Subject: Re: Calculation of the average core and cube corner temperatures
Date: Sunday, September 30, 2018 at 7:14:37 PM Eastern Daylight Time
From: richard matzner
To: David Arnold
CC: Phuc Hong Nguyen, Jason Wayne Brooks, Erricos C. Pavlis
Attachments: Modelling LARES temperature distribution and thermal drag II: Numerical computation of current-epoch thermal forces 10.1140-epjp-i2016-16222-4.pdf, Modelling LARES temperature distribution and thermal drag 10.1140-epjp-i2015-15206-2.pdf

Hi Dave,

-I first had the impression that you were addressing LARES2 (LAGEOS altitude), but in your notes you refer to LARES altitude. The attached papers show the results of our (Nguyen, Brooks, and me) studiesfor LARES. The later paper (with Brooks) provides more detailed results, and uses an integration method more suited to slow rotation.

-In the paper with Brooks you can see the results of a simulation of the behavior of LARES (not LARES2). If you look at Figure 4 (and zoom in to read the labels), you can see that the tungsten core has an average temperature of about 390K (upper left panel). Since LARES' core is sintered tungsten, its thermal conductivity is high enough that the core is almost isothermal. (We estimate a 1K spatial variation.)

FYI, in the figures he horizontal axis is in seconds; the gray bar indicates that an eclipse occured (satellite entered the shadow of the Earth) during that time.

Compare the core temperature to the other panels which show that the temperature of the CCRs is about 100K lower.

In this model, the CCRs are treated as unitary isothermal objects as you do. (The code does take into account the geometry of the retro in computing the view factors between the cavity and the retro.)

-When we learned that LARES2 might have a substantially lower thermal conductivity, we started an attempt to compute the spatial variation of temperature within the satellite. We are still working on an implementation of that. Variation of temperature within the retros was not our first concern. We were more concerned with surface temperature differences across the core.

A point of perhaps significant difference between our and your analysis is that we neglected the contribution of the mounting rings to CCR heating. But you show a dominant heating effect from the mounting.

Slabinski (Celestial Mechanics and Dynamical Astronomy vol 66 pp 131-179 (1997)) describes the CCR and its mounting in his Figure 4 and Figure 5. "Figure 4 based on construction prints and [Slabinski's] measurements of flight-spare CCR hardware", and his Figure 5 show the geometry involved. The CCR is held in place between two KEL-F fluoroplastic (chlorotrifluoroethylene) rings. Skabinski then says: "To avoid possible mechanical distortion of the CCR, a 0.08 mm vertical clearance within the open space prevents the mounting rings from actually gripping the CCR tabs." In our papers we have assumed that meant poor thermal contact between the KEL-F and the glass, so we ignored thermal conduction through the mountings.

On the other hand, if we assume good thermal contact as I suspect you did, I estimate thermal fluxes into the glass roughly what you give, of order 0.3 watts with a Delta T of 30K.

Moreever, our temperature difference is of order 100K, (390K - 290K) which would bring the heat conducted through the mount into the CCR to about 1 watt. The radiative heat transfer would amount to about 0.1 watt in this case. So the heat transfer would still be dominated by the mounting, though less so in our case.

So the question is, how tightly is the mount coupled to the CCR? Can I ask how you computed that coupling in the case of firm contact?

I have read through your calculations several times, and they appear correct to me. (It has taken me a while to internalize your terminology.) I will read the calculation carefully for typos, and will try to answer your other questions and let you know asap.

Best Regards,
Richard

> On Sep 29, 2018, at 6:21 AM, David Arnold <david-arnold2006@earthlink.net> wrote:
>
> Hi Richard,
>
> I noticed a couple of misprints in the ThermalEquilbrium paper (revision attached). There is a ")" missing in what I have labelled equation (1b) and a term Ab missing in equation (1c). These equations were a last minute additions that I did not proof read carefully – sorry. The derivation starting from equation (3) deals only with the sum of the radiation between the cube and the different parts of the mounting cavity.
>
> I assume you have had to try to model the temperature of the cubes corners for the thermal thrust calculations. The cubes need to be kept as cold as possible for optical reasons. However, I assume this would also be an advantage for the thermal thrust calculations. The cubes have a much shorter thermal time constant than the core. I expect this must be a problem in trying to

model the thermal thrust.

If you have any questions let me know.

Best,

David Arnold
Cell: 617-335-4113

From: richard matzner <richard.matzner@sbcglobal.net>
Date: Friday, September 28, 2018 at 5:03 PM
To: ErricosUmbc Pavlis <epavlis@umbc.edu>
Cc: David Arnold <david-arnold2006@earthlink.net>, Richard Matzner <matzner2@physics.utexas.edu>, Mike Pearlman <mpearlman@cfa.harvard.edu>
Subject: Re: Calculation of the average core and cube corner temperatures

Thanks Erricos,

I'll review the latest also -

Richard

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On Sep 28, 2018, at 3:35 PM, Erricos C. Pavlis <epavlis@umbc.edu> wrote:

> Thank you Richard, we all know of such times, no worries! I am including here another more recent memo that Dave generated the other day, with a bit more developed equations and information. This will likely give you a better picture of the issue and what he is trying to do. He really wants to have another expert's opinion as a sanity check of his development. If there are tests that can be done so much better, but we cannot ask for too much.
>
> Thanks for anything you can help with,
>
> ecp
>
> <ThermalEquilibrium 2018.09.28.pdf>

On Sep 28, 2018, at 4:24 PM, richard matzner <richard.matzner@sbcglobal.net> wrote:

Dave, Erricos,

Sorry it has taken me a couple of days to reply. Your note came at a particuarly busy time.I will try to understand your question and get back to you as soon as possible.

Best,
Richard

> On Sep 26, 2018, at 1:18 PM, David Arnold <david-arnold2006@earthlink.net> wrote:
>
> Hi Erricos,
>
> Thanks for getting them in the loop.
>
> I have attempted to extend the thermal balance analysis to include the core (see attached). It gets a bit complicated. Unless I have done something wrong it appears that the average core and cube corner temperatures can be calculated from the physical parameters directly as long as conduction is not included. The problem with conduction is that it is linear with temperature and radiation is fourth power. In space, the conduction should be negligible due to the floating mount.
>
> I will have to check and recheck this to make sure I have not made some stupid mistake. If someone else could check this also that would be helpful. If everything is correct, I can calculate how the cube temperature varies with emissivity of the cavity. This should resolve the question of whether reducing the emissivity of the cavity actually reduces the cube temperature.
>
> Best,
>
> David Arnold

From: ErricosUmbc Pavlis <epavlis@umbc.edu>
Date: Wednesday, September 26, 2018 at 1:06 PM
To: David Arnold <david-arnold2006@earthlink.net>, Richard Matzner <matzner2@physics.utexas.edu>
Cc: Mike Pearlman <mpearlman@cfa.harvard.edu>
Subject: Re: Emissivity of the cube corner cavities on LARES-2

Hello Dave,

I am not an expert on thermal issues but as you might recall we had a lot of work done on LARES' thermal drag by the team of Prof. Richard Matzner at UT, and they might be able to help with this study that you are looking for, by adapting some of their s/w to these new questions.

I am not sure if they are available or able to help, so I am carbon copying Richard on this reply and I am sending you copies of their two papers, so you can see what they have done for LARES. Naturally, we have new type/size of CCRs here and a slightly larger satellite at a much higher orbit, so it is by no means a small change of parameters, even if we were looking at the exact same topic, which you are not. But I hope that something, even at some approximate level can be done.

I am including here your document for them to review.

ecp

> On Sep 26, 2018, at 9:00 AM, David Arnold <david-arnold2006@earthlink.net> wrote:
>
> Dear Erricos,
>
> The material for the core of the LARES-2 satellite has not yet been finalized. When it is, the first thing that needs to be done is to

calculate the temperature of the core. This is the boundary condition needed to do the thermal analysis of the cube corner. The equilibrium temperature of the core depends on the temperature of the cube corners. The radiation from the core and the cubes has to equal the heat inputs to the satellite.

A thermal design study of LAGEOS was done by ADL under contract to SAO. The report is:

FINAL REPORT
THERMAL DESIGN STUDY OF THE
"CANNONBALL" SATELLITE
Contract PC 71-7026
Prepared for
SMITHSONIAN ASTROPHYSICAL
OBSERVATORY
CAMBRIDGE, MASSACHUSETTS
By
R. MERRIAM
ARTHUR D. LITTLE, INC.
CAMBRIDGE, MASSACHUSETTS
18 JUNE 1971
C-73510

The Summary and Conclusions of the report states the following:

Page vii

To decrease temperature gradients within the retro-reflectors, it is concluded that the reflectors should be radiatively decoupled from the satellite core. This can be achieved by using a low-emittance surface in the core cavities containing the reflectors…

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Sandblasted nickel or aluminum is

suggested for use as the satellite thermal control surface. These surfaces are highly diffuse and of relatively high reflectance in the visible region; they are, therefore, suitable for optical tracking of the satellite. At the same time, the emittance of these surfaces cannot be well specified and should be determined by test.

The emittance of the cavity can be chosen to be different from the emissivity of the core. The report states that the cube should be radiatively decoupled from the core. Decreasing the emissivity of the cavity will decrease the temperature of the cube and improve the optical performance. The problem is that decreasing the temperature of the cube will decrease the total energy radiated by the satellite as a whole. This will result in an increase in the temperature of the core.

A parametric study needs to be done to verify that using a low emissivity of the cavity will indeed result in lower temperature of the cube in spite of the fact that the temperature of the core will increase.

I made a start on this problem back in 2007. Attached is a copy of a report which studies the thermal balance for the cube corner given the temperature of the core. Equation (5) gives the average equilibrium temperature of the cube as a function of the temperature of the cavity. This study needs to be extended to compute the thermal balance for the satellite as a whole. Using this tool, a parametric study needs to be done to determine the optimum emissivity of the cavity to produce the lowest temperature of the cube.

Once the cube temperature is minimized, thermal-optical simulations need to be done to determine the difference between the isothermal cross section and the cross section with thermal gradients included. The expectation is that the small 1.0 inch cubes will show much smaller changes due to thermal gradients than the larger 1.5 in cubes used on LAGEOS 1&2 and on LARES-1.

Is there anyone who has studied this problem that might be able to help with the analysis?

Best regards,

David Arnold

<Thermal.pdf>

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<Thermalcore.doc>

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