Effect of Single-Wavelength Initial Conditions In Low-Atwood Rayleigh-Taylor Mixing

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Introduction

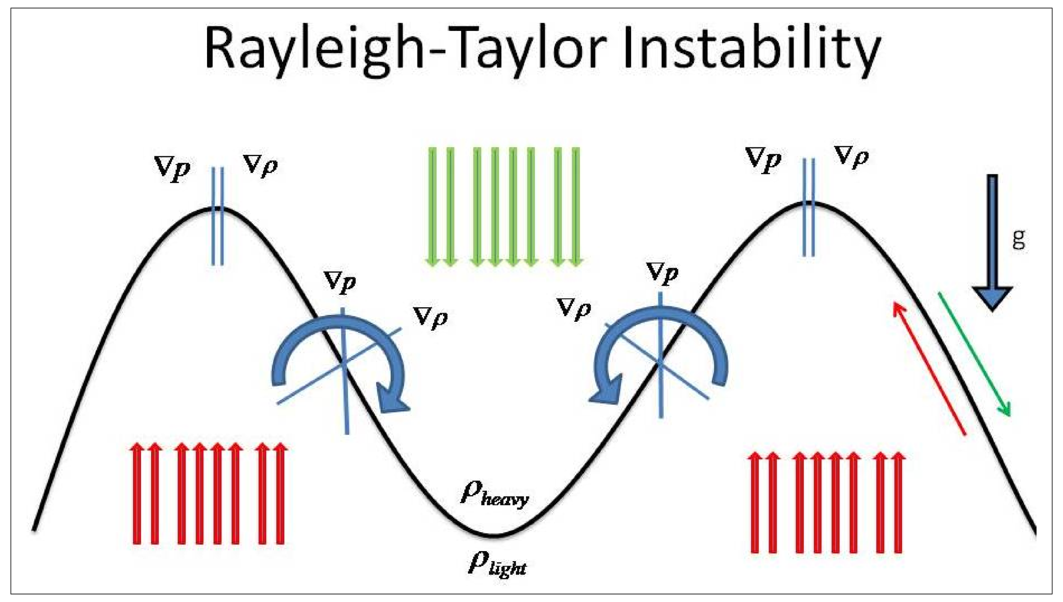

Figure 1: *Figure shows the physical meaning of the Rayleigh-Taylor instability. The cross product of the pressure gradient and density gradient is zero at the crest of the wave, however, sliding down to the side of the wave yields a non-zero cross product generating a vorticity.*

When a heavy fluid is accelerated into a light fluid as shown in Figure 1, mixing occurs. This mixing was first studied by Lord Rayleigh and G. I Taylor, for whom the title of this phenomena, Rayleigh- Taylor (RT) mixing, is named after. Today, these mixing flows are of special interest for inertial confinement fusion, magma diapers, astrophysics , and much more. In its unstable configuration of heavy over light, or $\nabla\rho \cdot \nabla P < 0$ in terms of the density gradient $\nabla\rho$ and pressure gradient ∇P, the interface must be infinitely smooth to remain unchanged. Even in this impossible case, mixing would still occur by diffusion across the interface (for miscible fluids). However, any perturbation to this interface, even infinitesimal, results in a generation of vorticity $\nabla\rho \times \nabla P/\rho^2$ at the interface that drives the system further away from equilibrium. This vorticity stretches and folds the interface, which gives rise to the familiar "bubble" and "spike" structures. The stretching and folding of the interface increases the total surface area of the interface and thus the total diffusion rate between the heavy and light fluid. The mixing is further enhanced through secondary instabilities (shear or Kelvin-Helmholtz instabilities) that further augment the area of the interface. Given enough potential energy, the flow becomes fully turbulent which introduces multiple length scales of motion that exponentially increase the interface area, resulting in quick and efficient mixing. The foundational paradigms formed over the last 25 years are that the temporal evolution of the mixing layer height is described by three consecutive regimes:

- **Exponential** growth from initial infinitesimal perturbations to finite size.
- **Mode** coupling, non-linear growth, and secondary instability. Transition to turbulence.
- **Similarity** for high Reynolds number turbulence with an infinite system size.

where the height of the mixing layer is defined as $h = (h_b - h_s)/2$ with h_b the point where the average non-dimensional density $\overline{f}_1 = (\rho - \rho_2)/(\rho_1 - \rho_2) = 0.95$ and h_s at $\overline{f}_1 = 0.05$ with $\rho_1 > \rho_2$.

Motivation

It has been shown that late time dependence on initial perturbations at the fluid interface and the assumption of memory loss of initial conditions has not yet occurred. Thus it appears that late-time mixing rate may be modified and possibly controlled by an appropriate initial condition. This has large implications to inertial confinement fusion where it may be possible to design a capsule to reduce mixing between the fuel and the shell thus increasing yield. To examine this, the low-Atwood number water channel facility at Texas A&M has been modified to implement a motor controller flapper at the end of the splitter plate.

Low Atwood Number Water Channel at Texas A&M

The water channel is constructed out of plexiglass which provides a 50 inch long, $12\frac{1}{2}$ inches tall by 8 inches wide test section shown in Figure 2. The channel is partitioned along the horizontal axis into top and bottom sections utilizing a splitter plate. Water from two separated 500 gallon tanks is pumped through individual pumps into the channel via an inlet plenum. The inlet plenum directs the water to the top and bottom sections of the channel respectively. Utilizing an Eulerian frame of reference distance down stream translates to time through $t = x/U$, where x indicates the axial distance downstream in the channel, and U is the uniform convective velocity.

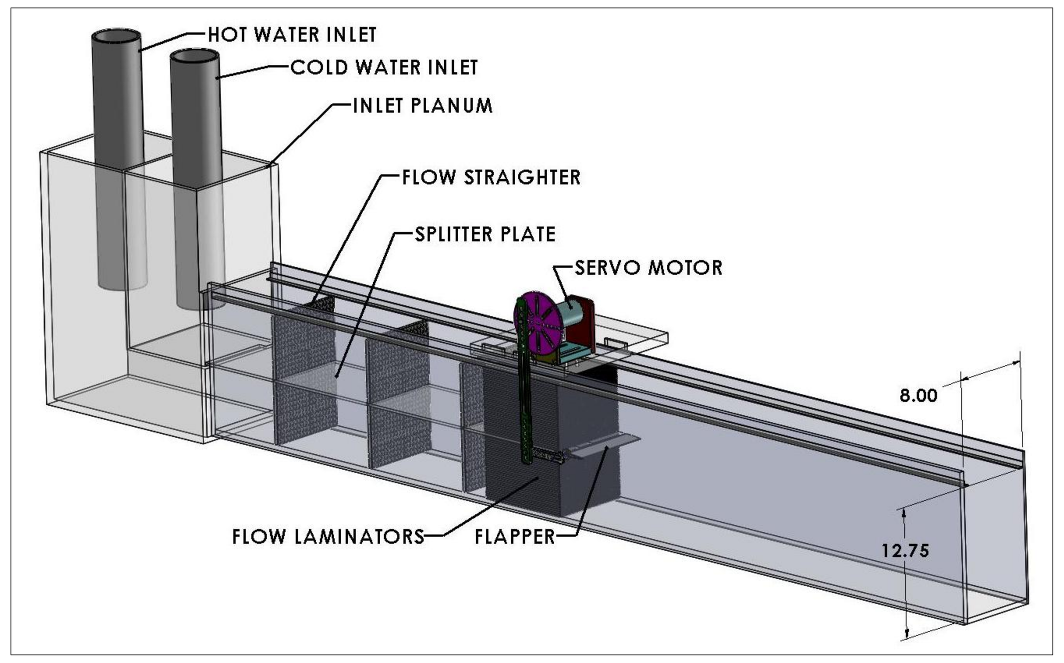

Figure 2: *Low Atwood number water channel facility at Texas A&M showing channel set up. Dimensions are in inches.*

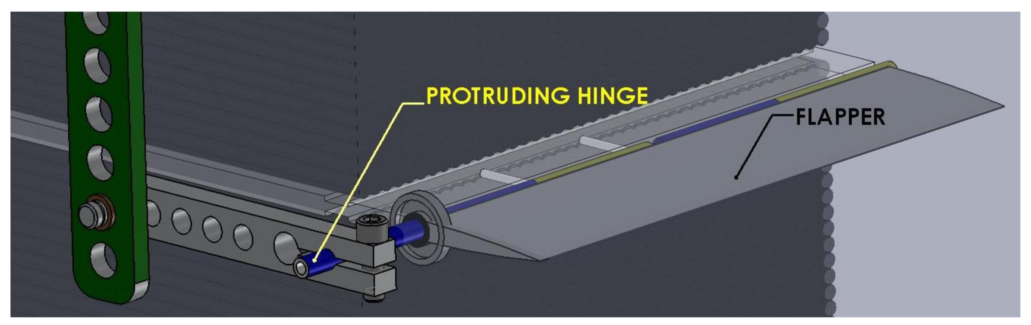

Figure 3: *Figure shows the flapper device that induces perturbations at the flow interface.*

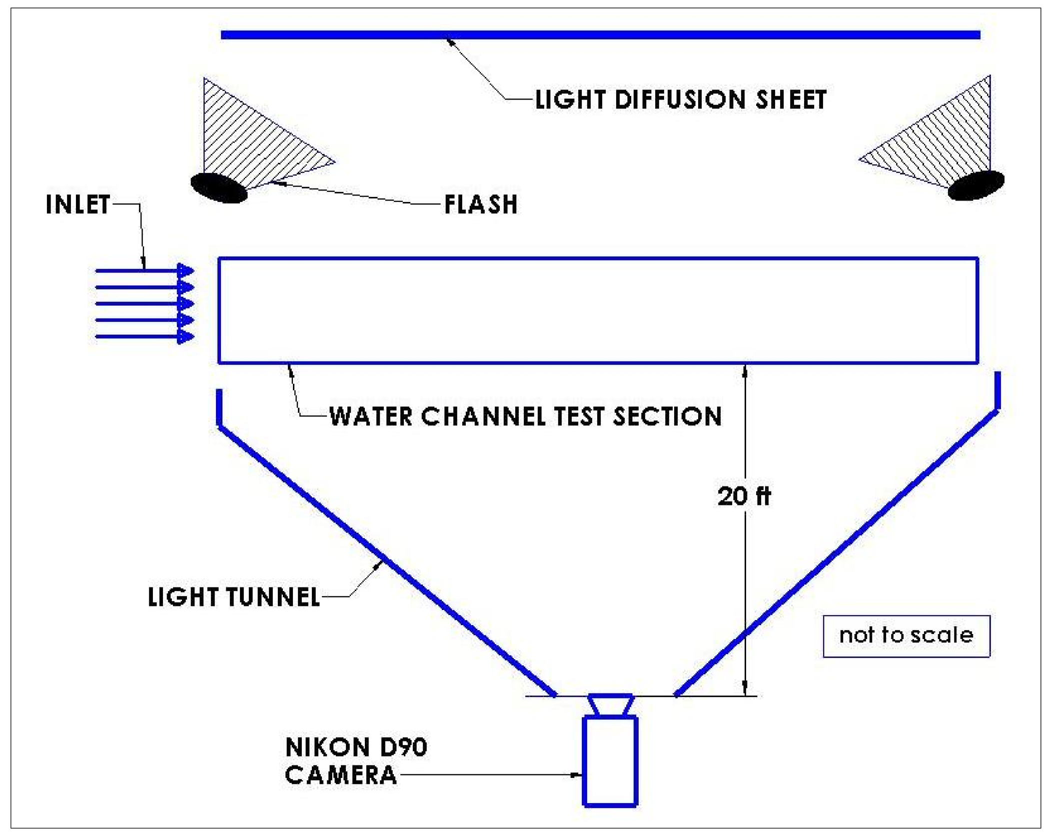

Figure 4: *Top view illustration of camera placement and flashes. The light emanating from the flashes impinges on the diffusion sheet behind the channel, travels through the experiment, and is recorded in the digital camera.*

Table 1: *Values of the flapper amplitude A_0 and period T, resulting initial condition wavelength λ, convective velocity U, and Atwood number A for each case.*

Run	A_0 (mm)	T (s)	λ (cm)	U ($\frac{cm}{s}$)	A
1	0	0	0	5.7	8.34 $\times 10^{-4}$
2	0.20	0.35	2	5.71	7.71 $\times 10^{-4}$
3	0.41	0.70	4	5.71	8.28 $\times 10^{-4}$
4	0.62	1.05	6	5.71	8.38 $\times 10^{-4}$
5	0.83	1.40	8	5.71	8.14 $\times 10^{-4}$
6	1.00	1.75	10	5.71	8.14 $\times 10^{-4}$

Results

Figure 5: *Sample pictures of the no flapping, 2 cm, 4 cm, 6 cm, 8 cm, and 10 cm wavelengths from left to right, top to bottom, respectively. Note the secondary wavelengths associated with the 1 cm boundary layer wake off the flapper. 400 images of each case are used to establish the average density distribution.*

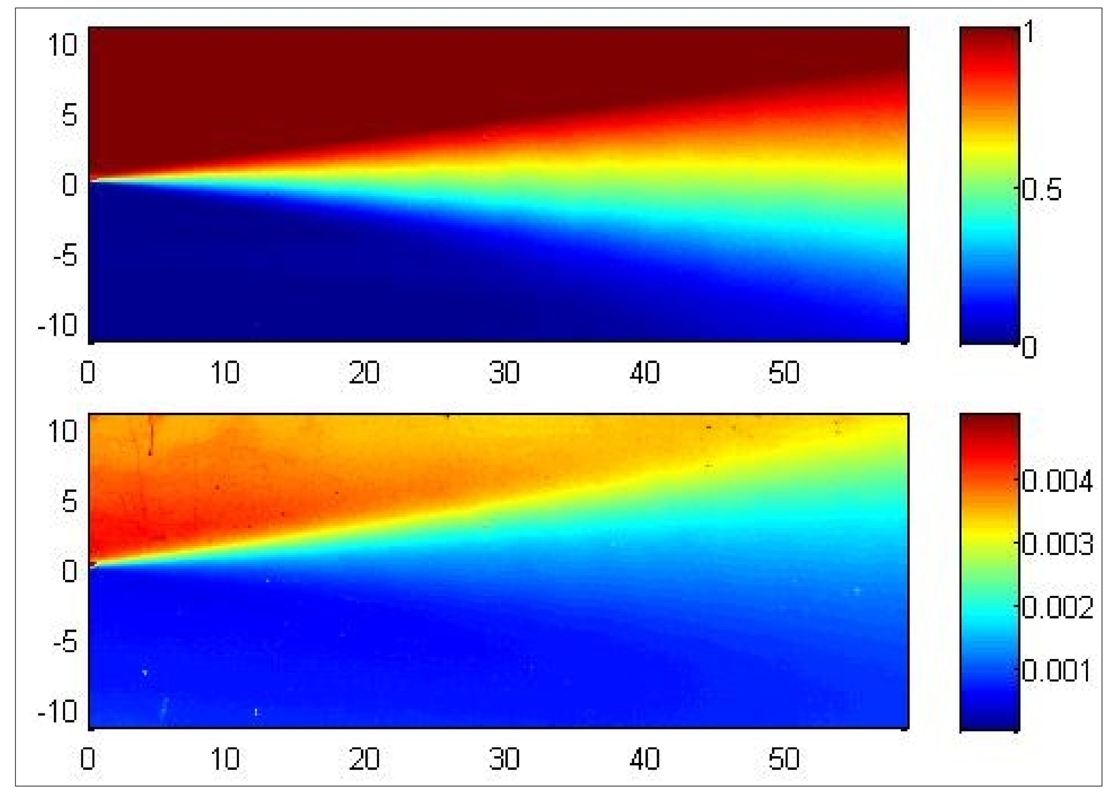

Figure 6: *Contours of the average density $\overline{f}_1$ (top) and uncertainty $d\overline{f}_1$ (bottom) contours versus downstream and vertical distance (cm) from the flapper tip for all cases are similar, shown for the 6 cm wavelength case.*

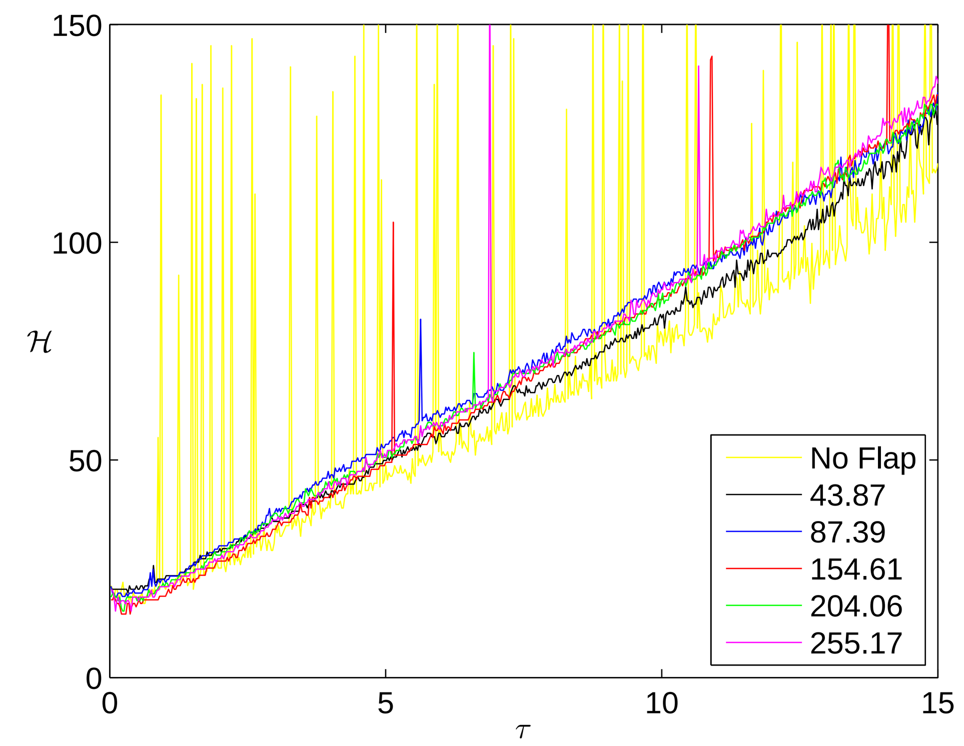

Figure 7: *Mixing height versus time $\tau = ((Ag)^2/\nu)^{1/3}$ for the single mode perturbation, normalized by viscosity ν, gravity g, and Atwood number A. The legend shows no flap and the wavelengths for 2, 4, 6, 8, and 10 cm normalized by $(Ag/\nu^2)^{1/3}$. Note that the no flap case is noisier and requires a longer time average. All cases show the same growth rate within uncertainty.*

Future Work

The mixing height H did not seem to have a discernable dependence on single mode initial perturbations. Therefore, this suggests that both later time and multi-mode perturbations should be explored.

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