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Thermal Management Through Resonant Instability in Reduced Gravity Environments

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Abstract

As space exploration advances, the need for effective thermal management becomes increasingly important. On Earth, buoyancy-driven convection serves as the primary mechanism for heat transfer; however, in space, unique challenges like the absence of gravity, extreme temperatures, and limited resources necessitate alternative approaches. The work proposed uses resonant instability by forcing an otherwise dormant system at its natural frequency to circumvent issues from traditional thermal management techniques. The natural frequency is the frequency at which a system oscillates when perturbed in the absence of external forcing. When a fluid bilayer is subjected to a vertical parametric forcing, it becomes unstable at a critical forcing amplitude for a given frequency. This phenomenon is known as Faraday instability. Faraday instability manifests as vigorous standing waves at the free surface, exciting flow in the bulk of the fluid. This work shows that the use of Faraday instability will dramatically enhance heat transfer in a system with diminished buoyancy driven convection. Electrostatic forcing experiments demonstrated during Parabolic campaigns have shown the effectiveness of this method, revealing a substantial increase in heat transfer in both terrestrial and reduced gravity environments. Ground-based trials showed a 40% improvement over unforced systems, while microgravity experiments exhibited up to a 1500% increase relative to their terrestrial counterparts. Other tests on ground incorporating a DC offset revealed destabilizing effects simulating reduced gravity. Furthermore, electrostatic forcing was compared to mechanical forcing to examine the distinct physics of the forcing method.

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