PALAMEDE thermal design with ESATAN/ESARAD

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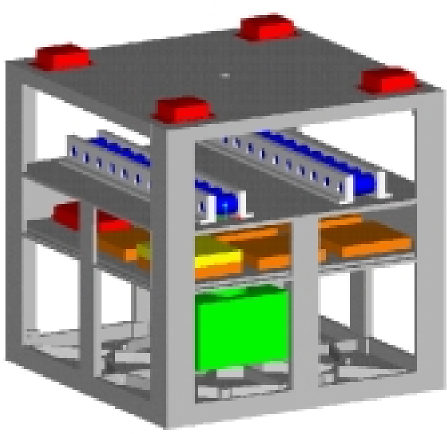
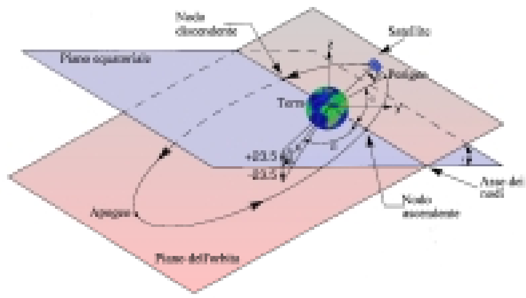
Palamede minisatellite



This small satellite (400x400x400 mm^3) is aimed at giving students the opportunity to gain experience on the development of a real space system. Moreover, from a scientific point of view the project aims to test and develop cheap and efficient technologies for small space missions. Equipped with a CCD and an Infra-Red camera, as payload, PalaMede will take photos of chosen areas of the Earth and space respectively.
The satellite is designed so that it is low cost and economic.
To fulfill the specifications, the satellite thermal control is passive.

Orbit



LEO Circular orbit (Low Earth Orbit)

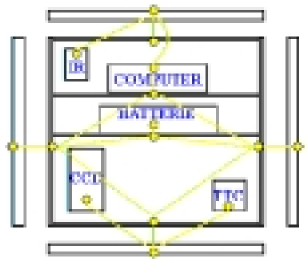
- h=800 Km
- T=6047 s
- i = 98.6°
- RAAN Ω=44.76°
- Sun declination -23.5° ≤ δ ≤ 23.5°
- satellite spin = 1 rpm

Thermal specifications temperature ranges

•CCD color camera	0÷60 °C	(-20 ÷70 °C)
• IR camera	-10÷50 °C	(-20 ÷60 °C)
• Computer, GPS receiver	-15÷70 °C	
• Batteries	0÷35 °C	
•Solar panels	-80÷100 °C	

Between brackets are the non-operational temperatures

Preliminary thermal model



Nodes
Conductive links

Preliminary satellite thermal design was done using a semplified thermal model and doing the analyses without any specific sw for the thermal analysis.

The whole satellite, with its payload, was modelled by means of 19 nodes that are linked one to the other by means of conductive (linear) links.

The radiation heat exchange of the model is very coarse: Only the external surfaces are taken into account, and are able to absorb and reject heat power.

The first iteration in the thermal design gave qualitative results, namely indications on the feasibility of the satellite's thermal design, but quantitatively questionable, due to the large approximations.

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Thermal model evolution

In order to obtain reliable results, specific thermal analysis software was used: ESATAN and ESARAD, in their PC version.

PC Esatan allows to do analysis with models smaller than :

- 300 Thermal and 300 Fluid Nodes
- 1000 GL conductors
- 5000 GR conductors

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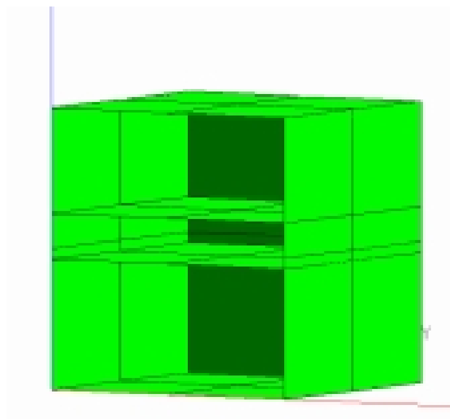
GMM

Each one of the four layers where the on board electronics is placed and the four solar panels are modelled by means of 32 surfaces in total.



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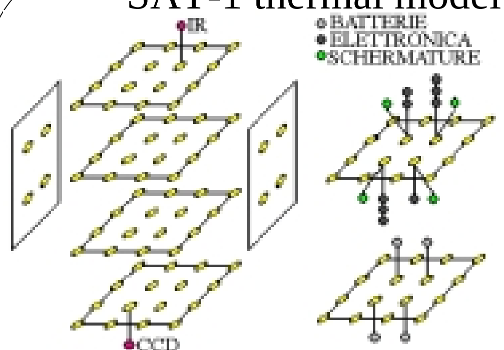
SAT-1 thermal model: first iteration



In the figure the nodal breakdown is shown: electronic boards stacked on the midplanes are clearly visible.

Features

- 32 active surfaces
- 99 nodes

Sizing cases

We have identified the following orbital conditions being the most demanding from a thermal point of view:

•winter solstice with all the onboard electronics switched on (hot design case)

•summer solstice with all the onboard electronics switched off (cold design case)

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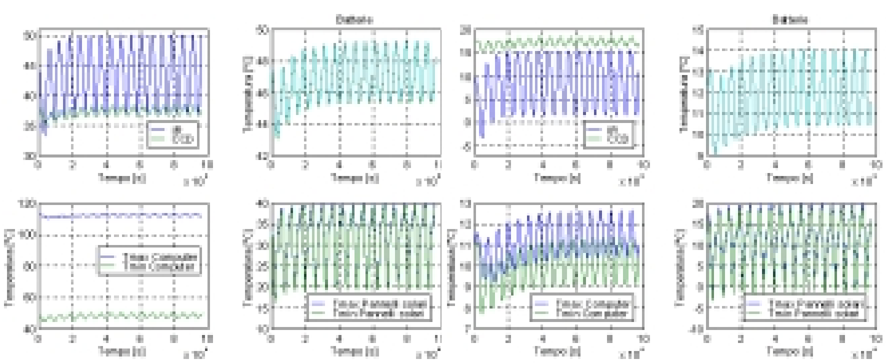
POSTPROCESSING

- C program for extracting time varying temperatures from ESATAN output
- MATLAB used for post processing and graphics

Results for SAT-1

Winter solstice **Summer solstice**



Critical elements

•Batteries	49 °C	(35 °C)
•Computer	>110 °C	(69 °C)
•IR camera	~50 °C	(50 °C)

Critical elements

None

Solutions and thermal design improvement

The cold case is not a critical one: the heat rejection capability of the satellite has to be improved.

Some modifications were done, bringing to an evolution of the thermal design :

•SAT-2

•SAT-3

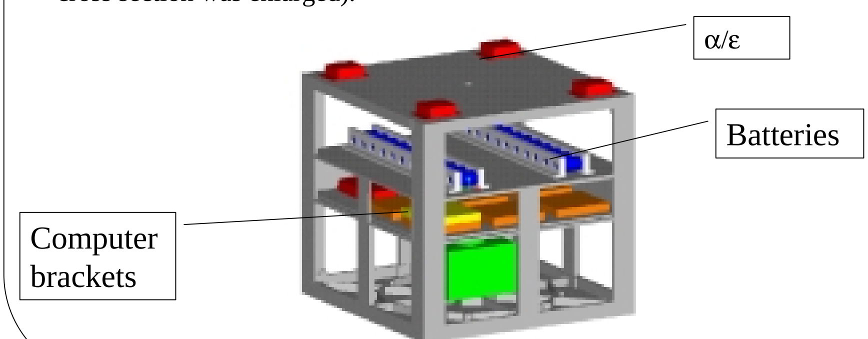
•SAT-4

each one is keeping the advantages obtained with the previous ones.

•The idea of making step-by-step modification has the advantage of better understanding the impact of the single modifications.

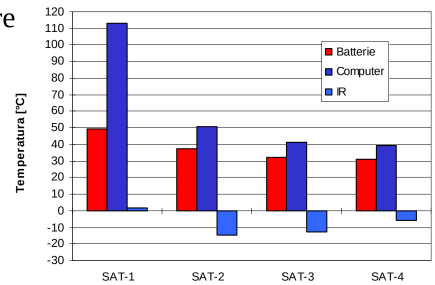
SAT-2 Thermal model

- External layers thermo optical properties changed to radiator, with a low α/ε ratio (white paint was assumed, with a=0.2 e=0.8)
- batteries and computer were swapped so that batteries were installed on the coldest plate
- computer and batteries mounting brackets were redesigned (namely: their cross section was enlarged).



SAT-3 SAT-4 Thermal model

- SAT-3
  - The two central planes were joined one to the other, in order to allow a better link also to the solar panels, colder in average.
- SAT-4
  - Solar panels were joined also to the upper and lower plate



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SAT-5 Thermal model: converting GL into height, width, length

The final (SAT-5) thermal model was essentially given by mechanical design needs: the structure had to be simple.
Moreover, in order to shield the commercial PALAMEDE electronic from radiation, a thick aluminum shield has to be placed around the electronic boards.
A unique, thick, electronic box was put in the middle of the satellite, in order to have the similar advantages like in model SAT3.
Solar panels’ substrates have been modelled as two layers; the conduction perpendicular to the plane, given by the honeycomb, was calculated as below:

$$A_{effective} = A_{plate} \frac{\rho_{honeycomb}}{\rho_{Aluminum}}$$

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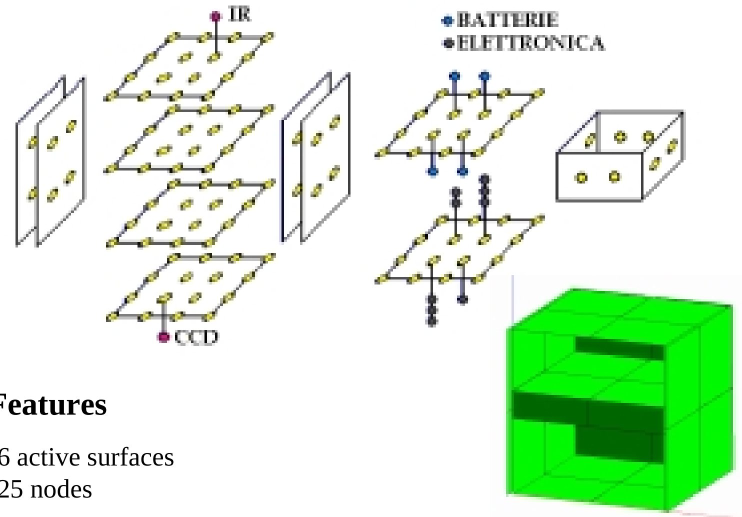
SAT-5 nodal breakdown



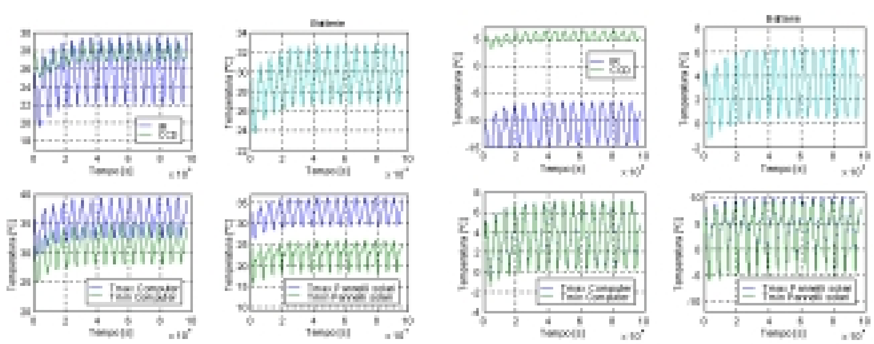
Features

- 56 active surfaces
- 125 nodes

Results

Winter solstice

Summer solstice



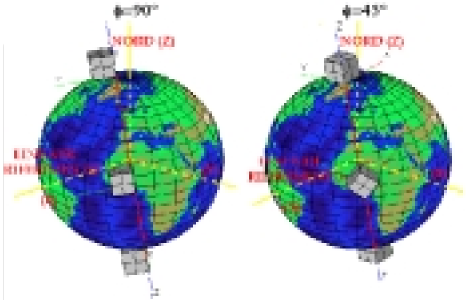
Critical elements

None

Critical elements

None

Despun satellite analysis



A non-spinning satellite was considered to complete the thermal analysis, in two different attitudes with respect to the sun vector

	Winter 45°		Winter 90°		Summer 45°		Summer 90°	
	T_{min}	T_{max}	T_{min}	T_{max}	T_{min}	T_{max}	T_{min}	T_{max}
CCD	22.78	24.71	27.58	30.05	1.05	2.99	5.6	8.09
Computer	21.42	36.96	27.77	46.13	-5.07	5.86	0.7	14.1
Batteries	19.72	31.42	26.16	**39.28**	**-5.15**	5.08	0.7	13.07
IR	18.76	26.73	23.71	31.65	-17.5	-9.16	-12.65	-4.31
Sol. panels	-0.69	52.25	4.29	50.28	-19.03	28.58	-14.23	23.98

Critical elements Φ= 45°

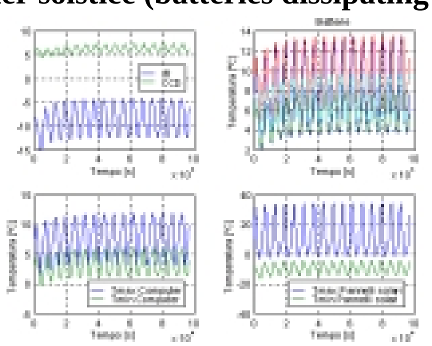
•Batteries T_{min}= -5.15 °C (0 °C)

Critical elements Φ= 90°

•Batteries T_{max}= 39.28 °C (35 °C)

The worst cold case analysis that is assuming non-dissipating batteries is not so realistic, because their thermal dissipation (both in the discharge and in the charge phase) will keep them above zero, as shown below.

Summer solstice (batteries dissipating power)



Parametric analysis: orbit parameters

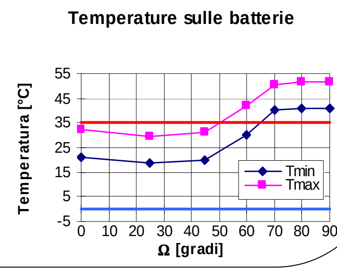
The orbit considered for the analysis is the ‘design’ or ‘reference’ orbit.
The sensitivity of the solution to the RAAN (Ω) change was investigated.

RAAN values between 0° and 90° were considered:

Ω=0° (maximum eclipse orbit)
Ω=90° (satellite always in the sun).

Critical elements

•Batteries when Ω>50°



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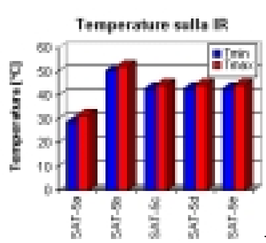
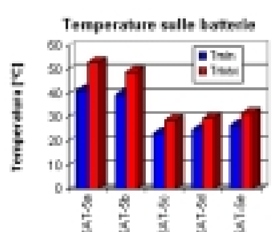
Ω=90°: RECOMMENDATIONS

- SAT-5a low emissivity coating (e.g. aluminized kapton) on the solar panels inner side in order to reduce the radiation heat exchange;
- SAT-5b 8 copper beams between the two upper plates as cold fingers;
- SAT-5c 8 copper beams (12 Kg!) to join batteries to upper layer, and thermal insulation from the mid plane;
- SAT-5d/e Copper bars mass reduction (4 - 2 Kg)





Effects

- Batteries temperature reduction
- IR camera temperature increase
- All the items are within the specs.

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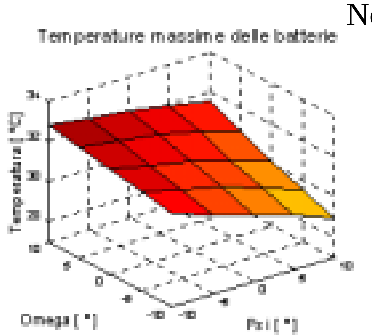
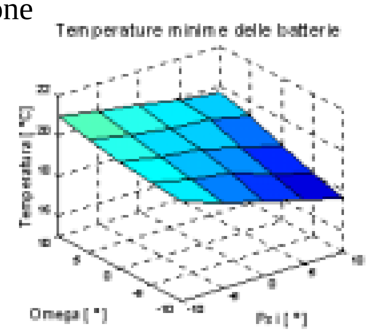
Thermal sensitivity wrt Attitude

An additional uncertain parameter is the attitude stability: combined oscillations of ±10° around lateral axes have been considered, limiting the study to the hot design case, which is the most severe one.

Critical elements

None





Conclusions

•The satellite equipments are within their limits also for conditions different from the nominal ones: orbit, de-spun and attitude.

•The thermal control has been achieved in a completeley passive way with the goal of keeping the project at low cost and reliable.

•ESATAN and ESARAD allowed a fast development of the thermal model, and the subsequent update was quick and easy.

The biggest problems encountered were
• PC crash when using ESARAD - **ALL THE DATA LOST**
• "SAVE AS" command that would have been useful for implementing the thermal model evolution was not working - **EVERY MODIFICATION REQUIRED A NEW MODEL**