Thermal convection induced by g-jitter in space environment

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Abstract. The article discusses thermal convection in an enclosure induced by spacecraft vibrations (g-jitter). Two theoretical investigations are described. The conclusions are that if the g-jitter is decomposed into a time-mean part and an oscillatory part, the mean part is more important than the oscillatory part, in determining the flow field and heat transfer rate. Under normal circumstances (no manoeuvres, no intentional spinning of the spacecraft) the g-jitter generates predominantly oscillatory velocity and temperature fields with zero time-mean values. The g-jitter can also generate secondary flows with non-zero mean but they are of much smaller order. Some implications of the g-jitter on materials processing in space are also discussed.

Keywords. g-jitter convection ; flows generated ; space processing;

1. Introduction

One of the primary objectives foreseen for processing materials in space is the reduction of natural convection associated with earth's gravity. However there have been some indications (Grodzka et al 1971; Bannister et al 1973) that spacecraft vibrations might cause appreciable thermal convection. Such convection may be important in fluids experiments and also affect the quality of crystals grown in space. Some indications of the effects of g-jitter on convection can be obtained by related research (Richardson 1967; Pek et al 1970; Gershuni et al 1970). It was found that vibrations can either substantially enhance or retard local heat transfer, significantly increase total heat transfer and drastically affect convection by altering the transitions from quiescent to laminar flow (critical Rayleigh number) and from laminar to turbulent flow. More detailed discussion of related work is presented in Spradley et al (1975).

This phenomenon merits special consideration not only because it represents a convection mode that is suppressed under normal gravitational conditions and which is significant at reduced gravity but also because it is inherent in all spacecraft environments and cannot, therefore, be easily controlled. Therefore to study the effectiveness of spacecraft vibrations in generating fluid flows, the present article discusses two theoretical investigations of a case in which a fluid-filled container with differentially heated walls is subjected to spacecraft vibrations. The article is divided into three parts.
(i) Brief discussion of numerical analysis for various geometric configuration by Spradley et al (1975) and by Forbes (1968) to evaluate effects of g-jitter on fluid motion.

(ii) Comprehensive theoretical study by the author and his co-workers (Kamotani et al 1980) of effects of g-jitter on a fluid filled container with differentially heated walls, in an orbiting spacecraft. The derivation in this part has been reproduced from that given in Kamotani et al (1980).

(iii) Implications of g-jitter for materials processing in space.

2. Numerical analysis

In this work (Spradley et al 1975) specific consideration was given to models for evaluating g-jitter effects and they are summarised in this part. These are shown in figure 1 and are a rectangle heated from the side, one heated from below, and a cylinder heated from below. Mercury, helium, and water were chosen as the fluids to span the Prandtl number range from $10^{-2}$ to 10. Three representative types of g-jitter (see figure 2) were investigated. Numerical solutions of the boundary-value problem were obtained and the results are shown in figures 3 and 4. Isotherms are presented in figure 3 for three cases: (i) rectangular box of water heated from the side, (ii) rectangular box of water heated from below, and (iii) cylindrical container of mercury heated from below. The constant $g$ solutions are for $10^{-3} g$ and the saw tooth g-jitter model is used with the minimum $g$ level being $10^{-3}$, the amplitude of $g$ variations is $10^{-3}$, and the period is 1 sec. The wall temperatures for the rectangular configurations were 95° C and 25° C with the other walls adiabatic. The 80° C isotherm in figure 3a is seen to be located farther into the water for the g-jitter case than for constant $g$ and the basic shape is the same. The 80° C isotherm in figure 3b has penetrated somewhat farther for g-jitter case. Thus, the g-jitter is shown to influence the temperature distribution significantly.

![Figure 1](image-url)