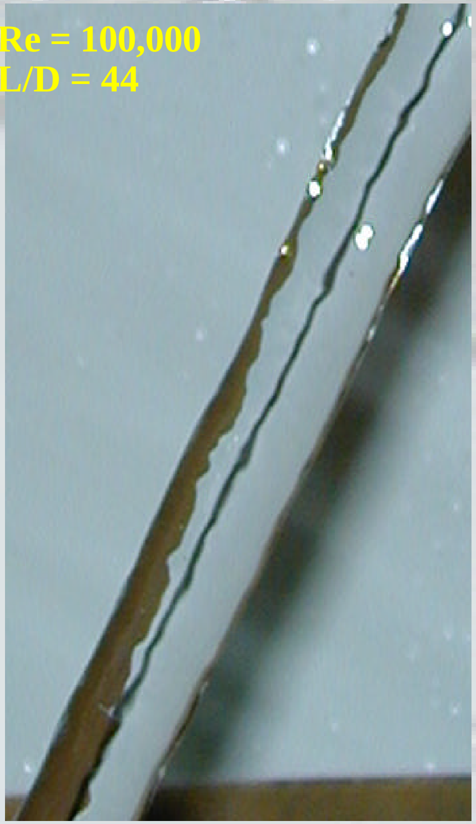
Understanding mechanisms of flow instability leads to improved control of jet surface smoothness for IFE

- Upstream turbulence and nozzle boundary layer thickness heavily influence downstream jet stability
- Turbulence conditioning and boundary layer trimming in nozzle dramatically improves jet quality



w/ conditioning

w/o conditioning

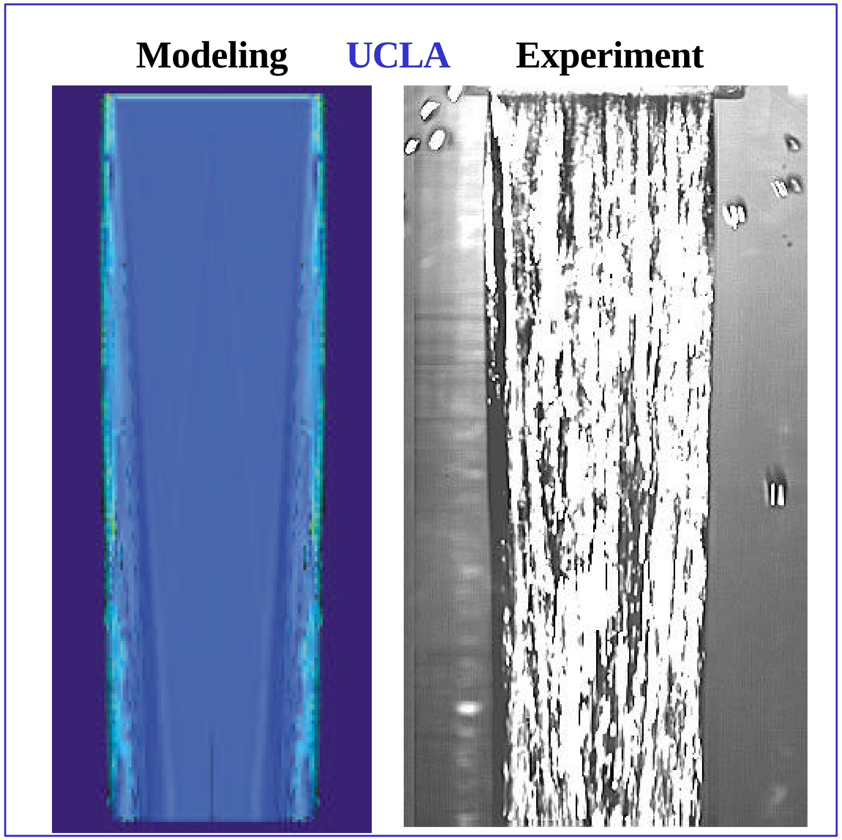
UC Berkeley data

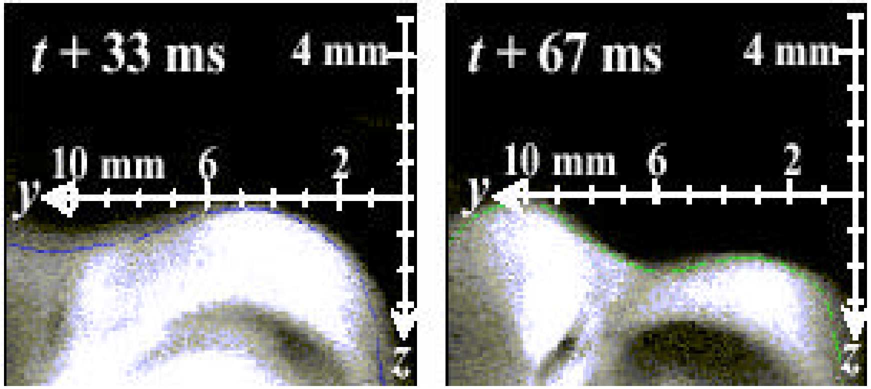
Modeling of Stationary Jet Deformation

•Initially rectangular jets deform due to **surface tension** and **corner pressurization** in nozzle

•Capillary waves from corner regions fan across jet face - **largest source of surface roughness!**

•Numerical simulations and quantitative surface topology measurements are critical tools for **understanding jet deformation,** and **controlling jet behavior** with nozzle shaping



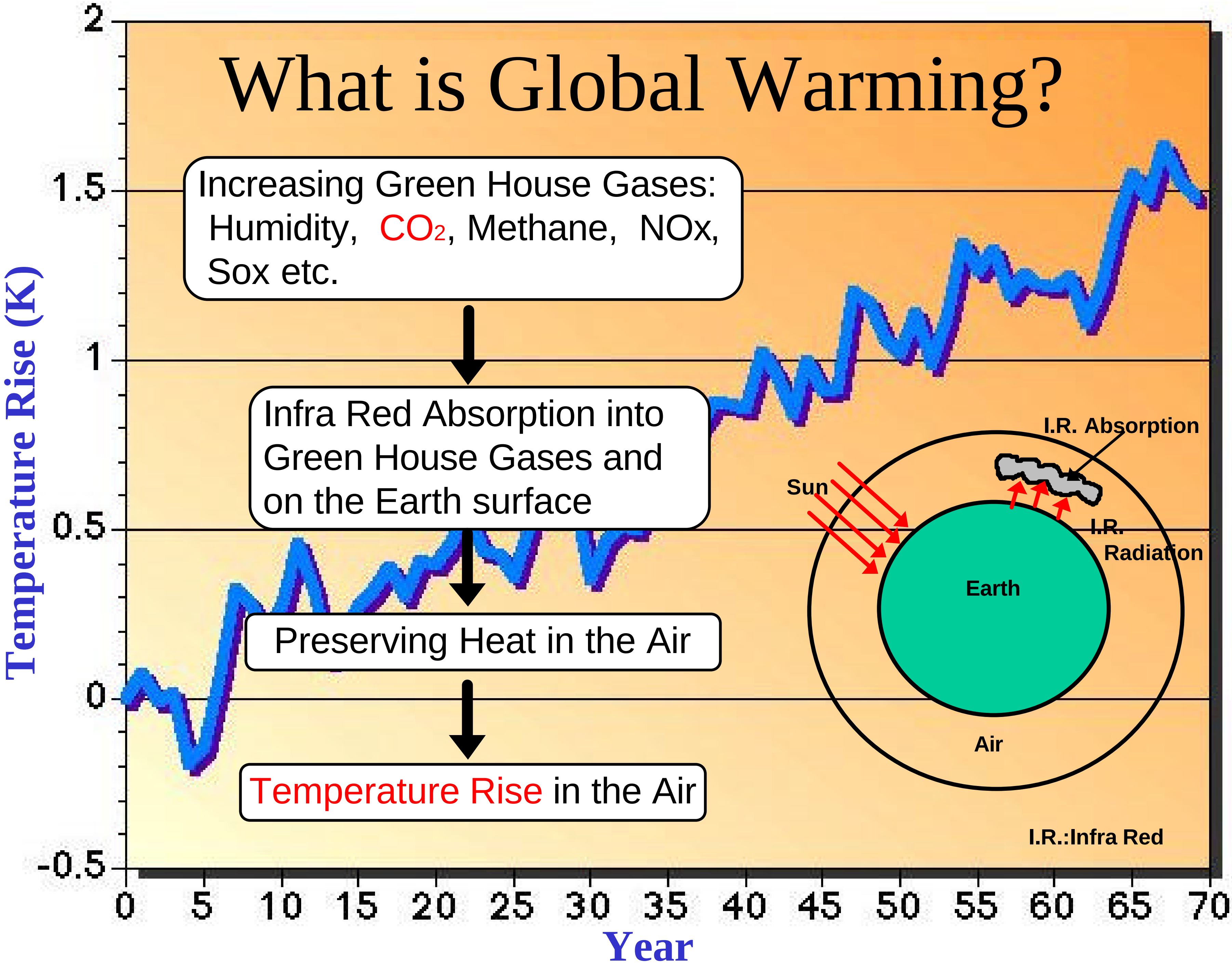


LIF measurement of surface topology at Georgia Tech

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 - Juric simulation


What is Global Warming?
Increasing Green House Gases: Humidity, CO_2, Methane, NOx, Sox etc.
Infra Red Absorption into Green House Gases and on the Earth surface
Preserving Heat in the Air
Temperature Rise in the Air
Sun
I.R. Absorption
I.R. Radiation
Earth
Air
I.R.:Infra Red
Temperature Rise (K)
2
1.5
1
0.5
0
-0.5
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
Year

Free surface mass transport is affecting CO_2 concentrations

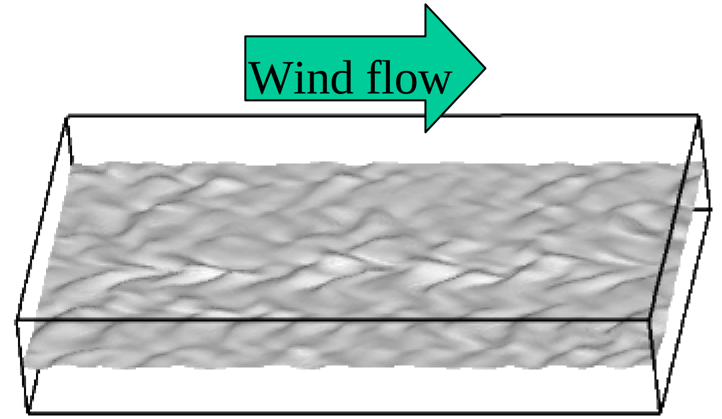
Missing Sink Problem over past 30 years

Measured atmospheric CO2 increase (34 ppm)

- Spent Fossile Fuel emissions (61 ppm)

= Missing Sink(-27 ppm)

Turbulent Heat and Mass transfer across Free Surface ?

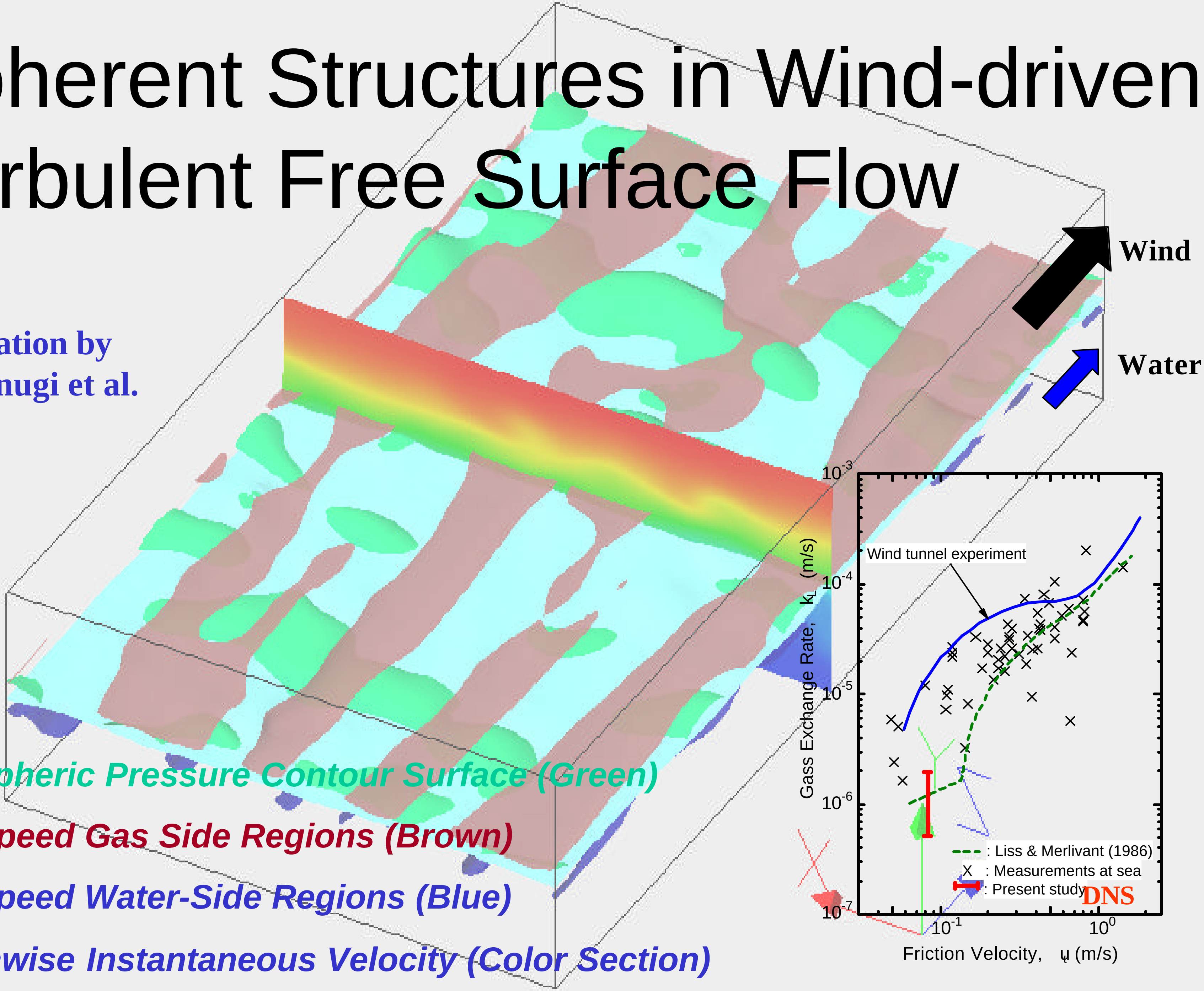


Free surface contour - wind-driven calculation

CO2 absorption at the turbulent free-surface deformed by the shear wind, by means of direct numerical solution procedure for a coupled gas-liquid flow

Coherent Structures in Wind-driven Turbulent Free Surface Flow

Simulation by
T. Kunugi et al.



Atmospheric Pressure Contour Surface (Green)

High Speed Gas Side Regions (Brown)

High Speed Water-Side Regions (Blue)

Streamwise Instantaneous Velocity (Color Section)

Some Common Aspects between Global Warming and Fusion Science Thermofluid Research

Similar Phenomena

•High Pr flow with radiation heating at free surface from plasma

•High Sc flow with CO_2 absorption at free surface of sea

Similar Flow Characteristics

•Re is high, both have the similar turbulence characteristics.

•MHD (fusion) and Coriollis (global warming) forces can influence the average velocity

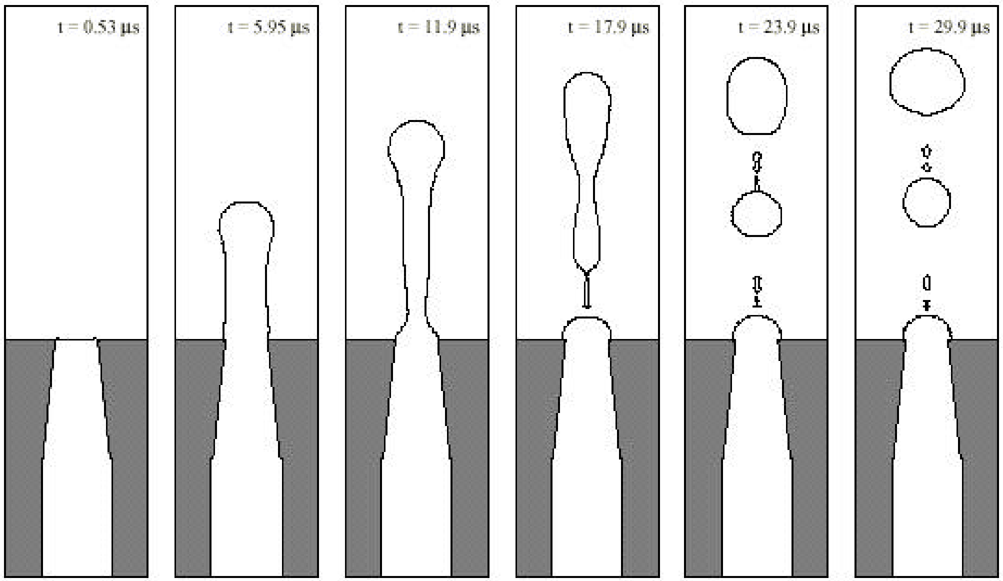
Heat and Mass Transfer Similarity

•High Pr, very low thermal diffusivity->very thin thermal boundary layer->large temperature gradient at interface

•High Sc, very low molecular diffusivity->very thin concentration boundary layer->large concentration gradient at interface

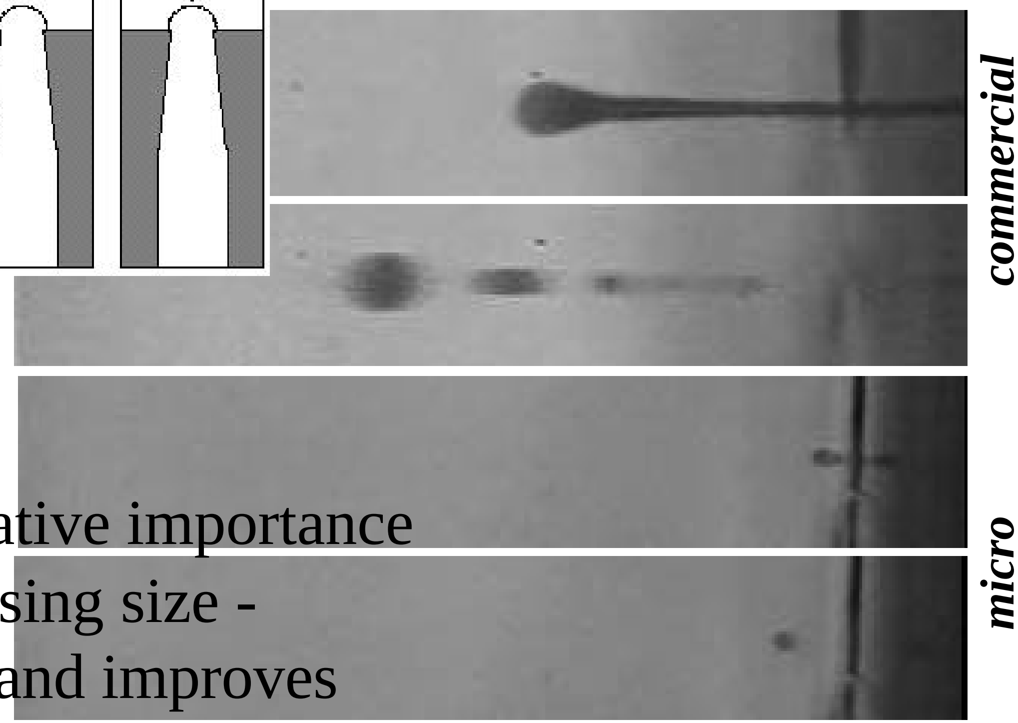
.

Liquid Jet Stability and Breakup



Inkjet Printer quality is hampered by formation of “satellite” droplets

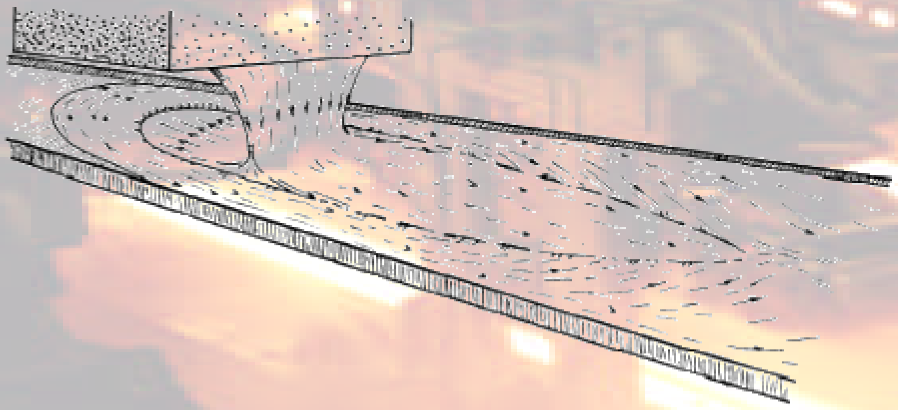
Simulation of commercial inkjet by Rider, Kothe, et al. - LANL



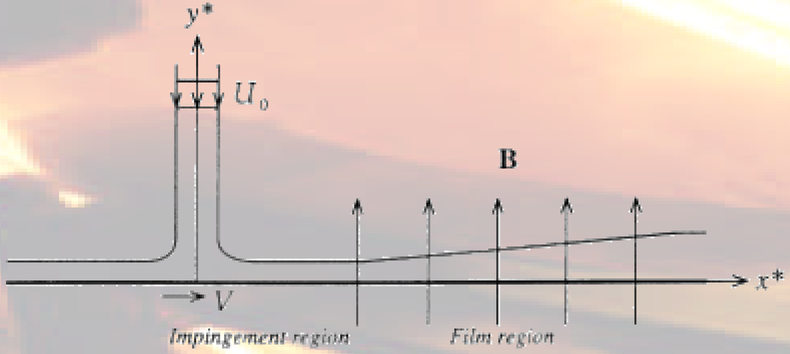
Micro-injector increases relative importance of surface tension by decreasing size - eliminates satellite droplets and improves precision

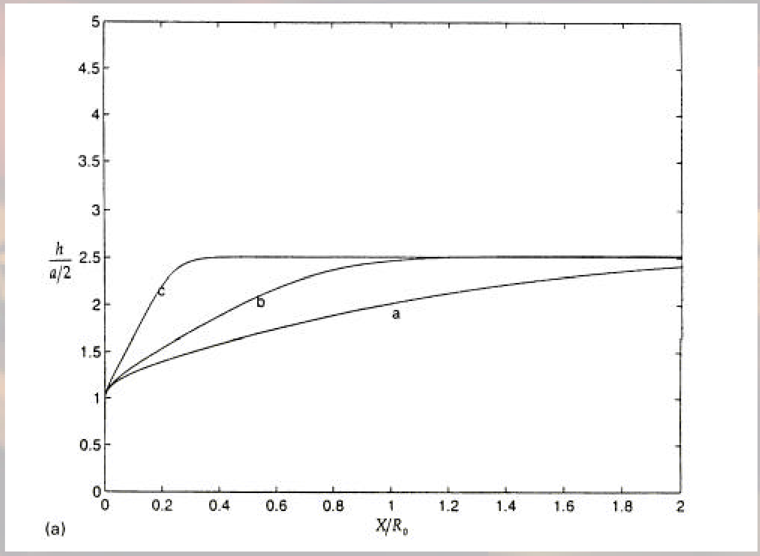
Data from Ho - UCLA

Vertical B field effects on Liquid Metal Film Flows



Continuous sheet casting can produce smooth free surfaces and film thickness control via MHD forces





Film thickness profiles for various Hartmann Numbers Simulation by Lofgren, et al.

Reflections on 19th & 20th Centuries

1850: Navier-Stokes Equation

1873: Maxwell's Equations

1895: Reynolds Averaging

1900-1960's:

-Averaging techniques, Semi-empirical approach. Heavy reliance on Prototype Testing (e.g. wind tunnels for aerodynamics).

1960's - 1970's:

-Supercomputers allow direct solution of N-S for simple problems. Advances in Computational Fluid Dynamics (CFD), e.g. utilization of LES technique.

1980's - 1990's:

-Rapid advances to Teraflop Computers
-Rapid advances in CFD and in experimental techniques
-Turbulence structure "simulated" and "observed" for key problems
-Better understanding of fluid physics and advanced "Prediction" tools
-Paradigm Shift:

- **From** "mostly experimental for empirical global parameters" **to** "larger share for CFD: simulation first followed by smaller number of carefully planned experiments aimed at understanding specific physics issues and verifying simulation."

21st Century Frontiers

Moving Beyond "Prediction" of Fluid Physics To "Control" of Fluid Dynamics

• With the rapid advances in teraflop computers, fluid dynamicists are increasingly able to move beyond predicting the effects of fluid behavior to actually controlling them; **with enormous benefits to mankind!**

Examples

• **Reduction in the Drag of Aircraft**

The surface of a wing would be moved slightly in response to fluctuations in the turbulence of the fluid flowing over it. The wings surface would have millions of embedded sensors and actuators that respond to fluctuations in the fluids, P, V as to control eddies and turbulence drag. DNS shows scientific feasibility and MEMS can fabricate integrated circuits with the necessary microsensors, control logic and actuators

• **Fusion Liquid Walls**

Control of "free surface-turbulence-MHD" interactions to achieve fast interfacial transport and "guided motion" in complex geometries ("smart-liquids")

• **Nano Fluidics: Pathway to Bio-Technologies**

Appropriately controlled fluid molecules moving through nano/micro passages can efficiently manipulate the evolution of the embedded macro DNA molecules or affect the physiology of cells through gene expression.