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Dear Anna,

As I told you in my short response by email, the last days of 2001 were very busy at ONERA, in particular for the space accelerometer team, with the CHAMP flight data expertise, the GRACE Preship Review and the MICROSOCPE Preliminary Design Review.

It seems that you are particularly interested in the MICROSCOPE mission, unfortunately to demonstrate that the expected performance will not be obtained. After all, I must confess that answering your letters is a new motivation to re-analyze and re-compute the discussed technical points for the benefit of the mission. So I red with interest your new paper on the radiometer effect in the MICROSCOPE mission.

In the first paragraph of your document, we all agree on the formula (1) and the specification (2) now rightly deduced from the MICROSCOPE design values. You then follow our classical consideration for the frequency filtering aspect mentioned in formula (3), thus leading to the specification of the difference of the temperatures, expressed in (4), at the two ends of the test masses -along the instrument sensitive axis pointing the Earth- and of the surrounding cores. Unfortunately, you misinterpret, in the paragraph which follows this formula, our considered values of 3 mK m^{-1} depicting the temperature gradient (see table 1). Over the 10 cm length that you rightly consider for the mass, the difference of temperature is 0.3 mK, and not 30 mK as you write, i.e. a factor 30 less than the specified value of 8.7 mK

		Acta Astrau. Feb01	Specs March 01	Class. Quant. April 01	Eval. Perf. Dec 01
Electronics temperature	PSD about f_{EP}	5 K $Hz^{1/2}$	1 K $Hz^{1/2}$	1 K $Hz^{1/2}$	1 K $Hz^{1/2}$
	Tone, sine at f_{EP}	10 mK	3 mK	3 mK	3 mK
Sensor temperature	PSD about f_{EP}	5 K $Hz^{1/2}$	1 K $Hz^{1/2}$	1 K $Hz^{1/2}$	0.1 K $Hz^{1/2}$
	Tone, sine at f_{EP}	10 mK	3 mK	3 mK	0.3 mK
Sensor thermal gradient	PSD about f_{EP}	1 K m^{-1} $Hz^{1/2}$	1 K m^{-1} $Hz^{1/2}$	1 K m^{-1} $Hz^{1/2}$	
	Tone, sine at f_{EP}	1 mK m^{-1}	1 mK m^{-1}	3 mK m^{-1}	

Table 1: Considered sets of values determining the thermal environment of the MICROSCOPE instrument. Two units are considered : the electronics unit and the sensor mechanics that will not be accommodated on board the satellite with the same thermal interface, the specifications and the consumed power being different. Because of the radiometer effect, the thermal gradient of the sensor mechanics has been always specified separately. PSD and Tone error are mentioned. The paper in Acta Astronautica is under press and has been written from the IAF presentation in October 00. The specifications of March 01 corresponds to the values considered at that time by Cnes and Onera for the satellite and the instrument design and have been mentioned in my answer to your first paper (unfortunately, you did not correct the values in your publication). The third column is the reference Touboul and Rodigues [2] of your new document. The last column is the present set of values that are considered as feasible by Cnes satellite team for the definition of the thermo-mechanic interface of the units.

You insist in your new document in the necessity of considering differently the random perturbing term and the ones at the same frequency and the same phase than the Earth monopole gravity field signal. That is clear and the reason of detailing our values for the instrument thermal environment in PSD and Tone. For the GRACE mission, this approach has been already considered for the specifications of the satellite environment and for the performance of the accelerometers.

Finite element thermal models of the instrument are now available and confirm that the values mentioned above for the thermal gradient of the sensor can be obtained and are even pessimistic with respect to the computed values.
According to the performed analysis, the thermal inertia and the insulation of the instrument lead to a reduction by a factor greater than 2.10^4 of the static difference of temperature observed on the mass with respect to the static external environment and a factor greater than one thousand for the silica core. Dynamic response to sine wave thermal fluctuations have also been computed and assessed this filtering factor.
Furthermore, the time constant of 2 hours taken into account in the formula 3 of your document has been measured on the STAR and the SuperSTAR accelerometers. With a conservative approach, this value is presently considered but the thermal model of the MICROSCOPE instrument shows that the response time is certainly larger by a factor of 5 : the instrument is larger, heavier and optimized with respect to this aspect.
So, the present thermal model of the instrument exhibits some margin with respect to the mission requirements. These results shall be assessed by more detailed models but the relaxation of the specifications considered in table 1 is under discussion.

In addition, it is scheduled to perform in 2002 on the Engineering Model direct measurement of the thermal behavior of the instrument, as it has been done with SuperSTAR. CNES also considers the possibility to produce a mock-up of the satellite instrument case in order to confirm the interfaces and the performance of the thermal controls.

In the second paragraph of your document, you mentioned the Earth radiation which modifies the temperature of the satellite skin at the same frequency than the EP test. This point has been considered by CNES engineers when they defined the thermal system of the satellite and the location of the radiators for the electronics units. But the fluctuations of the external temperature of the satellite faces are fortunately not applied directly to the instrument accommodated at the satellite center and whose temperature is controlled.

You regret the malfunctioning of the STAR accelerometer that would have been able to measure the radiometer effect. This would not have been possible because the resolution of the less sensitive axis, X, of the STAR accelerometer, is better than the specification (3.10^{-8} ms^{-2}) even with the malfunctioning but not sufficient to measure what you are considering ! The radiometer effect is not the limitation of performance of this instrument. Furthermore, CHAMP satellite is Earth pointing and so is not submitted to the same modulation of the Earth radiation as the MICROSCOPE satellite will be. In the case of CHAMP, the radiation fluctuations are induced by the eclipses and the days and nights alternations. The accelerometer is integrated inside an aluminum housing with temperature controls and we observe more the effects of the thermal control limitations than the thermal effects of the change of the Earth radiation on the satellite.

In the third paragraph, you discuss on the possibility to reject (or, not reject!) the radiometer effect. I disagree with many of your comments.
Not only, the radiometer effect is very limited, as shown above, but the thermal controls, of the instrument mounting plate and of the enclosure, decorrelate the instrument environment to the satellite

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external face temperatures : fortunately, the nature of the temperature field is much different to the gravity field and can be managed by insulation, thermal conductivity and inertia!
Furthermore, contrarily to your assessment, even with two masses of the same material, the radiometer effect does not vanish because of the difference of the two mass shapes leading to different ratios S/m. Thus, the differential accelerometer with two masses of the same material will not be useless. In a more general way, the possibility of having the Pt external mass with the same mass as the Ti one (as you rightly suggest) has been considered but the quality of the production is the major problem to be then solved. Compromise between many aspects has to be done.
About the EP test frequency and the rotation of the instrument, many comments. This frequency is not limited by the reason that you are mentioning for the MICROSCOPE experiment. The spin axis of the satellite is an axis of symmetry of the masses and is controlled by the instrument itself. There is no motion of the mass neither with respect to the instrument cage, nor with respect to the second mass : the masses are servo controlled motionless with respect to the same instrument reference through the capacitive sensing. The frequency of the satellite rotation is only limited because of the range of the FEEP thrusters. Increasing the frequency by a factor 5 should be indeed preferable if it were possible because the resolution of the instrument is better at upper frequency.

In the conclusion of your document, you relate the STEP consideration on the radiometer effect. Like in STEP, this effect is indeed one of the major contribution to the performance limitation of the EP test that will be performed with the MICROSCOPE experiment (see our references). But the factor one thousand between the objective of accuracy of MICROSCOPE with respect to STEP relaxes the requirements on the residual pressure inside the instrument core and/or the temperature gradient fluctuations. So, the present definition of both the instrument and the satellite confirms the objective of accuracy of the mission and the radiometer effect is not a show stopper.

At last, I would like to agree with you on the importance to perform all the possible calibrations of the instrument in the laboratory or in orbit. This is why we are developing a fruitful cooperation with Bremen University in order to complete the tests that will be performed in ONERA before the launch.
I note that your work is supported by ASI : let this work be effectively beneficial to the space missions and limited to a constructive and honest view of these space projects.

With my best wishes for the new year and success to your scientific projects,

Director
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Pierre Touboul

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