

Simulation of Geophysical Fluid Flows under Microgravity (GeoFlow): Flow diagnostics and experiment concept for Fluid Science experiments

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Abstract

This preliminary description has been prepared in order to identify and to describe the scientific, technical as well as the measurement concept of the GeoFlow-experiment to be integrated 2004 in the Experiment Container (EC) of the Fluid Science Laboratory (FSL) on the International Space Station (ISS). The FSL is a multi-user facility for conducting fluid physics research in microgravity conditions as illustrated in figure 1. In this paper we focus on a short description of the following topics:

- Scientific Objectives of the GeoFlow-experiment
- Experiment concept
- Operational Scenario
- Measurement concept and technical description

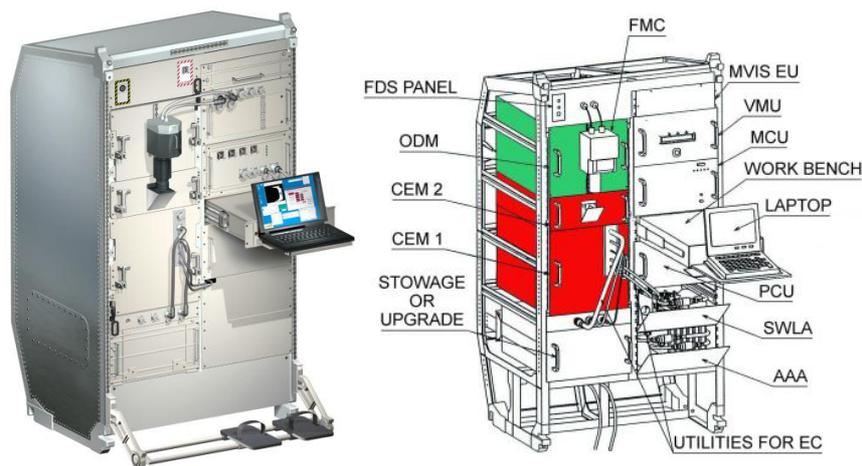


Figure 1: Fluid Science Laboratory flight configuration and its subsystems and equipment

The scientific equipment of the facility is contained in the Facility Core Equipment (FCE), that hosts the Experiment Container (EC), its interfaces and all the dedicated flow diagnostics modules. The EC houses the fluid cell and all the equipment assigned to the experiment itself. This part is completely experiment dependent. The EC is hosted inside and supported by a module called Central Experiment Module 1 (CEM1), providing all the needed interfacing to the EC, and supporting part of the FSL optical equipment and microgravity measurement.

1 Scientific Objectives of the GeoFlow-experiment

The „GeoFlow“ is an ESA (AO 990049) experiment under the scientific coordination (PI) of the Department of Aerodynamics and Fluidmechanics (LAS) at the Brandenburg Technical University (BTU) of Cottbus, Germany. The objective of the experiment is to study the thermal convection in the gap between two concentric rotating (full) spheres as illustrated in figure 2. A central symmetric force field similar to the gravity field acting on planets can be produced by applying a high voltage between inner and outer sphere using the dielectrophoretic effect (rotating capacitor). To counter the unidirectional gravity under terrestrial conditions, this experiment requires a microgravity environment. The requirement to the microgravity level of the experiment is about 10^{-2} g at frequencies greater than 0.5 Hz and 10^{-3} at frequencies below 0.5 Hz. The parameters of the experiment are chosen in analogy to the thermal convective motions in the outer core of the Earth. In analogy to geophysical motions in the Earth's liquid core the experiment can rotate as solid body as well as differential (inner to outer). Thermal convection is produced by heating the inner sphere and cooling the outer ones. To investigate the influence of friction on the fluid motion, silicone oils with different viscosities are foreseen as working fluids in the whole spherical shell system (inclusive heating/cooling loops). Furtheron, the variation of radius ratio between inner and outer sphere is foreseen as a parameter variation. The flows to be investigated will strongly depend on the width of the gap, i.e. small or large gaps. While the outer spherical glass shell system has an fixed outer diameter, this will be realized by varying the size of inner sphere.

The main part of the experiment is the rotating spherical gap cell, filled with fluid (silicone oil: type Baysilone, with different viscosities). The flows are visualized by the means of a Wollasten Shearing interferometer (FSL), which is adopted to the spherical geometry of the cell by an adaption optical system containing different lenses. This adaption optic is non-rotating. The Wollasten Shearing interferometer works in a backscattering mode, i.e. the inner sphere acts as a mirror. On the container side this adaption optics comes in/out with a parallel beam. A digital camera (of the FSL) is used to take the interferometric pictures.

2 Experiment concept

The experimental set-up is performed to investigate the problems of thermal convection in the fluid shell between two concentric half-spheres with and without rotation, and also with differentially rotating spheres (around the same axis). A central symmetric force field similar to the gravity field acting on planets can be produced by applying a high voltage potential between the inner and outer sphere, using the effect of dielectrophoretic force field.

The experiment concept is to simulate geophysical phenomena by generating and analysing fluid flows between two spheres. The stimuli are differential heating/cooling and electric field; differential rotation will be applied during later phases of the experiment. The optical diagnostics are interferometry, and for the experiment phases following the first one, interferometry will be replaced by miniaturized Laser Doppler Anemometry (LDA) in the 2. phase. Within the same modular EC, nine fluid cells will be processed sequentially: three cells with three different inner radii (same outer diameter but different gap widths, i.e. 3 different inner spheres) and three cells with different fluids (different viscosities).

The experiment may need Particle Image Velocimetry (PIV) by using a laser light sheet instead of the interferometry and the adaption optics.

Basically, the core of the experiment container is a set of two concentric and transparent outer spherical shells, a fluid being located between them. The fluid can be stimulated by a thermal gradient combined with an electric field between the inner and outer sphere, and by differential and/or non-differential rotation of the spheres.

3 Operational Scenario

9 samples (experiment cells) with the same outer glass sphere diameter are foreseen: 3 different sizes of inner spheres and 3 different viscosities are planned. 120 parameter variations (variation of rotation rate, temperature difference) are planned for each sample. The duration of one parameter variation is about 1 hour (= time for a stable state of the flow). The interferometer is used to document the development (few pictures/hour) and the final state of the flow. LDA is used to detect time series of the velocities and to calculate the chaosdynamic behavior.

Experiment duration : 45 days (9 samples x 120 parameter values x 1 hr)
The experiment Coordinator wishes these 45 days to be in sequences of 1 week of tests in flight, followed by 1 week of analysis on ground.

Crew involvement : 40' to exchange samples. Experiment automatic.

Video downlink : some minutes every hour

Commanding : some minutes every hour.

4 Technical description and measurement concept

The main part of the experiment are two concentric spherical shells (optical glass, Schott BK 7, thickness 4-5mm) and an reflecting (polished) inner sphere (Fig. 2). The gap between inner and outer sphere is filled with silicone oil (Baysilone) as well as the gap between the two glass spherical shells which is used to cool the outer sphere. Each of the two concentric spherical shells is divided into two hemispheres which are mounted mechanically and glued by Scotch-Weld (3M). The inner sphere is heated, the outer shells are cooled. The reflecting inner sphere is mounted on top of a shaft which carries the fluid to heat the inner sphere. Both, for cooling and heating the cell, the same silicone oil is used as coolant. The three fluid loops are closed and sealed. A pressure compensation volume is included in the loops to avoid pressurization. The impermeability can be granted by a pressurization test of 1 bar overpressure. The dielectrophoretic effect is used to generate the central directed force field inside the spherical gap between inner sphere and the inner glass sphere. The inner side of the glass shell (Schott BK7 optical glass) is coated with transparent indium tin oxide (ITO), to ensure conductivity for the high voltage (12-15kV rms). A second spherical glass shell encapsulates the coolant. The whole cell, including the outer glass shell, must have a diameter of maximum 80mm. This spherical gap cell is rotating about a common axis. Differential rotating of the inner sphere (clockwise or counter-clockwise) is also required.

To cool the oil for the outer shell, while the inner sphere is heated, a thermostatic unit (Peltier elements) should be used. Both temperatures (inner and outer loop) are measured by thermocouples mounted outside of the spherical shell system (but nearby) to determine the temperature gradient. The maximum temperature gradient is $\Delta T = 20 - 25$ K. The absolute temperatures (at inner and outer sphere) are not so important, they will be chosen close to the temperature of the heating or cooling loop. Including the pressure compensation volumes,

there will be a total of approximately 0.3 liters of silicone oil in the whole experiment cell, including the two loops for cooling/heating. All the parts of the cell are glued to seal the cell. The whole spherical experiment is rotating at a maximum rotation rate of 2 Hz around the center of the spheres. The inner sphere should be rotate also independently in the same range.

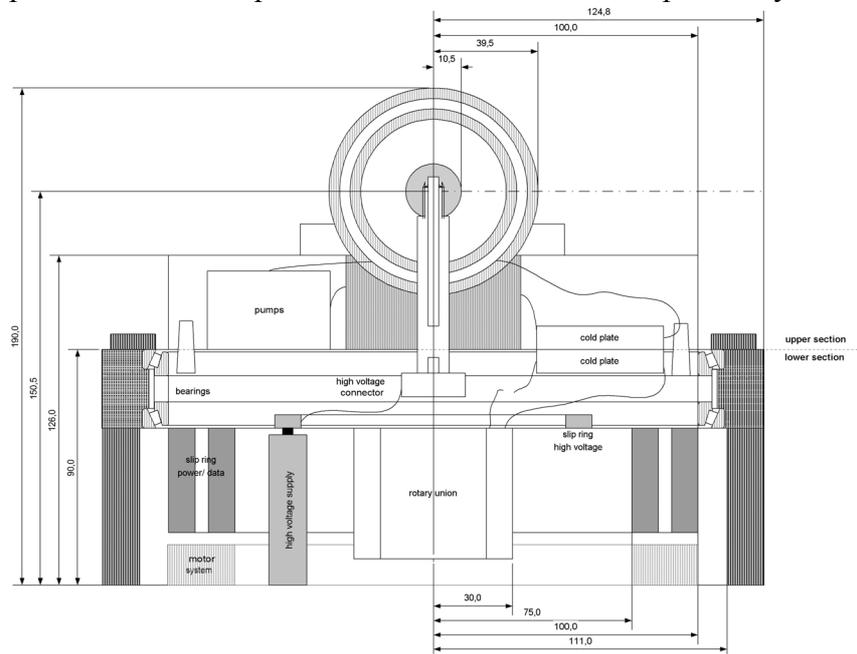


Fig. 2: Principle sketch of GeoFlow experiment, including cell system, slip ring for high voltage/ power/ data and thermostatic unit

The possible accommodation for the Experiment Container (EC) shows Fig. 3. The suggestive housing for the adaption optics contains 5-7 lenses. The focal point of this lens is the center of the inner sphere, with a view angle of approximately 90 degrees. The inner sphere is polished and acts as a mirror. The back scattered light is focussed by the adaption lens system and reaches the FSL-Diagnostics through window by arrangement of mirrors within the EC.

The flow is visualized with a Wollasten Shearing interferometer. This method is based on the variation of the refraction index of the silicone oil at different temperatures. It is a differential interferometer and visualizes temperature gradients. The interferometer should consist or take use of:

- Laser diode (wavelength: green, 532 nm), for example: 10 mW, class IIIa (FSL)
- Adaption optics containing different lenses with focal point in the center of the inner sphere and parallel beam on the other side (optical glass, Schott, BK7), (EC)
- Wollasten prism (FSL),
- Digital camera (FSL),
- Mirror(s), (EC)

During later phases of the experiment it is planned to investigate also highly time-dependent as well as turbulent convective flows. For this purpose, the adaption optics should be demounted and an additional miniaturized Laser-Doppler-Anemometer should be integrated into the Experiment Container to measure flow velocities and time series quantitatively as illustrated schematically in fig. 4. The use of PIV-techniques instead of interferometry based on lightsheet illumination should also be analysed.

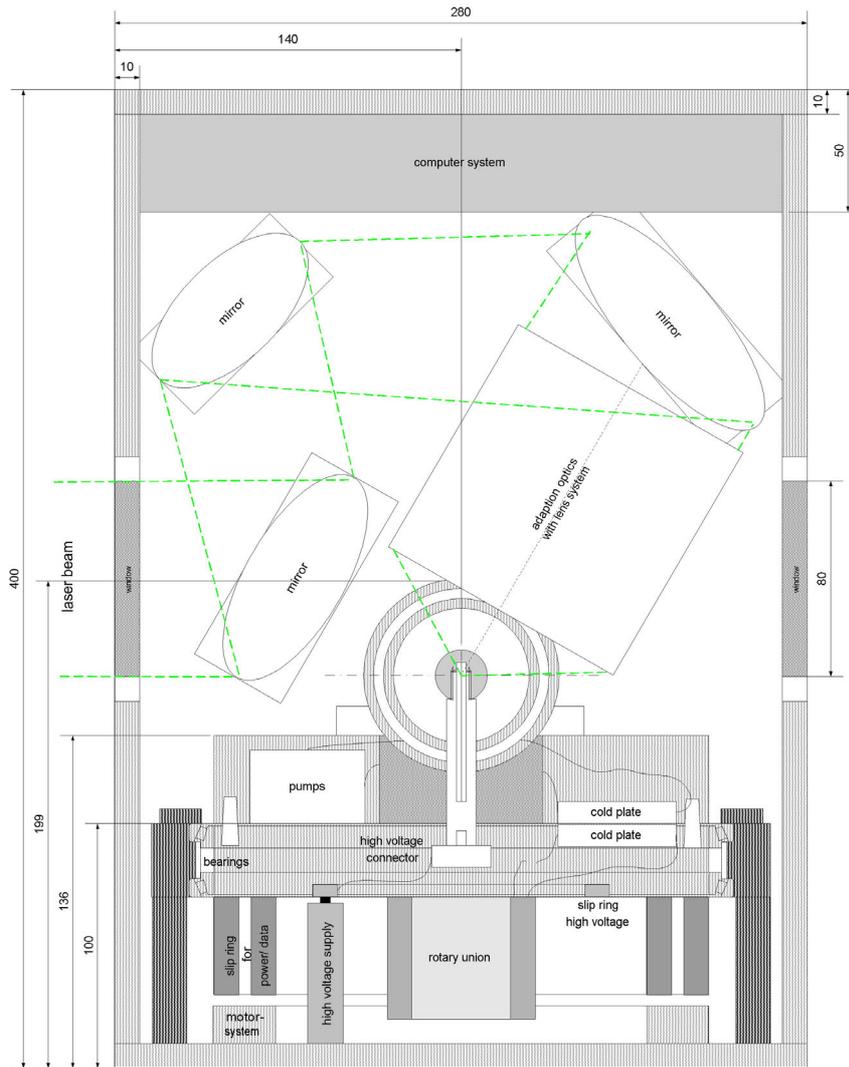


Fig. 3: Integration of experiment cell system, adaption lens system and mirror in the Experiment Container, the parallel beam goes out of the container into the interferometry module of the FSL

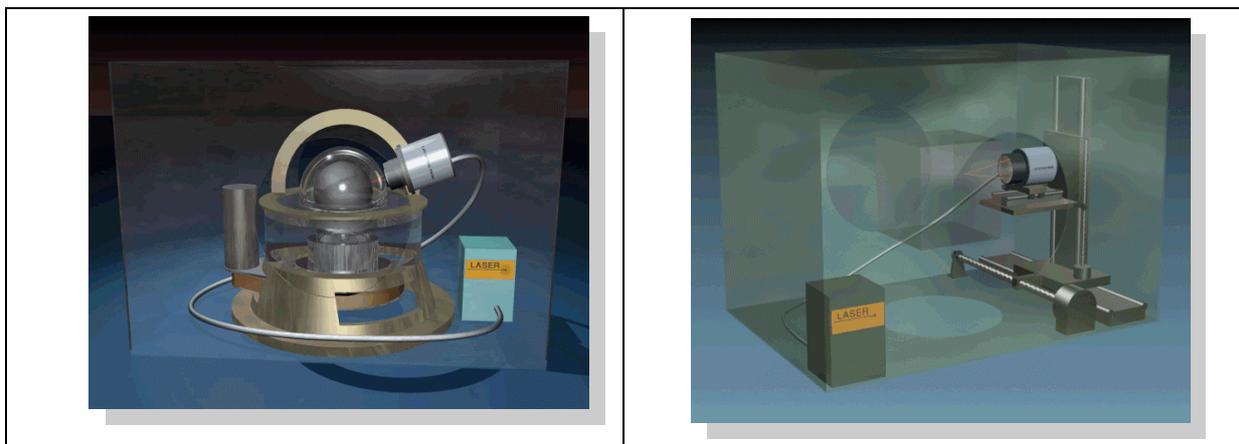


Fig. 4: Principle sketch of the integration of a miniaturized LDV-measuring system integrated at the GeoFlow experiment in the EC (left) or as universal measurement tool (right).

The financial support from DLR under grant 50 WM 0122 is gratefully acknowledged.