SHOCK TUBE & ADVANCED MIXING LAB

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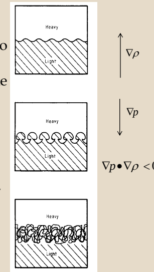
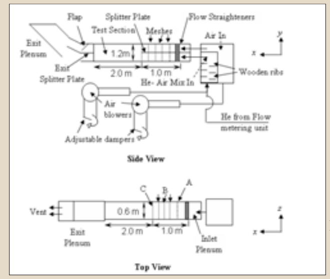
Investigation of Combined Rayleigh-Taylor and Kelvin-Helmholtz Instabilities

Rayleigh-Taylor (RT)/ Richtmyer-Meshkov (RM) Instability: Background

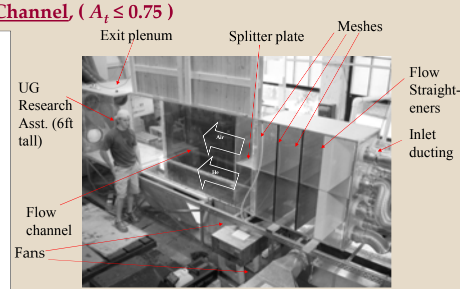
- Rayleigh-Taylor instability (R-T) occurs when a density gradient is accelerated by a pressure gradient such that $\nabla p \bullet \nabla \rho < 0$
- When a heavy fluid rests above a light fluid under the influence of gravity, the density interface is unstable to infinitesimal perturbations.
- KH instability occurs whenever two fluids of different velocities (same density) brought in contact with one another with a perturbed interface
- The resulting flow evolves in three stages:
  - Exponential growth of infinitesimal perturbations
  - Nonlinear saturation of perturbations
  - Transition to turbulence and self-similar growth
    - o Governing parameter for the flow is a non-dimensional density difference known as the Atwood number, $A_t = (\rho_{heavy} - \rho_{light}) / (\rho_{heavy} + \rho_{light})$
    - o During self-similar growth the half mix width, *h*, grows according to $h = \alpha A_t g t^2$. Where α is a growth constant, *g* is the acceleration due to gravity, and *t* is time.
- RT and RM flows occur in the ablation interface of Inertial Confinement Fusion capsules resulting in a mix which degrades final yield. RT flows also are found in the ejecta of supernovae and in atmospheric flows.



High Atwood Number He/Air Gas Channel, ($A_t \leq 0.75$)



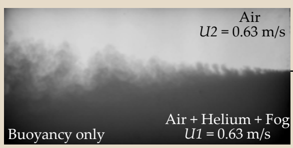
Schematic of the Experimental setup

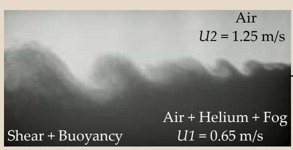


Experimental setup indicated with main components of the system

- Air and air + Helium mixture are used as working fluids to create density difference
- Air is used as top stream fluid and Helium is used as bottom stream fluid and both streams are separated by a splitter plate.
- Convective type system, opposed to conventional box type system
- Mixing region starts right after the splitter plate, distance from splitter plate is converted to time using Taylor's hypothesis
- Different concentrations of Helium can be used in bottom stream to obtain A_t up to 0.75
- Fans can pump air into the system up to 2m/s and different velocity ratios can be obtained by varying the fan opening

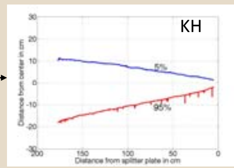
Flow Visualization



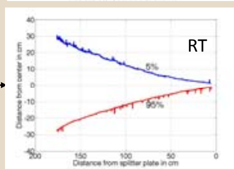


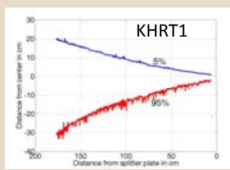
Mixing layer visualization for shear, buoyancy and compound buoyancy and shear

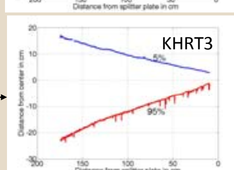
Image Analysis

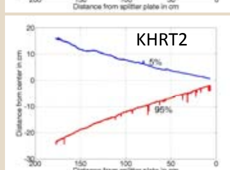


Case	U1 m/s	U2 m/s	A_t
RT	0.63	0.63	0.038
KHRT 1	0.63	0.86	0.038
KHRT 2	0.63	1.03	0.038
KHRT 3	0.63	1.25	0.038
KH	0.6	1.25	0

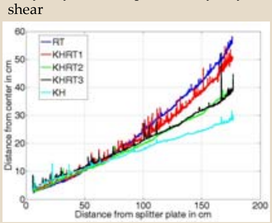


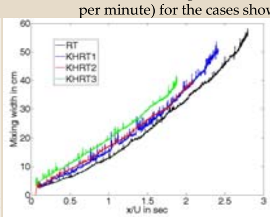




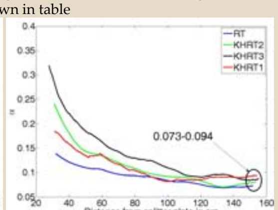


Downstream evolution of the mixture fraction along the channel (Ensemble average of 250 images taken at the rate of 60 images per minute) for the cases shown in table





Mixing width variation for difference cases with the distance from splitter plate and time x/U where U is the average velocity and x is the distance from splitter plate



Growth rate constant α variation with distance for different cases using

$$h_b = \alpha A_t g t^2$$

Diagnostics

- Two type of diagnostics are used for measurements; Image analysis and Simultaneous 3 Wire and Cold Wire Anemometry (S3WCA)

•Image Analysis:

- Channel is backlit using 35 fluorescent lights and light diffusing sheets are used to enhance the uniformity of the light intensity
- Smoke is injected into one of the streams for visualization purpose.
- Calibration is performed in a triangular wedge to determine the fog concentration at which light intensity is proportional to volume fraction of the fog.
- Images are taken during the experiment and ensemble average of these images is taken as the basis for calculating mixing width and its growth rate

• S3WCA:

- Two probes are used to measure density and velocity simultaneously at a particular point in the mixing region
- Temperature is used as a marker for density. Cold wire is used to measure temperature (can be correlated to density) and a 3 wire probe is used to measure the velocities in all the three directions
- 3 wire probe is calibrated at different velocities and volume fractions to obtain the velocities from experiments once density is evaluated from cold wire signal.

Image Analysis Results

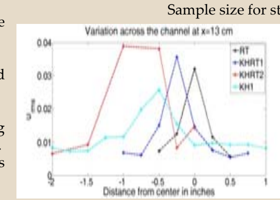
- Vertical plume structures are characteristic of RT instability and span wise vortical structures are observed for KH instability.
- For the combined KHRT case, span wise vortical structures are observed closer to the splitter plate and these structures are stretched by buoyancy within those structures
- Mixing width grows linearly for KHI and grows quadratically for RTI. For the combined case, mixing region grew linearly at earlier times and became quadratic at later times.
- If the shear is high enough, the quadratic behavior may not be observed
- From the mixing width data, growth rate constant α can be calculated from $h_b = \alpha A_t g \left(\frac{x}{U}\right)^2$ and its value found out to vary between 0.073-0.094, whereas it is found out to be constant for RTI experiments.

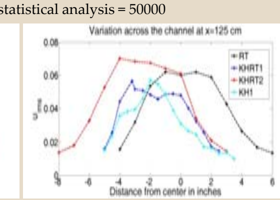
S3WCA Results

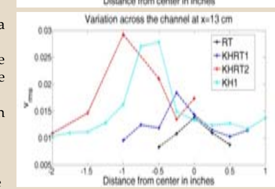
- This technique provided instantaneous velocity and density data at a particular point in the mixing region
- Different statistics including RMS values of velocities, densities and turbulent mass flux at a point
- Measurement are made at different axial locations and across the streams, obtained velocity RMS profiles are shown on right side. 'u' is the streamwise velocity and 'v' is crossstream velocity.
- All the velocity profiles have shown maximum values at the center of the mixing region and the maximum value point shifts towards lower velocity stream direction with the introduction of shear
- Closer to the splitter plate, KHRT2 has similar profile as KH1 showing that the mixing is mainly due to shear and v rms value is also 3 times larger than RT
- Difference between KHRT2 and KH1 grows at larger distances away from splitter plate and distribution shows similarities with RT
- V' rms value can be related to mixing growth rate constant α and the values obtained are in the same range from image analysis
- θ is the molecular mixing parameter, its value is equal to 1 when the fluids are fully mixed and equal to zero when they are segregated
- Introduction of shear has shown slight increase in the molecular mixing between the streams
- The increase in θ can be attributed to span wise vortices, stretched by buoyancy. These stretched structures improve the surface areas between the fluids and improve the molecular mixing

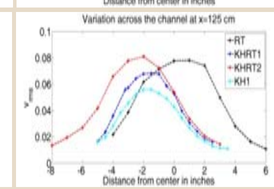
Hot Wire Anemometry

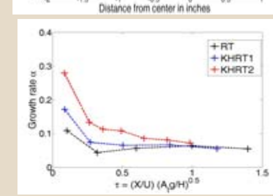
Sample size for statistical analysis = 50000

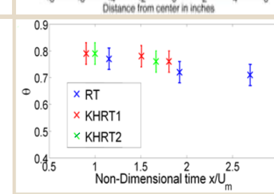












RMS fluctuations of streamwise and crossstream velocity fluctuations for different cases; Mixing growth rate constant α variation with time; Molecular mixing parameter θ for different cases with and without shear A_t~0.04

$$\theta = 1 - \frac{B_0}{B_2};$$

$$v' = \frac{dh}{dt} = 2\alpha A_t g \frac{x}{U}$$

$$B_0 = \lim_{T\to\infty} \frac{1}{T}\int_0^T \frac{(\rho - \bar{\rho})^2}{(\Delta\rho)^2} dt; B_2 = f_{v,1} f_{v,2}$$

$$\tau = \left[\frac{x}{U}\right]\sqrt{A_t g / H}$$

$$f_{v,1} = \lim_{T\to\infty} \frac{1}{T}\int_0^T \frac{\rho - \rho_2}{\rho_1 - \rho_2} dt; f_{v,2} = 1 - f_{v,1}$$

Progress and Future Work:

- Effect of shear on R-T mixing studied using Image Analysis and Hot Wire Anemometry at low Atwood number of 0.04
- 3 wire probe (Dantec 55P91) is used to measured 3 components of velocity and cold wire Anemometry is used to measure density using temperature as a density marker
- This technique allows to calculate vertical turbulent mass flux ($\overline{\rho' v'}$), v'_{rms}, molecular mixing parameter (θ), Reynolds stresses and BHR model parameter *b*.
- Simultaneous Stereo PIV/PLIF measurement system is being implemented to measure the velocity and density fields at different times, and higher Atwood number experiments ($A_t > 0.2$) have to be performed with shear.

References:

1. Chandrasekhar S. Hydrodynamic and hydromagnetic stability. International Series of Monographs on Physics, Oxford: Clarendon, 1961. 1961;1.
2. Youngs D L. Numerical simulation of turbulent mixing by Rayleigh-Taylor instability. Physica D: Nonlinear Phenomena. 1984;12(1-3):32-44.
3. BANERJEE A, KRAFT W N, ANDREWS M J. Detailed measurements of a statistically steady Rayleigh–Taylor mixing layer from small to high Atwood numbers. Journal of Fluid Mechanics. 2010;659(1):127-90.
4. Kraft W N. Simultaneous and instantaneous measurement of velocity and density in Rayleigh-Taylor mixing layers. 2008.