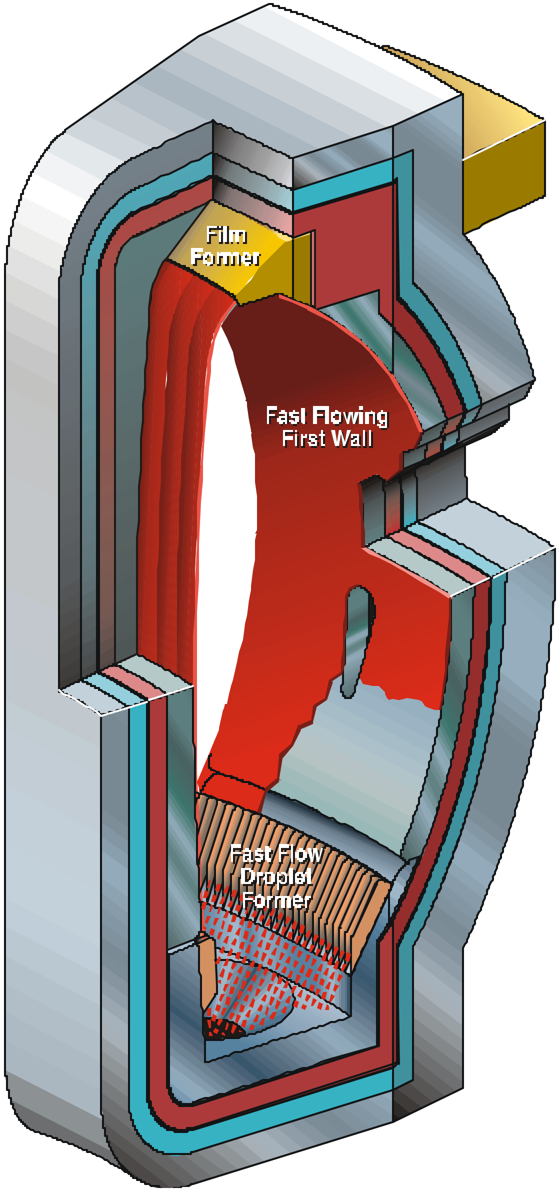
Liquid Wall Science is important in many scientific pursuits and applications

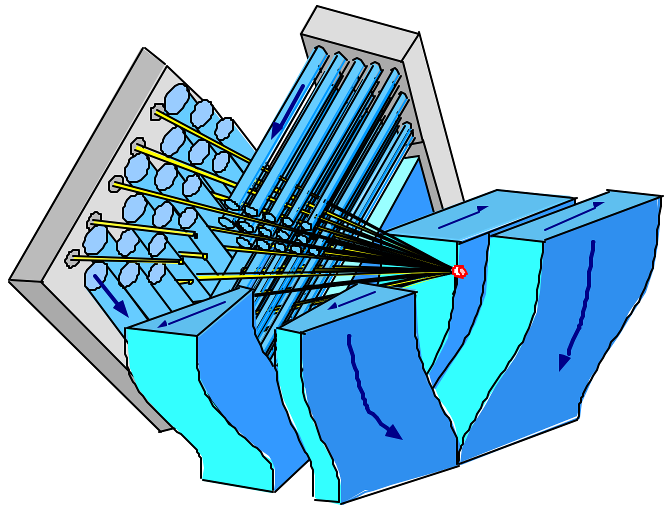
- **Liquid Jet and Film Stability and Dynamics:** fuel injection, combustion processes, water jet cutting, ink jet printers, continuous rod/sheet/ribbon/sphere casting, flood/jet soldering, ocean waves, hull design, ocean/river hydraulic engineering, surfing, liquid walls for fusion reactors
- **Liquid MHD / free surface interactions:** melt/mold stirring and heating, liquid jet/flow control and shaping, crystal growth, astrophysical phenomena, liquid metal walls for particle accelerators and fusion reactors
- **Liquid MHD / turbulence interactions:** microstructure control in casting, boundary layer control, astrophysical dynamos and plasmas, liquid walls for particle accelerators and fusion reactors
- **Free surface heat and mass transfer:** oceanography, meteorology, global climate change, wetted-wall absorbers/chemical reactor, condensers, vertical tube evaporator, film cooling of turbine blades, impurity control in casting, liquid walls for particle accelerators and fusion reactors

Watermark: Turbulent flow effect on dendrite formation in casting - LANL simulation

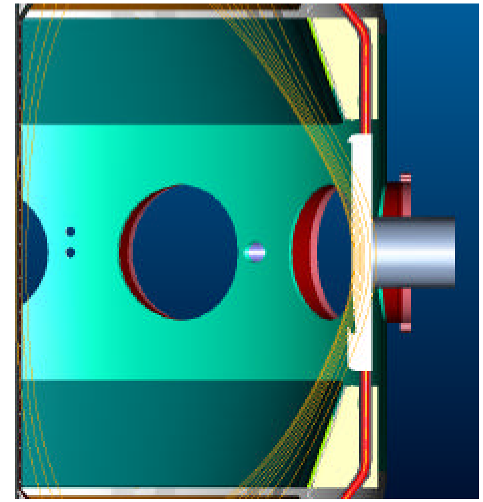
Liquid Wall Science is being Advanced in Several MFE & IFE Research Programs



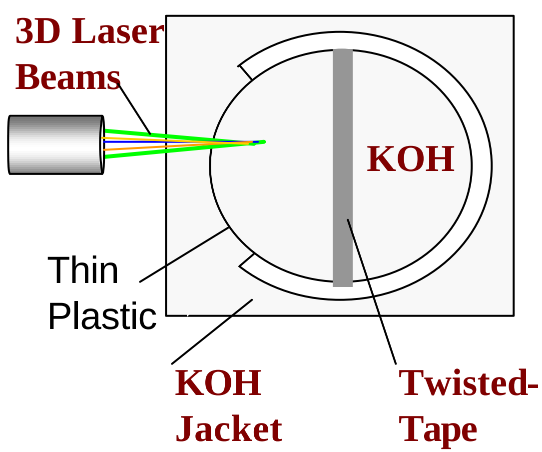
APEX CLiFF



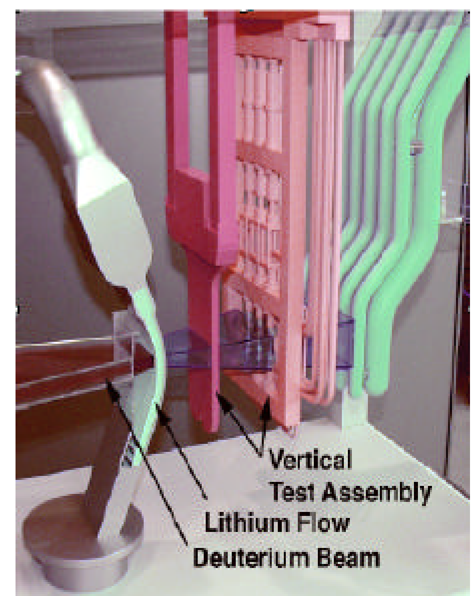
HYLIFE-II



NSTX Li module



JUPITER-II



IFMIF

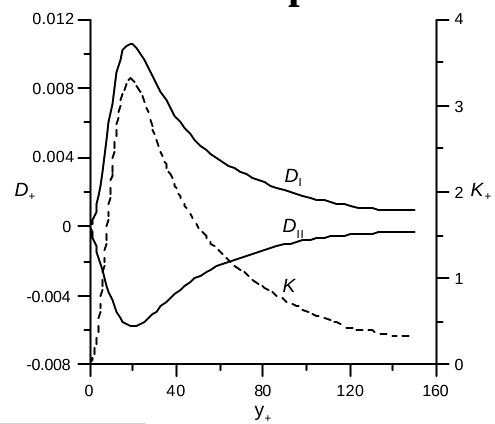
MODELING FREE-SURFACE MHD TURBULENCE

(from limited DNS/experimental data to real applications)

D N S

for free surface MHD flows developed as a part of collab-oration between UCLA and Japanese Profs Kunugi and Satake

Joule Dissipation



Statistical description of bulk and free surface MHD TURBULENCE

RANS TURBULENCE MODELS

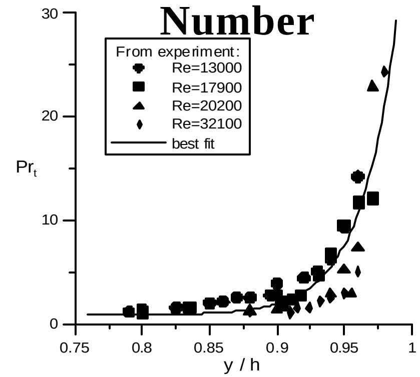
- **K-epsilon**
- **RST model**

DNS and Experimental data are used at UCLA for characterizing MHD turbulence phenomena and developing closures in RANS models

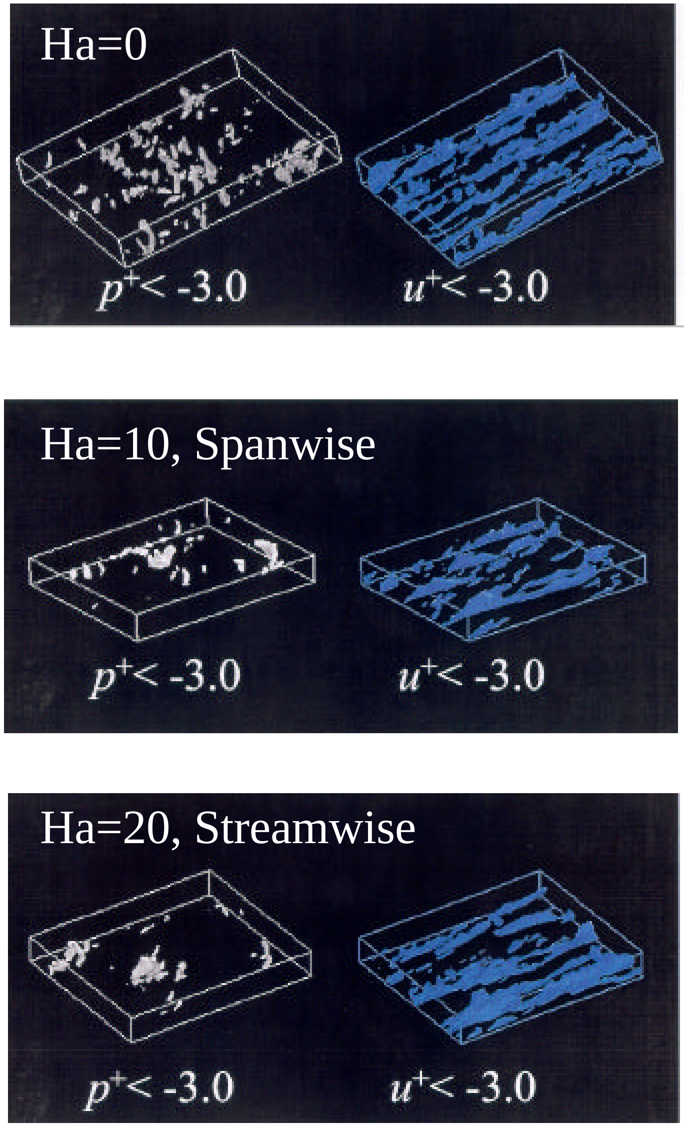
EXPERIMENTS

underway at UCLA for near surface turbulence and interfacial transport measurements

Turbulent Prandtl Number



A BIG STEP FORWARD -
(1st FREE SURFACE, MHD TURBULENT DNS)



- Strong redistribution of turbulence by a magnetic field is seen.
- Frequency of vortex structures decreases, but vortex size increases.
- Stronger suppresion effect occurs in a spanwise magnetic field
- Free surface approximated as a free slip boundary. Work proceeding on a *deformable* free surface solution.

"DNS of turbulent free surface flow with MHD at Ret = 150" - *Satake, Kunugi, and Smolentsev, Computational Fluid Dynamics Conf., Tokyo, 2000*

PUTTING DATA TO WORK

RANS EQUATIONS: “K-e” model

MHD K- e TURBULENCE MODEL

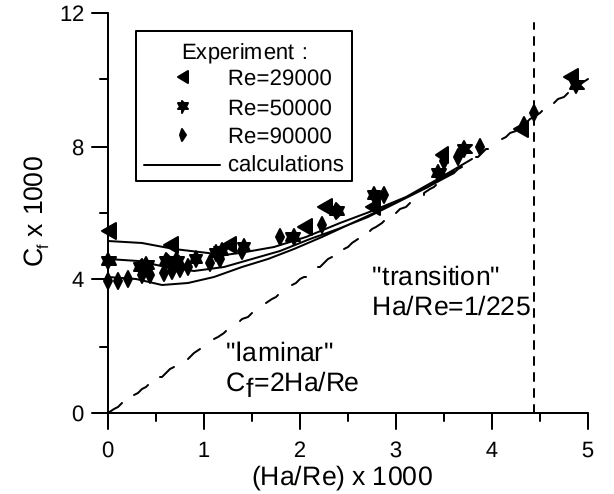
$$\frac{\partial K}{\partial t}+\langle v_j\rangle\frac{\partial K}{\partial x_j}=\underbrace{n_t\left(\frac{\partial v_i}{\partial x_j}\right)^2}_{Production}+\underbrace{\frac{\partial}{\partial x_j}[(n+\frac{n_t}{s_K})\frac{\partial K}{\partial x_j}]}_{Diffusion}-\underbrace{e-e^K_{em}}_{Dissipation};$$

$$\frac{\partial e}{\partial t}+\langle v_j\rangle\frac{\partial e}{\partial x_j}=C_1\frac{e}{K}n_t\left(\frac{\partial v_i}{\partial x_j}\right)^2+\frac{\partial}{\partial x_j}[(n+\frac{n_t}{s_e})\frac{\partial e}{\partial x_j}]-C_2\frac{e}{K}e-e^e_{em}.$$

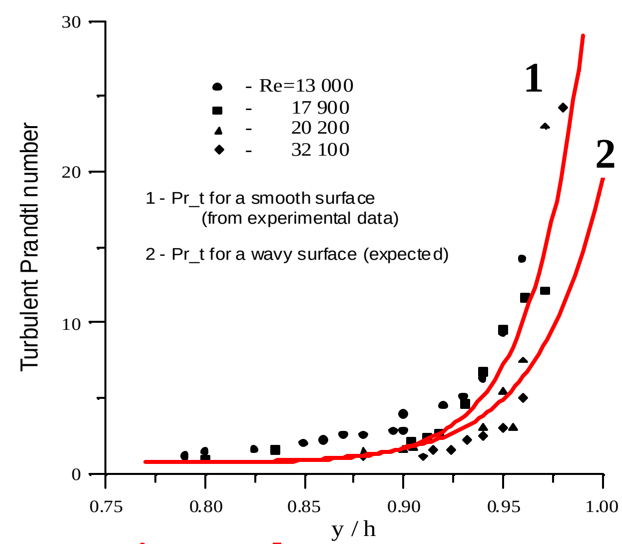
$$q_t=-rC_p<t'v_n'>=-rC_p\frac{n_t}{Pr_t}\frac{\partial T}{\partial n};\quad Pr_t=n_t/a_t$$

MHD DEPENDENT TURBULENCE CLOSURES

Magnetic field direction	e^K_{em}	e^e_{em}	C_3	C_4
Streamwise	$C_3\frac{s}{r}B_0^2K$	$C_4\frac{s}{r}B_0^2e$	0.02	0.015
Wall-normal	$C_3\frac{s}{r}B_0^2K$	$C_4\frac{s}{r}B_0^2e$	$1.9\exp\{-1.0N\}$	$1.9\exp\{-2.0N\}$
Spanwise	$C_3\frac{s}{r}B_0^2K$	$C_4\frac{s}{r}B_0^2e$	$1.9\exp\{-1.0N\}$	$1.9\exp\{-2.0N\}$



Comparison of UCLA model to experimental data



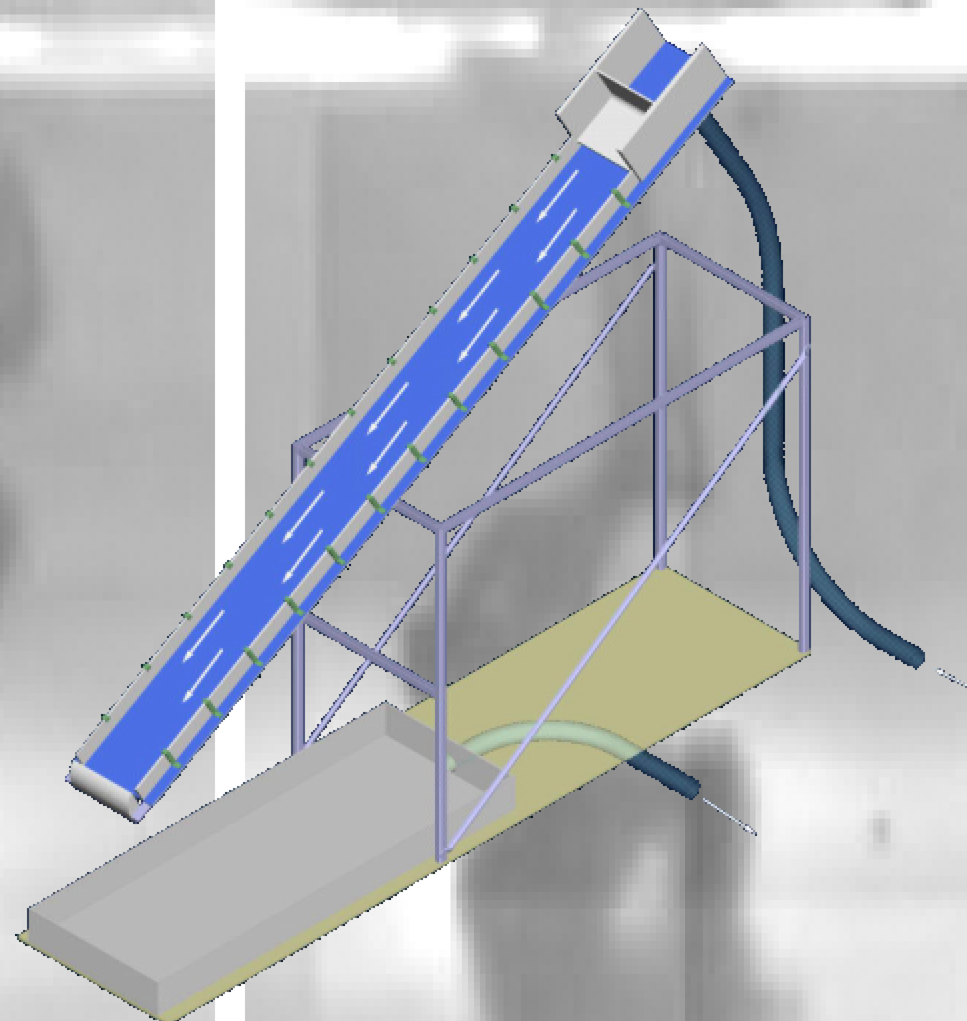
Experimental measurements of Turbulent Prandtl number

Interfacial Transport Experiments in FLIHY

- **Large scale test section with water/electrolyte flow will generate LW relevant flow**
- **Tracer dye and IR camera techniques will be used to measure interfacial transport at free surface**
- **PIV and LDA systems for quantitative turbulence comparison to DNS**

Visualization of sinking and dispersing milk drop in water

2 cm

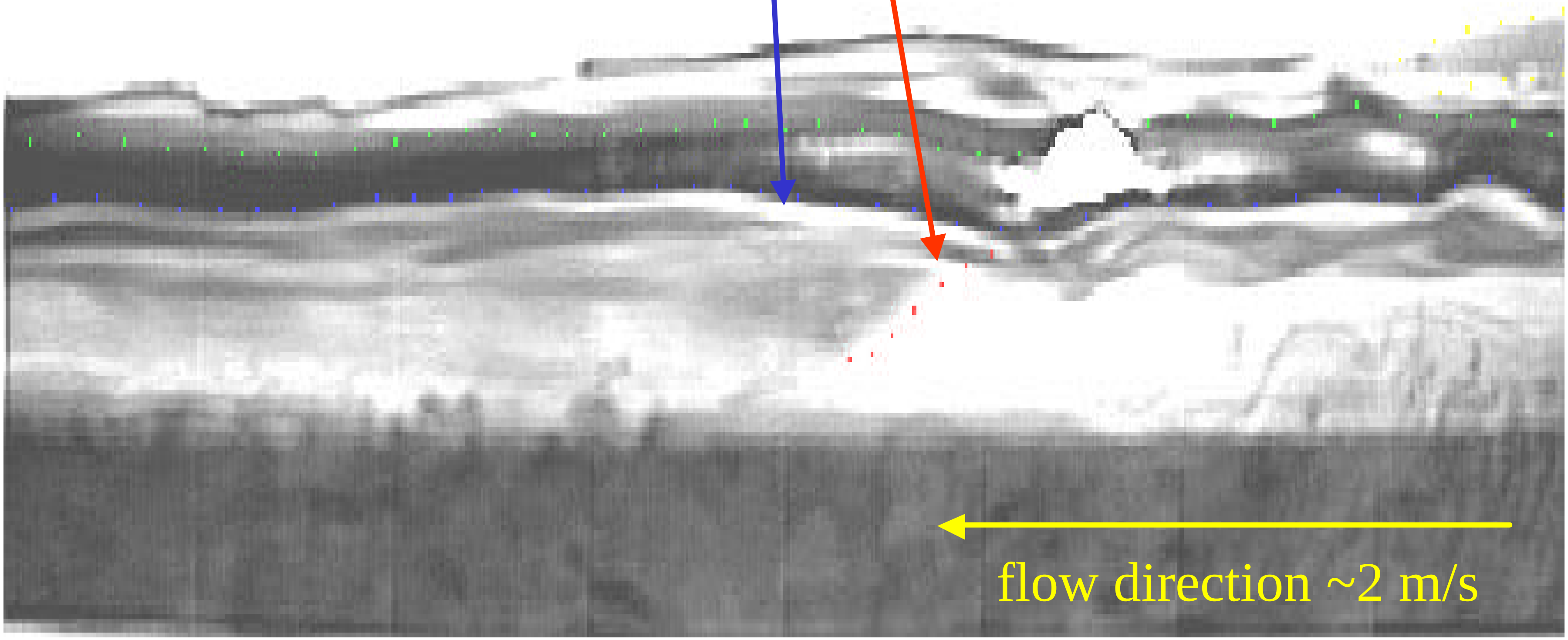


FLIHY Experiment at UCLA - Test section length = 4 m

Dye Diagnostics for Interfacial Mass Transport Measurements

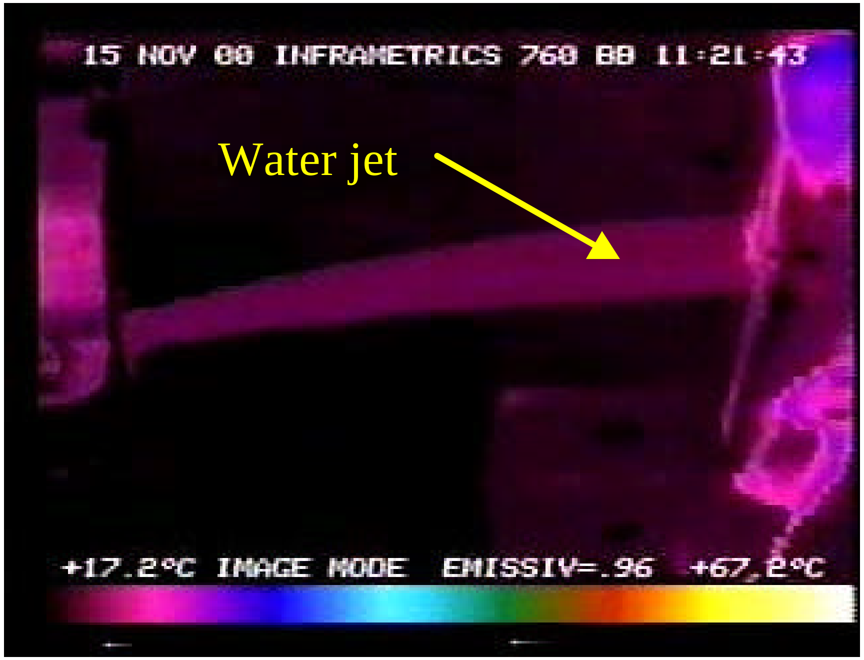
Profile of dye penetration (**red dots**)

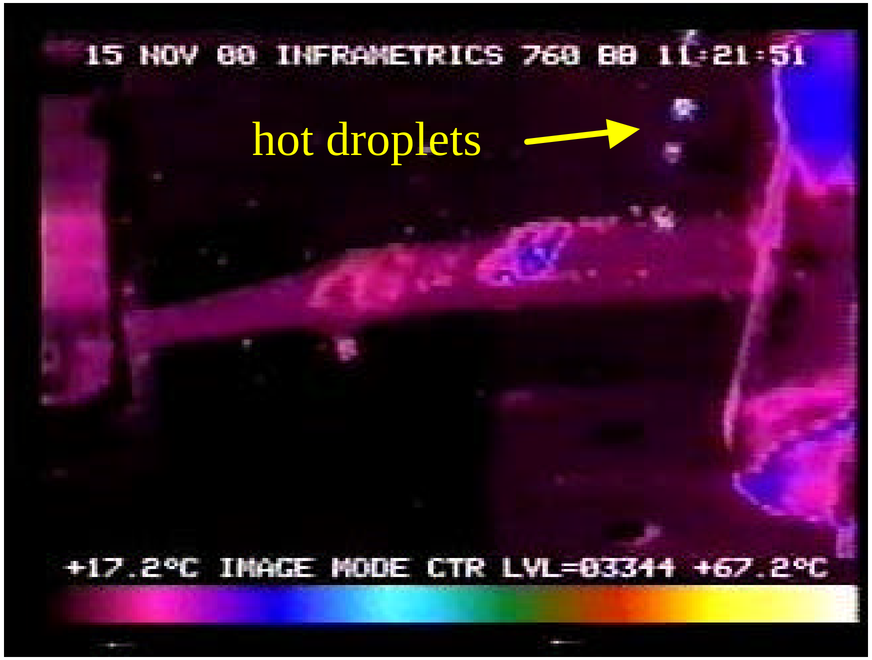
Local free surface (**blue dots**)

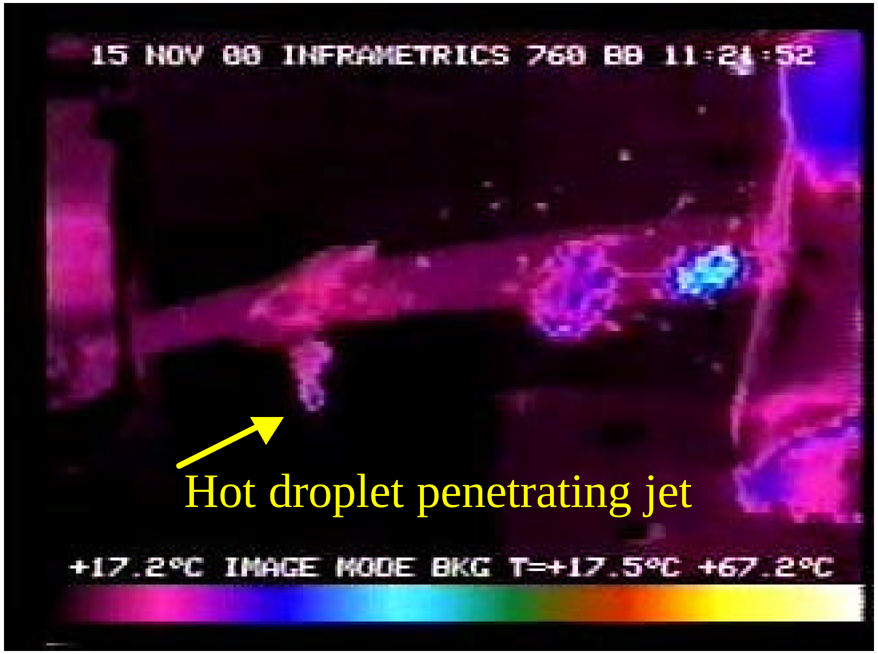


Dynamic Infrared measurements of jet surface temperature

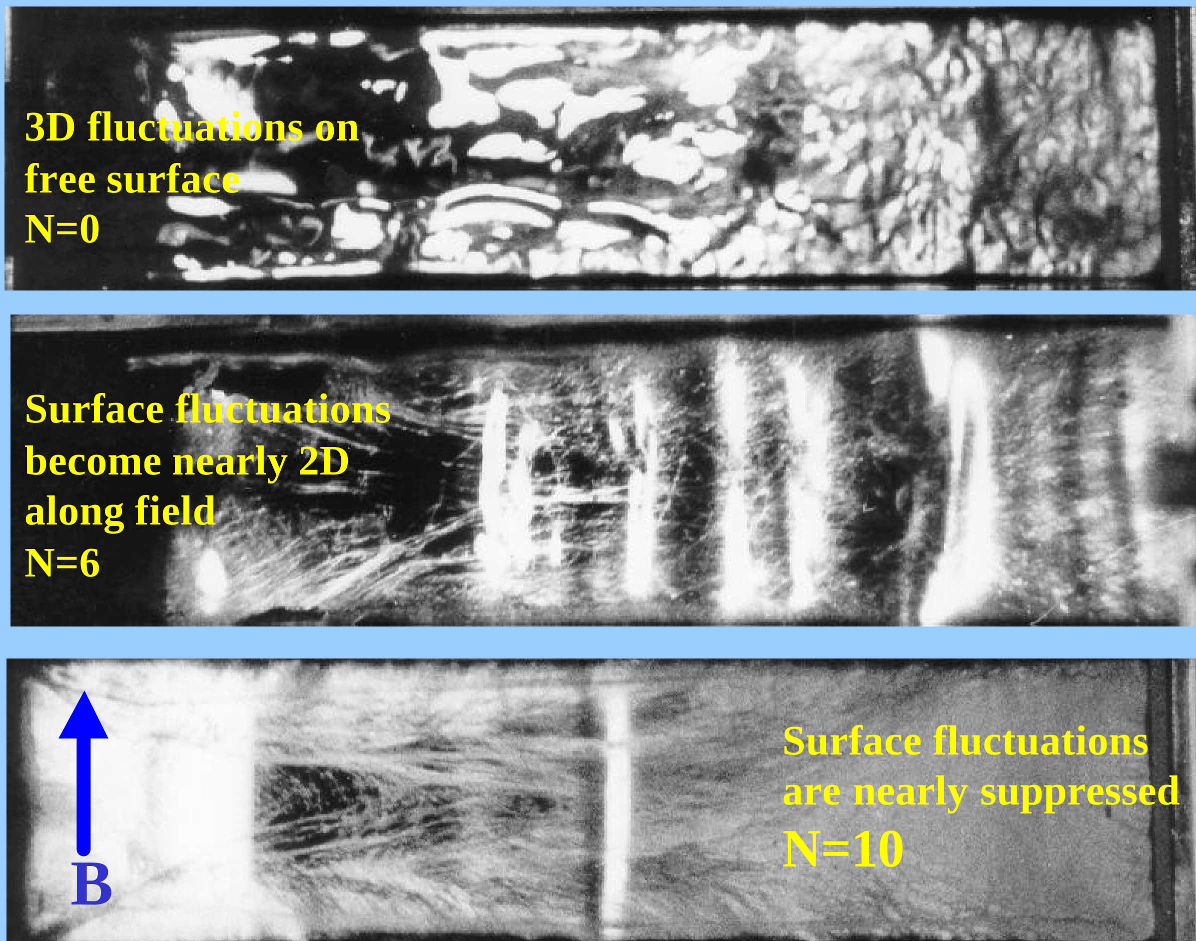
Impact of hot droplets on cold water jet (~8 m/s) thermally imaged in SNL/UCLA test



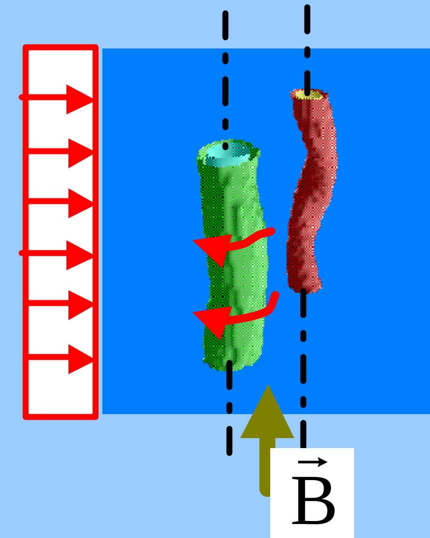




NEW PHENOMENA IN LM-MHD FLOW
2D Turbulence



LM free surface images with motion from left to right - Latvian Academy of Science Data



SOME PROPERTIES OF 2-D MHD TURBULENCE:

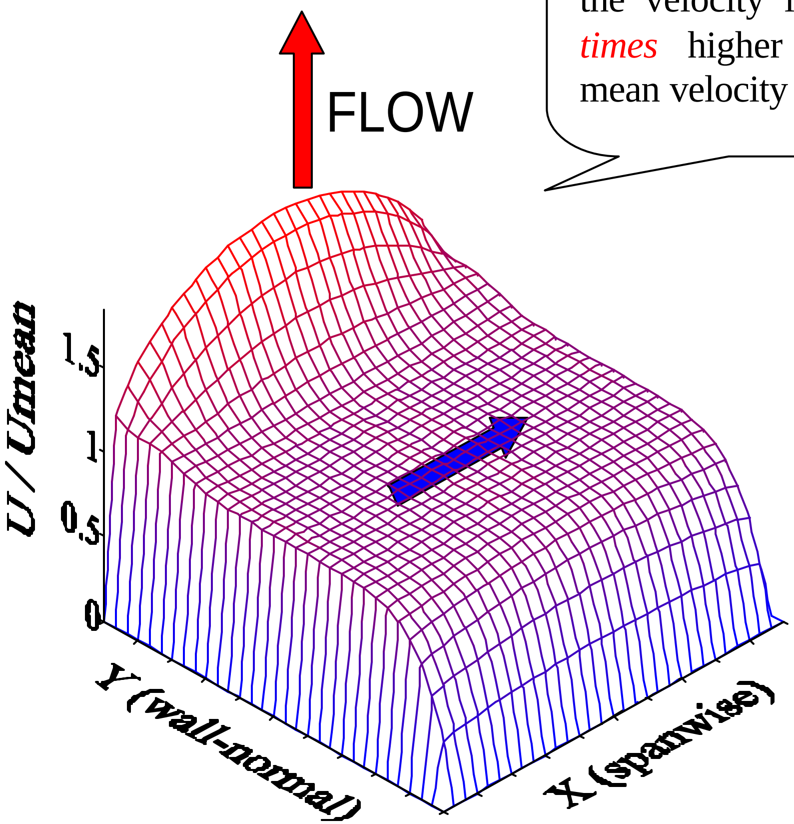
- Inverse energy cascade;
- Large energy containing vortices;
- Low Joule and Viscous dissipation;
- Insignificant effect on the hydraulic drag.

2-D turbulence could be very useful as a mean of intensifying heat transfer.

Electromagnetic Control of Heat Transfer

Velocity profiles with favorable features could be formed by making the side-walls slightly electrically conducting.

Isolated walls:
In the near-surface jet the velocity is about *2 times* higher than the mean velocity



Conducting walls:
In the near-surface jet the velocity is about *10 times* higher than the mean velocity