From: Antonio Paolozzi <antonio.paolozzi@uniroma1.it>
Date: Friday, March 23, 2018 at 3:55 AM
To: David Arnold <david-arnold2006@earthlink.net>
Cc: Reinhart Neubert <reinhart.neubert@web.de>, Ignazio Ciufolini <ignazio.ciufolini@gmail.com>, ErricosUmbc Pavlis <epavlis@umbc.edu>
Subject: Re: Extract from report to ASI

Dear all,
I am not sure a low emissivity is the best solution to go and so I want to share with you the following qualitative considerations. In the hypothesis of uniform emissivity all over the satellite, the flux from the metallic cavity is independent on the value of the emissivity. Please check this result: the flux from the metallic part of the cavity towards the CCR (mainly towards the back faces) is proportional to epsilon*T^4. Now consider that (epsilon*T^4) is proportional to (W*alpha) So this flux is independent on epsilon (in fact from the previous relation depends only on alpha). However the plastic rings have high emissivity and the flux from them also is proportional to T^4. So in the end it seems that a high emissivity has a beneficial effect because it lowers the temperature of the satellite. This lowering has no effect on the flux from the metallic part of the cavity (it is the same for all temperatures) but it has a beneficial effect on the flux from the plastic rings towards the CCR because a lower satellite body temperature will reduce the temperature of the plastic rings. Slightly different is the situation with non uniform emissivity, i.e. with a different emissivity in the cavities.
The low emissivity in the cavity will increase the satellite temperature which have two effects
(i) change the flux from the metal part of the cavity towards the CCR, reducing it because of the low emissivity, but increasing it because of the satellite higher temperature. So in other words the beneficial effect of reducing the cavity emissivity is mitigated by the increase on the satellite temperature
(ii) increase the flux from the plastic rings towards the CCR, because the emissivity of the plastic ring is fixed, while the satellite temperature will

increase.

Now let us consider the situation of the LAGEOS satellites. I found the best info on alpha and epsilon from Slabinski paper 1997. There are no evidence that the cavity of the LAGEOS satellites were treated differently from the rest of the satellite. Also in LAGEOS 1 there is an emissivity of 20% while on LAGEOS 2 of only 0.05%. see screenshot below:

SOLUTION FOR LAGEOS THERMAL THRUST 151

Table III. Solar absorptance and thermal emittance of LAGEOS parts

Component	Solar absorptance α_s		Thermal emittance ε	
	LAGEOS 1	LAGEOS 2	LAGEOS 1	LAGEOS 2
CCR fused silica	0.15^{a}		0.81^{d}	0.81^{e}
Fraction of CCR-incident solar radiation absorbed by cavity wall	0.42^{a}			
Al hemispheres	0.42^{b}	0.39^{c}	0.20^{c}	0.05^{c}
Al retainer rings	0.42^{b}		0.20^{d}	
KEL-F mounting rings (rough surface)			0.93^{d}	
KEL-F clear, transparent sample (optically smooth surface)				(0.92)

[a] Based on optical solar reflector (OSR) value after 2 years in space (Hyman, 1981, Figure 4; Pence and Grant, 1982, Figure 8); fraction absorbed by cavity wall = (1 − 0.15)/2.
[b] Handbook value for sandblasted aluminum (Gray, 1972, p. 6-207, Table 6k-8).
[c] Peter O. Minott (GSFC) measurement on assembled flight model.
[d] Author's 1990 measurement on flight spare CCR assembly.
[e] Assumed same as retainer ring value.

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2018-03-23 0:12 GMT+01:00 David Arnold <david-arnold2006@earthlink.net>:
Dear Antonio,

There is a misunderstanding. The effect of the high emissivity is much more serious than you realize.

The software for calculating the effect of thermal gradients models only a single cube. The range correction depends on the combined effect of all the cubes in the array.

The software I use for calculating the range correction models only the isothermal case. I have no software to compute the range correction with thermal effects included. The accuracy estimates are based on isothermal calculations only. All that can be done is reduce the thermal effects as much as possible hope for the best. There is no way to guarantee that the range correction in orbit will be the same as the isothermal range correction.

LAGEOS had the advantage of low emissivity in the cavity but the disadvantage of large cube size. LARES-2 will have the advantage of small cube size but the disadvantage of high cavity emissivity. My expectation is that the thermal problems will be about the same for both satellites.

The thermal effects for LARES-2 with a low emissivity cavity are so small that they can be neglected in calculating the range correction. The isothermal calculation is virtually the same as the in-orbit range correction. There has never before been a satellite where this could be done.

The emissivity of 29% comes as a complete surprise to me. This changes everything and destroys the ability to guarantee the range correction in orbit.

Best,

David Arnold

From: Antonio Paolozzi <antonio.paolozzi@uniroma1.it>
Date: Thursday, March 22, 2018 at 5:15 PM
To: David Arnold <david-arnold2006@earthlink.net>
Cc: Reinhart Neubert <reinhart.neubert@web.de>, Ignazio Ciufolini <ignazio.ciufolini@gmail.com>, ErricosUmbc Pavlis <epavlis@umbc.edu>
Subject: Re: Extract from report to ASI

Dear Dave,
the low emissivity in the cavity is well know to be the best condition for the satellite. However from preliminary measurements that is the case 29%. By the way high emissivity will lower sensibly the satellite temperature thus lowering the flux with the fourth power, to the CCR which I think it is in the end what

matters isnt'it?
Of course if can be considered to polish the surface of the cavity to reduce locally the emissivity, but I would like to see this extreme case what would produce in terms of accuracy reduction. 140 °C and 29% emissivity it not realistic because high emissivity cannot produce such a high temperature. More realistic is case 70°C and 29% emissivity.
Concerning the selection criteria we will have time to find a better one, but one has to be provided.
Antonio

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2018-03-22 20:21 GMT+01:00 David Arnold <david-arnold2006@earthlink.net>:

Dear Antonio,

Why are calculations being done for high emissivity of the cavity (29%)? I did not know any such design was being considered.

Low emissivity of the cavity has always been a requirement for good thermal behavior. It is not a question of cross section. The requirement of low emissivity is necessary to meet the range accuracy requirements. If the cross section changes the range correction changes also. Selecting the dihedral angles to try to compensate for the thermal effects is not a workable solution since the thermal conditions are constantly changing in orbit.

I have set up the programs to do the calculations for cases 16 and 17. However, I do not consider the high emissivity case to be an acceptable design.

Best,

David Arnold

From: Antonio Paolozzi <antonio.paolozzi@uniroma1.it>
Date: Monday, March 19, 2018 at 10:08 AM
To: David Arnold <david-arnold2006@earthlink.net>
Cc: Reinhart Neubert <reinhart.neubert@web.de>, Ignazio Ciufolini <ignazio.ciufolini@gmail.com>, ErricosUmbc Pavlis <epavlis@umbc.edu>
Subject: Re: Extract from report to ASI

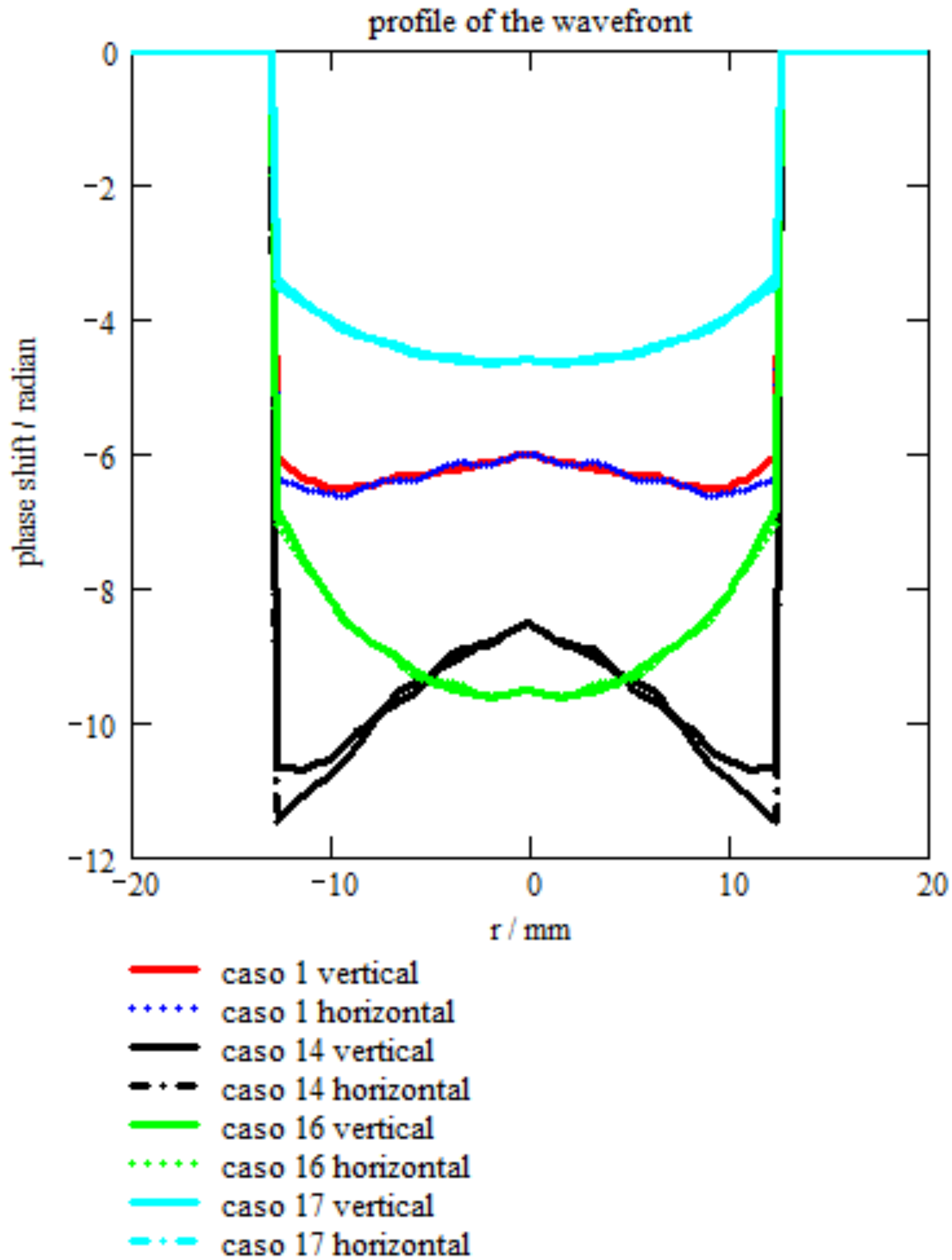
Dear Dave,
below there is a proposal from Reinhart to compute the phase surface of the high emissivity cases 16 and 17). We wander if you could do that. This will help in a better selection of the COTS CCRs. I also attach the document that I sent yesterday to Reinhart, where the selection criteria are proposed, but probably need to be changed also on the base of your calculation.
Thank you
Antonio and Ignazio

2018-03-19 11:48 GMT+01:00 Reinhart <reinhart.neubert@web.de>:

Dear Antonio,

I do have a first comment on the selection rules:

The phase change produced by thermal gradients depends strongly from the emissivity:



Case 1 and 14 corresponds to low emissivity and case 16 and 17 to high emissivity. The curvature of the cases is opposit (dont ask me why. For safety we could ask David Arnold to compute the phase surface of the high emissivity cases 16 and 17). Therefore for low emissivity negative offsets and for high emissivity positive offsets should be preferred.

In the isothermal case the sign of the offsets makes no difference. Thats why the cross sections of table 10 are almost equal for all samples.

hope this is useful for you
with best regards Reinhart
P.S.: there might be an intermediate emissivity for which the thermal phase change is almost zero.

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Am 19.03.2018 um 02:39 schrieb Antonio Paolozzi:

Dear Reinhart,
we wonder if you could revise the documeht attached within today. If you do not have time to see it all, just concentrate on pages 1 and 2. This document is an evolution of what you already saw some time ago. Particular interesting is table 10 where the discarded CCRs have approximately the same cross section as some good ones. See for instance CCR no.5 which has higher cross section than many others with Yes in the 6th column. If you have comments, suggestions addition or corrections, please let us know.
Thank you very much
Antonio and Ignazio