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Development of Optimal Bubble-Seeding Microheaters to Study Nucleate Boiling Heat Transfer in Microgravity

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Development of Optimal Bubble-Seeding Microheaters to Study Nucleate Boiling Heat Transfer in Microgravity

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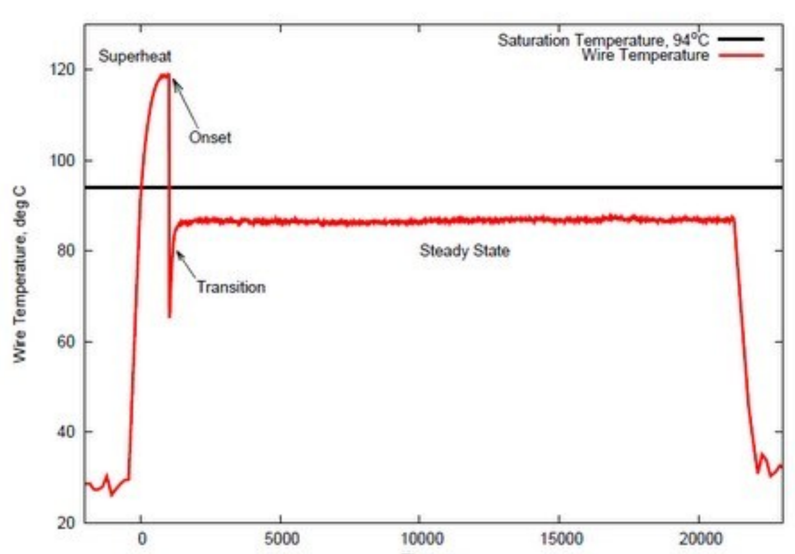
Abstract

Heat management is a critical issue facing engineers of spaceflight systems. Nucleate boiling has high heat transfer rates, but further study is needed to effectively apply this method to a heat transfer system in a microgravity environment. The USU Get Away Special (GAS) team is conducting a series of experiments aboard NASA's "Weightless Wonder" aircraft to further understanding of nucleate boiling in microgravity. Two specific focuses of the current experiment are determining optimal surface geometries of microheater arrays designed to induce nucleate boiling and constructing a lighting and video system to spatially and temporally resolve the anticipated jets of fine, high-speed bubbles. As we use these systems to collect and connect data, we expect to gain an increased understanding of the conditions, parameters, and applications of nucleate boiling in microgravity.

Boiling

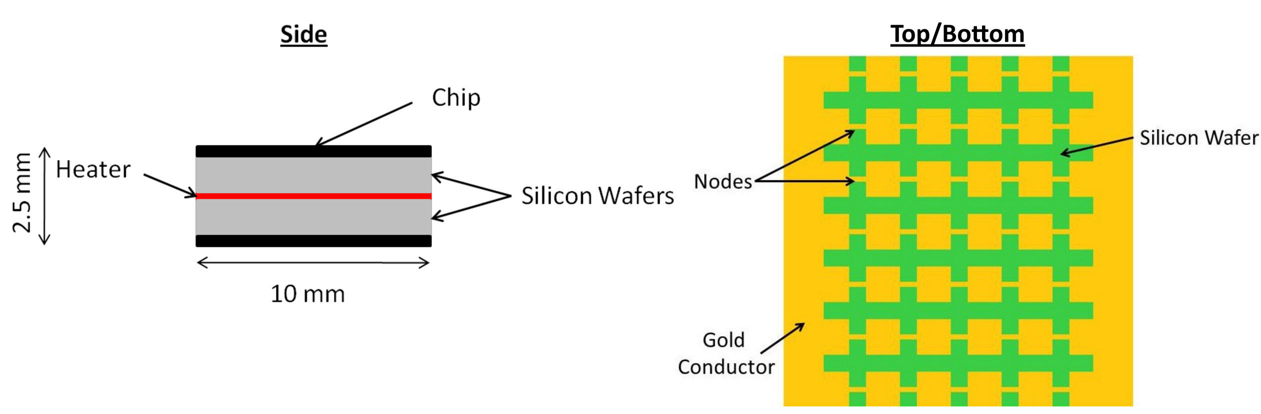
In order to improve current methods of heat transfer in both Earth-based and space applications, research is continuing on nucleate boiling. The USU GAS team performed an experiment in June 2010 to study nucleate boiling in microgravity: Follow-Up Nucleate Boiling On-Flight Experiment (FUNBOE). The results from FUNBOE show us that it requires a much higher temperature than the saturation temperature of water to achieve boiling (see figure 1).



As soon as boiling was initiated the surface temperature of the heating element quickly dropped well below the saturation temperature then stabilized to a sustained temperature, still lower than the water's saturation point while boiling continued. The goal of this project is to be able to initiate the onset of boiling on a microheater chip such that the temperature of a main heating element will not superheat prior to boiling.

Microheaters

The proposed idea to prevent superheating prior to boiling is to sandwich the element between two silicon wafers. On these wafers are printed gold microheater arrays (figure x) with nodes where the gold film is narrower. At these nodes, the resistance is increased, and additional heat is generated.



The additional heat causes a seed bubble to be formed and begins the boiling process. The node receives its power as a square wave signal, and heat is added in very short pulses. The small seed bubble will then continue to grow as heat from the plate heater continues to input heat into the bubble, eventually ejecting the bubble, after which another electrical pulse through the node will follow to create another seed bubble, perpetuating heat transfer.

Microgravity

Methods and ideas of this research have terrestrial application, but it is critical for future space exploration that heat transfer research is performed in microgravity to prepare for its application in space. In this experiment, microgravity is necessary to test heat transfer through the microheater, due to the fact that in terrestrial gravity the system will not heat and cool symmetrically, as it will in space. For this experiment, FUNBOE 2.0, NASA's "Weightless Wonder," a microgravity aircraft that simulates weightlessness by performing a series of altitudinal parabolas, will be utilized for microgravity through NASA's Reduced Gravity Program for undergraduate research. The relative weight on downward slope of each parabola is approximately 0.01g for about 25 seconds.

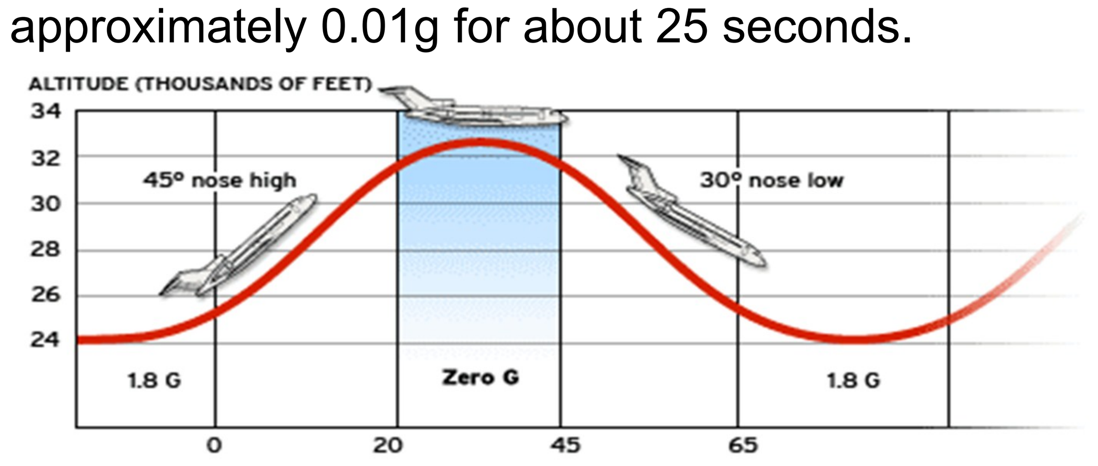


Figure 3 – Parabolic flight path of plane. Source: The Zero Gravity Corporation

Experimental Design

To study boiling of a single element in water without external variables, each experimental system will be contained in an individual boiling chamber. in order to obtain many data points in a single flight, a structure designed to house 30 boiling chambers and all necessary power supplies and instrumentation is being built to be accommodated by the microgravity aircraft.

Three boiling chambers will be tested during each test parabola, and six high definition cameras will move to different sets of boiling chambers that will be tested with different nodal configurations of the microheater arrays and different power levels.

Video and Lighting

High definition video is important for recording growth and motion of bubbles. This allows correlation of heat transfer and temperature gradients with actual bubble behavior. Like its predecessor, FUNBOE 2.0 uses Kodak Zi8 pocket video cameras mounted at right angles to each other to record boiling video from two directions.

Plastic magnifiers glued to the cameras give nominal resolution of 15 micrometers per pixel at the heater's distance of five and a half centimeters from each camera. Video is taken in full HD (1920 x 1080 pixels) at 30 frames per second.

Due to the small size of the bubbles, short focal length of the camera lenses, and desired framerate, special lighting is required for video recording. The experimental structure will be covered with dark material to block ambient light, and individual lighting will be applied to each boiling chamber.

Since jet boiling is expected to dominate for all heater types at most heat fluxes FUNBOE 2.0 will test, the lighting system is designed to best illuminate small, fast -moving bubbles with diameters of 0.1 mm or less. A single bright white LED with a 45° field of view is glued onto the boiling chamber's exterior opposite both cameras, shining obliquely onto the heater allowing individual bubbles to be distinguished in many jets and casting jets sharply against the dark background.

Analysis

FUNBOE 2.0's flight will take place in June in Houston, Texas. After the flight, the GAS team will correlate video data with temperature, voltage, pressure, and accelerometer data and analyze it to improve the understanding of nucleate boiling behavior in microgravity. It is expected that the data acquired from this project will allow for better application of nucleate boiling heat transfer systems and enable further research into such technology.