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Microgravity sensitivity of typical fluid physics experiment

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ABSTRACT

This report summarizes a number of numerical results concerning the g-jitter sensitivity and the performances of Isolation Mounts for a typical Fluid Physics experiment in the Fluid Science Laboratory of the ISS. The results corresponding to the ideal (zero-g) purely diffusive situation are compared with the real case of residual-g superimposed to g-jitters, in the presence or in the absence of ARIS. The investigated cases correspond to the predicted accelerations on the ISS according to the NASA Design Analysis Cycles (DAC3 and DAC4), and to the worst situation, in which residual-g and g-jitters are supposed to be both perpendicular to the density gradient. In this situation buoyancy effects, induced by residual-g, and thermovibrational effects, induced by high frequency periodic oscillations, are concurrent and produce the maximum disturbances of the temperature and/or of the concentration fields, compared to the ideal diffusive (zero-g) situation.

The report addresses the following relevant points that help to take decisions on the suitability of implementing an isolation mount on the ISS for these categories of experiments.

a) The exact knowledge of the real ISS microgravity environments. At the moment a number of analyses (Dynamic Analysis Cycles, DAC) are being refined according to the most recent data on the operation and on the H/W existing on board the ISS. For instance the last DACs (DAC-3 and DAC-4) present completely different scenarios for the ISS microgravity environment so much that DAC-3 would justify the introduction of the ARIS that, conversely, is not justified by DAC-4 (at least for the Columbus Orbital Facility, COF) because of the marginal improvements that could be achieved.

b) The equivalence criterion between the convective disturbances caused by the residual-g existing at different locations of the ISS (mainly due to gravity gradients and to aerodynamic drag) and the relatively high frequency g-jitter caused by on board machinery and crew operations. Establishing an equivalence between these two kinds of perturbations could allow an evaluation of the relative importance of the residual-g and of the g-jitter and may provide a clear picture of the improvements that one can expect from ARIS.

c) The benefits that one could expect from the orientation of the experiment cell with respect to the residual-g and to the g-jitter. In fact properly orienting the cell may result in benefits larger than killing all the high frequency g-jitter (by ARIS) that are likely to be present on the ISS.

d) The possibility of taking advantage of the presence of the residual-g also to simulate on ground ISS experiments. In fact one is able to reproduce on ground the same convective effects that prevail in orbit due to both residual-g and g-jitters, by means of model liquids and appropriate dimensions. Experiments on ground and on the ISS have been identified that should exhibit similar behaviour.

INTRODUCTION

Over the past two years, the University of Naples has carried out for ESA a series of studies on the numerical modelling of g-jitter effects in microgravity experiments with fluid phases and densities non uniformities. The numerical simulation is performed using three-dimensional codes. Two methods for g-jitter analysis are considered: a) numerical solution of the full non-linear and time-dependent Navier-Stokes equations with a time-dependent body force that give the instantaneous time-dependent flow; b) solutions of the time-averaged field equations for the thermovibrational convection problem, obtained under the assumtion of sufficiently small amplitudes and sufficiently large frequencies of the g-jitter. These studies have indicated that vibrations in fluid systems with density gradients (induced by temperature or concentration gradients), produce an average thermovibrational force that is responsible for steady convective flows that in turn produce steady distortions of the temperature distribution, compared to the purely diffusive distribution [1-6]. These effects could be important during fluid and material science microgravity experimentation on the International Space Station (ISS), where the residual gravity is reduced by several orders of magnitude and high frequency g-jitter may be sources of disturbances. In particular, a number of computations for different study cases pointed out that the velocity field V, induced by periodic $\underline{g}$ is made up by an average value $\overline{V}$ plus a periodic oscillation of amplitude V' (V=$\overline{V}$+V', see Fig. 1a). As a result of this convective field a thermal (or concentration) distortion is induced (also formed by an averaged and an oscillatory part ($\varepsilon_T = \overline{\varepsilon_T} + \varepsilon_T{}'$, see Fig. 1b). The thermal distortion ε_T can be taken to be the difference of the total heat flow through a fluid cell (Q) and the total heat flow in a purely diffusive condition ($Q_D = k \frac{\Delta T}{L} S$). In terms of the Nusselt number (Nu=Q/Q_D), ΔNu=Nu-1=(Q- Q_D)/ Q_D represents the percentage increase of the heat flow due to the convective motions induced by the non-zero environment. Fig. 1b shows, for a typical microgravity experiment, that the relative value of $\frac{\varepsilon_T{}'}{\overline{\varepsilon_T}}$ (or equivalently of $\frac{Nu'}{\overline{Nu}}$) is sufficiently small. More specifically, in the frequency range of the ISS (f > 0.1 Hz) the average thermal (or concentration) distortion is typically much higher than the oscillatory one ($\frac{\varepsilon_T{}'}{\overline{\varepsilon_T}} << 1$).

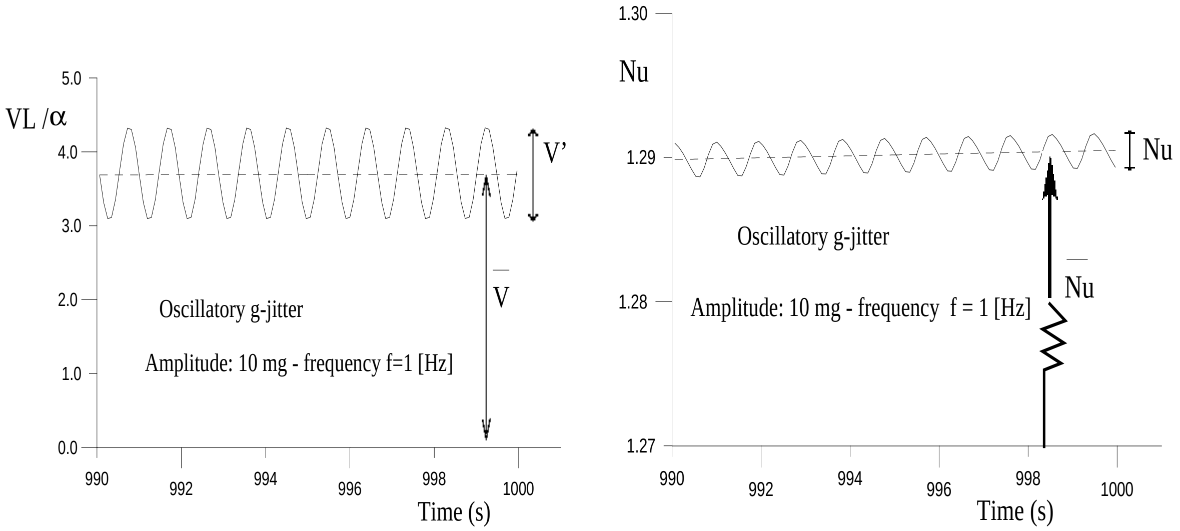


Fig. 1. Oscillatory and time-averaged distortions for a typical study case

The presence of the unavoidable residual-g on the International Space Station (ISS), that depends on the distance from the center of mass of the ISS (gravity gradient and centrifugal acceleration), may have a large impact on microgravity experiment sensitivity. In particular, the tolerability curves for g-jitter g(f), that are based upon the assumption of a reference zero-g state and of a single-frequency periodic oscillation, might be of no use if the residual-g effects are not negligible.
Based on these considerations one could ask if Isolation Mounts, like ARIS, are the best solution to mitigate acceleration effects during microgravity experiments on the International Space Station (ISS). As a matter of fact, one should consider that: 1) the g-jitter-induced disturbances depend, apart on the frequency and on the amplitude of the vibration, also on the relative directions of the

residual-g vector, of the vibration and of the density gradient; 2) for the European module COF there is a relatively large residual-g (between 1 and 2 μg) and Isolation Mounts can reduce only oscillatory g-jitters with relatively large frequency, but they reduce neither quasi-steady acceleration (due to gravity gradient and aerodynamic drag) nor large g-pulses (due e.g. to docking, meteorite impacts, ISS attitude control, etc.). This imply that the solution for COF may be not necessarily similar for the US Lab that is located rather close to the centre of mass of the ISS.

STUDY CASE FOR A TYPICAL FLUID SCIENCE EXPERIMENT

When selecting a microgravity experiment to evaluate the effects of g-jitter of the kinds that are likely to occur on the Space Station one must keep in mind the following requirements:
1) The experiment must exhibit a very high sensitivity to g-jitter (typically this occurs when the liquid medium is quiescent at 0-g); 2) Very simple experiments must be identified for which the zero-g conditions are clearly computed and for which the differences between the disturbed and undisturbed conditions are clearly quantified; 3) Easy experimental measurements of the internal TFD (e.g. two dimensional velocity and refraction index distribution) must be possible.
To fulfill the above requirements: a) the liquid must exhibit a very low value of the diffusivity to achieve Peclet number sufficiently high (even with small values of the velocities); b) a single driving force should be present (i.e. isothermal with variable concentration or single component with variable temperature); c) a one dimensional temperature or concentration distribution should be established and g-jitter direction oriented either along or orthogonal to the temperature or concentration gradients to obtain a quasi 2-D TFD field in the fluid cell.
The choice between energy and species transport experiments depends mainly on the fact that in the first case it is easy to control the boundary conditions at the hot and cold side of the cell (e.g. constant temperature walls) but it is difficult to ensure a truly adiabatic conditions at the lateral walls. Conversely, truly impermeable conditions at lateral walls conditions can be achieved in the second case, however the concentration conditions at the solid liquid interface is not easily established. Typically, in the case of species diffusion, only unsteady experimentation could be performed.
The study case extensively analyzed within the ESA contract [1, 2] deals with a fluid cell with a single-component liquid in the presence of thermal gradients (Fig. 2).

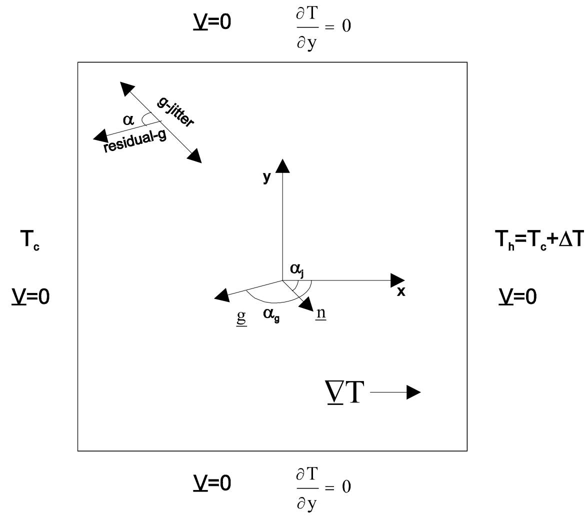


Fig. 2. Geometry of the problem and boundary conditions

A test cell with square section of side L in the plane xy is filled with a homogeneous Newtonian liquid. All the boundaries of the cavity are solid walls. The walls at x=0 and x=L are maintained at constant temperatures T_C and $T_h=T_C+\Delta T$; the other boundaries are adiabatic. A quasi-steady residual acceleration vector is present (denoted by $\underline{g}$) and, in addition, a high frequency, periodic, oscillatory acceleration is characterized by magnitude g_j and direction $\underline{n}$. In general, different relative orientations of the vibration and of the residual-g with respect to the x-axis can be considered, characterized by the angles α_j and α_g, respectively (see Fig. 2). The relative orientation between residual-g and g-jitter is characterized by the angle ($\alpha = \alpha_g - \alpha_j$). The cases α_g=0 and $\alpha_g=\pi$ correspond to $\underline{g}$ parallel or anti-parallel to the temperature gradient; the case $\alpha_g=\pi/2$ corresponds $\underline{g}$ perpendicular to the temperature gradient. In the case α=0 residual-g and g-jitter are concurrent, whereas for $\alpha=\pi/2$ the directions of $\underline{g}$ and $\underline{n}$ are perpendicular.

MICROGRAVITY ENVIRONMENT OF THE ISS

The expected disturbances on the International Space Station are:

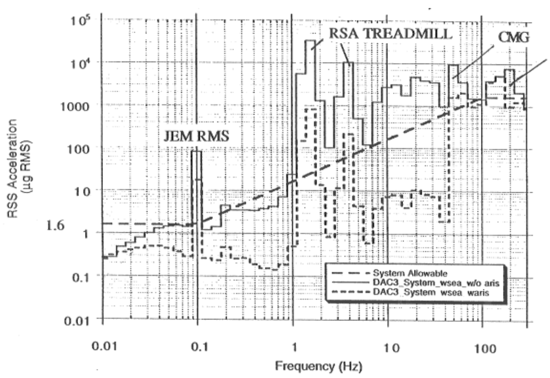
1) Steady (or quasi-steady) (residual-g). These include aerodynamic drag (1-3 10^{-7} g_o) . radiation pressure (10^{-8} g_o), micrometeorites impacts (10^{-9} g_o) and, for points distant from the center of mass, gravity gradient and rotation periodic with the orbit (1.1 x 10^{-7} g_o/[m] along x, y -3.3x10^{-7} g_o/[m] along z);

2) Pulse-like (single or compensating), due to thruster firings (10^{-4} g_o), crew activities (10^{-3}-10^{-2} g_o) or external forces (docking/berthing , of the order of 10^{-4} g_o);

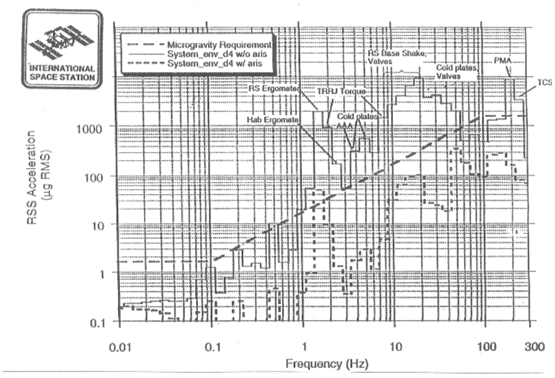
3) periodic, high frequency, due to on board machineries and natural frequencies excited by external forces ($10^{-6} < g/g_o < 10^{-2}$, 0.1 [Hz] < f <300 [Hz]).

The predicted residual-g is of the order of magnitude of 0.3 μg, for the US Lab, between 1 and 1.8 μg, for the European COF, and about 2 μg, for the Japanese module. The predicted high frequency g-jitter are usually reported in a plot of acceleration amplitudes vs. frequencies and compared with the System Allowable (so called «ISS requirements curve», see Figs. 3).

An extensive numerical experimentation has been carried out in terms of TFD distortions on the selected microgravity experiment. The computations have been performed for the ideal (zero-g) purely diffusive case and for the worst situation, in which residual-g and g-jitters are both perpendicular to density gradient ($\alpha_g=\pi/2$ and α=0), on the basis of the outputs of the NASA Design Analysis Cycles (DAC3 and DAC4, see Figs. 3).



DAC3



DAC4

Figs. 3: DAC3 and DAC4 results

All the numerical calculations correspond to steady solutions and are obtained for a Prandtl number (Pr=15) corresponding to a silicone oil with kinematic viscosity ν=1 [cs]. In the absence of acceleration disturbances (i.e. in the ideal zero-g conditions) a purely diffusive temperature distribution would be obtained at the steady state, with isotherms stratified and parallel to the walls at different temperatures. In the presence of a steady residual-g field, orthogonal to the temperature gradient, buoyancy effects induced by density differences give rise to convective flows. Fig. 4 shows the computed stream-lines and isotherms for a typical value (Rag=800) of the relevant gravitational Rayleigh number, defined as:

$$Ra_g = \frac{g\beta_T \Delta T L^3}{\nu\alpha}$$

where g is the quasi-steady acceleration, β_T the thermal expansion coefficient, ΔT the temperature difference, L the characteristic length, ν the kinematic viscosity and α the thermal diffusivity. This value corresponds, for the considered study case, to a quasi-steady acceleration of about 1 μg.

Fig. 5 and 6 show the stream-lines and the isotherms in the case of zero residual-g (corresponding to the ideal case of negligible aerodynamic drag for an experiment located in the center of mass of the Space Station), in the presence of high frequency g-jitters corresponding to the DAC3 and DAC4 predictions, respectively. The relevant dimensionless parameter in this case is the vibrational Rayleigh number defined by:

$$Ra_v = \frac{(\mathrm{b}\omega\beta_\mathrm{T}\Delta T L)^2}{2\nu\alpha}$$

where b is the displacement and ω the angular frequency.

The real cases of residual-g superimposed to g-jitters, in the presence or in the absence of ARIS, are shown in Figs. 7, 8 and 9.

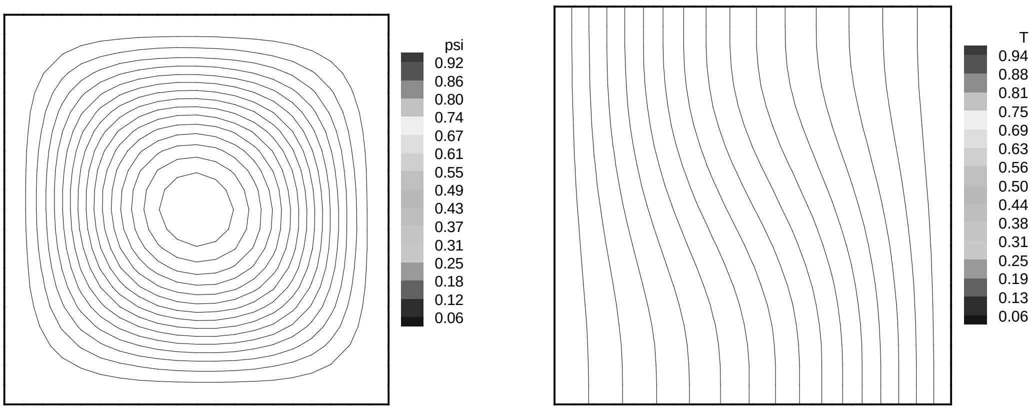


Fig. 4 Streamlines and isotherms for residual-g only (Rag = 800, Rav=0)

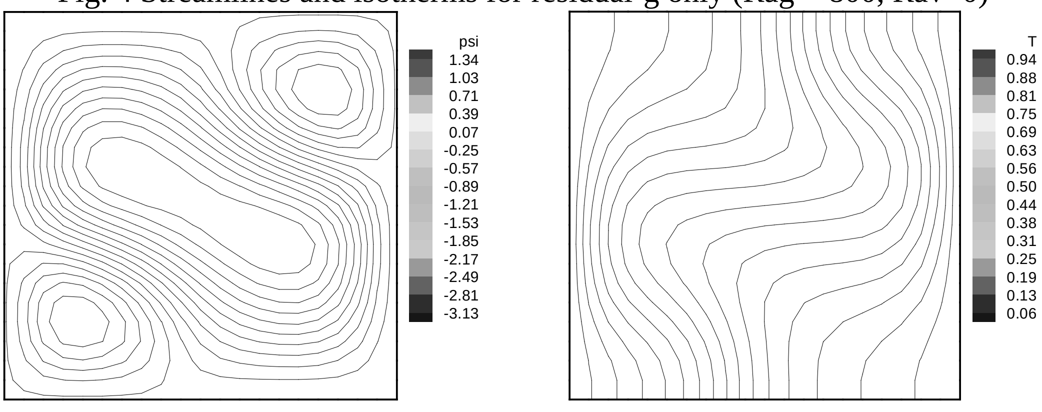


Fig.5 Streamlines and isotherms for g-jitter only, corresponding to DAC3 (Rav = 50000)

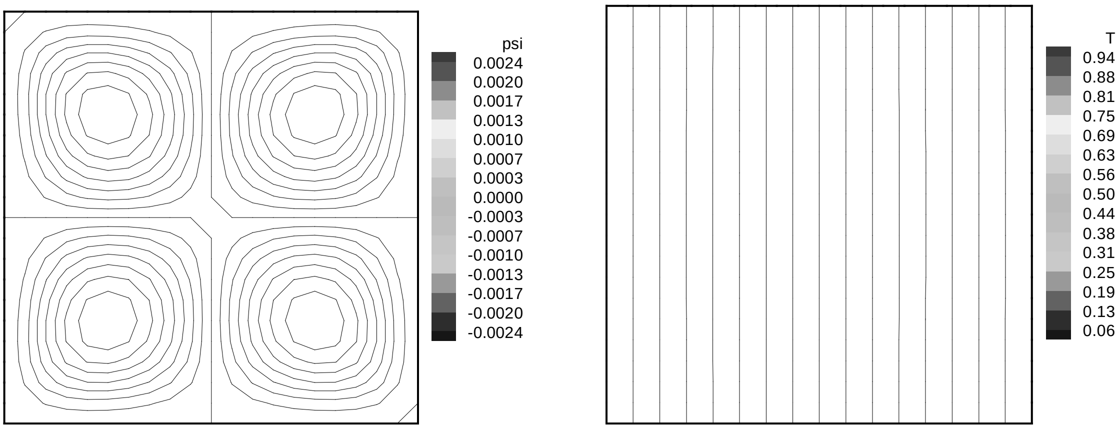


Fig. 6 Streamlines and isotherms for g-jitter only, corresponding to DAC4 (Rav = 80)

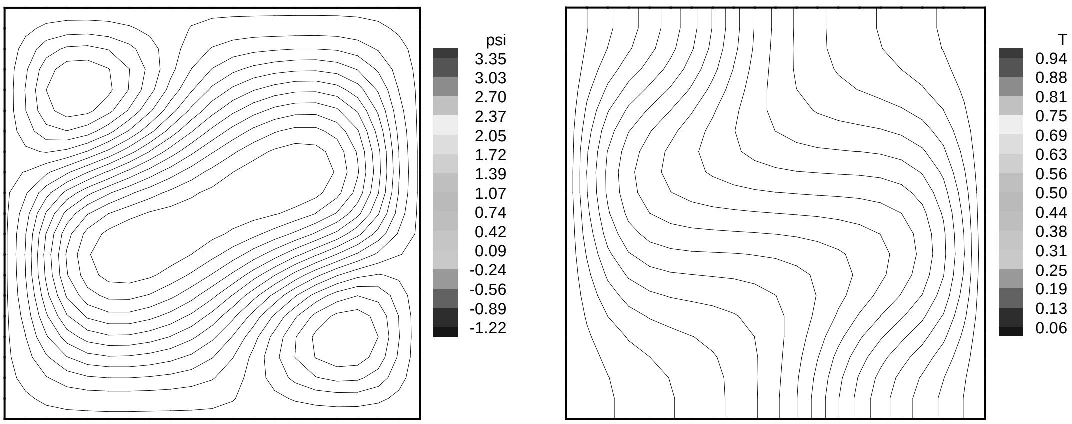


Fig. 7 Streamlines and isotherms for residual-g plus g-jitter, corresponding to DAC3 (Rag =800 Rav = 50000)

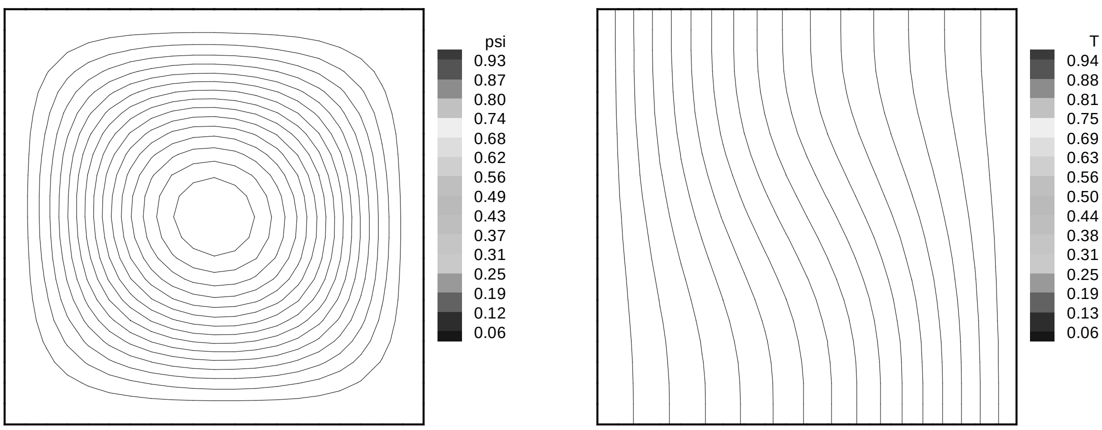


Fig. 8 Streamlines and isotherms for residual-g plus g-jitter, corresponding to DAC4 (Rag =800 Rav = 80)

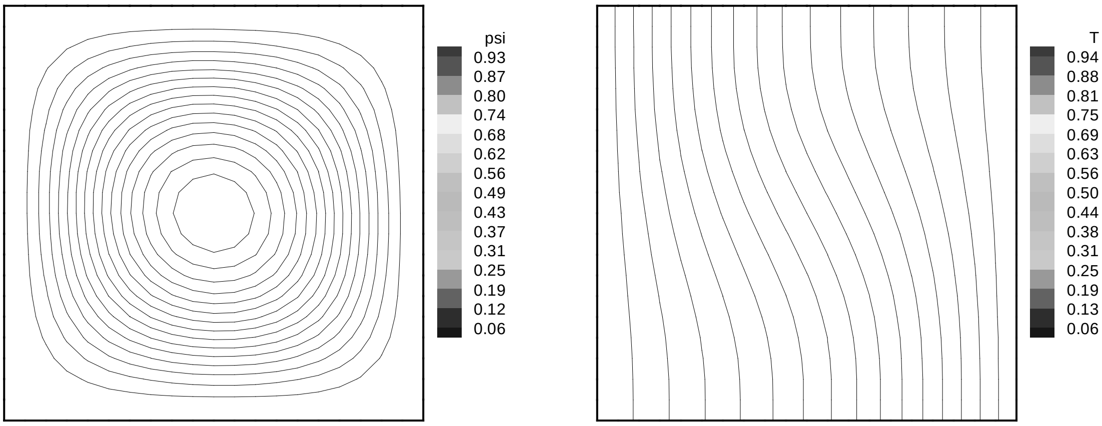


Fig. 9 Streamlines and isotherms for residual-g plus g-jitter filtered by ARIS (Rag =800 Rav =0)

Fig. 10 summarizes the computed TFD distortions, expressed in terms of differences of the computed Nusselt numbers (ΔNu), corresponding to different g-fields. This allows: 1) to check the microgravity relevance, for the selected experiment1; 2) to evaluate the distortions due to residual-g only or to g-jitter only; 3) to assess the efficiency of the ARIS Isolation Mount. For this particular case the computations show that the experiment sensitivity to g-jitter strongly depends on the vibrational accelerations predicted for the ISS. In particular, Isolation Mounts seem to be necessary if the g-jitter will be those predicted by DAC-3, but for the DAC-4 predictions g-jitter effects are negligible compared to residual-g disturbances.

Computed Field		TFD differences (ΔNu)		Comments
Ideal 0-g	$Nu_0=1$	$\Delta Nu=0$ ($Nu=1$)		Purely Diffusive Processes
Ground 1-g	$Nu_G=11.2$	$\Delta Nu_{G0} = 10.2$		Highly ideal MG relevant
Ideal MGE residual g	$Nu_R=1.092$	$\Delta Nu_{R0} = 0.092$		ISS is a Suitable MG platform
DAC3 results	DAC4 results	DAC3 results	DAC4 results	
Only G-jitter due to RS ergometer $Nu_j=2.002$	$Nu_j=1.001$	$\Delta Nu_{j0}=1.002$	$\Delta Nu_{j0}=0.001$	Experiment sensitive to G-jitter only for DAC3
Filtered G-jitter $Nu_F \simeq 1$	$Nu_F \simeq 1$	$\Delta Nu_{Fj} = 1.002$	$\Delta Nu_{Fj} \cong 0.001$	ARIS needed for DAC3
Actual MGE residual + g-jitter $Nu_A=2.098$	$Nu_A=1.092$	$\Delta Nu_{AR}=1.006$	$\Delta Nu_{AR} \cong 0$	The experiment needs ARIS in presence of special events
		$\Delta Nu_{GA}= 9.1$	$\Delta Nu_{GA}=10.1$	High actual MG relevance
Actual on ARIS $Nu_I=1.092$	$Nu_I=1.092$	$\Delta Nu_{IA} \cong 1$	$\Delta Nu_{IA} \cong 0$	ARIS needed for special events

Fig. 10 Summary of the numerical results

EQUIVALENCE CRITERION

Fig. 1 shows how, at relatively high frequencies (say f > 0.1 [Hz]), the g-jitter induce an average velocity and a periodic velocity at the same frequency of the g-jitter. It is therefore very important to “compare” high frequency g-jitter effects (that could be reduced) with those induced by residual steady state g (that exist in any case on the ISS, independend of ARIS). This comparison shows the benefits that one can expect with the use of Isolation Mounts. There are two ways in which one can make this assessment: 1) an order of magnitude analysis by looking at the time averaged of the momentum equation where the source terms are respectively of the order of the residual-g Rayleigh number (Rag) and of the vibrational (thermal) Rayleigh number (Rav); 2) numerical simulations, for different values of the Rag and Rav parameters, that allow one to evaluate the thermo-fluid-dynamic distortions in terms of ΔNu=Nu-1 (see above discussion).
Fig. 11 summarizes the results of a numerical parametric analysis for the case considered in the present study. For each value of the residual-g, reported on the y-axis (and corresponding to a specific value of the residual-g Rayleigh number, Rag), the corresponding value on the x-axis gives the “equivalent” velocity of the g-jitter g(ω)/ω (proportional to the vibrational Rayleigh number, Rav) that induces the same thermal distortion (i.e. the same value of ΔNu. In particular Fig. 11 shows that a quasi-steady acceleration of 1μg (that corresponds to a value of ΔNu of about 0.13) is equivalent to a periodic g-jitter with g(ω)/ω =1.5[mg x s]. This value is below the peak corresponding to the RS Treadmill in the DAC3 (g(ω)/ω= 3.3 mg x s]) but well above the typical values of the high frequency g-jitter corresponding to the DAC4 predictions (g(ω)/ω=0.4 mg x s]). Therefore, the equivalence criterion confirms the results of the computations discussed above and shows that the distortions induced by high frequency g-jitter (that could be reduced by Isolation Mounts) are of the same order of magnitude or larger than those induced by residual-g only for the accelerations predicted by DAC-3; more specifically DAC-4 g-jitters are equivalent to a residual-g of abotu 0.1 μg and DAC3 correspond to a residual-g of about 5.5 μg.

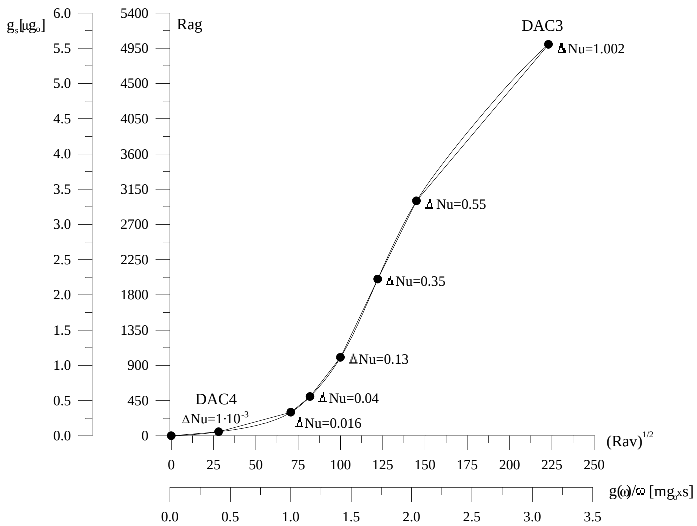


Fig. 11 Equivalence between residual-g and high frequency g-jitter

FACILITY ORIENTATION

Many authors pointed out that convection due to quasi-steady residual acceleration during microgravity experiments could be minimized by suitable alignment of the residual-g vector with the direction of the density gradient (e.g. with the direction of the ampoule centerline for directional solidification experiments). Recent numerical studies have shown that quasi-steady residual-g and oscillatory g-jitter may be beneficial to approach pure diffusion conditions, if density gradients are

in the same direction of the acceleration direction [3]. The effect of high frequency vibrations, like that of quasi-steady acceleration, strongly depends on the direction of the vibration relative to the density gradient. In particular, it was pointed out in [6] that vibrations parallel to the density gradient tend to stabilize the purely diffusive regime, damping any residual convection due, e.g., to a destabilizing residual-gravity vector orthogonal to $\nabla\rho$. The above considerations suggest to focus the attention on possible experiment orientation, in order to minimize thermo-fluid-dynamic distortions due both to residual-g and g-jitters on the Space Station.
The effect of the facility orientation has been investigated for the same study case considered in the previous Section, consisting in a test cell bounded by rigid walls, completely filled with liquid, in the presence of a prescribed temperature difference. Although the quantitative results presented here are restricted to this particular study case, conclusions could be extended to different classes of microgravity experiments (e.g. Bridgman crystal growth, directional solidification, diffusion or thermodiffusion measurements experiments) in which the temperature or the concentration gradient direction is well defined, and for which the facility orientation can be properly changed to reduce undesirable convection disturbances.

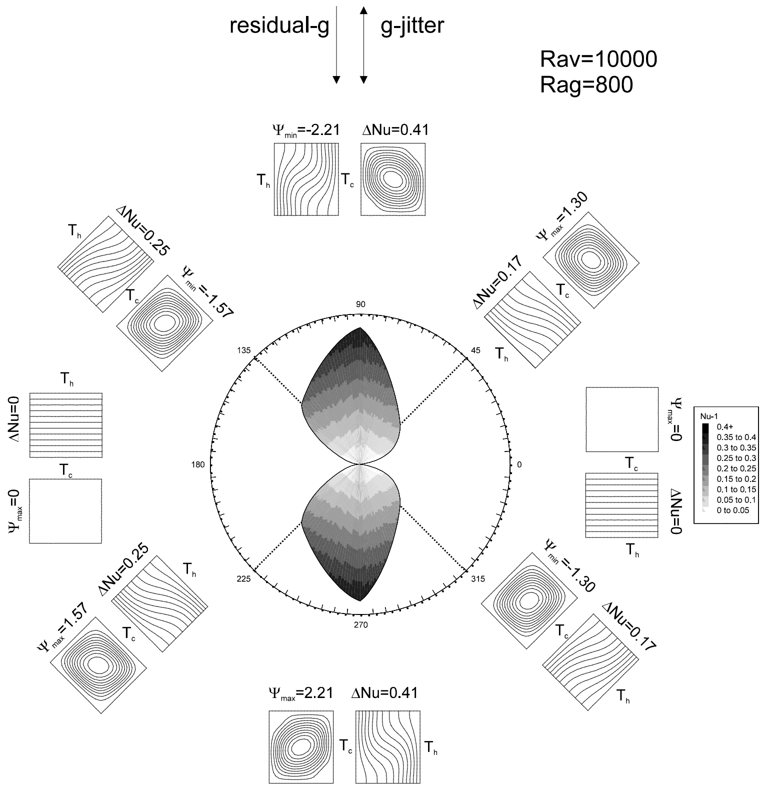


Fig. 12 Numerical results obtained changing the facility orientation.

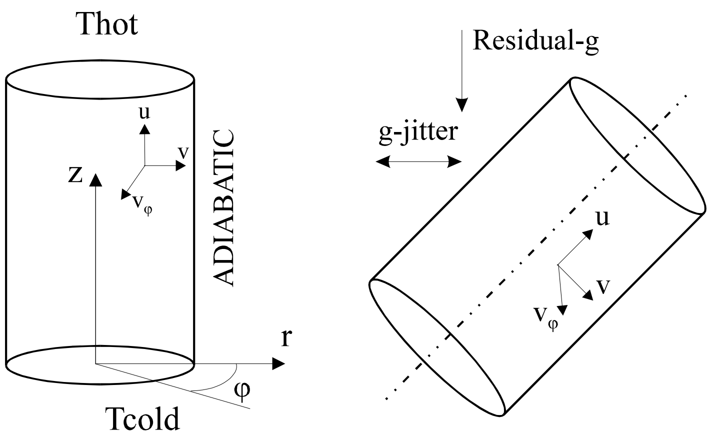
The results of an extensive numerical experimentation obtained for all possible orientations of the residual-g and g-jitter, with respect to the density gradient, are reported in [6] (see e.g. Fig. 12, relative to the case of residual-g and g-jitter both acting along the same direction). In particular, the numerical computations show that, in the absence of g-jitter, when the residual-g is opposite to $\underline{\nabla\rho}$ the residual-g has no effect (does not induce convective flows) for any value of its magnitude; when the residual-g is concurrent to $\underline{\nabla\rho}$ then TFD distortions arise only if the critical conditions for the onset of convection are exceeded (i.e. if the Rayleigh number is larger than the critical one, so that instability sets in). Finally, when the residual-g is orthogonal to $\underline{\nabla\rho}$ then TFD distortions arise for any value of the residual-g (and are somehow proportional to the Rayleigh number).

Similarly, the effect of high frequency vibrations strongly depends on the direction of the vibration relative to the density gradient. In particular, vibrations parallel to the density gradient tend to stabilize the purely diffusive regime, damping any residual convection due, e.g., to a destabilizing residual-gravity vector orthogonal to $\nabla\rho$. The above considerations suggest to change the facility orientation as a solution alternative to passive or active isolation devices, in order to minimize g-disturbances during microgravity experiments. In particular, for the typical study case considered in the present study, the numerical results indicate that, for the different possible configurations, corresponding to different relative orientations between residual-g and g-jitter, one shoud be able to properly orient the experiment to minimize the convection disturbances.

NUMERICAL AND EXPERIMENTAL STUDY FOR THE COMPARISON BETWEEN ARIS AND FACILITY ORIENTATION

The presence of a fixed residual-g axis on the ISS allows a possible simulation on ground (i.e. in the presence of the gravity field) of the ISS conditions by scaling laws. Two experiments on the ISS and on ground have been designed for the evaluation of residual-g and g-jitter effects and for the study of the facility orientation. The two experiments are characterized by the same "steady acceleration" Rayleigh number and by the same "periodic disturbances" vibrational Rayleigh number. For the ISS microgravity experiment a cylindrical enclosure having length equal to the diameter (L=D=10[cm]) is considered (see Figs.13). The liquid employed is silicone oil having viscosity 1 [cs]. The applied temperature difference is $\Delta T=50$ [K], for the residual g a typical value of g/go= 1.6 x 10^{-6} is considered, corresponding to the averaged value of the quasi-steady acceleration in the European COF. This corresponds to a value of the gravitational Rayleigh number of $Ra_g=12000$. For the g-jitter the typical amplitudes and frequencies corresponding to the NASA DAC-4 predictions are considered, giving a corresponding vibrational rayleigh number $Ra_V=300$.

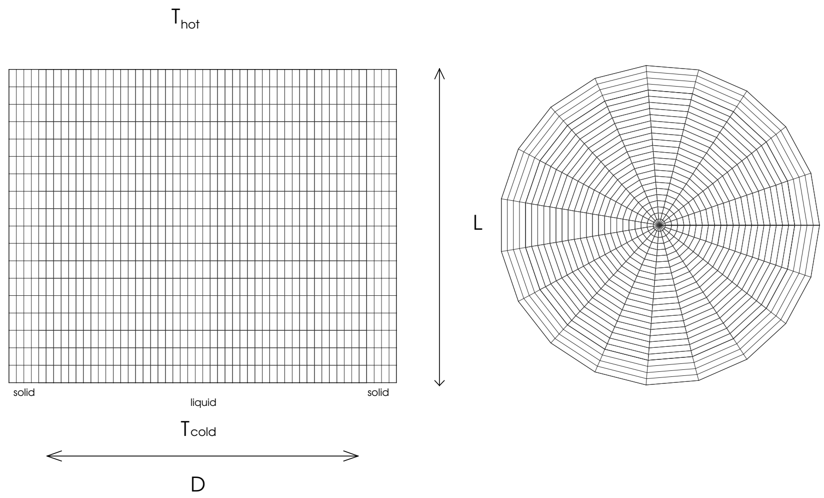
For the on ground experiment (g=go) scaling laws have been applied in order to realize the same gravitational and vibrational Rayleigh numbers of the ISS experiment. The length and diameter are L= D= 2 [cm], the viscosity of the silicone oil is 1000 [cs] and $\Delta T=10$ [K].



Figs. 13. Sketch of the cylindrical enclosure and of the "driving forces"

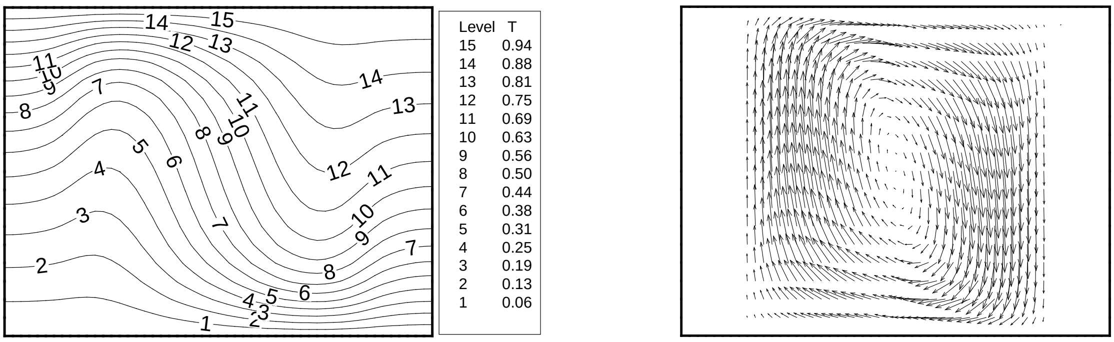
Preliminary three-dimensional numerical simulations of these experiments have been performed. Figs. 14 show the computational grids used for the numerical computations.

Figs. 15, 16 and 17 show the numerical results for the ISS experiment corresponding to the “worst case” (i.e. residual g and the g-jitter both orthogonal to the density gradient).
Fig. 15 shows that the temperature field is strongly deformed, with respect to the diffusive situation (i.e. absence of convective driving forces), due to the convective cell arising in the meridian section φ=0 (where the gravity vector and the g-jitter apply) (Fig. 15b).

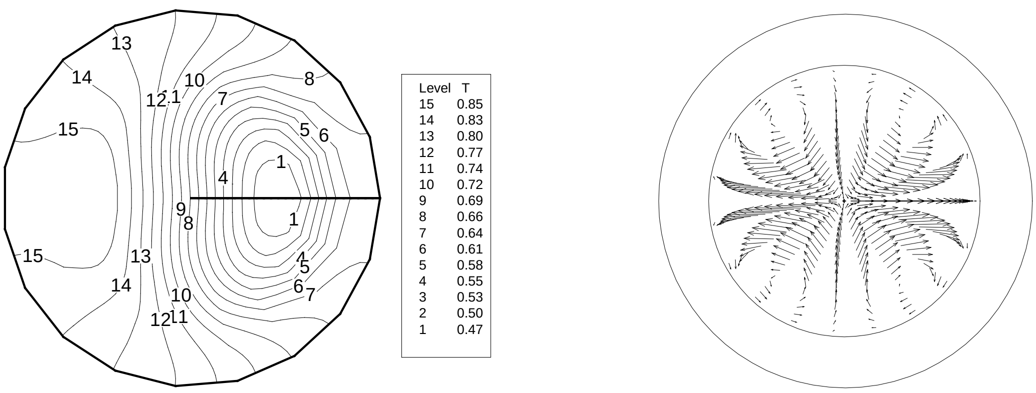


Figs. 14. Computational grid employed for the 3D numerical computations

WORST CASE WITHOUT ARIS



Figs. 15. Temperature and velocity field in the section φ=0



Figs. 16. Temperature and velocity field in the section z=0.75, for the case of Fig. 15.

Fig. 17 illustrates the distribution of the local Nusselt number on the hot disk. In the purely diffusive situation this parameter would be, by definition, Nu=1.

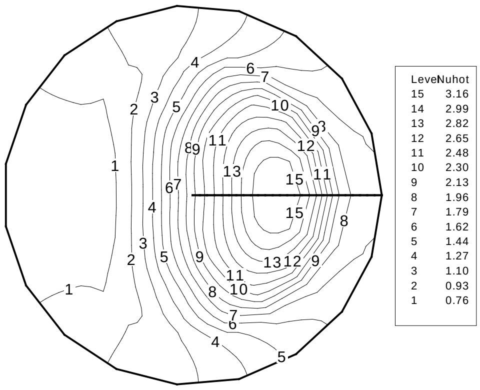


Fig. 17. Distribution of the Nusselt number on the hot disk, for the case of Fig. 15.

Due to the presence of the buoyancy and thermovibrational convection induced by the residual g and by the g-jitter the Nusselt number is locally increased or decreased. When the facility is properly oriented with the density gradient parallel to the residual-g vector and the ARIS is applied (Figs. 18-21) the thermo-fluid-dynamic field is very close to the diffusive situation. ARIS in fact reduces the g-jitter whereas residual g is stabilizing by the facility orientation (fluid cell heated from above). Other situation have been considered, e.g, the facility properly oriented without ARIS, and the g-jitter reduced by ARIS without facility orientation. The results obtained in the different situation are summarized in Figs. 21.

FACILITY ORIENTED WITH ARIS

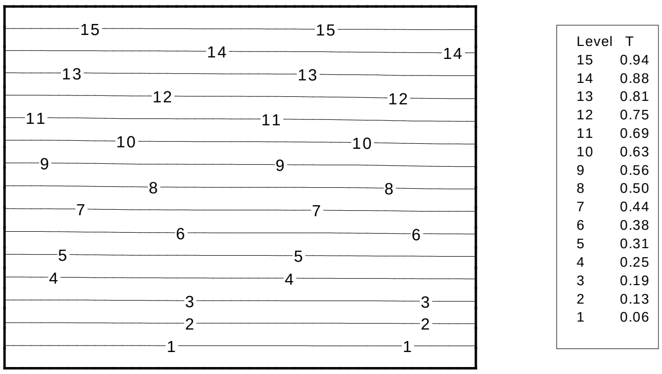
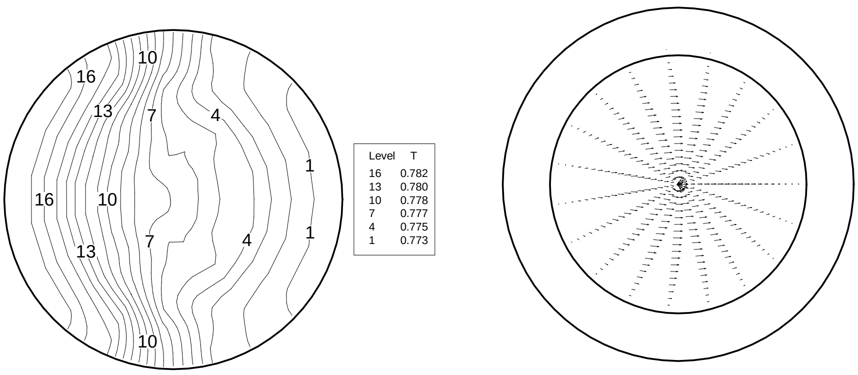


Fig. 18. Temperature field in the section φ=0



Figs. 19. Temperature and velocity field in the section z=0.75, for the case of Fig. 18.

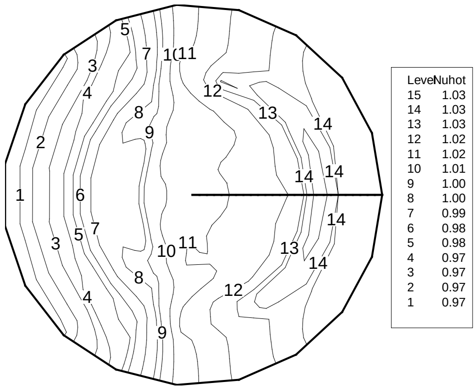
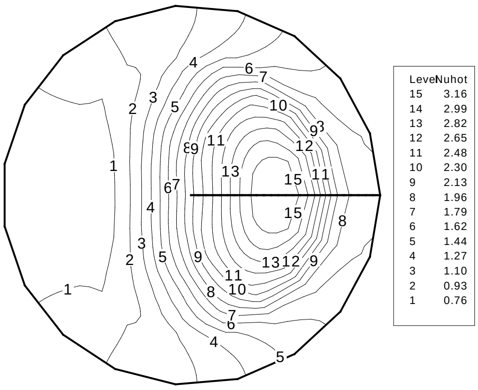
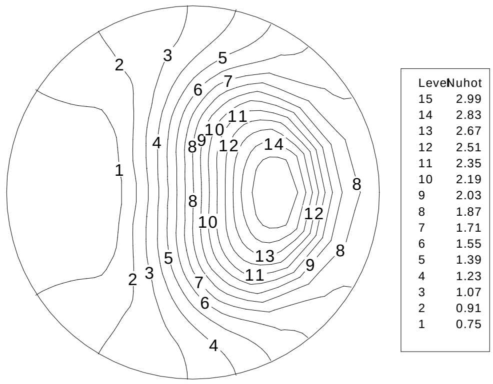


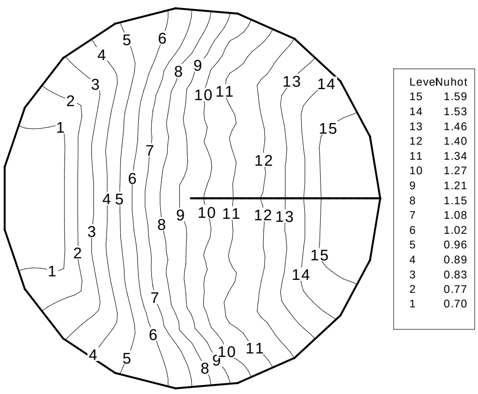
Fig. 20. Distribution of the Nusselt number on the hot disk, for the case of Fig. 18.



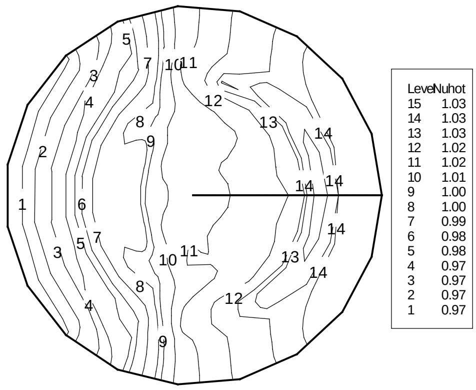
WORST CASE WITHOUT ARIS



WORST CASE WITH ARIS



BEST CASE (FACILITY ORIENTED) WITHOUT ARIS



BEST CASE (FACILITY ORIENTED WITH ARIS

Fig. 21. Nusselt number on the hot disk for different situations

CONCLUSIONS

The overall conclusions from the above presented numerical experimentations are summarized in Fig. 22. To give an idea of the transition times between different steady state microgravity conditions Fig. 22 shows the value of the Nusselt number time profile on the hot disk starting from the worst case conditions in the absence of any g-jitter (worst case with ARIS) at which the value of Nu=1.63. From these conditions one can follow different paths by: a) shuting-off the ARIS (upper curve); b) orienting the test cell without ARIS and c) orienting the test cell with ARIS.
The TFD distortions are only partially reduced by the ARIS (in the worst situation, corresponding to both residual-g and g-jitter, the average Nusselt number is 1.8).
Orienting the facility without ARIS, the average Nusselt number is decreased to 1.2. this means that, at least for COF, where the residual-g is sufficiently large, the facility orientation improves the diffusive conditions more than the ARIS. Using both experiment orientation and ARIS, a purely diffusive situation is established and the Nusselt number Nu becomes almost unitary.

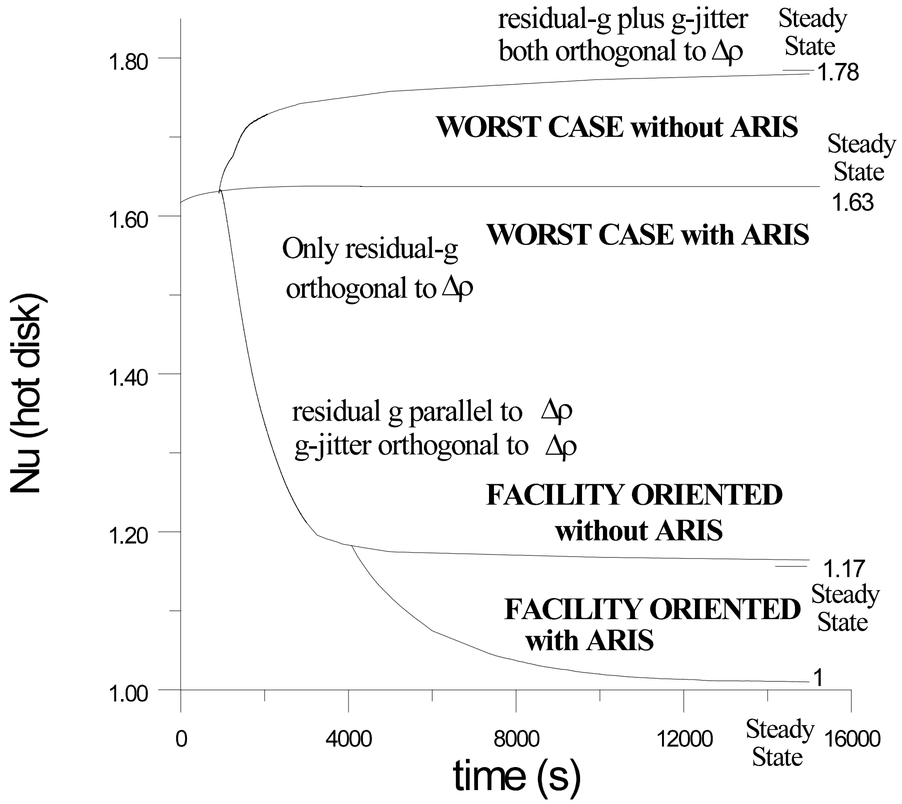


Fig. 22. Summary of the numerical results

All the numerical results presented so far need an experimental check both on ground and on board a microgravity platform. On ground activities are in progress for the measurement of Nusselt numbers in cylindrical enclosures filled with liquid in presence of temperature differences, changing the experiment orientation with respect to the steady and to the periodic acceleration vectors. Objectives of these experiments are: 1) correlation of experimental results with numerical results obtained by three dimensional CFD codes; 2) simulations of flight experiments taking into account the typical microgravity conditions on the ISS; 3) numerical computations for the comparison between effects of ARIS and of the facility orientation.

Acknowledgments

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REFERENCES

[1] R. Monti, R. Savino, "Study on g-jitter for the evaluation of tolerability limits". *ESA Final Report N. 22054/94/F/FL* (June 1995)

[2] R. Monti, R. Savino, "Study on g-jitter for the evaluation of tolerability limits". *ESA Final Report N. 11597/95/F/FL* (December 1997)

[3] R. Monti, R. Savino, "Influence of g-jitter on fluid physics experimentation on-board the International Space Station". *ESA SP-385*, 215-224 (1996).

[4] R. Monti, R. Savino, "A new approach to g-level tolerability for Fluid and Material Science experiments". *Acta Astronautica* 37, 313-331 (1994)

[5] R. Monti, R. Savino, G. Alterio, "Modelling and simulation of g-jitter effects on fluid science experimentation. Impact on the utilization of ISS". Paper IAF-96-J.2.03. In course of publication on *Acta Astronautica*

[6] R. Savino, R. Monti, "Improving diffusion-controlled microgravity experiments by facility orientation". *In course of publication* (1998)