# A SYSTEM FOR MEASUREMENT OF CONVECTION ABOARD SPACE STATION

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## ABSTRACT

A simple device for direct measurement of buoyancy driven fluid flows in a low-gravity environment is proposed. A system connecting spacecraft accelerometers data and results of thermal convection in enclosure measurements and numerical simulations is developed. This system will permit also to evaluate the low frequency microacceleration component. The goal of the paper is to present objectives and current results of ground-based experimental and numerical modeling of this convection detector.

## INTRODUCTION

Estimations based on theoretical studies and terrestrial experiments show that the spacecraft acceleration level is sufficiently high in order to induce the buoyancy- driven convection and to influence the heat- and mass transfer processes ( refs. 1 and 2 ). At present the existence of buoyancy- driven motions in low-gravity environment can be judged only from indirect indications because there have been few space flight experiments with the objective of directly and quantitatively measuring the effect of this convection and conclusions of the experiments contradict one another. Accordingly, it is desirable to conduct a simple experiment to detect and investigate the buoyant convection phenomenon directly in orbit.

On the other hand, the gravitational and inertial sensitivity of flows in nonisothermal liquid and gaseous mediums makes it possible to propose a method of measuring the microaccelerations aboard a spacecraft based on recording the temperature stratification due to buoyant convection (refs. 1 and 2 ). Especially promising is the utilization of a convection detector to measure the magnitude and direction of the low- frequency components of a force field inaccessible to most other instruments currently in use.

A possibility of detecting weak convection based on observing the propagation of a thermal front between coaxial cylinders was considered in ( refs. 3 and 4 ). The justification of the method and preliminary results of a laboratory and numerical simulation of the motions in a cubic enclosure were presented in ( refs. 5 and 6 ). The modern opinion at the concept, design and testing of the convective sensor is described below.

## EXPERIMENTAL APPARATUS AND PROCEDURES

Figure 1 shows a sketch of the cell module. In order to reduce the influence of the cavity corners and to simplify a structure of the motion, especially in the case of pendulum swinging of the sensor, it was solved to use the convective chamber in the form of a circular cylinder instead of cubic one. The 45.4 mm diameter ×45.0 mm height test container consisted of two parallel flat aluminium plates separated by an annular plastic wall. An air was used as the working fluid. The left hot plate was resistively heated and the right cold plate was fan air cooled. Sealing and thermal insulation were used to minimize the influence of surrounding atmosphere pressure, composition and temperature changes. The temperature difference $\Delta T$ between hot and cold enclosure bounds was measured by thermocouple junctions embedded into the heat exchangers. The junctions of a second differential thermocouple placed within the cavity at a 10 mm distance from the heater and side wall measured the temperature deviations $\Delta t$ from thermal diffusion profiles, i. e. , identified convection.

Figure 2 shows the nondimentional intensity of convection $\Theta=\Delta t/\Delta T$ as a function of Rayleigh number $Ra=g\beta\Delta TH^3/\nu\chi$. Here , $\beta$, $\nu$ and $\chi$ are the coefficients of thermal expansion, kinematic viscosity and thermal diffusivity, H is the cell diameter and g is the gravity acceleration. For small values of Ra a linear relationship $\Theta=a\,Ra + b$ may be obtained, where $a=(1.2 \pm 0.2)\times 10^{-4}$ and $b=(5.8 \pm 0.4)\times 10^{-4}$ . This formula permits to estimate the threshold of sensitivity of testing sensor in weightlessness. For temperature difference $\Delta T = 50°C$ the minimum measured acceleration can be equal to $(3.5 \pm 0.4)\times 10^{-6}\, g_o$ , where $g_o$ is terrestrial gravity.

## THEORETICAL ANALYSIS AND MODELING

Last time the computer laboratory COMGA for analysis of convectional processes in a weightlessness environment is developed including widespread class of gravity and non-gravity motive forces in one- and two component mediums and taking into consideration the complicated spatial-temporal changes of microaccelerations ( ref. 7 ). This laboratory contains the specially worked out interface for analysis both the real tape-records of spacecraft microaccelerometers and the results of numerical simulations taking into account the space station characteristics and the dynamics of its flight ( ref. 8 ).

Figure 3 shows an example of time evolution of a low-frequency part of microaccelerations along one of the coordinate axes (x) calculated from the initial acceleration data of the Orbital Complex " Mir " with the method described in ( ref. 8 ).

Figure 4 illustrates the behavior of the liquid temperature found on the base of two dimensional COMGA model for the quasi-static microgravity environment represented in figure 3. The case of 10 cm characteristic size, 50 °C temperature difference applied and ethanol as a testing fluid is considered. The amplitude of fluid temperature oscillations in this realization reaches 8 °C. This result demonstrates the gravitational sensitivity of the described system and the possibility of determination of low- frequency accelerations through the fluid motion response (ref. 2 ).

Figure 5 shows the instantaneous pictures of flow and temperature fields obtained with the help of discussed computer laboratory. At the same time the momentary direction and value of microacceleration vector and the magnitudes of velocity and temperature for one of the cavity points are shown at the interface screen. This results are corresponding also to the parameters refereed in figures 4 and 5. An example of computation of thermal convection in melting semiconductor using the accelerations data obtained by setup SAMS onboard Space Shuttle is given in ( ref. 8 ).

For modeling described experiments we used the Navier-Stokes equations in the Boussinesq approximation in the right-handed coordinate system xyz related to the enclosure, which moves with angular velocity $\Omega(\tau)$ about the fixed axis. In this coordinate system the axis of rotation is parallel to the z axis and is given by the equations $x=x_o$ and $y=y_o$:

$$\rho\left(\frac{\partial V}{\partial \tau} + (V\nabla)V - 2(V \times \Omega)\right) = -\nabla p + \mu\Delta V + \rho(g(\tau) - \Omega \times (\Omega \times r') - \dot{\Omega} \times r')$$

$$\frac{\partial T}{\partial \tau} + (V\nabla)T = \chi\Delta T$$

$$\text{div} V = 0$$

where $\rho$ is the density, V is the velocity , p is the pressure, r' is the radius vector connecting the axis of rotation with a certain point inside the enclosure, $r'=(x', y')=r-r_0$, $r=(x, y)$, $r_0=(x_0, y_0)$, $\dot{\Omega}$ is the angular acceleration, and $g(\tau)$ is the acceleration of gravity vector.

On all-the walls boundary conditions for the velocity are the no-slip ones. The temperature on the cold boundary of the enclosure was assumed to be equal to 20°C, and the temperature on the heated boundary was made constant on the interval 24-80°C. On the side faces of the enclosure for the temperature we consider either adiabatic conditions or a linear profile.

The results presented here were obtained by the finite-difference method using $17\times17$ and $33\times33$ grids. Some control calculations were also made by the finite-difference method in the two-dimensional and three-dimensional cases for a constant angle of inclination of the chamber using $33\times33$ and $15\times15$ grids. Test calculations on various grids using different methods showed that acceptable accuracy ( within 5% with respect to temperature and 10% with respect to velocity ) can be achieved using a $17\times17$ grid, and this grid was adopted for main calculations.

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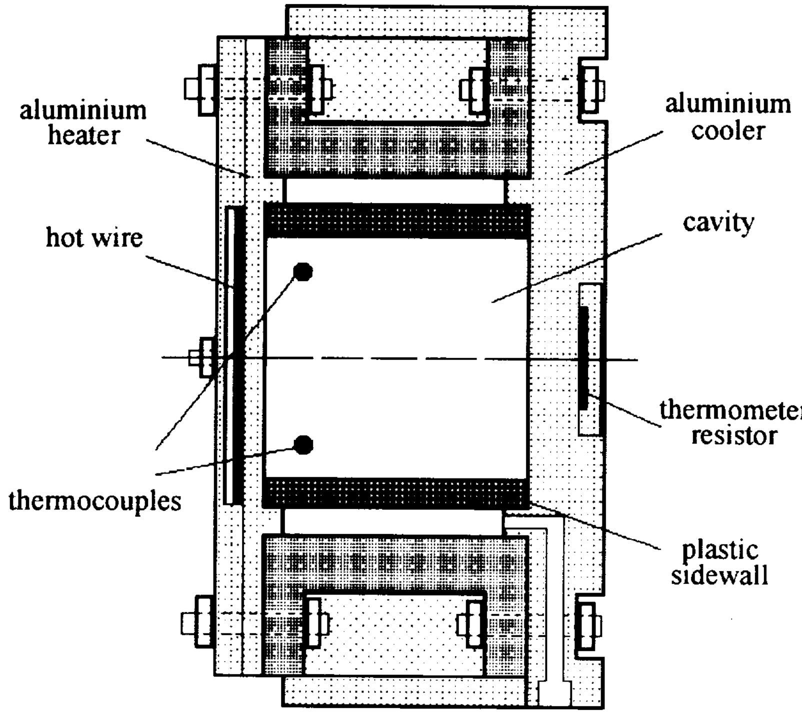


Figure 1.- Schematic of the test enclosure.

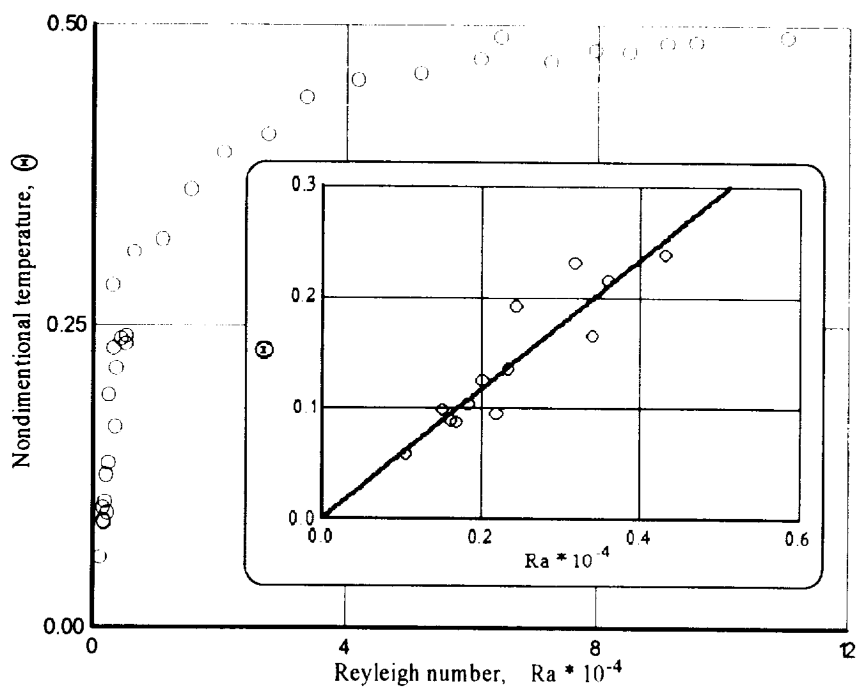


Figure 2.- Plot of the intensity of convection of air versus Rayleigh number.

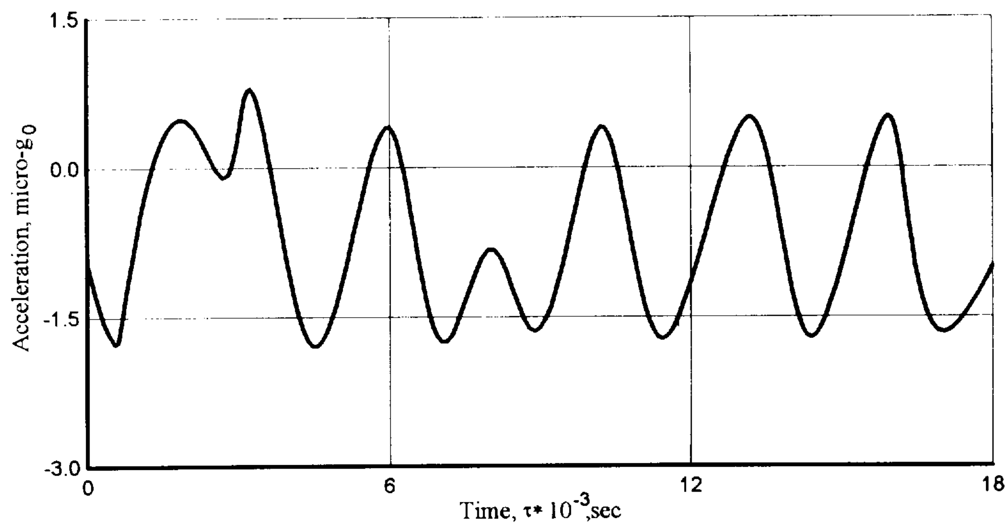

Figure 3.- Time variation of computed quasi-static microacceleration component.

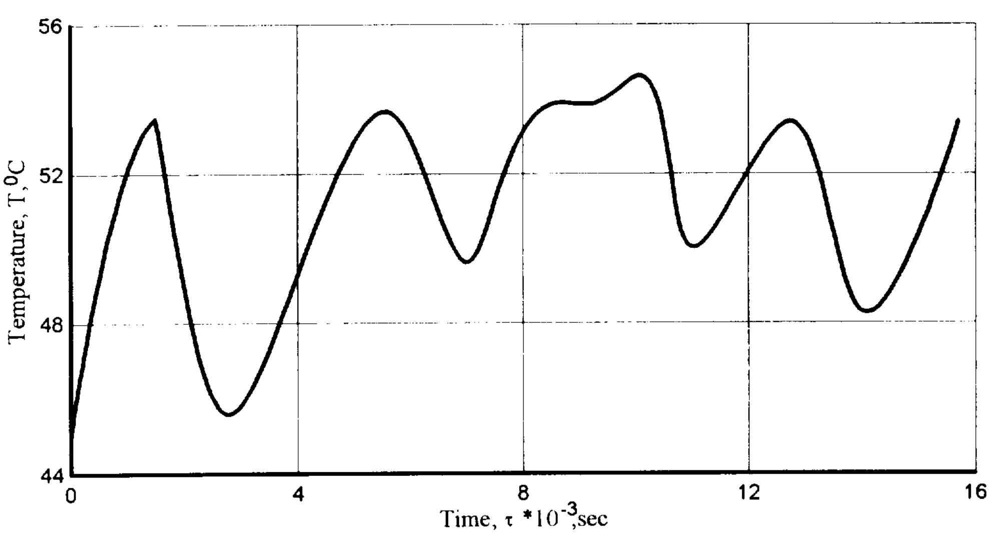


Figure 4.- Computed temperature time variation in the cell.

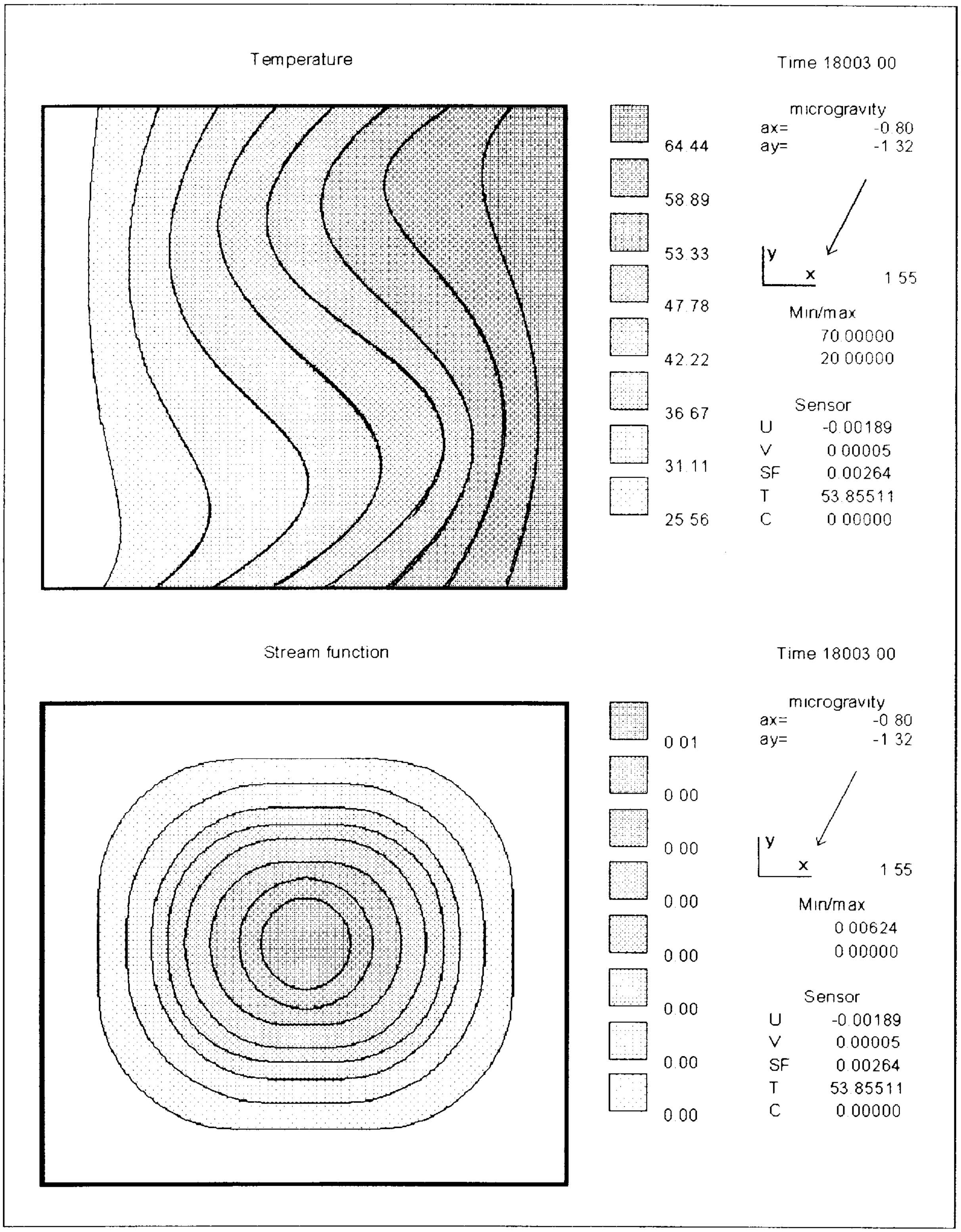


Figure 5.- Temperature and flow fields in a cell heated from the right side.

# Experimental Techniques