber was kept at a temperature of  $-180^{\circ}\text{C}$ . Several tests were carried out varying equally the wattage of the lamps. A Tectrol DC power source of 500W, Fig 6, was used to control the wattage, and 56 thermocouples TT-T-30, HP 3054 scanner and a Pentium 166MMX computer were used to obtain temperature data from each of the radiometers. The LIT data acquisition system handles 500 measuring channels with acquisition at 30 seconds intervals.



Figure 6: Power supplies (four sources to four lamps).

#### 4. Results

Values of absorbed heat radiation field (measured by radiometers and radiation sources from tungsten filament lamps) were obtained by carrying out experimental tests. Positions of the lamps were in agreement with Fig. 6. The distance of the lamps from the radiometer base plates (height) was fixed in 400 mm. The tests are carried out using the following lamp powers (P): 497, 317, 168, 88 and 30 Watts.

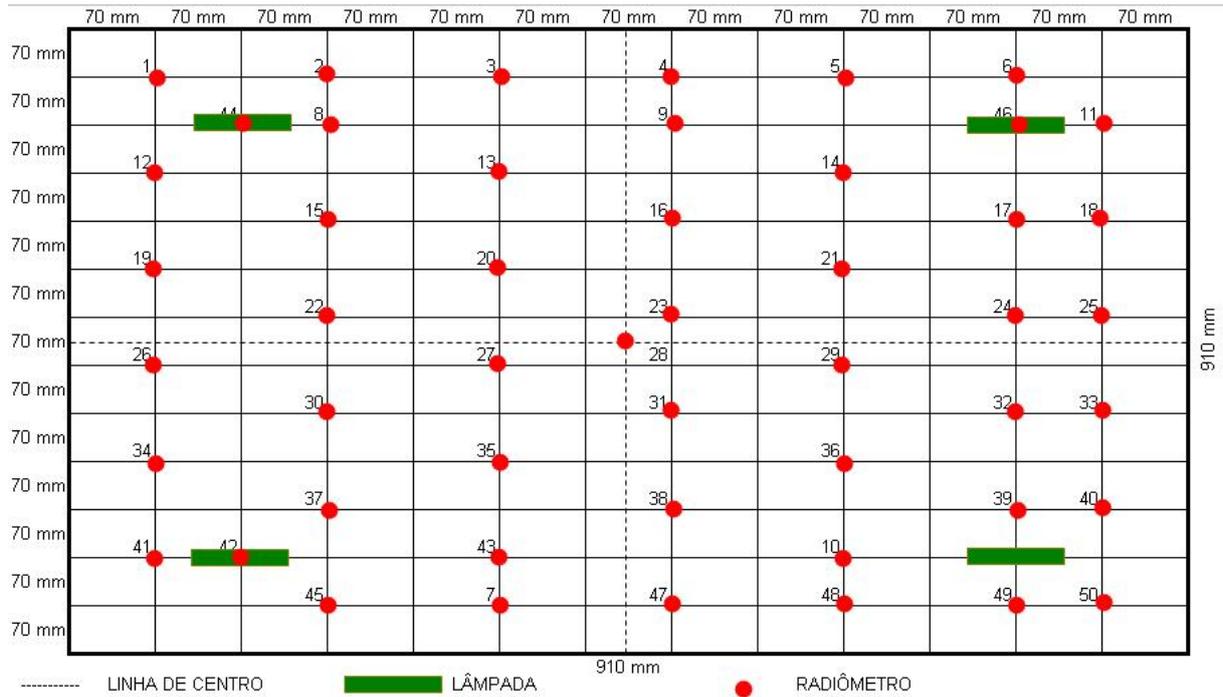


Figure 7: Positioning of the radiometers (green color: position of lamps; red: positions of radiometers).

Once the temperatures were obtained (emissivity of each radiometer was previously measured), it was possible to calculate the absorbed heat flux using Eq. (1). It considers that the radiometer emits a heat flux (to cryogenic thermal-vacuum chamber shroud) equal to absorbed heat radiation from the lamps. This consideration implied to say that the heat losses are negligible.

$$Q = \alpha I = \varepsilon \sigma T^4 \quad (1)$$

#### 4.1. Uncertainty analysis

With the obtained data from the experiment, it was fulfilled an uncertainty analysis to give more confidence to the results. The measurement temperature ( $T$ ) was obtained by thermocouples. Then, the heat flux ( $Q$ ) was evaluated from Eq. (1), which are:  $\sigma$  is a Stefan – Boltzmann constant;  $\varepsilon$  is the sensor emissivity, which was obtained experimentally;  $T$  is the temperature in each radiometer.

The total uncertainty of each variable was composed by combination of random and bias uncertainties as describe by Coleman and Steele (1999). Method of Kline and McClintock (1953) was employed for propagation of primary variable uncertainties, for a level of confidence of 95% (or 20:1), as described ahead.

- For a given primary variable:

$$U_X^2 = U_{X,bias}^2 + U_{X,random}^2 \quad (2)$$

Where:

$$U_{X,random} = \frac{tS_x}{\sqrt{N}} \quad (3)$$

Where  $S_x$  is standard deviation of a finite sample for a given number of measurements  $N$  and  $t$  is t-student variable.

- For propagation of primary variable uncertainties:

$$\left(\frac{U_Q}{Q}\right)^2 = \left(\frac{\varepsilon}{Q} \cdot \frac{\partial Q}{\partial \varepsilon}\right)^2 \cdot \left(\frac{U_\varepsilon}{\varepsilon}\right)^2 + \left(\frac{T}{Q} \cdot \frac{\partial Q}{\partial T}\right)^2 \cdot \left(\frac{U_T}{T}\right)^2 \quad (4)$$

or

$$\left(\frac{U_Q}{Q}\right)^2 = \left(\frac{U_\varepsilon}{\varepsilon}\right)^2 + 16 \cdot \left(\frac{U_T}{T}\right)^2 \quad (5)$$

#### 4.2. Results

Figures 7, 8, 9, 10 and 11 show the results of Absorbed Heat Radiation Flux by each radiometer for a given wattage (P).

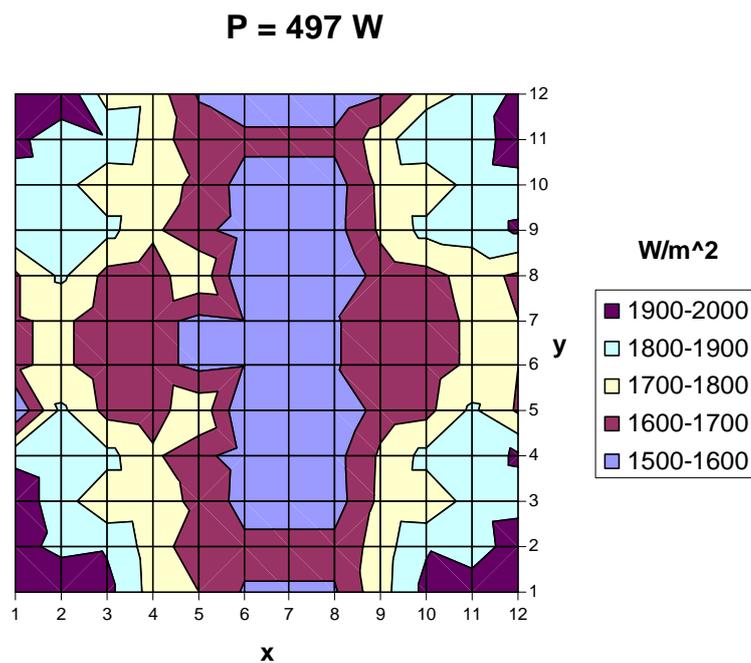


Figure 8: Absorbed Heat Radiation ( $W/m^2$ ) in the radiometer plate for an uncertainty of  $\pm 177$  (20:1), for lamp power  $P = 497W$ .

**P = 317 W**

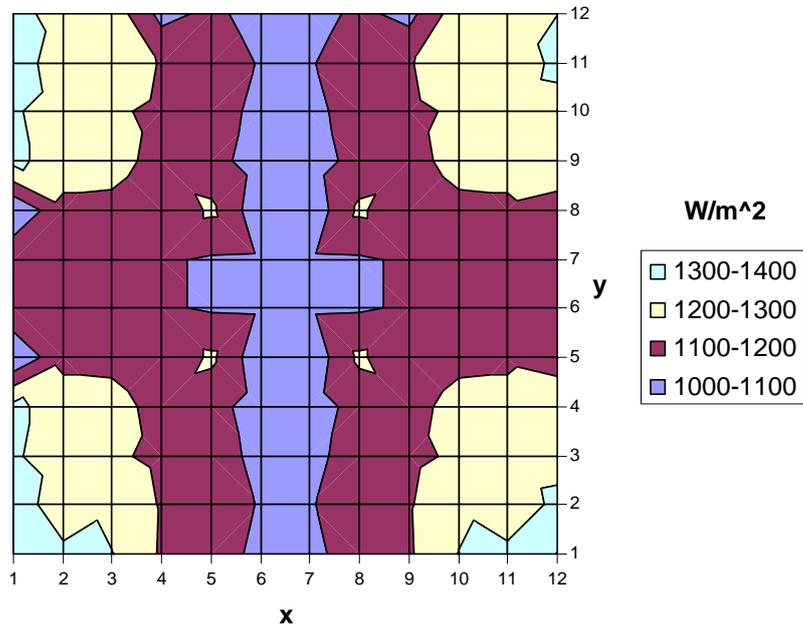


Figure 9: Absorbed Heat Radiation (W/m<sup>2</sup>) in the radiometer plate for an uncertainty of  $\pm 119$  (20:1), for lamp power P = 317W.

**P = 168 W**

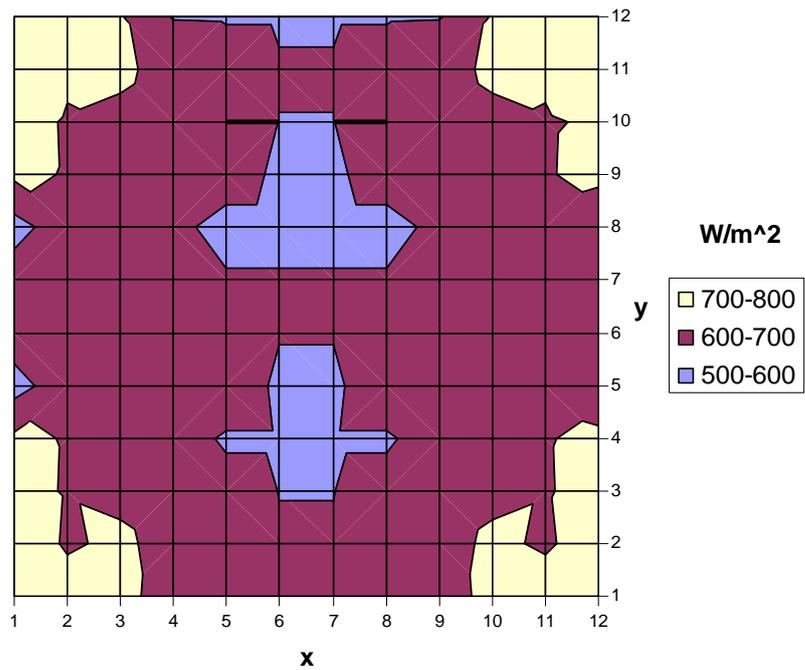


Figure 10: Absorbed Heat Radiation (W/m<sup>2</sup>) in the radiometer plate for an uncertainty of  $\pm 83$  (20:1), for lamp power P = 168W.

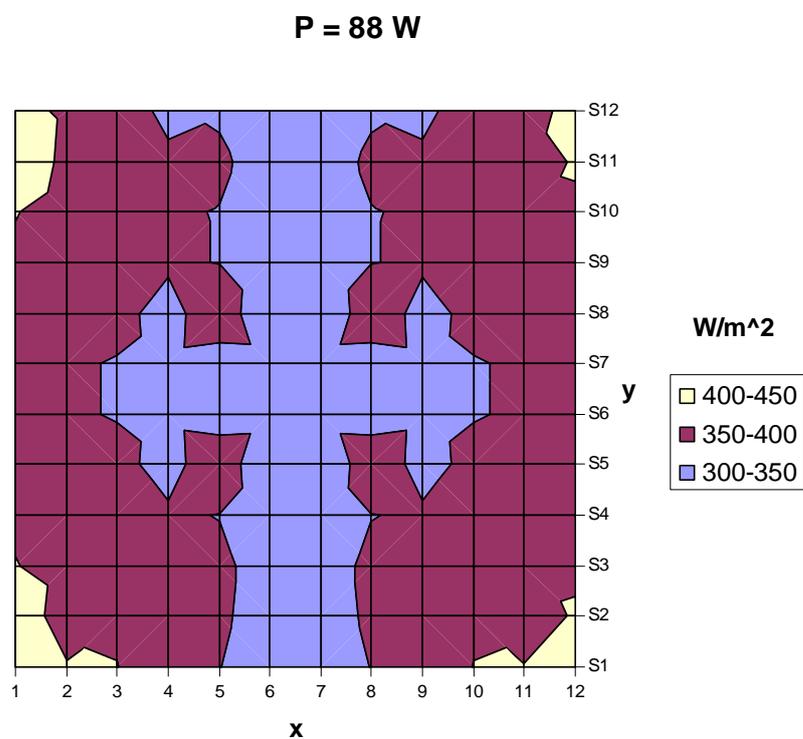


Figure 11: Absorbed Heat Radiation ( $W/m^2$ ) in the radiometer plate for an uncertainty of  $\pm 42$  (20:1), for lamp power  $P = 88$  W.

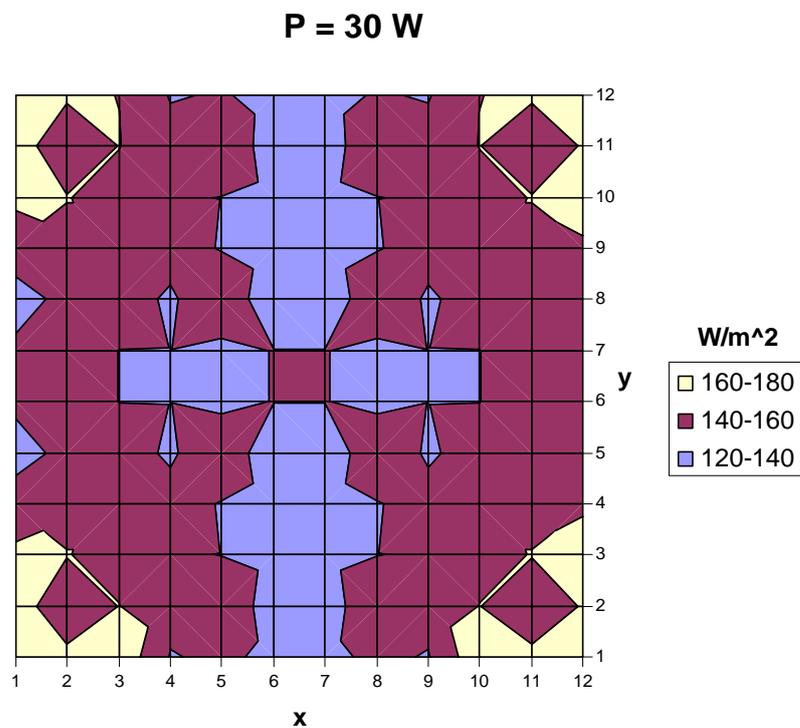


Figure 12: Absorbed Heat Radiation ( $W/m^2$ ) in the radiometer plate for an uncertainty of  $\pm 19$  (20:1), for lamp power  $P = 30$  W

## 5. Conclusions

The principal effect of this work was to analyze the real influence of the baffles over the absorption of the heat radiation. It was verified that the heat flux was really increased, thought more than necessary under the point of view of the uniformity. The conclusion of these results drive us to fulfill the next steps: a) we have to change of the setup, in order to put lamps closer of the center positions; b) analyze the influence of base plate thermal emission to baffles, which can reflect to radiometers again; c) identify theoretical correlations to develop a computation model which could be useful for development of space simulation of satellites.

## 6. Acknowledgements

We would like to thank the CNPq/RHAE and INPE/LIT for their support in helping us carry out this research and also LIT Thermal Vacuum group for their help in manufacturing the experimental apparatus and carrying out of the tests.

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