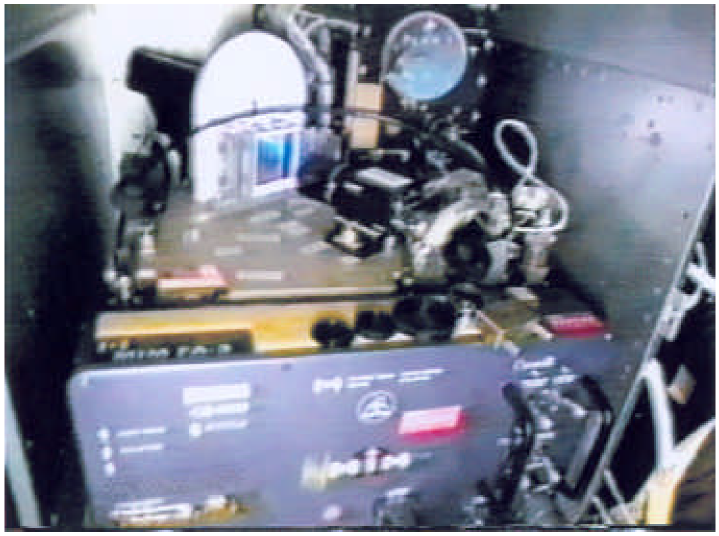
Effects of g-Jitter on Diffusion in Binary Liquids

The microgravity environment offers the potential to measure the binary diffusion coefficients in liquids without the masking effects introduced by buoyancy-induced flows due to Earth's gravity. However, the background g-jitter (vibrations from the shuttle, onboard machinery, and crew) normally encountered in many shuttle experiments may alter the benefits of the microgravity environment and introduce vibrations that could offset its intrinsic advantages. An experiment during STS-85 (August 1997) used the Microgravity Vibration Isolation Mount (MIM) to isolate and introduce controlled vibrations to two miscible liquids inside a cavity to study the effects of g-jitter on liquid diffusion.

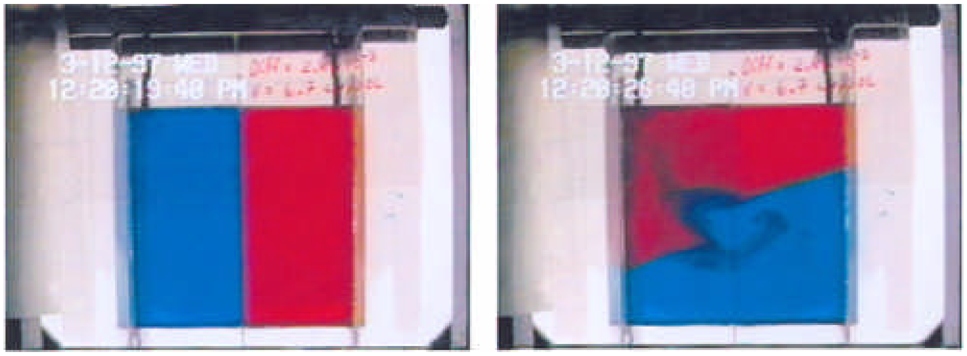
Diffusion in a nonhomogeneous liquid system is caused by a nonequilibrium condition that results in the transport of mass (dispersion of the different kinds of liquid molecules) to approach equilibrium. The dynamic state of the system tends toward equilibrium such that the system becomes homogeneous. An everyday example is the mixing of cream and coffee (a nonhomogeneous system) via stirring. The cream diffuses into the coffee, thus forming a homogeneous system. At equilibrium the system is said to be mixed. However, during stirring, simple observations show complex flow field dynamics-stretching and folding of material interfaces, thinning of striation thickness, self-similar patterns, and so on. This example illustrates that, even though mixing occurs via mass diffusion, stirring to enhance transport plays a major role. Stirring can be induced either by mechanical means (spoon or plastic stirrer) or via buoyancy-induced forces caused by Earth's gravity. Accurate measurements of binary diffusion coefficients are often inhibited by buoyancy-induced flows. The microgravity environment minimizes the effect of buoyancy-induced flows and allows the true diffusion limit to be achieved. One goal of this experiment was to show that the microgravity environment suppresses buoyancy-induced convection, thereby mass diffusion becomes the dominant mechanism for transport. Since g-jitter transmitted by the shuttle to the experiment can potentially excite buoyancy-induced flows, we also studied the effects of controlled vibrations on the system.



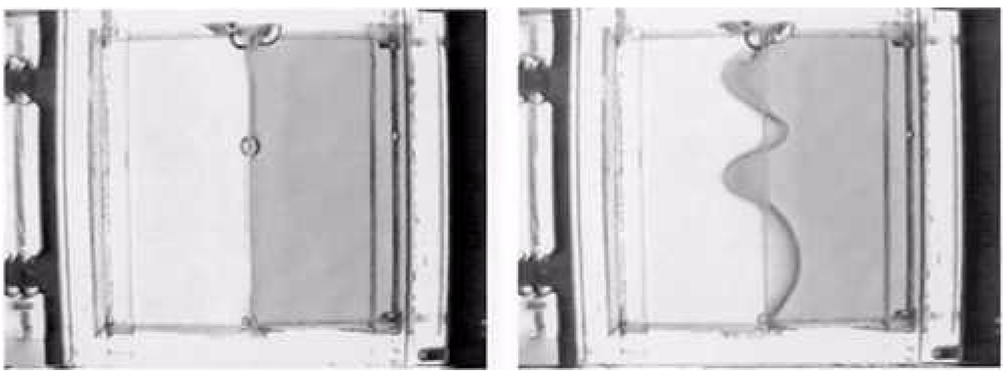
Experiment mounted on the MIM platform on STS-85

The physics of the interface behavior of two miscible liquids subjected to steady and oscillatory body forces was predicted, and the results were documented in a series of publications (refs. 1 to 4). The experiment was conceived and designed by W.M.B. Duval at the NASA Lewis Research Center. However, because an important finding of the theoretical prediction was the presence of standing waves due to oscillatory body forces (refs. 1 and 3), a special experimental apparatus was needed. Showing the existence of standing waves required the use of a platform that could both isolate the experiment from vibrations and input known vibration sources to it. These requirements were fulfilled by the use of the Microgravity Vibration Isolation Mount (MIM), designed by B.V. Tryggvason through an international collaboration with the Canadian Space Agency. The experimental setup flown on STS-85 is shown in the preceding photo. Hardware consisted of the mixing cell, a light source, a motor to remove the shim, and a black & white camera that was mounted on the MIM platform. Experiments on the MIM were performed in two different modes: (1) an isolation mode to damp out background g-jitter and (2) an active mode to input known vibration sources to the experiment.

The following top and bottom photos, respectively, show ground-based and microgravity results. Because of the large size of the mixing cell, 5-cm high by 5-cm wide by 1-cm deep, it was extremely challenging to damp out buoyancy-induced forces, which can stretch and fold the interface. The top photos capture a typical scenario showing the effect of a steady body force on the ground. The initial condition at time zero consists of two miscible liquids separated by a thin shim, as in the top left photo. Once the shim is pulled, the hydrostatic pressure imbalance between the two liquids causes an overturning motion that stretches and folds the interface. The top right photo shows the evolution of an internal breakwave after approximately 7 sec.



Ground-based experiment. Left: Initial condition of two miscible liquids at time zero. Fluid on the left side of the photo is 2.2-vol % deuterium oxide with deionized water and blue dye; fluid on the right side of the photo is 100-vol % deionized water with red dye--a specific gravity difference of 0.0026. Right: Configuration of the interface after removal of the shim showing an internal breakwave after approximately 7 sec.



Microgravity experiments. Left: Isolation mode 17 sec after removal of the shim, showing a stationary interface (fluid on the left side of the photo contains 20-vol % ethylene-glycol with water and blue dye; fluid on the right side of the photo contains 100-vol % deionized water with red dye--a specific gravity difference of 0.028). Right: Forcing mode at a frequency of 1 Hz and an amplitude of 0.02g, showing a four-mode standing wave.

In contrast, the microgravity result in the bottom left photo shows a stationary interface after 17 sec. The MIM was operating in isolation mode; the background acceleration was nearly steady on the order of a micro-g (10^{-6}g). This result illustrates the effectiveness of the microgravity environment in damping buoyancy-induced flows, thus permitting liquids to mix via mass diffusion. Note that the presence of any residual buoyancy-induced force would cause the interface to deform. Mass diffusion over a long time scale would cause the two fluids to mix while the interface remained stationary in the vertical configuration. Given that the interface can remain stationary over a time interval, the MIM was operated in the excitation mode with a frequency of 1 Hz and an amplitude of 0.02g with a sinusoidal input. The bottom right photo shows that the interface becomes unstable against Kelvin-Helmholtz instability and produces a four-mode standing wave. In this case, the instability of the interface enhances local mass transport.

The analysis of the vibration data input by the MIM on the experiment is ongoing. Recent computational results in fiscal year 1998 agreed with the experimental findings of the four-mode standing wave; however, subtleties of the experimental findings are being addressed. These results are expected to shed light on the use of isolation systems for the International Space Station.

References

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Headquarters program office: OLMSA (UG)
Programs/Projects: Microgravity Science
Special recognition: Superior Accomplishment Award given in 1998 for space flight experiment conducted on STS-85 in August 1997