Surface Tension Driven Convection Experiment Apparatus

Project Scientist: Dr. Alexander Pline,
NASA Lewis Research Center

The Surface Tension Driven Convection Experiment on USML-1

In the production of high-tech crystals, metals, alloys, and ceramics, materials are heated until they form a liquid or vaporize into a gas and then cooled until they solidify. During this process, unwanted flows in the liquids and gases, created as the material heats and cools, often cause defects that can keep these materials from performing as predicted or designed. For example, along the surface of a material where solidification is occurring, currents can cause an inappropriate amount of an element to be present in pockets of the final product. In electronic materials, this can change the performance of a device, or it may make the device unreliable by weakening its structure. Advanced products, such as the crystals used to make computer chips and infrared detectors and the alloys used to make turbine engine blades, require material that is as free from defects as possible.

Buoyancy flows are known to cause defects in crystals on Earth. In microgravity, buoyancy-driven flows are greatly reduced, but other fluid motions can become more prominent. Temperature variations along the surfaces that do not come into contact with a container — called *free surfaces* — create fluid motions called *thermocapillary flows*. While thermocapillary flows exist on Earth, they are masked by gravity-driven fluid motions and are very difficult to measure. However, these flows occur in many industrial and materials processing methods, and investigators want to understand their effects. Additionally, because gravity creates flat surfaces on liquids on Earth, investigators want to study the effects in microgravity that different surface shapes might have on these flows. On Earth, different surface shapes cannot be simulated.

The Surface Tension Driven Convection Experiment Apparatus will allow scientists to investigate the basic fluid mechanics and heat transfer of thermocapillary flows generated by temperature variations along free surfaces of liquids in low gravity. In the process, scientists will evaluate fluid flow models and theories of how these flows transition from steady (2-dimensional) to oscillatory (3-dimensional) states. This experiment will determine how and when oscillatory thermocapillary flows are created; how flows are affected by different heat sources and surface shapes; how flows affect surface shape; and what relationships exist among free surface deformation, surface temperature distribution, and fluid flow velocity.

Knowledge of the behavior of thermocapillary flows and their effects is not only scientifically important but is also important because these flows influence applications (such as bubble and droplet migration, fuel management and storage, and life support systems) and material processing methods (such as crystal growth from liquids, containerless processing, and welding). As we enter the era of longer spaceflights and space station operations, understanding and controlling the effects of thermocapillary flows will become increasingly important.

Instrument Description

The Surface Tension Driven Convection Experiment Apparatus consists of the experiment package and an electronics package located in a double Spacelab rack. The experiment package can accommodate on-orbit installation of test-chamber modules. The modules include a test chamber, made of copper to assure good thermal conductivity along the walls, and a silicone oil system consisting of a storage reservoir and a fluid management system for filling and emptying the test chamber. Low viscosity silicone oil is used because it is not susceptible to surface contamination, which can ruin surface tension experiments. Six modules will be used to study three different test chamber diameters (1.2, 2, and 3 centimeters) and two different heating systems. A submerged heater system will be used to study thermocapillary flows over a range of imposed temperature differences, while a surface heating system will be used in investigations of fluid flows that are generated by various heat fluxes distributed across the surface of the liquid. The surface heating system consists of a carbon dioxide laser and various optical elements that direct the laser beam to the test chamber and vary the imposed heat flux and its distribution. Analysis of the flows resulting from the diverse imposed thermal signatures will provide options for properly tailoring the fluxes.

A laser diode and associated optical elements will illuminate aluminum oxide particles suspended in the silicone oil, and particle motion will be recorded by a video camera attached to a chamber viewport. An infrared imaging system will record oil surface temperature. A third camera, in concert with an optical measurement system, will be used to monitor oil filling to a flat surface and oil surface deformations and motions associated with oscillatory thermocapillary flows.

Surface Tension Driven Convection Experiment

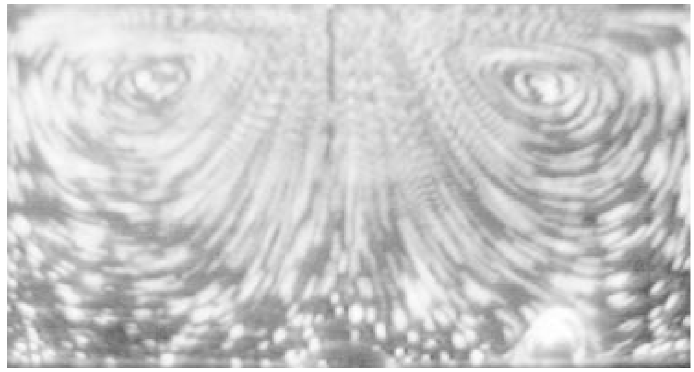
Principal Investigator: Dr. Simon Ostrach,
Case Western Reserve University,
Cleveland, Ohio

Purpose: To measure the transition from steady flows (2-dimensional) to oscillatory flows (3-dimensional), to identify the conditions for the onset of oscillatory flows, and to determine the nature and extent of these flows

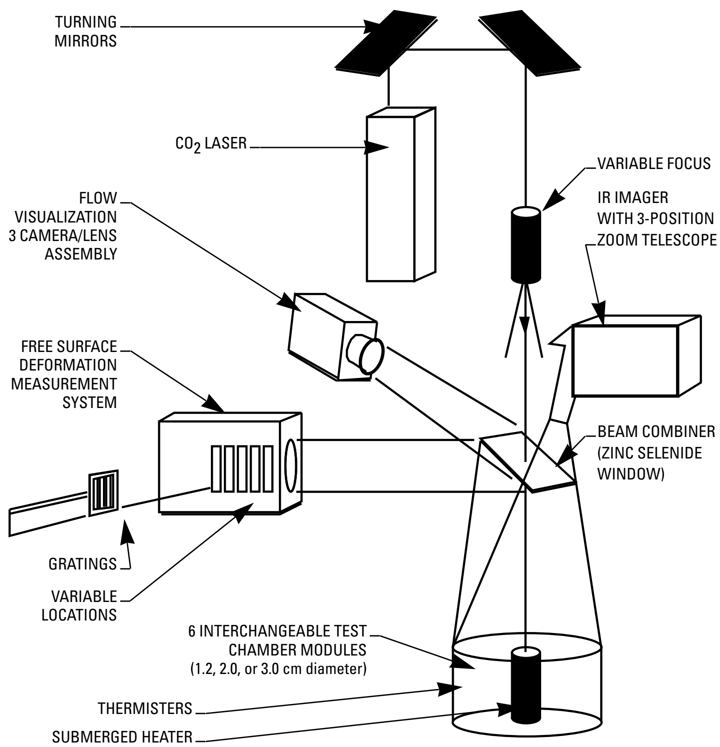
Significance: Thermocapillary flows occur in many industrial and materials processing methods but are masked on Earth by gravity-driven fluid motions. However, in microgravity, these flows become prominent and can be studied in detail. The Surface Tension Driven Convection Experiment Apparatus will allow scientists to investigate the basic fluid mechanics and heat transfer of oscillatory thermocapillary flows generated by temperature variations along free surfaces of liquids in low gravity, from their onset to determining the relationships that exist among free surface deformation, surface temperature distribution, and fluid flow velocity.

Method: A cylindrical container will be filled with silicone oil, and two different heater systems will be used to heat the free surface to generate thermocapillary flows. The submerged heater will impose a constant temperature difference between the heater and container walls, while a carbon dioxide laser will impose a heat flux on the liquid surface to produce various temperature distributions along the liquid's surface. The container will be filled with oil to different levels to create both flat and curved surfaces, and a sophisticated data acquisition system will provide temperature and flow field measurements. A laser-light source will be reflected by aluminum oxide particles mixed into the oil to allow observation of fluid flows. A scanning infrared imager will measure oil surface temperature, an important measurement because it determines the driving force of the flow, and a free-surface deformation measurement system will allow very small disturbances from flatness to be recorded to determine how they are related to oscillatory flow.

Data will be downlinked to the Spacelab Mission Operations Control Center at the Marshall Space Flight Center and to the User Operations Facility at the Lewis Research Center, enabling scientists to observe and measure the driving force, fluid flows, surface shapes, and temperature distributions under varying conditions. Based on results, a new set of test parameters for the next series of experiments will then be uplinked to the experiment computer. These data will be used to develop complete physical models of oscillatory thermocapillary flows.



This streak photograph shows convection flow during experimentation on USML-1.



A Schematic View of the Surface Tension Driven Convection Experiment Apparatus on the USML-2 Mission